# A study on the Change of Surface Water in Zhejiang Province Based on Long-Series Remote Sensing Data

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**Abstract.** Surface water bodies are characterized by dynamics, complexity and seasonality, so it is important to accurately portray the dynamics of surface water body changes for regional water security, water resources utilization and the construction of happy rivers and lakes. Based on the long-series remote sensing data, this study explores the spatial and temporal variability of surface water bodies such as rivers, lakes, reservoirs and ponds in Zhejiang Province over the past four decades, taking 1980, 2000 and 2020 as the time nodes. The results of the study show that: (1) Continuous expansion of surface water bodies in Zhejiang Province over the past forty years, with reservoirs showing the most significant growth rates and extents; (2) Lakes and reservoirs in Zhejiang Province are predominantly small in size, with approximately 85% having an area $\leq 0.25km^2$. Nevertheless, larger lakes and reservoirs, though fewer in number, play crucial roles in the aquatic landscape; (3) From the point of view of the spatial distribution, the area of the upper and middle reaches of the rivers are relatively stable, whereas the downstream areas experience notable shrinkage. Lakes are mainly concentrated in the East Tiaoxi River basin and continue to expand, while reservoirs are mainly concentrated in Hangjiahu area, upper reaches of the Qiantang River, and upper reaches of the Ou River, showing discernible expansion trends; (4) From the interactive relationship between watersheds and other land use types, the expansion of water bodies is mainly derived from the transfer of cultivated land and forest land, while the construction of towns and cities is the main driving force for the disappearance of water bodies.

**Keywords:** surface water; remote sensing; Zhejiang province; spatiotemporal variation


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# 1 Introduction

Water serves as the fundamental source of life, whereas river-lake-reservoir systems constitute the vital lifelines underpinning the emergence and progression of human society [1-2]. Although surface water occupy a small proportion of the Earth's surface, they play crucial roles in providing water sources, maintaining ecosystems, regulating climate, purifying the environment, and mitigating floods and droughts. In recent years, with the deepening of climate change and the extensive influence of human activities, the spatial and temporal distribution pattern of surface water bodies has been severely disturbed, and the natural law of hydrology and water resources evolution has been changed and caused a series of environmental problems, which has had certain impacts on the safety of people's lives and properties. Numerous scholars have delved into the surface water dynamics during the last decades. Extensive datasets pertaining to surface water bodies, characterized by moderate to coarse spatial resolutions, have been developed and employed to observe and monitor these water bodies. Examples include the downscaled GIEMS-D15 (15 arc-second) [3], the Global Water Body data (GLOWABO, 0.5 arc-second) [4], the Global Lake and Wetland Database (GLWD, 1km) [5], and the global monthly surface water extent data (0.25-degree resolution) [6]. Remote sensed achieve provide higher spatial resolutions ranging in the tens of meters to effectively identify smaller inland surface water bodies, especially in high developed regions [7-8]. With the help of the remote sensed data, a serious decline in the area of watersheds over the past 30 years have been detected at the global level, including a total of $1.15\times10^5$ km$^2$ of land converted to water, but more watersheds (about $1.73\times10^5$ km$^2$) have been lost due to the conversion to non-watersheds [9]. Within China, surface water area decreases in water-poor northern China but increases in water-rich southern China from 1989 to 2016 [10], although there were strong spatial and temporal differences in the expansion process [11]. In the highly economically and socially developed Yangtze River Delta region, human interference is the main driving factor of the surface water dynamics [12-13]. The coexistence of large-scale urban expansion encroaching on river and lake systems and artificially constructed new lakes and reservoirs has led to more complex regional water surface changes. Identifying the spatiotemporal characteristics, patterns, and long-term trends of surface water changes is the basis for regional hydrological and water resources situation analysis, as well as an important environmental aspect of regional water ecology and water environmental security. However, research on long-term, high spatiotemporal resolution surface water changes at regional scales remains quite limited. With the rapid development of computer science and remote sensing technology, multi-source remote sensing image data have been widely used in the monitoring and research of surface water bodies. Comparative studies have shown that various products such as MODIS data (MOD09A1) and Landsat data (Multi-spectral Scanner, MSS; Thematic Mapper, TM; Enhanced Thematic Mapper+, ETM+; and Land Imager, OLI) have good potentials for application in water body identification [3].

