Zoning and Development Strategies for Agricultural Water Security in China (Postprint)

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Abstract

Aiming at the regional differentiation characteristics of agricultural water use in China, this study selected 10 indicators from four aspects: water resources status, agricultural water use characteristics, economic development level, and agricultural production conditions. Employing cluster analysis with 2013 as the baseline year, agricultural water use in China was zoned to provide a basis for ensuring agricultural water use security in China. The results show that based on provincial-level administrative units, agricultural water use can be divided into 8 categories. Category 1 includes Jiangxi, Hunan, and Hubei provinces, with agricultural water use and grain output accounting for 13.3% and 12.5% of national totals, respectively. Category 2 includes Guizhou, Yunnan, Anhui, Sichuan, Chongqing, and Guangxi provinces (municipalities, autonomous regions), with these two indicators being 23.6% and 20.3%, respectively. Category 3 is Hainan Province, with the indicators at 0.9% and 0.3%, respectively. Category 4 includes Shandong, Henan, Hebei, Liaoning, Shanxi, Shaanxi, and Gansu provinces, which with 6.8% of water resources and 19.2% of agricultural water use, produce 33.7% of agricultural output value and 32.4% of grain. Category 5 includes Jilin, Heilongjiang, and Inner Mongolia provinces (autonomous regions), which with 6.9% of water resources and 12.0% of agricultural water use, produce 20.5% of grain. Category 6 includes Ningxia, Xinjiang, Tibet, and Qinghai provinces (autonomous regions), with agricultural water use and grain output accounting for 16.2% and 3.2%, respectively. Category 7 includes Fujian, Guangdong, Jiangsu, and Zhejiang provinces, with agricultural water use and grain output accounting for 19.5% and 10.2% of national totals, respectively. Category 8 includes Tianjin, Shanghai, and Beijing municipalities, with the lowest agricultural water use and grain output at 1.1% and 0.6% of national totals, respectively. Categories 4 and 5 combined account for 31.2% of agricultural water use and 52.9% of grain output nationwide, representing regions of particular concern for agricultural water resources management in China. Based on this, zoning strategies were proposed: Category 1 should focus on water conservation; Category 2 on improving irrigation water use efficiency; Category 3 on increasing effective irrigation area; Category 4 on increasing total water resources through inter-basin water transfer or water rights trading while tapping local water-saving potential; Category 5 on improving agricultural water security; Category 6 on water resources protection and water source conservation; and Categories 7 and 8 on improving agricultural water use efficiency. The research results can provide a scientific basis for agricultural water use security in China.

Full Text

Agricultural Water Security Zoning and Developmental Countermeasures in China

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Abstract

Water is indispensable in agricultural production. The 2011 “No. 1 Central Document”defined water as the “source of life, essential for production, and foundation of ecology.” China’ s per capita water resources amount to approximately 2,300-2,500 m^3, about one-fourth of the world average, leading the United Nations to classify China as one of 13 water-poor countries. Agricultural water shortage is severe, with a deficit reaching 300 billion m^3. Water resource security forms the basis of food security, which must be guaranteed by water resources. As China’ s grain imports continue to increase, food security was elevated to the nation’ s top strategic priority in 2014. China’ s major grain-producing regions —the middle and lower Yangtze Plain, North China Plain, Northeast Plain, and Northwest region—are particularly crucial for water resource security. Beyond general scarcity, agricultural water use suffers from uneven spatial distribution and misaligned land-water resources: southern China contains 53% of the population, 35% of cultivated land, but 81% of water resources, while northern China has 47% of the population, 64% of cultivated land, but only 19% of water resources. Simultaneously, regional disparities exist in both water use efficiency and assurance levels, with irrigation water use coefficients varying by 0.33 across regions, further exacerbating issues of agricultural water security and consequent threats to food security, agricultural ecological environmental security, agricultural economic security, and rural social security. Therefore, regional classification of agricultural water use and targeted countermeasures are critically important for effective water utilization.

Previous research provides valuable references. Chen et al. employed fuzzy clustering for national water resource zoning, while other scholars focused on basin-level zoning for the Haihe River, Yellow River, and upper Yangtze River. Liu et al. used geomorphology, climate, irrigation levels, and water scarcity as indicators in a fuzzy clustering approach to divide North China into 10 water-saving agricultural zones, proposing 节水 priorities for each. Shen et al. divided western China into five eco-agricultural zones based on geographic location and macro-landform patterns, identifying directions for characteristic agriculture development. Lü et al. applied cluster analysis to 88 counties in Guizhou Province using indicators of agricultural product supply, employment and livelihood security, ecological regulation and constraints, and cultural heritage, dividing them into four functional zones. Ni et al. used analytic hierarchy process considering drought disaster conditions, water conservancy facility capacity, irrigation rates, and water resource status to classify drought-vulnerable areas into four categories. These studies primarily focused on water resource zoning, water-saving agriculture zoning, eco-agriculture zoning, agricultural function zoning, and agricultural drought vulnerability zoning, with few addressing agricultural water use specifically. Drawing on these foundations, this study employs cluster analysis with key agricultural water use indicators at the administrative unit level to zone China’ s agricultural water use, providing a basis for agricultural water security.

