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Research Article

Jingyi Fu and Yong Liu*

Monitoring plateau lake area changes in Yunnan province, southwestern China using medium-resolution remote sensing imagery: applicability of water indices and environmental dependencies

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Abstract: Lake area dynamics are closely linked to climate change, and accurate shoreline extraction is critical for monitoring lake area changes, with significant implications for water resource management, ecological conservation, and regional sustainable development. This study focuses on the key plateau lakes in Yunnan Province, Southwestern China, utilizing multi-source medium-resolution remote sensing data from Landsat-8 OLI, Sentinel-2 MSI, and GF-1 WFV to compare the shoreline extraction accuracy of three water indices, Normalized Difference Water Index (NDWI), Modified Normalized Difference Water Index (MNDWI), and Automated Water Extraction Index (AWEI). The results indicate that (1) the medium-resolution remote sensing data is suitable for rapid monitoring of the area change of large-scale lakes with regular shorelines and low vegetation coverage, and higher spatial resolution data can significantly improve the lake shoreline extraction accuracy. (2) Different remote sensing water indices demonstrate significant variations in applicability. NDWI is sensitive to open water but prone to vegetation interference. MNDWI improves accuracy in vegetated areas by enhancing the separability between water and vegetation/soil. AWEI effectively suppresses shadow noise, making it ideal for complex terrains with mountainous shadows. Therefore, it is essential to integrate multi-source remote sensing data with ground-based monitoring technologies to establish a multi-scale lake shoreline monitoring system. This integrated approach enables real-time and precise monitoring of plateau lake dynamics, which is of great significance for ecological conservation and management of the plateau lakes in Yunnan Province.

Keywords: shoreline extraction; water index; plateau lakes; overlay analysis

***Corresponding author: Yong Liu**, Faculty of Geography, Yunnan Normal University, Kunming 650500, China; and Yunnan Key Laboratory of Plateau Geographic Processes and Environment Change, Kunming 650500, China, E-mail: 3637@ynnu.edu.cn
Jingyi Fu, Faculty of Geography, Yunnan Normal University, Kunming 650500, China

1 Introduction

Lakes, as critical components of terrestrial ecosystems, are highly sensitive to climate variations [1]. Fluctuations in temperature and alterations in precipitation patterns directly impact the water balance of lakes, leading to either expansion or shrinkage in their surface area. The shoreline, as the transitional zone between water and land, undergoes positional and morphological changes that precisely reflect dynamic variations in lake area. Accurately extracting lake shorelines not only enables a clear understanding of spatial changes across different time periods but also facilitates deeper investigations into the lake evolution dynamics, holding significant implications for climate change research.

The shoreline of a lake, located at the interface between water bodies and land, serves not only as a crucial morphological feature of lakes but also as a non-renewable land resource with significant socio-economic and ecological functions [2]. The dynamic changes of lake shoreline not only visually reflect variations in lake morphology and evolutionary patterns but also play an indispensable role in water resource supply, ecological environment maintenance, and biodiversity conservation.

Traditional shoreline extraction methods rely on field surveys and photogrammetry, which suffer from limitations such as low efficiency, high costs, and poor spatiotemporal continuity, making them inadequate for large-scale dynamic monitoring [3]. In recent years, remote sensing technology has emerged as a powerful tool for rapidly and accurately extracting lake shorelines and monitoring lake area changes [4–7], owing to its advantages of wide coverage, high temporal and spatial resolution, multispectral capabilities, and multi-temporal data acquisition. There are various methods for extracting lake shorelines from remote sensing imagery, such as threshold method [8], single-band method [9], multi-band spectral relationship method [10], water index method [11], ratio method [12], image-based classification method [13]. The water indices are widely used in water body extraction due to their simplicity, high efficiency, and low constraints. For example, McFeeters [14] constructed a model to extract water body boundaries by using the difference between green light and near-infrared bands and proposed the Normalized Difference Water Index (NDWI) for water body extraction based on two bands. Xu [15] improved on McFeeters' basis and proposed the Modified Normalized Difference Water Index (MNDWI) with better water body extraction effect. Feyisa et al. [16] constructed the Automated Water Extraction Index (AWEI) through a large number of water body extraction experiments, which can effectively amplify the difference between water bodies and non-water bodies in shadowed backgrounds. Liu et al. [17] explored the use of NDWI and extended indices to monitor surface water changes by using multi-temporal Sentinel-2 optical images from 2018 to 2022. Shu et al. [18] compared the performance differences of multiple water indices in automatic surface water extraction based on Landsat data.

