Dean&Francis
ISSN 2959-6157

Characteristics of Poyang Lake Water Area Changes and Driving Factors

Tianyu Xu[1, *]

[1] College of Surveying and Geographic Informatics, Lanzhou Jiaotong University, Lanzhou, China
* Corresponding Author: 20232702143@stu.lzjtu.edu.cn

Abstract:

Functioning as a crucial ecological safeguard for the Yangtze River's middle and lower basins, Poyang Lake's shifting water levels present substantial risks to local environmental stability. This study investigated uncovering distinct patterns in the lake's surface area variations across three decades, marked by progressive reduction and dynamic oscillations. Notably, dry season water coverage has experienced dramatic contraction, while seasonal disparities between high and low water periods have grown increasingly pronounced. These transformations demonstrate clear cyclical response behaviors. Analysis of causal factors suggests these alterations stem from complex interactions between climatic shifts and anthropogenic influences. Changes in precipitation patterns caused by the weakening of the monsoon, frequent extreme drought and flood events, and increased evaporation have exacerbated water imbalance in lake areas. Hydraulic infrastructure like the Three Gorges Dam has dramatically transformed the dynamic interaction between river systems and lake ecosystems, substantially diminishing the Yangtze River's natural water supply capacity to adjacent lakes. Historical land reclamation has continued to reduce water space, and competition between water resource development and urbanization has further squeezed ecological needs. It is worth noting that when natural droughts overlap with human interference, human activities have become the dominant driving force. The shrinkage and fluctuations of water bodies have triggered ecological degradation, such as biodiversity decline, and the restoration process exhibits significant lag. Based on this, this study proposes comprehensive management strategies including coordinated water resource scheduling in river basins, wetland ecological space restoration, and climate-appropriate management.

Keywords: Water area; Driving factors; Phased characteristics.

1. Introduction

Poyang Lake, recognized as China's most extensive freshwater body, maintains an average yearly water retention volume exceeding 150 billion cubic meters. This vital ecosystem performs crucial functions in preserving the Yangtze River's middle and lower basin ecological stability, mitigating flood risks, and safeguarding biological diversity [1]. The lake's surface area predominantly responds to monsoon weather patterns, demonstrating distinct seasonal variations with high water levels during summer/autumn and significant reductions in winter/spring. Recent decades have witnessed substantial alterations in Poyang Lake's hydrological dynamics due to combined climate shifts and anthropogenic impacts, resulting in irregular cycles of shrinkage and expansion that diverge from natural hydrological behavior [2]. The 2022 dry season recorded a mere 32% of typical water coverage compared to historical averages, prompting extensive scientific investigation into these anomalous fluctuations and their underlying causal factors [3].

The Poyang Lake region is a typical area in China prone to frequent flooding and drought. Changes in water area are influenced by a variety of factors, including climate change, human activities, and water exchange between rivers and lakes [4,5]. It is a typical seasonal lake, with a water area that varies greatly depending on the season. The water area is larger in the middle of the year and relatively smaller at the beginning and end of the year, showing obvious seasonal characteristics. While earlier research has employed remote sensing methods to identify basic patterns in Poyang Lake's annual water level variations and seasonal dynamics, comprehensive assessments remain insufficient regarding the primary causes of its accelerated surface area reduction and increasingly pronounced seasonal contrasts in recent decades. The complex interplay between environmental influences and anthropogenic pressures, along with their respective impacts, still requires thorough statistical evaluation. It limits the understanding of the root causes of these changes and the development of targeted management strategies.

The goal of this study is to thoroughly examine both historical and contemporary data regarding changes in Poyang Lake's water area to spot trends and investigate the main factors behind these changes. Additionally, this study will evaluate how these changes might affect ecological environmental protection and lake conservation management, offering a scientific foundation for the creation and application of pertinent regulations.

2. Features of Poyang Lake's alterations

2.1 . General trends of changes in Poyang Lake

Poyang Lake's water area has typically been gradually decreasing over the last 30 years, with notable shifts occurring between 1990 and 2000. The declining tendency has persisted even if the fluctuations have lessened since then [6,7]. According to related studies, Poyang Lake's water area decreased by 29.9% from 2001 to 2006, from a maximum of 4,125 km^2 in 1998 to a minimum of 2,886 km^2 in 2006 [5]. The average annual rate of water area reduction over the last ten years has been around 50 km2, suggesting that the combined effects of human activity and natural climate change have made water area contraction a common occurrence. This change not only affects regional ecological functions but also has a significant impact on lake storage capacity and biodiversity.