Many studies on water body changes are carried out at the global, national, river basin or regional scales [14-15], while few are conducted at the provincial administrative scale. Although the water cycle is based on river basins, water resource governance and management are mostly carried out at the provincial level. Therefore, it is necessary to conduct research on water body changes at the provincial level, especially in the high developed province. Zhejiang is known for its water and has prospered because of its water, with many rivers and a dense water network. In the past twenty years, Zhejiang has launched the "Thousand Village Demonstration and Ten Thousand Village Rectification", "Small and Medium-sized River Management", "Five Waters", "Beautiful River and Lake" and "Happy River and Lake". "Five Water Control", "Beautiful Rivers and Lakes", "Happy Rivers and Lakes" and other projects. Therefore, this study takes Zhejiang Province as an example and, based on 30-meter spatial resolution remote sensing images, draws maps of the distribution of surface water in Zhejiang Province for the years 1980, 2000, and 2020. Therefore, the spatial and temporal dynamics of the surface water area are analyzed, and the driving mechanisms of the changes are investigated, to comprehensively understand the regional water surface dynamics under climate change and anthropogenic disturbances. The purpose of this study is to ascertain the characteristics of surface water distribution, elucidate the spatiotemporal variations in rivers, lakes, and reservoirs, and identify the driving forces behind changes in the river-lake-reservoir system. The ultimate aim is to provide guidelines for the development of sustainable river-lake infrastructure projects and the assessment of the ecological health of river-lake-reservoir systems. This, in turn, will reinforce the security of regional water resources and foster the sustainable development of the regional economic and social environments.

# 2 Methods and Materials

## 2.1 Overview of the Study Area

Zhejiang Province is located in the south wing of China's Yangtze River Delta (27°02′~31°11′N, 118°01′~123°10′E), east of the East China Sea, south of the border with Fujian, west of Jiangxi and Anhui, north of Jiangsu and Shanghai. Located in the middle of the subtropics, it is characterized by a monsoon-influenced humid climate with abundant rainfall and temperatures generally warm. The average annual precipitation ranges between 1100-2000 mm, resulting in abundant runoff and numerous rivers and lakes crisscrossing the region. The topography of the territory slopes from southwest to northeast, giving rise to rivers like the Qiantang River, Yongjiang River, Cao'e River, Tiaoxi River which flow southwest to northeast and empty into Hangzhou Bay. Additionally, there are east-west rivers such as the Ou River, Ling River, Fei Yun River, and Ao River, which flow directly into the sea. The other West Lake in Hangzhou, East Lake in Shaoxing, South Lake in Jiaxing, and East Qianhu Lake in Ningbo, four major lakes[16] (Fig. 1). In addition, due to the low per capita water resources, the spatial distribution of water resources and the degree of economic development is low, Zhejiang Province has built a large number of reservoirs, ponds and canals in order to realize the regional water security.