However, remote sensing images with different spatial resolutions exhibit significant trade-offs in shoreline detail delineation, feature recognition accuracy, and data acquisition costs. High-resolution imagery can precisely capture micro-topographic features of shorelines but faces challenges in data volume, processing complexity, and economic costs. In contrast, medium-to-low-resolution imagery enables broad coverage and high-frequency monitoring, yet suffers from mixed-pixel effects, leading to blurred shoreline boundaries.

The plateau lakes in Yunnan Province are vital components of the ecosystem in Southwestern China, playing critical roles in maintaining regional water cycles, supporting biodiversity, and ensuring water supply for local communities [19]. However, due to their high-altitude location, fragile ecological conditions, and limited self-regulating capacity, combined with long-term unsustainable human activities, these lakes face severe environmental challenges, including shoreline erosion, ecological degradation, and resource depletion [20]. Thus, selecting appropriate remote sensing data and lake shoreline extraction methods has become a critical issue for dynamic monitoring of lakes on the Yunnan Plateau.

This study aims to identify optimal data and methods for plateau lake shoreline delineation, by evaluation of the shorelines extracted from different spatial-resolution remote sensing images and water indices. The results will provide a scientific basis for rapid and accurate plateau lake dynamic monitoring using medium-resolution remote sensing data.

2 Geographic features of the plateau lakes in Yunnan province

There are numerous lakes on Yunnan Plateau, nine of which exceed 30 square kilometers in area, including Dianchi Lake, Erhai Lake, Fuxian Lake, Chenghai Lake, Lugu Lake, Yilong Lake, Qilu Lake, Xingyun Lake, and Yangzonghai Lake (Figure 1). These key plateau lakes are primarily distributed in the watershed areas of major rivers in northwestern and eastern Yunnan, most of which are fault-basin lakes [21]. The area experiences a plateau monsoon climate with distinct wet and dry seasons and notable vertical climatic variations [22].

These key plateau lakes serve as ideal subjects for comparative analysis of shoreline extraction using multi-resolution remote sensing imagery, owing to their diverse morphologies and varying shoreline complexities. For example, the shorelines of Dianchi Lake and Yangzonghai Lake show significant urban expansion impacts, with a high proportion of artificial embankments that can be effectively identified using 10-m resolution imagery [23]. The west bank of Erhai Lake is adjacent to Cangshan Mountain, while the east bank is distributed with gentle farmland. The boundary between water and land cannot be effectively distinguished from low-resolution remote sensing images, due to the large number of artificial wetlands distributed along the lakeshore [24]. There are karst cliffs developed on the north bank of Fuxian Lake, with a high degree of tortuosity along the shoreline [25]. The Chenghai Lake Basin is narrow and elongated, with a significant difference in slope between the east and west bank. The smoothing effect of low-resolution data may affect the accuracy of shoreline length calculation [26].

3 Data and methods

3.1 Experiment data

The medium-resolution remote sensing images, including Landsat-8/9 OLI at 30 m, Sentinel-2 MSI at 10 m, and GF-1 WFV at 16 m, are obtained from United States Geological Survey (USGS), European Space Agency (ESA), and China Center for Resources Satellite Data and Application,