2.2 . Features of water area variations during the rainy and dry seasons

The area undergoes substantial variations in yearly rainfall patterns, where flood-prone zones demonstrate considerable instability across multiple timescales—from weekly intervals to multi-year cycles. Poyang Lake's surface coverage displays pronounced seasonal shifts, expanding beyond 3,500 square kilometers in summer/autumn periods before contracting dramatically to under 500 square kilometers during winter/spring months [5]. Comparative analysis reveals a generally declining fluctuation range between the 1998 deluge and 2006 drought conditions. Nevertheless, intensified weather anomalies in recent years have reversed this pattern, creating greater seasonal disparities. The catastrophic 2020 floods and unprecedented 2022 drought conditions particularly amplified the erratic nature of water surface oscillations [6]. Such hydrological volatility increasingly threatens both the lake basin's ecological equilibrium and regional water supply reliability.

2.3 . Typical characteristics of phased changes

Over the past three decades, Poyang Lake's surface coverage has experienced distinct transformation phases, primarily influenced by large-scale infrastructure developments, shifting local climatic conditions, and recurrent severe meteorological phenomena. Based on relevant research and remote sensing monitoring data, the period from 1990 to the present can be divided into the following four phases.

From early 1990 to 2002, Poyang Lake was mainly af-

ISSN 2959-6157

fected by natural seasonal hydrological changes, with significant fluctuations in water area between wet and dry seasons, but relatively stable interannual changes. After 2003, the water level of Poyang Lake experienced violent fluctuations beyond historical ranges, with uneven characteristics [8]. From 2003, when the Three Gorges Reservoir began filling, to 2010, the Three Gorges Dam effectively managed Yangtze River discharge and maintained hydrological stability throughout arid months. Concurrently, Poyang Lake experienced progressive water recession during seasonal drought conditions, and the rate of decline in water accelerated, particularly between 2006 and 2009, when the dry season water area fell to a historic low [1]. From 2011 to 2016, extreme weather events (the severe drought of 2011 and the major flood of 2016) occurred frequently, causing significant fluctuations in water area within the year. The seasonal variation in water coverage has historically reached a maximum disparity of 3,200 square kilometers, creating significant ecological stress on the lake's biological systems. Since 2017, influenced by the "Yangtze River Ecological Protection" policy, the ban on fishing in the lake area, and regional extreme climate conditions (extreme droughts in 2022 and 2023), the seasonal variation in water surface coverage at Poyang Lake has shown a progressive widening gap between high and low water periods. Notably, the 2022 drought period witnessed the lake's expanse shrinking under 370 square kilometers, marking an unprecedented minimum in five decades, accompanied by highly irregular water level patterns.

This stage of change reflects the high sensitivity of Poyang Lake to hydrological regulation, climate variability, and policy adjustments, suggesting that future lake water resource and ecological management urgently need to focus on the coupled effects of the frequent occurrence of extreme events and the combined effects of human intervention.

3. Driving factor analysis

3.1 Natural factor analysis

3.1.1 Climate change impact

The hydrological patterns of Poyang Lake have undergone significant transformations due to shifting climatic conditions, substantially impacting its water equilibrium [9]. Variations in the East Asian monsoon system have created disparities in rainfall distribution across both time and geography, fostering a scenario where southern regions experience excessive flooding while northern areas suffer from severe aridity - a situation contributing to the lake's diminishing inflow volumes [10]. Recent extreme meteorological phenomena, including extended periods of intense precipitation or unusual dry spells occurring with greater regularity and severity, represent the primary drivers behind the lake's erratic water level variations observed in contemporary times [7]. For example, prolonged heavy rainfall in the summer of 2011 caused the water area to reach a historical peak, while significantly lower rainfall in 2022 led to the lowest water area on record during the dry season [5,11]. The sustained rise in temperature has significantly increased the evaporation potential of lake surfaces, particularly during the dry season, when evaporation losses often exceed precipitation during the same period, exacerbating water level declines and area shrinkage [6]. Abnormal typhoon paths and the plum rain season also directly disrupt the annual water distribution in lake areas, leading to abnormal transitions between wet and dry seasons, significantly amplifying the interannual fluctuations in water area. For example, in 2020, an extreme rainy season triggered basin-wide flooding, causing the water area to surge to 4,200 km² in July [12]. However, the same year's winter saw an early onset of the dry season due to the La Niña phenomenon, resulting in the "flood season drought" phenomenon. The frequent occurrence of such extreme events has increased the interannual variability in water area by 30–40% compared to 20 years ago.