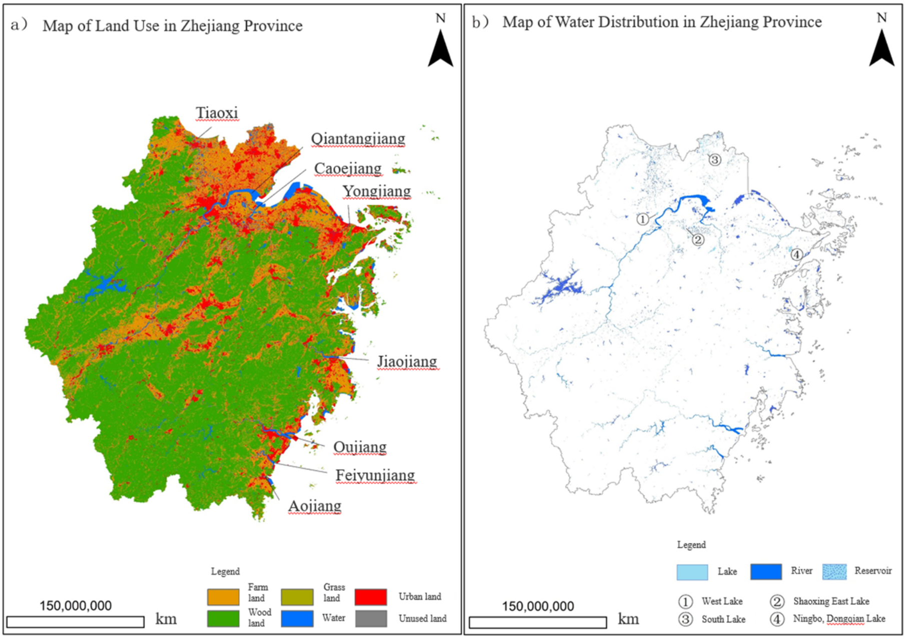


**Fig. 1.** Land use (a) and water bodies distribution in Zhejiang Province (b) (2020)

## 2.2 Research Methods

Remote sensing images with long series and high spatial resolution have obvious advantages for revealing surface changes. In this study, a total of three Landsat series remote sensing images were collected in 1980, 2000 and 2020 (Table 1). Based on interactive interpretation techniques involving both manual and automated processes, information regarding rivers, lakes, and reservoirs within the study area was extracted. The interpretation results were supplemented, corrected and verified by means of Zhejiang Provincial Rivers Handbook[17], topographic maps, thematic maps, statistical data, Google images and field research. Random sampling validation showed that the accuracy of water body deciphered data was above 90%.

**Table 1.** Data sources used in this study

| Study period | 1980 | 2000 | 2020 |
|---|---|---|---|
| Satellite Imaging time | 1979 - 1982 | 1999 - 2001 | 2020 |
| | Landsat MSS/TM | Landsat-TM/ETM | Landsat 8 |

## 2.3 Validation

To validate the quality of our interpretation, we conducted a random sampling inspection of field survey points. We categorized the accuracy levels into eleven distinct grades, ranging from A0 to A10. Here, A10 represents the highest level of accuracy, signifying that all sampled grids align perfectly with the interpreted results, achieving a 100% accuracy rate. In contrast, A0 denotes the lowest level of accuracy, indicating a complete mismatch between the interpreted image and reality. Based on validation results obtained from 26 randomly sampled points across the Zhejiang Province, the accuracy of water was approximately 89%. Among them, reservoirs have the highest accuracy with regular boundary (93%), while rivers showed the lowest accuracy (82%), due to the winding, narrow, and elongated river channel. The interpreted results were then overlaid with data from the third national land survey map and Google imagery within specific representative timeframes to evaluate the classification accuracy. Specifically, we focused on Xinanjiang, Tankeng, Hunanzhen reservoirs and Xihu Lakes, and discovered that the water body boundaries aligned with those defined by the third national land survey to approximately 90%.

