Comparative Study of Water Area Changes and Influencing Factors in Guanting and Miyun Reservoirs (Postprint)

Authors: Ma Zhengang1,2, Li Lili1,2, Zhang Jungui1

Date: 2023-08-26T00:00:00+00:00

Abstract

This study examines Guanting Reservoir and Miyun Reservoir within the capital water conservation functional area, evaluating water surface area changes of the two reservoirs since 1980 and analyzing the influences of three factors: precipitation, vegetation coverage, and anthropogenic water consumption. Utilizing long-term remote sensing imagery from 1980 to 2022, reservoir water surface areas were extracted, vegetation coverage was calculated, and Pearson correlation analysis was employed to explore relationships among influencing factors. The results indicate: (1) Since 2013, the water surface areas of both reservoirs have continuously increased to historical high levels, demonstrating significant water conservation effectiveness. (2) Over the past 40 years, the water surface area change processes of the two reservoirs have demonstrated clear synchrony, both characterized by five stages: rising phase-high level maintenance phase-declining phase-feature maintenance phase-recovery phase. (3) No correlation was observed between annual precipitation in the Zhangjiakou section of the upstream watershed and reservoir area; nor was any correlation found between June-July precipitation (contemporaneous with the interpreted imagery) and reservoir area. (4) Vegetation coverage in the Zhangjiakou section upstream of Guanting Reservoir showed an overall upward trend, with 2000 being a change point. Vegetation coverage in the Zhangjiakou section upstream of Miyun Reservoir remained stable at the 0.7 level. Correlation analysis indicated no relationship between vegetation coverage and reservoir water surface area. (5) Anthropogenic water consumption in the Zhangjiakou section of the Yongding River basin has exhibited an overall annual decrease of $0.2\times10^{8}m^{3}$ since 2000, showing a significant negative correlation with the water surface area of Guanting Reservoir and effectively increasing reservoir inflow volume. (6) Since 2019, centralized water transfer from basin reservoirs and Yellow River water supplementation have significantly impacted the water surface area of Guanting Reservoir and ecological water replenishment in riparian

areas. It is recommended that the water conservation effectiveness of Zhangjiakou be comprehensively evaluated from aspects including surface runoff inflow volume, groundwater recovery volume, and ecological water replenishment volume.

Full Text

Comparative Study on Water Area Changes and Influencing Factors in the Guanting and Miyun Reservoirs

MA Zhengang[1],[2], LI Lili[1],[2], ZHANG Jungui[1]

[1]College of Tourism and Environment, Zhangjiakou University, Zhangjiakou 075000, Hebei, China
[2]Zhangjiakou Ecological Monitoring and Comprehensive Management Technology Innovation Center, Zhangjiakou 075000, Hebei, China

Abstract

This study focuses on the Guanting and Miyun reservoirs within the capital water conservation functional area, evaluating water area changes since 1980 and analyzing the impacts of three factors: precipitation, vegetation coverage, and anthropogenic water consumption. Using long-term time-series remote sensing imagery from 1980 to 2022, we extracted reservoir water areas and calculated vegetation coverage. Pearson correlation analysis was employed to explore relationships between influencing factors. The results indicate: (1) Since 2013, water areas in both reservoirs have continuously increased to historical highs, demonstrating significant water conservation achievements. (2) Over the past 40 years, the water area change processes of the two reservoirs have shown clear synchronization, exhibiting five distinct phases: rising period, high-level maintenance period, declining period, ground feature maintenance period, and recovery period. (3) No correlation was observed between annual precipitation and reservoir area in the Zhangjiakou sections upstream of the reservoirs; similarly, June-July precipitation during the same period as the imagery also showed no correlation. (4) Vegetation coverage in the Zhangjiakou section upstream of Guanting Reservoir displayed an overall upward trend, with 2000 identified as a variation point. Vegetation coverage in the Zhangjiakou section upstream of Miyun Reservoir has remained stable at approximately 0.7. Correlation analysis revealed no relationship between vegetation coverage and reservoir water area. (5) Anthropogenic water consumption in the Zhangjiakou section of the Yongding River Basin decreased by 0.2$\times10^{8}$ m^3 annually since 2000, showing a significant negative correlation with Guanting Reservoir water area and effectively increasing inflow. Since 2019, centralized water conveyance from upstream reservoirs and Yellow River water supplementation have substantially influenced Guanting Reservoir's water area and ecological water replenishment along the river. We recommend comprehensive evaluation of Zhangjiakou's water conservation effectiveness through surface runoff into reservoirs, groundwater

recovery, and ecological water replenishment.