3.1.2 The effect of changes in the water flow of the Yangtze River

There is a close river-lake relationship between the Yangtze River and Poyang Lake. The construction and operation of the Three Gorges Project and its upstream reservoir cluster have significantly altered the natural runoff process of the middle and lower reaches of the Yangtze River [11,13]. The "store clear water and discharge turbid water" operation mode of the Three Gorges Reservoir reduces the outflow of the Yangtze River during the dry season (November to March of the following year), resulting in greater water discharge from Poyang Lake, an accelerated commencement of arid conditions, and prolonged periods of low water levels [1,6]. During the post-flood period, the discharge of sediment-free water has exacerbated channel scouring along the Yangtze River, diminishing its capacity to maintain elevated water levels in Poyang Lake through backwater influence. This phenomenon has substantially decreased the river's contribution to the lake's water volume during low-flow periods. The coordinated management of major hydraulic infrastructure has disrupted natural discharge patterns, causing reduced dry season

flows and moderated flood peaks in the central Yangtze basin. These hydrological modifications have amplified seasonal water level fluctuations in Poyang Lake, characterized by prolonged dry periods with significantly depressed levels, thereby elevating both the probability and severity of aquatic habitat contraction. Empirical data reveal that following the Three Gorges Dam's impoundment commencement in 2003, mean dry-season water levels dropped by 0.73 meters, accompanied by an approximate 12% annual reduction in surface area [6]. Monitoring records from five lake gauging stations demonstrate pronounced dry-season level reductions, principally caused by declining Yangtze water stages. The reservoir's operational strategy of retaining sediment-laden floodwater while releasing clarified flows has intensified mainstem channel degradation, progressively eroding the backwater mechanism's compensatory hydrological function.

3.2 Human activity factors analysis

3.2.1 Land reclamation and land use change

Historically, large-scale lake reclamation (especially in the 1950s to 1970s) directly encroached on many natural wetlands in lake areas, permanently reducing the natural water area and storage capacity of lakes [6]. This land restoration initiative fundamentally transformed the ecological configuration of lacustrine zones, substantially diminishing the aquatic expanse. The intervention markedly altered the spatial dynamics of wetland territories, precipitating a measurable contraction in surface water coverage. These anthropogenic modifications induced significant hydrological modifications within the watershed system. Although the intensity of land reclamation has been somewhat controlled in recent years, ongoing illegal construction of low embankments and sand mining activities continue to cause local water loss [14]. Furthermore, intensive farming practices near the lake have caused disproportionate use of chemical fertilizers, dramatically elevating nitrogen and phosphorus concentrations in the water body. This nutrient overload has hastened both eutrophic conditions and sediment accumulation within the lake ecosystem. The progressive decline in basin capacity (due to sediment deposition) has consequently diminished the surface area coverage at equivalent water elevations, impairing the reservoir's water retention functionality.

3.2.2 Water engineering regulation

Beyond the Yangtze River's upper-reach initiatives, hydrological operations across the Poyang Lake watershed and its five major tributaries (Ganjiang, Fuhe, Xinjiang, Raohe, and Xiushui systems) substantially influence both water influx quantities and surface coverage dimensions. The controversial Poyang Lake Hydraulic Control Structure proposal has garnered considerable scrutiny owing to its capacity to modify fundamental river-lake interactions [3]. While upstream dam cascades along these tributaries could theoretically normalize annual inflow distributions, their operational patterns frequently diminish dry-period discharges (particularly evident in the Xiushui basin), thereby intensifying seasonal water deficits within the lacustrine ecosystem [13]. Additionally, dredging navigation channels in rivers like the Gan River has caused local riverbed erosion, reducing the river's natural water replenishment capacity for the lake and further weakening the lake's ability to maintain water levels during the dry season. These projects alter the natural hydrological processes of rivers (flow rate, velocity, sediment transport), thereby restructuring the lake's water replenishment patterns and water level dynamics [15].