# 3 Findings

## 3.1 Trends in Quantitative Changes

### 3.1.1 Trend of Surface Water Area Change.

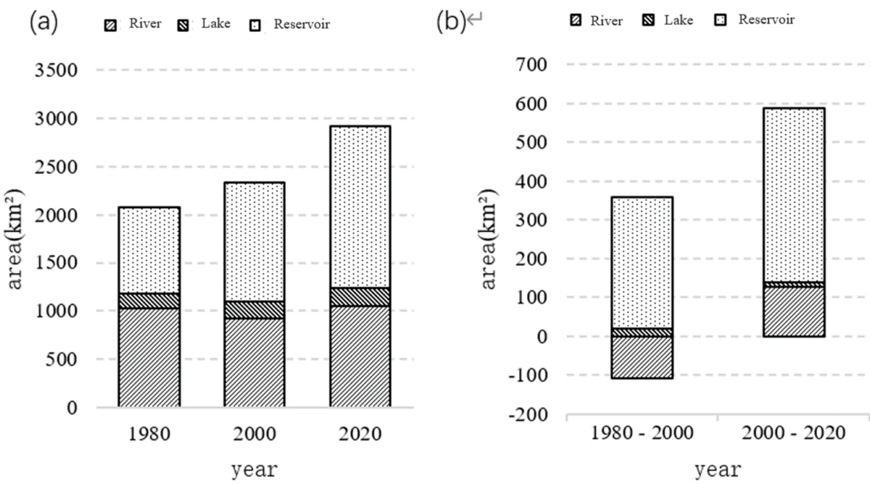


**Fig. 2.** Area of rivers, lakes and reservoirs (a) and their trends (b), 1980-2020

The study shows that over the past 40 years, the area of rivers, lakes, and reservoirs in Zhejiang Province has continuously expanded, with an expansion rate of nearly 40%. The area of water bodies increased from 2083.21km$^2$ in 1980 to 2923.33km$^2$ in 2020, with an annual expansion rate of 1% (Fig. 2), the relevant results are basically the same with the literature[18], which indicates that the results of remote sensing imagery interpretation are reasonable. From 1980 to 2000, except for the total area of rivers decreased by 10.32%, the total areas of the other two types of water bodies showed an increasing trend. The total area of lakes and reservoirs ponds increased by 13.48% and 37.59%, respectively. From 2000 to 2020, the total area of the three types of water bodies showed different degrees of increase. Among them, the total area of reservoirs increased by 447.47 km², an increase of 36.21%, and the total areas of rivers and lakes also showed different degrees of increase, with the values of 127.31km² and 12.32km² respectively. The regional water surface rate increased accordingly, from 1.95% in 1980 to 2.73% in 2020.

### 3.1.2 Changes in the Number of Lakes and Reservoirs.

Lakes in Zhejiang Province show a continuous expansion trend, and the expansion rate has obvious time differences (Table 2). As far as the number of lakes is concerned, it increased from 687 in 1980 to 738 in 2000, and then decreased to 700 in 2020, showing a trend of initial growth followed by a decline. The number of small lakes (≤0.25 km²), which account for more than 85% of the number, first increased and then decreased, while the rest of the lakes showed a steady increasing trend. Both the average area and total area have been continuously increasing, particularly the total area, which has grown by over 20% during the study period, while the contribution of the area of small lakes (≤0.25 km²) to the overall area decreased from 28.60% in 1980 to 23.92% in 2020.

**Table 2.** Changes in the area and number of lakes since 1980 to 2020

| single area / km² | quantity | | | average area / km² | | | total area / km² | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1980 | 2000 | 2020 | 1980 | 2000 | 2020 | 1980 | 2000 | 2020 |
| ≤0.25 | 687 | 738 | 700 | 0.07 | 0.06 | 0.07 | 45.33 | 47.65 | 45.96 |
| 0.25 - 0.5 | 47 | 48 | 53 | 0.34 | 0.35 | 0.35 | 16.1 | 16.61 | 18.42 |
| 0.5 - 1 | 28 | 35 | 35 | 0.69 | 0.7 | 0.71 | 19.42 | 24.61 | 24.72 |
| 1 - 10 | 27 | 31 | 32 | 2.2 | 2.35 | 2.22 | 59.42 | 72.77 | 71.14 |
| ≥10 | 1 | 1 | 2 | 18.21 | 18.21 | 15.96 | 18.21 | 18.21 | 31.91 |
| overall changes | 790 | 853 | 822 | 0.2 | 0.21 | 0.23 | 158.48 | 179.84 | 192.16 |
| | - | 7.97% | -3.63% | - | 5.00% | 9.52% | - | 13.48% | 6.85% |