Keywords: water area; water conservation; evaluation; factor analysis; Guanting Reservoir; Miyun Reservoir

Introduction

Spatial zoning and construction to strengthen specific functions represent a fundamental approach to spatial governance, encompassing complex human-environment interactions. Clarifying the direction, intensity, and mechanisms of these interactions remains an eternal research topic. Water conservation constitutes one of the ecosystem service functions, representing the comprehensive benefits generated through interactions among water, vegetation, soil, and other factors. Its mechanisms and processes are complex, influenced by multiple factors including space (different regions and scales), time (short-term and long-term), and beneficiaries (local or external).

The construction of water conservation functional zones represents a human-environment functional region with water conservation as its primary objective. Zhangjiakou has been designated as a capital water conservation functional area, making it representative of such initiatives. In January 2017, during his inspection of Zhangjiakou, General Secretary Xi Jinping emphasized the need to strengthen ecological construction, establish ecological priority awareness, build the capital water conservation functional area and ecological environment support zone, and explore an ecological development path for economically underdeveloped regions. Subsequently, in March 2019, the National Development and Reform Commission and the Hebei Provincial Government officially released the "Zhangjiakou Capital Water Conservation Functional Area and Ecological Environment Support Zone Construction Plan (2019-2035)." The "Zhangjiakou Capital Water Conservation Functional Area" designates Zhangjiakou as the main water conservation region, with both the capital and Zhangjiakou itself as beneficiary areas, prioritizing the maintenance of water security for Beijing.

As Guanting and Miyun reservoirs serve as two important water sources for Beijing, with most of their upstream areas located in Zhangjiakou, this study selects these reservoirs as observation points for evaluating Zhangjiakou's water conservation effectiveness for the capital. Previous research on water conservation in the Beijing-Zhangjiakou region has been extensive, covering water quantity and quality, climate impacts, land cover effects, and ecological benefits. Studies have analyzed water quality evolution in Guanting Reservoir, water quality status in Miyun Reservoir, and spatiotemporal changes in reservoir areas. Research on climate impacts has examined runoff evolution patterns and driving factors in the Chaobai River upstream of Miyun Reservoir, identifying human activities as the primary driver of runoff changes. Studies on land cover have investigated optimal forest coverage for water conservation and canopy interception capacities of different tree species. In terms of influencing factors,

precipitation, vegetation coverage, and anthropogenic water consumption are widely recognized as primary factors, though their relative importance varies temporally and spatially.

However, comparative studies focusing specifically on Guanting and Miyun reservoirs remain rare. Given that both reservoirs share similar water conservation functions, are geographically adjacent, and have similar natural environments, comparative analysis can deepen understanding of their differences and provide targeted recommendations for capital water conservation functional area construction. The primary manifestation of Zhangjiakou's water conservation effectiveness is the increase in water areas of Guanting and Miyun reservoirs. Key measures involve increasing water sources and reducing consumption, with the former depending on precipitation changes and water production capacity under vegetation coverage, and the latter depending on human water use patterns. This study uses water area changes in both reservoirs as indicators of water conservation effectiveness, analyzing relationships between changes and three main influencing factors—precipitation, vegetation coverage, and water consumption—from 1980 to 2022.

Study Area Overview

The study area encompasses the upstream watersheds of Miyun and Guanting reservoirs in Zhangjiakou (Figure 1). Miyun Reservoir, Beijing's largest surface drinking water source, is fed by the Chao-Bai River basin, which spans Beijing, Chengde, and parts of Zhangjiakou. The region features a continental monsoon climate transitioning from mid-temperate to warm-temperate zones and from semi-arid to semi-humid conditions, with a multi-year average temperature of 9.2°C and average precipitation of approximately 479 mm. Rainfall concentrates in summer, forming the main river recharge source. The basin's vegetation consists primarily of natural secondary forests and artificial plantations.