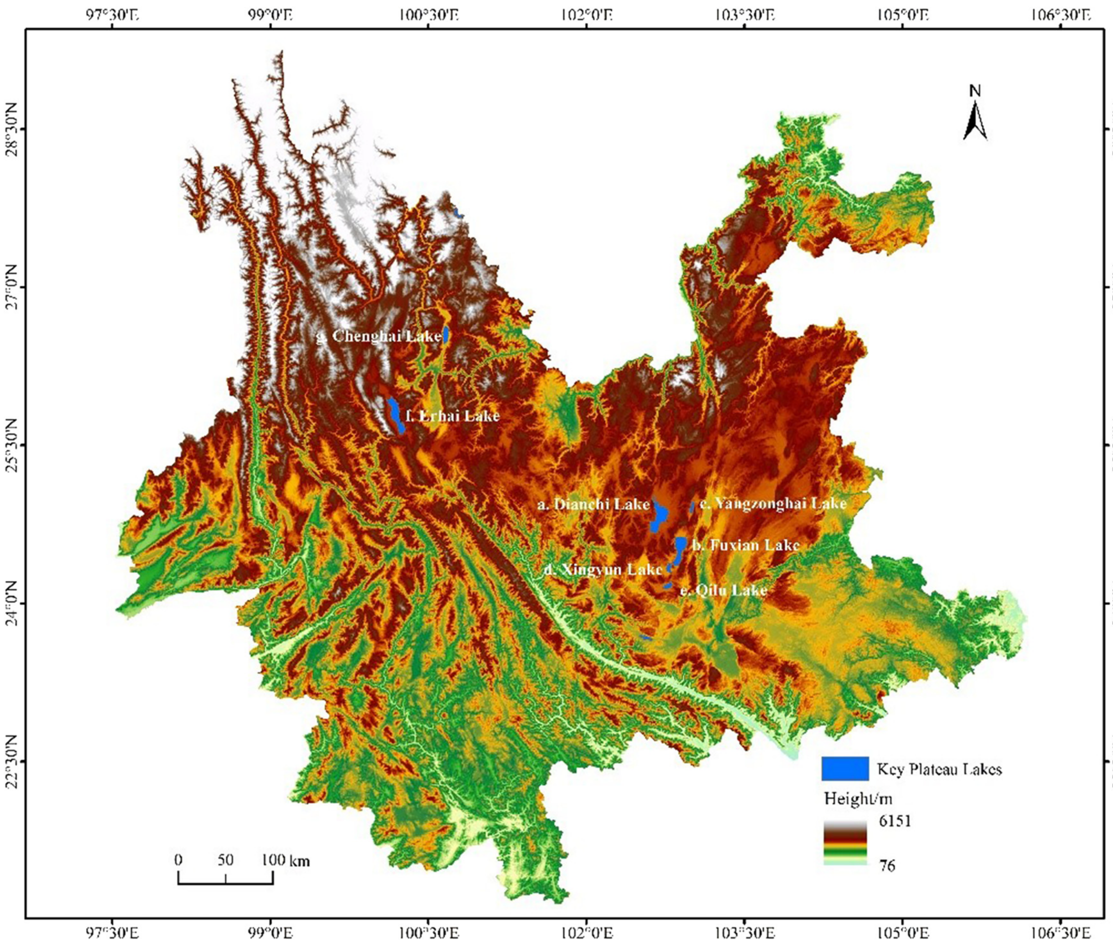

Figure 1: Location of the key plateau lakes in Yunnan province: a. Dianchi lake, b. Fuxian lake, c. Yangzonghai lake, d. Xingyun lake, e. Qilu lake, f. Erhai lake, g. Chenghai lake.

respectively. Specifically, the Landsat-8 OLI multispectral sensor provides nine spectral bands with a spatial resolution of 30 m [27, 28]. The Sentinel-2 MSI covers almost all spectral bands ranging from 10 m to 20 m [29], while the GF-1 WFV includes four spectral bands at 16 m [30]. All remote sensing images were acquired in winter, and the downloaded data are Level 1A products.

3.2 Extraction of the shorelines of the key plateau lakes

All remote sensing images were converted to reflectance after radiometric calibration [31] and atmospheric correction [32]. Three water indices, NDWI, MNDWI, and AWEI, are then calculated by band math of specific bands of the remote sensing images. Due to the lack of the short-wave infrared bands in the GF-1 data, it is only feasible to extract the NDWI water index.