The number of reservoirs in Zhejiang Province increased continuously during the study period, and the growth rate from 2000 to 2020 was much higher than that from 1980 to 2000 (Table 3). In terms of quantity, the number of reservoirs increased slightly from 2,663 in 1980 to 3,239 in 2000, and then to 4,606 in 2020, the vast majority of which were small in size (≤0.25km²) and accounted for nearly 85% of the total number of reservoirs, and the number of mega-reservoirs was small (>1km²). While the number of super-large reservoirs (>10km²) has exhibited a steady growth trend, their average area has been shrinking. Conversely, the average area of other reservoirs has remained relatively stable, with an overall pattern of initial expansion followed by a subsequent reduction in individual reservoir size. At the same time, the overall surface area of reservoirs has expanded dramatically, first from 898.15 $km^2$ in 1980 to 1,235.74 $km^2$ in 2000, and then to 1,683.21$km^2$ in 2020, with an expansion rate of more than 85%. In addition, although the number of small reservoirs was large, their contribution to the reservoir area was small and decreasing, from 20.06% in 1980 to 16.43% in 2020; the number of large reservoirs with more than 10$km^2$ was small, their contribution to the water surface area was high and the contribution rate was decreasing, from 53.55% in 1980 to 41.57% in 2020; and the area of reservoirs with 0.5-10$km^2$ had a higher and decreasing contribution rate, from 53.55% in 1980 to 41.57% in 2020; the area of reservoirs with 0.5-10$km^2$ had a higher and decreasing contribution rate, its overall area share continued to expand, from 20.69% in 1980 to 30.74% in 2020, which indicates that new reservoirs are mainly small and medium-sized during the study period, resulting in a fragmented phenomenon.

**Table 3.** Reservoir area and number variation since 1980 to 2020

| single area / km² | quantity | | | average area / km² | | | total area / km² | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1980 | 2000 | 2020 | 1980 | 2000 | 2020 | 1980 | 2000 | 2020 |
| ≤0.25 | 2323 | 2778 | 3879 | 0.08 | 0.08 | 0.07 | 180.17 | 214.58 | 276.63 |
| 0.25 - 0.5 | 198 | 246 | 341 | 0.35 | 0.35 | 0.36 | 69.41 | 86.11 | 122.22 |
| 0.5 - 1 | 76 | 109 | 187 | 0.68 | 0.69 | 0.7 | 51.46 | 74.89 | 129.75 |
| 1 - 10 | 62 | 98 | 187 | 2.17 | 2.02 | 2.43 | 134.39 | 198.37 | 454.94 |
| ≥10 | 4 | 8 | 12 | 115.68 | 82.72 | 58.31 | 462.72 | 661.79 | 699.66 |
| overall changes | 2663 | 3239 | 4606 | 0.34 | 0.38 | 0.37 | 898.15 | 1235.74 | 1683.21 |
| | - | 21.63% | 42.20% | - | 11.76% | -2.63% | - | 37.59% | 36.21% |

## 3.2 Spatial Dynamic Variation

### 3.2.1 Spatial Dynamic Change of Rivers.

The water surface of rivers in Zhejiang Province is highest in the Qiantang River and Ou River system (Fig. 3a). From 1980 to 2000, the water surface of rivers in the province generally shrunk, and the main river channel was constantly narrowed, especially in the estuary of the Qiantang River, which is strongly interfered by human activities (Fig. 3b). From 2000 to 2020, the phenomenon of shrinking and expanding existed side by side. During this period, as the government, society and the public deepened their understanding of the importance of the river network and water system, the protection and restoration of river water surfaces were gradually on the right track, with the upper reaches of the Ou River in the south and the lower reaches of the Qiantang River in the east showing more obvious growth in river water surface area (Fig. 3c).