Guanting Reservoir serves as one of Beijing's most important backup water sources. Its upstream water systems, the Yanghe and Sanggan rivers, belong to the Yongding River basin and converge at Niuguantun in Huailai County before entering Guanting Reservoir. The basin has a continental monsoon climate, characterized by dryness, coldness, strong winds, and low rainfall due to the blocking of humid southeastern airflow by the Jundu and Taihang Mountains. The multi-year average precipitation is 405 mm, with frequent consecutive dry years in interannual distribution.

Data and Methods

Considering data availability and dynamic monitoring objectives, this study employed 43 periods of annual remote sensing imagery from 1980 to 2022 (Table 1). Data were primarily obtained from the USGS website and the "Geospatial Data Cloud" platform. To minimize seasonal impacts on reservoir water areas, imagery was selected from June to August during the rainy season, with each

scene covering both reservoirs to reduce temporal inconsistencies. Precipitation data represent annual precipitation for corresponding districts and counties in the Zhangjiakou sections upstream of the reservoirs. Vegetation coverage was derived from remote sensing imagery interpretation, calculated every two years since 1980. Water consumption data (agricultural, industrial, and domestic) were obtained from Zhangjiakou Water Resources Bulletins.

The water area extraction method involved manual vectorization using ArcGIS screen digitization. Vegetation coverage was calculated using the pixel dichotomy model:

$$FVC = \frac{NDVI - NDVI_{soil}}{NDVI_{veg} - NDVI_{soil}}$$

where FVC represents vegetation coverage, $NDVI$ is the normalized difference vegetation index for a specific pixel, $NDVI_{soil}$ represents the normalized difference vegetation index for bare soil, and $NDVI_{veg}$ represents the normalized difference vegetation index for pure green vegetation.

Results

Water Area Change Characteristics

Guanting Reservoir: Analysis of Landsat imagery revealed that since 1980, Guanting Reservoir's maximum area reached 97.2 km^2, minimum area was 34.7 km^2, multi-year average area was 61.0 km^2, maximum variation amplitude was 62.5 km^2, and coefficient of variation was 0.52. The overall change exhibited five stages: 1980-1985 as a gradual rise period, 1985-1999 as a high-level maintenance period, 1999-2006 as a rapid decline period, 2006-2015 as a low-level maintenance period, and 2015-2021 as a recovery period (Figure 2). These findings align with Wang Mengqi et al.'s research on area changes during 1999-2013 (Figure 3) and 2013-2021 (Figure 4).

Miyun Reservoir: Landsat imagery analysis showed that since 1980, Miyun Reservoir's maximum area was 160.4 km^2, minimum area was 108.4 km^2, multi-year average area was 137.4 km^2, maximum variation amplitude was 52 km^2, and coefficient of variation was 0.10. The change process also displayed five stages: 1980-1985 as a gradual rise period, 1985-1995 as a high-level maintenance period, 1995-2006 as a rapid decline period, 2006-2015 as a low-level maintenance period, and 2015-2021 as a recovery period (Figure 5). These results are consistent with conclusions from Cao Ronglong and Li Zijun et al. (Figure 6, Figure 7).

Synchronization Analysis

A scatter plot of water areas between Guanting and Miyun reservoirs revealed a correlation (Figure 8). Linear fitting yielded the equation: Guanting Reservoir Area = 24.073 + 0.460 × Miyun Reservoir Area. Pearson correlation analysis

indicated a correlation coefficient of 0.760, significant at the 0.01 level, demonstrating a significant positive correlation between the two reservoirs' water areas.