1. Methods

1.1 Cluster Analysis Method Cluster analysis offers simplicity and intuitive results, making it widely applicable in regional classification studies. Seven classification methods and seven distance measurement approaches exist. This study selected Ward’ s method (sum of squared deviations) with squared Euclidean distance, which yields high sensitivity by minimizing within-class variance and maximizing between-class variance according to variance analysis principles. Classification quantity was determined using the dendrogram generated by Ward’ s method and squared Euclidean distance, following the principle of proceeding from large to small distances. Implementation used SPSS 19.0 statistical software for Q-type clustering, with data standardized using the software’ s built-in function to address comparability issues arising from different measurement units and magnitude scales among indicators.

1.2 Zoning Indicators and Evaluation Standards The key to zoning lies in indicator selection. Referencing water resource evaluation, sustainable agricultural water use assessment, and relevant zoning indicators from previous studies, we initially established 13 candidate indicators covering four dimensions: water resource conditions, agricultural water use characteristics, economic development level, and agricultural production conditions. Pearson correlation tests revealed significant correlations at the 0.05 level (two-tailed) among per capita GDP, rural residents’ net income, and per capita fiscal revenue, and at the 0.01 level (two-tailed) between water consumption per 10,000 Yuan agricultural output and water consumption per unit grain production. Consequently, we removed the three highly correlated indicators (rural residents' net income, per capita fiscal revenue, and water consumption per unit grain production), retaining 10 indicators for the final zoning scheme (Table 1).

Evaluation standards were established based on: (1) historical statistical data using certain probability thresholds (50%, 75%, 90%) as benchmarks; (2) international standards where available, such as for per capita water resources, per capita GDP, and primary industry output value proportion; and (3) 2013 national averages as standard levels. The final indicator standards are listed in Table 1.

1.3 Data Sources Data were obtained from three primary sources: (1) Statistical yearbooks providing direct access to indicators such as agricultural water consumption, cultivated land area, reservoir capacity, grain output, and primary industry output value proportion; (2) National and provincial water resource bulletins and comprehensive water resource plans, providing data on total water resources and irrigation water use coefficients; and (3) Calculated indicators derived from the above sources, including water resources per unit land area, per capita water resources, per capita GDP, per capita cultivated land, grain yield per unit area, water storage capacity per unit cultivated land, and water consumption per 10,000 Yuan agricultural output value.

2. Results and Analysis

Based on the above methodology and using 2013 as the baseline year, cluster analysis was conducted for 31 provinces, autonomous regions, and municipalities, dividing national agricultural water use into eight distinct zones with significantly different characteristic values (Tables 2 and 3).

2.1 Agricultural Water Consumption and Grain Production by Zone

Zone I includes Jiangxi, Hunan, and Hubei provinces, accounting for 13.3% of national agricultural water consumption and 12.5% of grain production. **Zone II** comprises Guizhou, Yunnan, Anhui, Sichuan, Chongqing, and Guangxi, representing the largest share of agricultural water consumption at 23.6% and ranking third in grain production at 20.3%. Guangxi' s agricultural water consumption exceeds 20.94 billion m^3, ranking fourth nationally. **Zone III** is Hainan Province alone, contributing 0.9% of agricultural water consumption and 0.3% of grain production. **Zone IV** includes Shandong, Henan, Hebei, Liaoning, Shanxi, Shaanxi, and Gansu, producing 32.4% of national grain output with only 6.8% of water resources and 19.2% of agricultural water consumption. **Zone V** includes Jilin, Heilongjiang, and Inner Mongolia, generating 20.5% of grain production with 6.9% of water resources and 12.0% of agricultural water consumption; Heilongjiang' s agricultural water consumption ranks second nationally at 31.02 billion m^3. Combined, Zones IV and V account for 31.2% of agricultural water consumption and 52.9% of grain production, representing critical regions for agricultural water management. **Zone VI** comprises Ningxia, Xinjiang, Tibet, and Qinghai, using 16.2% of agricultural water but producing only 3.2% of grain; Xinjiang has the highest agricultural water consumption nationally at 55.77 billion m^3. **Zone VII** includes Fujian, Guangdong, Jiangsu, and Zhejiang, representing 19.5% of agricultural water consumption but only 10.2% of grain production; Jiangsu ranks third in agricultural water consumption at approximately 30.19 billion m^3. **Zone VIII** includes Tianjin, Shanghai, and Beijing, with the lowest agricultural water consumption (1.1%) and grain production (0.6%).