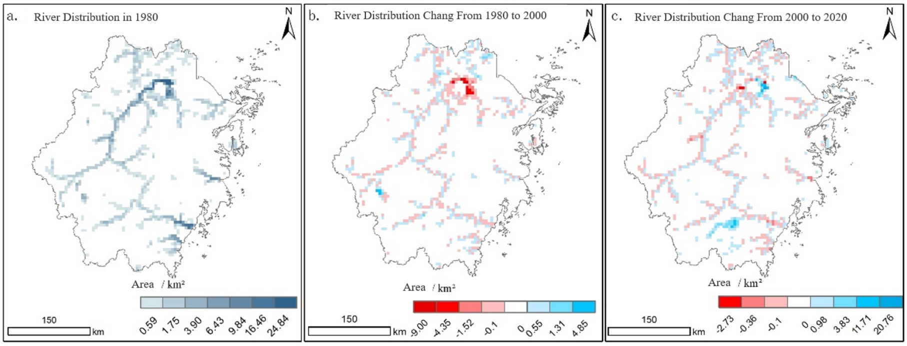


**Fig. 3.** Distribution and dynamic change of rivers in Zhejiang Province (5km*5km Resolution)

### 3.2.2 Spatial Dynamic Change of Lakes.

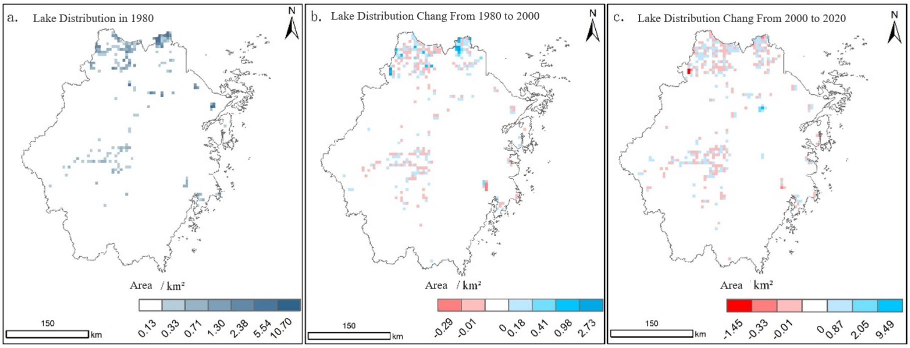


**Fig. 4.** Distribution and dynamics of lakes in Zhejiang Province (5km*5km Resolution)

Lakes in Zhejiang Province are mostly concentrated in the East Campsis River basin in the northern part of the province and the upper reaches of the Qiantang River in the south-central part of the province, and the number of lakes in the southeastern part is very sparse (Fig. 4a). During the study period, lakes expanded significantly in the northern part of the province, while shrinkage dominated in the central and southern parts. Especially during the period from 1980 to 2000, lakes in the East Campsis Creek basin expanded extensively (Fig. 4b). From 2000 to 2020, lakes in the upper reaches of the Qiantang River continued their extinction pattern under the control of continuous warming of the climate and artificial gates and pumping stations, etc., while lakes in the lower reached expanded one after another, or new lakes appeared (Fig. 4c). This indicates that the expansion of lakes mainly occurs in the downstream plains where agriculture is well developed, while the area of lakes in the hilly and mountainous regions continues to shrink.