Influencing Factors Analysis

Precipitation

Yongding River Basin Zhangjiakou Section: The Zhangjiakou section of the upper Yongding River basin includes the main urban area, Huailai, Zhuolu, Xuanhua, Wanquan, Chongli, Yangyuan, Huai'an, and Yu counties. Based on annual precipitation data from these districts, the multi-year average precipitation was 394 mm, maximum annual precipitation was 557 mm, minimum was 278 mm, and coefficient of variation was 0.18. Years exceeding the 75th percentile occurred in 1980, 1995, 1996, 1998, and 2012. Pearson correlation analysis showed no correlation between Guanting Reservoir area and annual precipitation. To match the imagery interpretation timing (June-July), correlation analysis between Guanting Reservoir area and June-July precipitation in Huailai County also revealed no correlation ($r = -0.067$). Wang Xia's research indicates that Guanting Reservoir basin precipitation exhibits periodic variations, with alternating wet and dry year groups, though total precipitation remains relatively stable across cycles while measured runoff allocation becomes extremely unstable, decreasing sharply over time—consistent with our findings.

Chaobai River Basin Zhangjiakou Section: The upstream Chao-Bai River basin in Zhangjiakou is primarily located in Chicheng County. Analysis of precipitation data from 1980-2021 showed a multi-year average of 424 mm, maximum of 640 mm, minimum of 260 mm, and coefficient of variation of 0.20. Years exceeding the 75th percentile occurred in 1990, 1994, 1995, 1996, 1998, 2012, 2013, 2016, 2018, and 2019. Pearson correlation between Miyun Reservoir area and annual precipitation showed no relationship ($r = -0.029$). June-July precipitation analysis for Chicheng County also revealed no correlation ($r = 0.027$).

Vegetation Coverage

Yongding River Basin Zhangjiakou Section: Using Landsat imagery, vegetation coverage was calculated every two years since 1980 (Figure 10). Results showed a multi-year average vegetation coverage of 0.42, minimum of 0.31, maximum of 0.52, and coefficient of variation of 0.12. Coverage steadily improved overall, with 2000 identified as a variation point when coverage declined then continuously recovered. The 1999-2000 precipitation drop from 315 mm to 278 mm (nearly 100 mm below normal) likely caused this decline. Pearson analysis indicated significant positive correlation between vegetation coverage and precipitation ($r = 0.412$, $p < 0.05$), but no correlation between vegetation coverage and Guanting Reservoir area ($r = 0.071$).

Chaobai River Basin Zhangjiakou Section: Biennial extraction of vegetation coverage upstream of Miyun Reservoir showed a multi-year average of

0.71, maximum of 0.75, with coverage remaining stable at high levels. Pearson correlation analysis revealed no relationship between Miyun Reservoir area and vegetation coverage (r = 0.081).

Water Consumption

Anthropogenic water consumption represents the primary aspect of water resource consumption affecting reservoir inflow. Limited by data availability, we analyzed water consumption statistics from Zhangjiakou Water Resources Bulletins since 2000.

Yongding River Basin Zhangjiakou Section: Annual water consumption decreased continuously from 7.09$×10^{8}$ m^3 in 2001 to 5.85$×10^{8}$ m^3 in 2017 (Figure 11). This period corresponds to Guanting Reservoir's low-level maintenance and recovery phases. Pearson correlation analysis between Guanting Reservoir area and upstream water consumption showed a significant negative correlation (r = -0.624, $p < 0.05$), indicating that reduced water consumption slowed reservoir area decline and supported basic water demands.

Chaobai River Basin Zhangjiakou Section: Annual water consumption fluctuated around the 0.5$×10^{8}$ m^3 average since 2000 (Figure 12), with a range of 0.2$×10^{8}$ m^3 and coefficient of variation of 0.20. This period primarily corresponds to Miyun Reservoir's low-level maintenance phase. However, no correlation was observed, mainly because Chao-Bai River basin consumption (only 7.8% of Yongding River basin consumption) is too small to significantly impact Miyun Reservoir area.