2.2 Agricultural Water Security and Water-Saving Potential Due to seasonal mismatches between precipitation and crop water demand, irrigated agriculture predominates in most regions, making water conservancy infrastructure crucial. In 2013, China's total reservoir capacity reached 829.821 billion m^3, with a provincial average of 26.768 billion m^3. Major grain-producing Zones IV and V have reservoir capacities accounting for 17.7% and 8.4% of the national total, respectively. Particularly concerning, Shanxi, Shaanxi, and Gansu in Zone IV have reservoir capacities of only 6.92, 8.85, and 10.54 billion m^3, indicating low agricultural water security.

The irrigation water use coefficient—the ratio of water actually available to crops in fields to total water diverted at canal heads—has improved from 0.43 in 2000 to 0.49 currently, but remains substantially below the 0.7–0.8 typical in developed countries. Zones IV and V have coefficients of 0.51 and 0.54, respectively. Within Zone IV, only Hebei exceeds the national average at 0.64, while Shanxi and Gansu fall below 0.5 at approximately 0.49; in Zone V, Heilongjiang and Jilin have coefficients of 0.54 and 0.51. Zone II averages 0.43, below the national level, with Guangxi at 0.39. Zone VI averages 0.45, with Ningxia and Xinjiang at 0.43 and 0.47, respectively.

No universally accepted standard exists for defining water-saving potential, resulting in inconsistent calculation methods. Most literature uses irrigation water use coefficients and field net irrigation quotas as evaluation criteria. This study calculated water-saving potential for each zone based on irrigation water use coefficients (Table 3). Results show that by 2030, with constant cultivated area and planting structure but improved irrigation water use coefficients, China' s agricultural water-saving potential could reach approximately 73.19 billion m^3, with Zones II, IV, and V offering potentials of about 15.93, 11.87, and 7.73 billion m^3, respectively.

2.3 Agricultural Product Composition by Zone Examining regional differences in agricultural product output (Table 4) reveals that Zones IV, V, and II are the primary grain-producing regions, collectively accounting for 73.1% of national grain output. Cotton production concentrates in Zones VI, IV, and I, representing 39.6%, 36.2%, and 12.8%, respectively, with the first two zones alone comprising 75.8%. Oil crops are mainly distributed in Zones IV, II, and I, totaling 79.4% of national output. Fruits, meat, and poultry eggs primarily come from Zones IV, VII, and II, accounting for 77.6% of fruit, 72.0% of meat, and 78.6% of poultry eggs. Aquatic products concentrate in Zones IV, VII, and I (82.4% combined), while milk production is dominated by Zones IV and V (78.9%). In summary, grain and oil crops concentrate in Zones IV, II, and V, while cotton concentrates in Zone VI. Zone IV is particularly significant, producing over 30% of grain, cotton, oil crops, meat, and milk, and over 46% of fruit and poultry eggs, making it the most important agricultural production region.

3. Discussion and Conclusions

This study divided China' s 31 provinces, autonomous regions, and municipalities into eight zones, identifying characteristic values for agricultural water security, water-saving potential, grain production, and other agricultural products. This provides a foundation for future strategies to ensure food security through agricultural water management and offers references for zonal water resource management.

1) Based on agricultural water use characteristics combined with water resource conditions, agricultural production, and economic development, the zoning identifies important grain-producing regions and their water-related challenges, providing scientific support for agricultural water security and management strategies. Zones II, IV, and V, covering 49.9% of land area, 75% of cultivated land, 44.7% of water resources, and 54.8% of agricultural water consumption, produce 70.8% of national grain output. These three zones are strategically critical for national food security and agricultural development. Zone IV is particularly noteworthy, generating 33.7% of agricultural output value and 32.4% of grain with only 6.8% of water resources and 15.3% of land area, warranting special attention in agricultural water management.

2) Future agricultural water strategies should reflect zone-specific priorities. **Zone I**, with relatively scarce water resources and lagging economic development (per capita GDP and rural income below national averages), should focus on water saving through improved irrigation technology and infrastructure, with central financial support for water-saving investments. **Zone II**, with an irrigation water use coefficient of approximately 0.42 (below national average), should prioritize improving irrigation efficiency. **Zone IV**, where water resource development utilization rates far exceed warning levels (some areas exceeding 100%) and 后备 water resources are severely limited, should focus on 挖掘 local water-saving potential while increasing total water resources through inter-basin water transfer or water rights trading to ensure food security. **Zone V**, where Heilongjiang and Jilin have increasingly prominent grain production positions but limited water-saving potential (only 7.73 billion m^3), should emphasize water saving, improved irrigation coefficients, and enhanced water conservancy infrastructure to increase water security. **Zone III** (Hainan), with