The calculation formula are as follows:

$$\mathrm{NDWI} = \frac{\mathrm{GREEN} - \mathrm{NIR}}{\mathrm{GREEN} + \mathrm{NIR}} \tag{1}$$

$$\mathrm{MNDWI} = \frac{\mathrm{GREEN} - \mathrm{SWIR}}{\mathrm{GREEN} + \mathrm{SWIR}} \tag{2}$$

$$\mathrm{AWEI} = \mathrm{BLUE} + 2.5\mathrm{GREEN} - 1.5(\mathrm{NIR} + \mathrm{SWIR1}) - 0.25 SWIR2 \tag{3}$$

Note: All symbols in the formulas represent the reflectance of corresponding bands: GREEN = Reflectance of green band; NIR = Reflectance of near-infrared band; SWIR = Reflectance of short-wave infrared band; SWIR1 = Reflectance of short-wave infrared band 1; SWIR2 = Reflectance of short-wave infrared band 2.

Then, the lake shoreline can ultimately be extracted from the water index images by determining an appropriate threshold. After multiple validations, the threshold value used in this study is set to 0. The extracted lake shorelines underwent minor polygon removal and topological validation, ultimately yielding relatively complete shoreline data.

3.3 Accuracy assessment of the lake shorelines

The lake shorelines were accurately delineated through visual interpretation using 0.5-m resolution Jilin-1 imagery, serving as reference shorelines for accuracy assessment. Then, a 30-m buffer zone was established, using the reference shoreline as a baseline. Then, the number of intersecting pixels, and the length of the shoreline could be calculated by overlay analysis between the shoreline and the buffer zone [33]. The calculated pixel coincidence reflects the proximity between the extracted shoreline and the reference shoreline, with values closer to 1 indicating higher accuracy.

4 Results and discussion

4.1 Water index results of the plateau lakes in Yunnan province

The water index results for NDWI, MNDWI, and AWEI of the key plateau lakes were obtained by Landsat 8–9 and Sentinel-2 images, respectively (Figures 2 and 3). All three water indices effectively identified water bodies and clearly distinguished water from non-water features, making the lake shorelines more evident (Figure 4).

AWEI demonstrated superior performance in complex environments by eliminating shadow interference, particularly in differentiating water from adjacent features. MNDWI reduced vegetation and soil interference, excelling in vegetated areas. Although the NDWI index exhibits high sensitivity to water bodies, it is prone to interference from soil and vegetation. As shown in Figures 2f–f, the water