Discussion

This comparative analysis of water area changes and influencing factors in Guanting and Miyun reservoirs enhances understanding of Zhangjiakou's capital water conservation functional area construction. However, several aspects require deeper exploration:

Water Conservation Effectiveness Evaluation: Water conservation concepts remain inconsistent, with some scholars emphasizing ecosystem water retention capacity (equivalent to "green water"). Based on Zhangjiakou's functional positioning, this study defines water conservation effectiveness as water volume delivered to Beijing. While this includes atmospheric, groundwater, and surface runoff components, our analysis focuses on target-oriented outcomes using single-period rainy-season remote sensing imagery. Although we visually compared adjacent months to avoid anomalies, full-sample statistical analysis was not conducted, limiting result robustness.

Influencing Factors: Water conservation mechanisms are complex with diverse influencing factors, making it difficult to clearly separate natural and anthropogenic impacts. Our comparative approach analyzed precipitation, vegetation coverage, and water consumption. However, factor importance varies by

stage. Since 2013, natural precipitation has fluctuated around the multi-year average without substantial increase, yet reservoir water areas have continuously reached historical highs, indicating dominant anthropogenic influences. Future research should quantitatively determine certain factors before analyzing others.

Reservoir Operations: Water area changes depend on both upstream inflow and reservoir discharge. Inflow includes surface runoff from precipitation and upstream reservoir releases. Studies show Guanting Reservoir's storage increased from insufficient levels in 2007 to 1$×10^{8}$ m^3 in 2019 through centralized water conveyance from Cetian Reservoir (starting 2007) and Yellow River water transfer (first implemented in 2019). Thus, multiple factors affect water area changes. Our analysis focuses on Zhangjiakou's water conservation role for Beijing, lacking 论证 on reservoir discharge and upstream supplementation—areas for future research with additional data.

Conclusion

Since 1980, Guanting and Miyun reservoirs' water areas have continuously increased to historical highs, demonstrating significant water conservation achievements. Over the past 40 years, the change processes have shown clear synchronization across five stages: rising period, high-level maintenance period, declining period, low-level maintenance period, and recovery period. Despite belonging to Beijing and Zhangjiakou with different development levels, the consistent outcomes align with the capital water conservation functional area's positioning and policy orientation.

No linear correlation was found between reservoir water areas and upstream annual precipitation or vegetation coverage, while a significant negative correlation existed with anthropogenic water consumption. This conclusion is important for evaluating Zhangjiakou's water conservation effectiveness and scientifically understanding upstream afforestation impacts on downstream reservoirs. Recent intensification of centralized reservoir water conveyance and Yellow River supplementation has significantly affected reservoir water areas and ecological replenishment, potentially altering relationships between precipitation, vegetation coverage, and reservoir area—requiring further research. We recommend comprehensive evaluation of Zhangjiakou's water conservation effectiveness through surface runoff into reservoirs, groundwater recovery, and ecological water replenishment.

References

[1] Ma Hailong, Fan Jie. Discussion on the human hypothesis in geography[J]. Human Geography, 2016, 31(1): 1-7, 80.

[2] Fan Jie. Frontier approach of the sustainable process and pattern of human environment system[J]. Acta Geographica Sinica, 2014, 69(8): 1060-1068.

[3] Lv Yihe, Hu Jian, Sun Feixiang, et al. Water retention and hydrological

regulation: Harmony but not the same in terrestrial hydrological ecosystem services[J]. Acta Ecologica Sinica, 2015, 35(15): 5191-5196.

[4] Lang Tao, Wang Hao, Ding Shiming, et al. An evolution of water quality in Guanting reservoir during the past three decades[J]. Progress in Geography, 2003, 22(1): 38-44.

[5] Li Yanan. Analysis of the water quality status and dynamic change trend of the lake in Miyun reservoir[J]. Beijing Water Affairs, 2020(S1): 36-40.

[6] Ma Zhengang, Li Lili, Ai Lizhi. Temporal and spatial analysis of the area change of Guanting reservoir from 1978 to 2013[J]. Arid Zone Research, 2015, 32(3): 428-434.

[7] Li Lijuan, Zheng Hongxing. Characteristics and driving forces of annual runoff changes for rivers in North China: A case study in the Chaobaihe River[J]. Acta Geographica Sinica, 2000, 55(3): 309-317.