**3.2.3 Spatial Dynamic Changes of Reservoirs and Ponds.**

Reservoirs and pit-ponds are widely distributed in Zhejiang Province, especially in the Hangjiahu area in the northeastern part of the province, where reservoirs and pit-ponds are concentrated and widespread (Fig. 5a). During the study period, the expansion of the area of lake reservoirs and ponds was extremely dramatic. In 1980, reservoirs and pit-ponds were mainly found in the hilly fringe of the Hangjiahu Plain, aiming to provide flood safety and water security for the densely populated downstream plains with extensive farmland. In recent decades, due to the double impact of climate change and human activities, the regional flood control and drainage situation has become more severe, the demand for clean energy such as hydropower has become increasingly strong, and the water use for industry, agriculture, and domestic use has increased dramatically, so the construction of reservoirs has been carried out in full swing. From 1980 to 2000, a large number of newly constructed reservoirs and ponds in the hinterland of the Hangjiahu Plain in Zhejiang Province, and the upstream areas of the Qiantang River and Ou River have also become hotspots for the expansion of reservoir pits (Fig. 5b). From 2000 to 2020, the trend of large-scale and continuous expansion of reservoirs and ponds became more obvious, and the demise of reservoirs was common in areas with rapid urban construction expansion, such as Hangzhou and Ningbo (Fig. 5c).

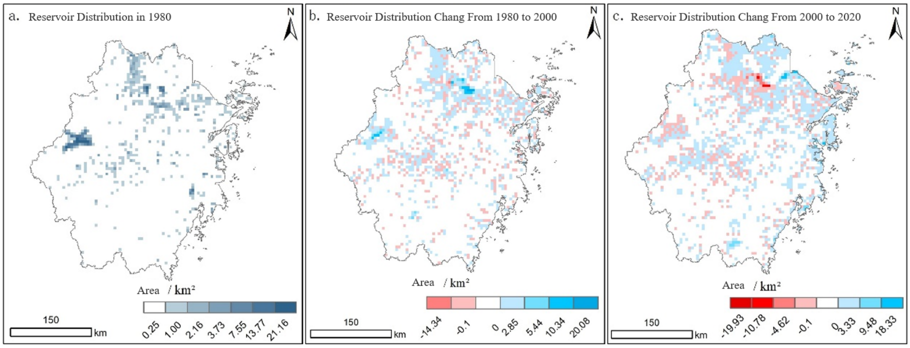


**Fig. 5.** Distribution and dynamic change of reservoir pit ponds in Zhejiang Province (5km*5km Resolution)

## 3.3 Land Use Transfer

The land use transfer analysis shows that there was a strong interaction between water bodies and urban land, cultivated land and forest land during the study period (Table 4). Among them, the town construction encroached on the water body in large quantities, and about 326.46km² of the water body was encroached by the town during the study period. The transfer in and out between arable land and water bodies were both very strong, with slightly more transfer in than out, and about 90km² of arable land was converted to water bodies on a net basis. Forested land was dominated by net loss, with about 148.23km² of forested land being inundated by expanding waters, with a net conversion rate of about 50%. This indicates that the net loss of water bodies is mainly caused by urban construction, and the disturbance of surface water body dynamics by intense human activities is very obvious. In contrast, the net income of water bodies mainly comes from the inundation of farmland and forest land brought about by the construction of locks and dams and the expansion of reservoir pits and ponds.

**Table 4.** Land use transfer matrix of Zhejiang Province, 1980-2020

| land-use type | | 2020 /km² | | | | | |
|---|---|---|---|---|---|---|---|
| | | Grass land | Urban land | Farm land | Wood land | Water | Unused land |
| 1980 /km² | Grass land | 1695.91 | 58.99 | 34.76 | 227.53 | 5.35 | 6.41 |
| | Urban land | 4.25 | 2457.72 | 213.78 | 31.49 | 36.93 | 0.04 |
| | Farm land | 60.73 | 5171.38 | 22680.08 | 1678.44 | 515.39 | 2.31 |
| | Wood land | 528.33 | 877.65 | 1247.90 | 63672.01 | 148.23 | 12.00 |
| | Water | 47.08 | 326.46 | 425.14 | 73.41 | 2287.76 | 1.11 |
| | Unused land | 3.16 | 4.35 | 1.57 | 42.15 | 0.73 | 16.20 |

Note: Underline indicates the number of transfers in and out of water bodies and other land use, and bold indicates transfers in or out of larger areas.