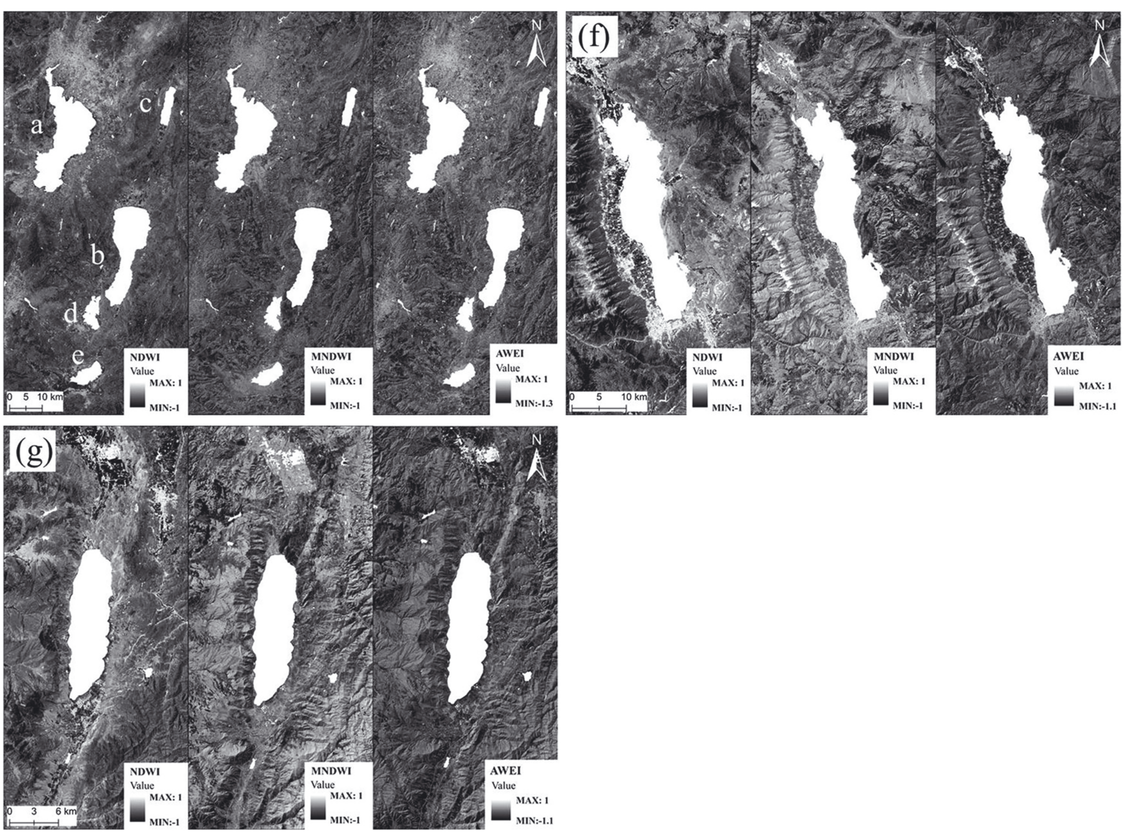

Figure 2: Water index results of the key plateau lakes in Yunnan province from Landsat 8–9 images: a. Dianchi lake, b. Fuxian lake, c. Yangzonghai lake, d. Xingyun lake, e. Qilu lake, f. Erhai lake, g. Chenghai lake.

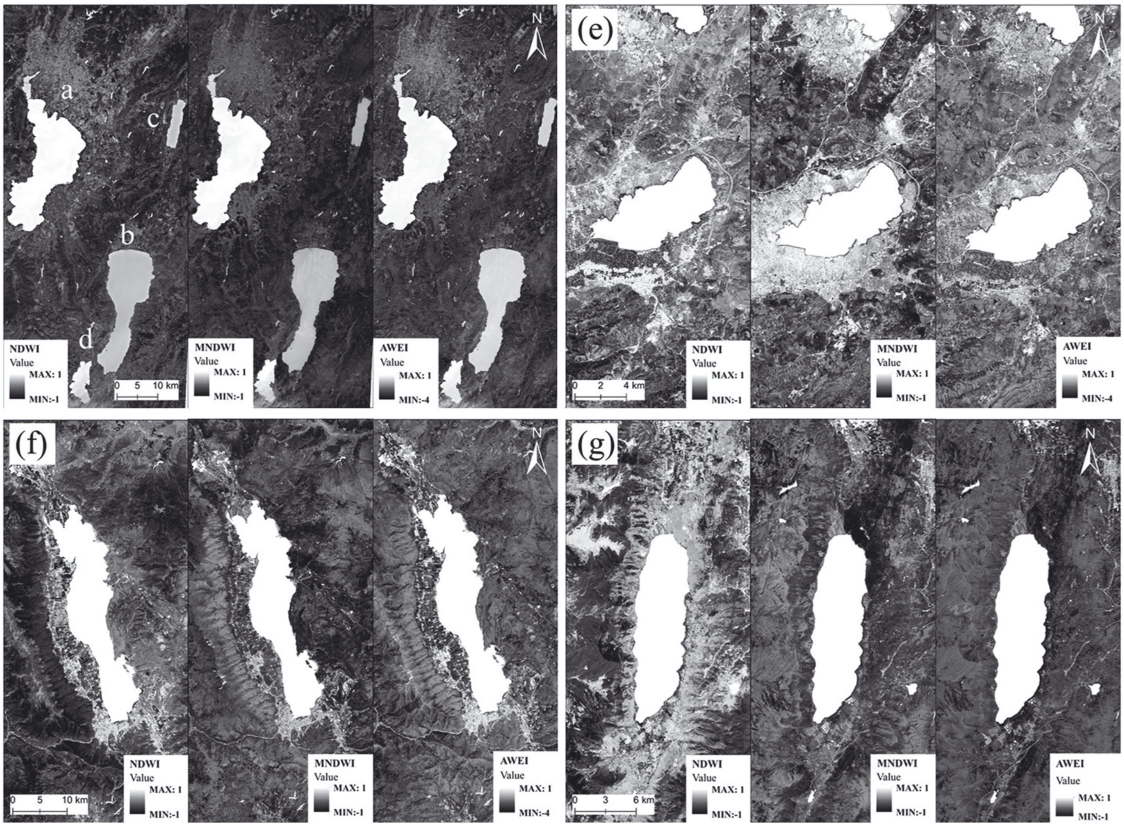

Figure 3: Water index results of the key plateau lakes in Yunnan province from Sentinel-2 images: a. Dianchi lake, b. Fuxian lake, c. Yangzonghai lake, d. Xingyun lake, e. Qilu lake, f. Erhai lake, g. Chenghai lake.