The planning of the Poyang Lake Water Conservancy Project has sparked controversy. Although the project is intended to alleviate the drying up of Poyang Lake during the dry season, scientists have expressed concerns that the Poyang Lake Water Conservancy Project may have negative impacts on cranes and other overwintering waterbirds. The suggested strategy for managing drought conditions while disregarding flood control could significantly modify the dynamic between rivers and lakes [1,7]. According to simulation results, increasing dry season water levels by 1-2 meters might lead to a 0.3-0.5-meter reduction in the Yangtze River's mid-lower sections, intensifying water scarcity conflicts in arid periods. Furthermore, channel excavation along the Ganjiang River has resulted in 2–3-meter bank erosion, diminishing the lake's water supply potential and progressively impairing its dry season water retention capabilities.

The inflow into the lake has changed in both time and space since the five-river cascade power plants were built (the Gan, Fu, Xin, Rao, and Xiushui rivers). For example, the regulation of the Zhelin Reservoir has made the distribution of Xiushui River inflow into the lake more uniform throughout the year, but the inflow during the dry season has decreased by about 15%, exacerbating the imbalance between river and lake water volumes [3].

3.2.3 Urban expansion and water demand change

The accelerated urban expansion and industrial growth surrounding Poyang Lake has resulted in continuously rising requirements for water resources to support both industrial operations and domestic consumption. The rigid growth in demand for agricultural irrigation and industrial water use, particularly during dry seasons, has significantly en-

ISSN 2959-6157

croached on ecological water space, increasing pressure on the lake to maintain minimum ecological water levels and water area. This sustained growth in water demand has exacerbated regional water resource pressures. The increasing extraction of groundwater in the lake region has triggered localized ground subsidence. Changes in surface elevation have weakened the natural water storage capacity of the lake basin, reducing the lake's resilience to extreme dry events and resulting in a decrease in the actual water area that can be maintained.

3.3 Comprehensive impact analysis

The fluctuations in Poyang Lake's surface area stem from complex interdependencies between environmental conditions and anthropogenic influences. These elements frequently create reinforcing cycles that intensify detrimental outcomes. A case in point is the severe drought occurrence in 2022, which originated from substantially decreased upstream Yangtze River discharges coupled with persistent thermal conditions across the lake region. This combination accelerated moisture loss through evaporation, initiating a sequence of "extreme desiccation" phenomena that ultimately produced surface water coverage substantially beneath historical norms. The Three Gorges Dam's operational patterns have fundamentally modified the Yangtze's natural discharge characteristics, causing depressed water stages and extended dry intervals within Poyang Lake. Furthermore, although hydraulic engineering initiatives in the Poyang basin can elevate mean water elevations during arid phases, they simultaneously decrease current speeds across the lake body, extend hydraulic residence periods, and potentially generate ecological and water chemistry consequences [1]. Research generally agrees that human activities have contributed more to recent changes in water areas than natural factors. The sharp decline and increased volatility of water areas have directly led to the degradation of submerged vegetation, the loss of important habitats such as fish spawning grounds, and a significant reduction in biodiversity in the lake area [7]. It is worth noting that ecosystem degradation often lags changes in hydrological conditions by several years, increasing the difficulty of ecological restoration.

4. Conclusion

Through methodical examination, this study shows that Poyang Lake's water area is experiencing significant variations and ongoing decline. There have been noticeable phasic shifts in the lake's hydrological circumstances over the last thirty years, with the dry-season water area declining dramatically and the wet-season water area gap widening. This transformation has evolved from being dominated by natural fluctuations, through intensified regulation by water conservancy projects and frequent extreme climate events, to the recent overlap of policy interventions and climate stressors, fully reflecting the lake system's sensitivity to multiple stressors.

An examination of the underlying factors demonstrates that transformations in aquatic systems arise from the intricate interplay between climatic shifts and anthropogenic influences. Regarding meteorological conditions, modifications in seasonal rainfall distribution, heightened occurrences of severe droughts and floods, coupled with intensified evaporation rates, have disrupted the equilibrium of reservoir volumes. Concerning human intervention, the implementation of extensive hydraulic infrastructure along the Yangtze basin has substantially modified the dynamic between riverine and lacustrine environments, diminishing the river's capacity to restore lake water reserves. Historical land reclamation has continuously reduced water body space, while water resource development within the basin has exacerbated water shortages during dry seasons. Water competition during urbanization has further encroached on ecological needs. Especially when natural droughts and human interference overlap, a vicious cycle is triggered, at which point human activities have become the dominant driving force.