[8] Xia Jun, Li Lu, Yan Maochao, et al. Impacts of climate change on water resource of Miyun reservoir and adaptation managements[J]. Advances in Climate Change Research, 2008, 4(6): 319-323.

[9] Gao Chengde, Tian Xiaorui. Study on the optimal forest coverage of water source protection forest in the Miyun reservoir catchment area of Beijing[J]. Practical Forestry Technology, 2005(8): 3-5.

[10] Sun Qingyan, Yu Xinxiao, Yang Xinbing, et al. Study on canopy interception of different tree species in protective forests in Miyun reservoir watershed[J]. Chinese Journal of Soil and Water Conservation, 2009, 7(3): 73-78.

[11] Luo Guangtian. Study on the Water Conservation Capacity of Typical Forests Upstream of Miyun Reservoir[D]. Beijing: Beijing Forestry University, 2019.

[12] Liao Langtao, Ding Sheng, Wu Shuirong. Evaluation and compensation of ecological benefits of water source conservation forests in Miyun reservoir[J]. Forestry Construction, 2000(6): 19-22.

[13] Qi Na. Construction and application of water ecological service evaluation index system for Miyun reservoir[J]. Water Resources Planning and Design, 2021(2): 15-18, 130.

[14] Zhou Lianxiong, Cui Wanjing, Zhao Yunjie. Temporal and spatial distribution characteristics of precipitation and drought in the Miyun reservoir catchment area of Beijing[J]. Chinese Journal of Soil and Water Conservation, 2020, 18(5): 35-42.

[15] Wang Mengqi, Zhang Wen, Meng Lingkui. Analysis of spatiotemporal changes in Miyun and Guanting reservoirs in Beijing from 2014 to 2019[J]. Surveying and Mapping Geographic Information, 2022, 47(4): 100-104.

[16] Cao Ronglong, Li Cunjun, Liu Liangyun, et al. Extraction and change monitoring of Miyun reservoir area based on water body index[J]. Surveying and Mapping Science, 2008(2): 158-160.

[17] Li Zijun, Li Xiubin. Analysis of the trend and causes of runoff changes in the upper reaches of the Chaobai River from 1961 to 2005[J]. Journal of Beijing Forestry University, 2008, 30(S2): 82-87.

[18] Wei Xingtao, Oliver Valentine Eboy, Cao Guangchao, et al. Spatiotemporal variation of water conservation and its impact factors on the southern slope of Qilian Mountains[J]. Regional Sustainability, 2023, 4(1): 54-67.

[19] Ma Pu, Lyu Shihai, Diao Zhaoyan, et al. How does the water conservation function of Hulunbuir forest steppe ecotone respond to climate change and land use change?[J]. Forests, 2022, 13(12): 2013.

[20] Liu Lin, Xiong Donghong, Zhang Baojun, et al. Litter accumulation characteristics and water holding capacity of poplar plantation in Lhasa valley[J]. Arid Zone Research, 2021, 38(6): 1674-1682.

[21] Wu Qiong, Song Jinxi, Sun Haotian, et al. Spatiotemporal variations of water conservation function based on EOF analysis at multi time scales under different ecosystems of Heihe River Basin[J]. Journal of Environmental Management, 2023, 325(PA): 116532-116532.

[22] Li Xiaolin, Pan Xingyao, Yang Moyuan, et al. Analysis of runoff changes in the Yongding River Basin based on ecological replenishment[J]. Journal of Beijing Normal University(Natural Science Edition), 2022, 58(6): 886-892.

[23] Wang Xia. How to improve the water supply guarantee of Guanting reservoir in continuous dry years[J]. Beijing Water Affairs, 2008, 138(1): 33-35.

[24] Wang Xin, Song Qian, Duan Weijun, et al. The role of Guanting reservoir water supply scheduling in ecological replenishment of the Yongding River[J]. Beijing Water Affairs, 2023(1): 47-52.

[25] Xu Liting, Liu Haihong, Huang Lijie, et al. Spatiotemporal changes of ecological environment and water conservation in the Fenhe River Basin from 2000 to 2020[J]. Arid Zone Research, 2023, 40(2): 313-325.

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