extraction accuracy of NDWI is significantly lower than that of AWEI and MNDWI in the densely vegetated southeastern region of Erhai Lake. Theoretically, MNDWI is preferable for vegetated lakes like Erhai Lake and Fuxian Lake, while AWEI suits urbanized lakes like Dianchi Lake to avoid shadow-induced errors.

Although the spatial resolution of Landsat 8–9 data is lower, it can still achieve a similar overall contour of water bodies to the higher-resolution Sentinel-2 data when the water area is large and the shape is relatively regular.

4.2 Lake shoreline analysis of the plateau lakes in Yunnan province

The shorelines of the key plateau lakes were extracted using Landsat 8–9 and Sentinel-2 images, and their accuracy was validated through overlay analysis with the buffer zone established based on reference shorelines.

Dianchi Lake is significantly affected by urban expansion, with a high proportion of artificial embankments. Due to its higher spatial resolution, Sentinel-2 images can clearly capture the details of artificial embankments, exhibiting strong coincidence with reference shoreline buffer zone. In contrast, Landsat images, with its coarser resolution, tends to misclassify wetlands and land, resulting in greater shoreline extraction deviations and lower coincidence.

The western bank of Erhai Lake borders the Cangshan Mountains, while the eastern bank consists of sloping farmland with high vegetation coverage. Sentinel-2 data demonstrate higher accuracy in identifying water-land boundaries in vegetated areas, though both datasets face challenges in the wetland regions. The AWEI index perform notably well in complex backgrounds, effectively reducing shadow interference and improving shoreline delineation accuracy.

The northern bank of Fuxian Lake features karst cliffs with highly irregular shoreline morphology. Sentinel-2 images, with its higher spatial resolution, effectively captures water boundaries within cliff shadows and accurately delineates the sinuous shoreline, showing a high coincidence with buffer zones. In contrast, Landsat data, limited by pixel-mixing effects, exhibits weaker performance in extracting intricate shoreline details, resulting in lower coincidence. Furthermore, the MNDWI index enhances shoreline extraction accuracy in vegetated areas by effectively suppressing vegetation noise.