abundant water resources but low agricultural water efficiency (1.53 times the national average) and effective irrigation ratio of 33.4%, should focus on improving water use efficiency and expanding effective irrigation area. **Zone VI**, located in upstream areas of major rivers with abundant water resources (except Ningxia) and serving as important ecological function zones, should prioritize water resource protection and conservation. **Zone VII**, with irrigation water use coefficients slightly above national average and advantages in economic and technological development, should extend agricultural industrial chains, adjust agricultural structure, and develop eco-agriculture to enhance economic benefits. **Zone VIII**, already achieving high water use efficiency and economic benefits nationally but still with potential compared to developed countries, should leverage its economic and technological capacity to further improve water use efficiency, expand water-saving irrigation area, and enhance water productivity.

3) Zoning enables better identification of regional differences to propose tailored development strategies. Existing national zoning schemes such as the National Water Resource Zoning, China' s Comprehensive Natural Regionalization, National Ecological Zoning, and China' s Comprehensive Agricultural Regionalization have played important roles in water resource evaluation and planning, natural resource development and protection, ecological function identification, and agricultural production development. This study provides a preliminary macro-level analysis of agricultural water use zoning, revealing characteristics, water-saving potential, and agricultural product features of each zone to support decision-making for agricultural water security and management. Data limitations suggest that indicator system development and standard determination could be improved in future research.

References

[1] Liu C M. Agricultural water issues in China: Discussions on research highlights[J]. Chinese Journal of Eco-Agriculture, 2014, 22(8): 875-879
[2] Kang S Z. Towards water and food security in China[J]. Chinese Journal of Eco-Agriculture, 2014, 22(8): 880-885
[3] Zhang Z B, Xu P, Duan Z Y. Food security should be the ultimate goal of agricultural modernization in China[J]. Chinese Journal of Eco-Agriculture, 2015, 23(10): 1215-1219
[4] Zhang Z B, Duan Z Y, Xu P, et al. Synergy strategy of food and water security in China[J]. Chinese Journal of Eco-Agriculture, 2013, 21(12): 1441-1448
[5] Li Y M, Wang J X. Situation, trend and its impacts on cropping pattern of water shortage in the rural areas: Empirical analysis based on ten provinces' field survey in China[J]. Journal of Natural Resources, 2009, 24(2): 200-208
[6] Jiang W L. Research on adaptation strategies for coping with problems of water resources in China[J]. Impact of Science on Society, 2010(2): 24-29

[7] Chen S Y, Li Y W. Fuzzy clustering iterative model and its application in water resource partition[J]. Journal of Liaoning Technical University, 2004, 23(6): 848-851
[8] Liu C S, Liu C M, Yang H. Zoning for water resource management in the Haihe River basin[J]. Acta Geographica Sinica, 2004, 59(3): 349-356
[9] Pan Q M, Zhang R S, Li Z Y. Analysis on Zonal Volume of water resources and its distribution characteristic of the Yellow River basin[J]. Yellow River, 2008, 30(8): 54-55
[10] Liang C, Liu Y B. Hydro-ecological protection and zoning in the upper valley of the Yangtze River[J]. Journal of Beijing Normal University: Natural Science, 2009, 45(5): 501-508
[11] Liu Y F, Huang J S, Wu J W. North China' s water-saving agricultural zoning based on the maximum tree[J]. China Rural Water and Hydropower, 2013(12): 80-84
[12] Shen Y C, Zhang H Y, Wang X H. The role of agriculture in the development of western China and eco-agricultural division[J]. Journal of Arid Land Resources and Environment, 2003, 17(3): 1-6
[13] Lü J T, Lü D M, Zhang H. A cluster district method for agricultural function based on SPSS[J]. Chinese Journal of Agricultural Resources and Regional Planning, 2010, 31(1): 68-74
[14] Ni S H, Gu Y, Wang H R. Study on frangibility zoning of agricultural drought in China[J]. Advances in Water Science, 2005, 16(5): 705-709
[15] Jia S F, Zhang J Y, Zhang S F. Regional water resources stress and water resources security appraisement indicators[J]. Progress in Geography, 2002, 21(6): 538-544
[16] Huang C L, Deng W, Yang J F. On construction and application of indicators system of sustainable utilization of agricultural water resources[J]. Research of Agricultural Modernization, 2005, 26(6): 422-425
[17] The Ministry of Water Resources of Peoples Republic of China. Technical Terminology for Rural Water Conservancy [SL56—2013][S]. Beijing: China Water Power Press, 2013
[18] Peng S Z, Gao X L. Discussion on improvement of irrigated water use coefficient[J]. China Water Resources, 2012(1): 33-35
[19] Cui Y L, Xiong J. Advances in assessment indicators of irrigation water use efficiency[J]. Advances in Water Science, 2009, 20(4): 590-598

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