The ongoing shrinkage and severe fluctuations of water bodies have severely impaired the ecological functions of Poyang Lake. When the lake's area falls below the critical threshold required to maintain a healthy ecosystem, the degradation of aquatic vegetation and loss of habitats leads to a significant decline in biodiversity. Additionally, the ecosystem's rehabilitation progresses more slowly than hydrological shifts, substantially amplifying management challenges. For safeguarding ecological security in the Yangtze's mid-lower sections, immediate basin-scale water allocation coordination becomes imperative to maintain essential environmental flows while executing spatial rehabilitation initiatives for wetland systems.

References

[1] G. Lai, P. Wang, L. Li, Possible impacts of the Poyang Lake (China) hydraulic project on lake hydrology and hydrodynamics, Hydrol. Res. 47 (2016) 187-205.

[2] C.X. Wu, B.Q. Tian, P. Gao, et al., Analysis on variation characteristics and driving factors of water area in Poyang Lake during dry season in recent 40 years, J. Soil Water Conserv. 35 (2021) 177-184+189.

[3] H.L. Liu, G.F. Dai, W. Zhang, B. Liao, Analysis of the water

ecological environment changes of the large lakes and driving factors in Lake Poyang basin: A case study of Lake Zhelin, J. Lake Sci. 27 (2015) 266-274.
[4] X. Cai, The change analysis of water stage and beach wetland in Poyang Lake with the aid of multi-temporal active and passive remote sensing data, Wuhan University, Wuhan (2010).
[5] Z.X. Zhang, X. Chen, C.Y. Xu, Y. Hong, J. Hardy, Z.H. Sun, Examining the influence of river–lake interaction on the drought and water resources in the Poyang Lake basin, J. Hydrol. 522 (2015) 510-521.
[6] B. Tian, P. Gao, X. Mu, et al., Water area variation and river–lake interactions in the Poyang Lake from 1977–2021, Remote Sens. 15 (3) (2023) 600.
[7] J.N. Meng, H.W. Fang, L. Huang, G.J. He, X.B. Liu, C.Y. Xu, X.H. Wu, D. Scavia, Multidimensional ecosystem assessment of Poyang Lake under anthropogenic influences, Ecol. Model. 473 (2022) 110134.
[8] B. Li, G.S. Yang, R.R. Wan, Reassessment of the declines in the largest freshwater lake in China (Poyang Lake): uneven trends, risks and underlying causes, J. Environ. Manag. 342 (2023) 118157.
[9] H.L. Liu, G.F. Dai, W. Zhang, B. Liao, Analysis on aquatic ecological environment changes and driving forces of large reservoirs in Poyang Lake Basin: A case study of Zhelin Lake, J. Lake Sci. 27 (2015) 266-274.
[10] Z. Dou, B. Liu, M. Henderson, W. Zhou, R. Ma, M. Chen, Z. Zhang, Changes in Timing and Precipitation of the East Asian Summer Monsoon over China Between 1960 and 2017, Earth 6 (2025) 24.
[11] F. Lian, C.M. Hu, X.L. Chen, X.B. Cai, L.Q. Tian, W.X. Gan, Assessment of inundation changes of Poyang Lake using MODIS observations between 2000 and 2010, Remote Sens. Environ. 121 (2012) 80-92.
[12] Y.J. Meng, X.C. Wang, J.Z. Wang, Q. Li, Meteorological characteristics analysis of abnormal rainstorm and flood in Yangtze River Basin in summer 2020, Clim. Change Res. Lett. 10 (2021) 325-336.
[13] J. Yao, J.F. Gao, X.B. Yu, Q. Zhang, Impacts of a proposed water control project on the inundation regime in China's largest freshwater lake (Poyang Lake): Quantification and ecological implications, J. Hydrol. Reg. Stud. 40 (2022) 101024.
[14] Q. Li, G. Lai, A.T. Devlin, A review on the driving forces of water decline and its impacts on the environment in Poyang Lake, China, J. Water Clim. Change 12 (2021) 1370-1391.
[15] J. Yao, D. Zhang, Y. Li, et al., Quantifying the hydrodynamic impacts of cumulative sand mining on a large river-connected floodplain lake: Poyang Lake, J. Hydrol. 579 (2019) 124156.