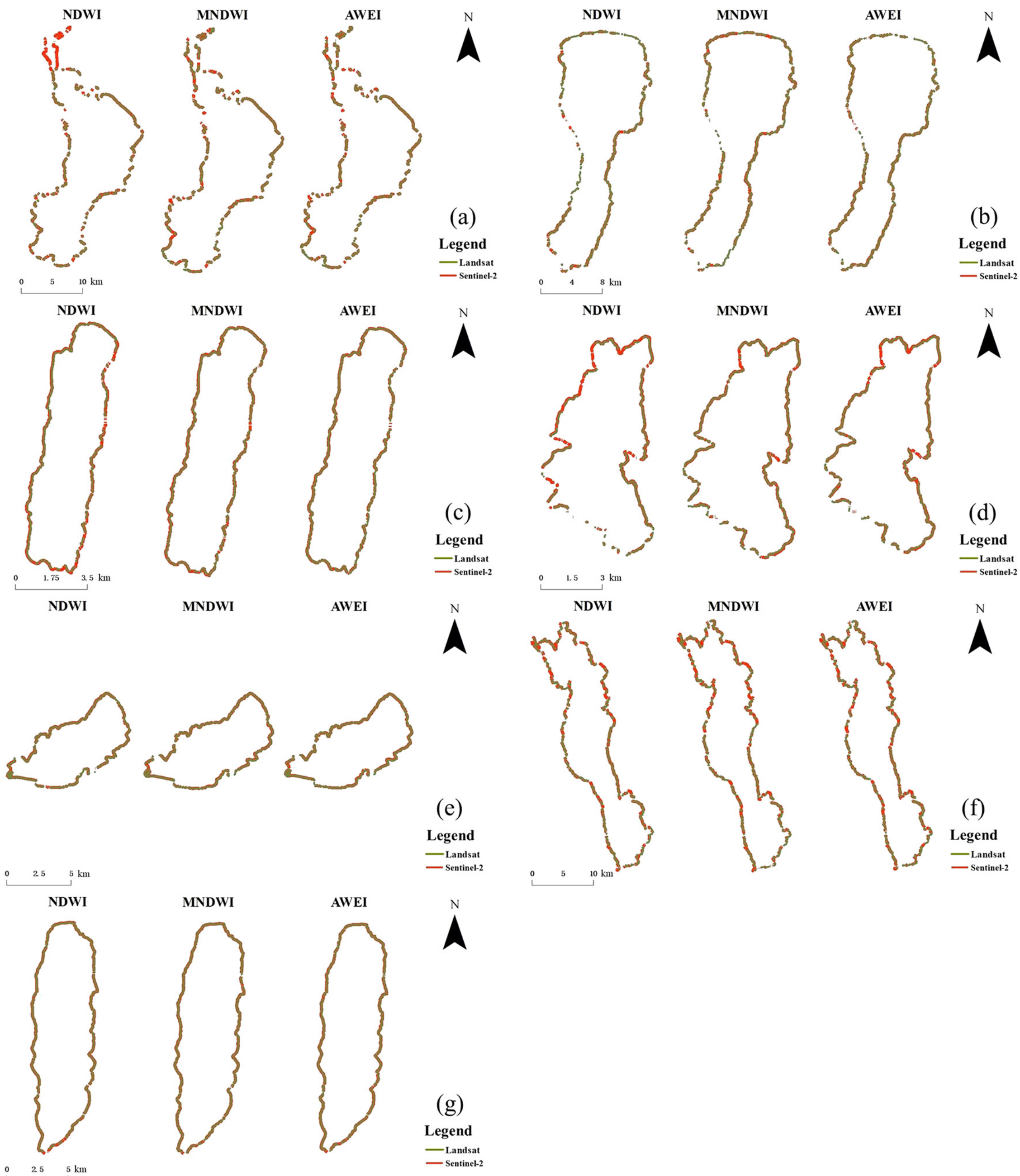

Figure 4: Overlay analysis between the extracted shoreline and the buffer zone of the reference shoreline: a. Dianchi lake, b. Fuxian lake, c. Yangzonghai lake, d. Xingyun lake, e. Qilu lake, f. Erhai lake, g. Chenghai lake.

Xingyun Lake has a regular shoreline and is predominantly surrounded by urban areas, resulting in a relatively homogeneous geographical environment. The shorelines extracted from both Landsat and Sentinel-2 data show high coincidence with the buffer zone of the reference shoreline, with Sentinel-2 exhibiting superior detail representation. All three water indices performed well, with MNDWI and AWEI effectively mitigating interference from vegetation and shadows, thereby improving extraction accuracy.

Qilu Lake is located in a stable geographical environment with minimal human disturbance. Sentinel-2 data provide higher shoreline extraction accuracy by capturing fine-scale morphological details. The AWEI index effectively removes shadow interference, while MNDWI reduces vegetation and soil noise, resulting in more realistic shoreline delineation.

Yangzonghai Lake is situated at the junction of Chenggong, Yiliang, and Chengjiang counties, with significant human activity impacts. Sentinel-2 data, due to its high resolution, accurately captures the detailed shoreline features of Yangzonghai Lake, showing high coincidence with the buffer zone, whereas Landsat data lacks such detail. For shadow processing, the AWEI index performs exceptionally well, while MNDWI is more effective in extracting shorelines within vegetation-covered areas.

Chenghai Lake exhibits an elongated basin morphology with distinct slope differences between its eastern and western banks. Sentinel-2 data accurately captures the intricate shoreline variations, yielding high-precision length calculations. In contrast, Landsat data introduces smoothing effects, resulting in significant shoreline length deviations and low coincidence. The MNDWI index performs optimally in vegetation-covered areas, while AWEI demonstrates superior robustness against topographic shadow interference in complex terrains.