# 4 Discussion

Reservoirs serve as crucial storage facilities for managing water supply during droughts and floods, making their growth indicative of increased investments in water infrastructure and a potential enhancement in water availability and resilience [19-20]. This study reveals the continuous expansion of surface water bodies, particularly in reservoirs. This underscores the environmental impacts of reservoir construction and operation, such as alterations to downstream flows, habitat fragmentation, and greenhouse gas emissions from reservoirs [19, 21-22].

The finding that lakes and reservoirs in Zhejiang Province are predominantly small in size but larger ones play crucial roles in the aquatic landscape highlights the importance of protecting and managing both small and large water bodies. Small water bodies, while numerous, can be vulnerable to pollution, degradation, and loss due to land use changes [11, 23]. On the other hand, larger lakes and reservoirs provide essential ecosystem services, including biodiversity support, water purification, and recreation [24-25]. This underscores the need for a holistic approach to water resources management that addresses the needs of both small and large water bodies.

The study's analysis of spatial distribution reveals stability in upstream and middle reaches of rivers compared to notable shrinkage in downstream areas. This could be attributed to a combination of factors, including increased water extraction for agriculture and urbanization, sedimentation, and altered flow patterns due to upstream damming. The continued expansion of lakes in the East Tiaoxi River basin and reservoirs in specific regions indicates targeted investments and policies. However, the downstream shrinkage highlights the need for comprehensive watershed management strategies that consider the cumulative effects of upstream activities on downstream ecosystems [26-27].

The identification of cultivated land and forest land as the primary sources of water body expansion, and urbanization as the main driver of water body disappearance, underscores the complex interactions between land use change and hydrological processes. This highlights the importance of integrating land use planning and water resources management policies. Policymakers must consider the trade-offs between agricultural productivity, forest conservation, urban expansion, and water resource sustainability. Additionally, it underscores the need for adaptive management strategies that can respond to changing land use patterns and their impacts on water bodies [28-30].

This study significantly contributes to the current understanding of surface water changes in Zhejiang Province by providing a comprehensive, long-term, and spatially detailed analysis of the dynamics of rivers, lakes, reservoirs, and ponds over the past four decades. By leveraging long-series remote sensing data and focusing on key time nodes (1980, 2000, and 2020), the study fills critical gaps in the historical record of surface water changes in this province, and integrating both research boundaries and administrative boundaries. The study of rivers, lakes, and reservoirs' changes in Zhejiang Province is crucial for the River and Lake Chief System. It informs decision-making by providing accurate data on water resources, directs targeted governance efforts, and evaluates the system's outcomes. This research also promotes public engagement, raises awareness, and drives innovation in water management. By understanding the dynamics of waterbodies, the system can ensure effective and sustainable policies that respond to the region's evolving needs.

## 5 Conclusion and Prospect

(1) In terms of time change, during 1980-2020, the area of water bodies such as rivers, lakes and reservoirs and ponds in Zhejiang Province has been expanding, especially reservoirs, the expansion speed and magnitude is far more than the rest of the two types of water bodies, presenting a contiguous expansion trend;

(2) From the aspect of quantity statistics, lakes and reservoirs in Zhejiang Province are all small in area, and the waters are highly fragmented, with 85% of the lakes and reservoirs having an area of $\leq 0.25$ km$^2$;

(3) From the perspective of spatial change, the middle and upper reaches of the rivers in Zhejiang are more stable, and the lower reaches are shrinking more obviously, lakes are mainly distributed in the East Tiaoxi River Basin and continue to expand, reservoirs, pits and ponds are mainly expanded from the edge of the HangJiHu Plain to the hinterland, and the upper reaches of the Qiantang River and Ou River are also hot spots for the distribution and expansion of reservoirs and pit-ponds;

(4) The land use transfer matrix shows that cultivated land and forest land are the main sources of land for the expansion of watersheds, while the net loss of watersheds mainly stems from the encroachment and encroachment of urban construction on river and lake water systems.

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