The overlay analysis results demonstrate that the shorelines extracted from both Sentinel-2 and Landsat data can effectively capture the variations in lake boundaries. Among the three indices extracted, Sentinel-2 consistently demonstrated higher accuracy and detailed feature capture capability, benefiting from its higher spatial resolution. The subtle shoreline variations, including intricate curvatures and complex topographic features could be effectively identified by Sentinel-2 images. In contrast, Landsat, due to its coarser resolution, struggled to delineate fine-scale details in complex shorelines, resulting in minimal coincidence with the buffer zone of the reference shorelines.

The three water indices exhibit similar shoreline extraction accuracy in areas with less vegetation coverage, but MNDWI demonstrates better fitting performance in vegetated shoreline regions. When shorelines are highly irregular, the AWEI index demonstrates superior performance by effectively mitigating shadow interference and achieving higher coincidence with reference shorelines. However, shorelines extracted by all three indices exhibit significant gaps in shallow water areas. For instance, in the southern part of Erhai Lake, none of the indices perform well in delineating shorelines within shallow zones.

4.3 Accuracy assessment of the extracted lake shorelines

The accuracy assessment results of the extracted lake shorelines indicate that shorelines derived from Sentinel-2 data are generally more accurate than those from Landsat data, with results closer to the reference length. Sentinel-2 data not only confirmed the reliability of Landsat-8/9 in extracting large-scale lake contours but also compensated for Landsat's limitations in capturing fine-scale shoreline details, verifying that high-resolution data can validate and improve the accuracy of medium-resolution data. For example, in the case of Dianchi Lake, the shoreline lengths extracted using the three water indices based on Sentinel-2 data have errors of around 30 km compared to the reference shoreline, with pixel coincidence rates of approximately 90 %, indicating relatively small errors. In contrast, the shoreline extracted from Landsat images is only about half of the actual length, failing to align with the true boundary. Therefore, the higher spatial resolution of Sentinel-2 images enables superior detail capture in complex environments or meandering shorelines, significantly improving extraction accuracy.

In terms of water indices, the AWEI index performs best with Sentinel-2 data, achieving higher accuracy. For instance, in Yangzonghai Lake, the shoreline length extracted using Sentinel-2 AWEI is 30.4 km, very close to the reference length of 32.1 km, with a pixel coincidence rate as high as 94.70 %. However, its performance is relatively lower with Landsat data, where the AWEI-extracted length is 27.5 km, with a pixel coincidence rate of only 85.68 %. The MNDWI index performs well with both Sentinel-2 and Landsat data, especially in Chenghai Lake, where the extracted shorelines have accuracies above 85 %, extremely close to the reference shoreline. Overall, the NDWI index exhibits the poorest extraction capability among the three indices. For example, the Sentinel-2 NDWI-extracted length of Erhai Lake is 85.4 km, with a pixel coincidence rate of only 71.94 %. However, its extraction accuracy is relatively closer to the reference length when using Landsat data.

Moreover, the morphology of lakes and their surrounding geographical environments significantly affect the shoreline extraction results. For example, Fuxian Lake and Xingyun Lake generally achieve higher extraction accuracy than Erhai Lake and Dianchi Lake, likely due to their more regular shoreline shapes and relatively stable, less complex surrounding environments. For instance, the Sentinel-2-extracted shoreline length of Fuxian Lake has a small error compared to the reference length and a high pixel coincidence rate. In contrast, Erhai Lake, with its complex surrounding vegetation cover, exhibits relatively lower extraction accuracy, with significant differences in pixel coincidence rates among different indices (Tables 1 and 2).

Table 1: Accuracy assessment of the lake shoreline extracted from Landsat 8–9 images.

Lake name	Pixel coincidence (%)			Length of the extracted shoreline (km)			Reference shoreline length (km)
	AWEI	MNDWI	NDWI	AWEI	MNDWI	NDWI	
Dianchi lake	44.56 %	44.92 %	36.88 %	68.8	69.5	57.1	154.6
Fuxian lake	65.06 %	64.25 %	61.86 %	58.2	57.5	55.4	89.5
Yangzonghai lake	85.68 %	80.85 %	69.56 %	27.5	26.0	22.4	32.1
Xingyun lake	74.53 %	36.20 %	57.05 %	26.8	13.0	20.5	35.9
Qilu lake	80.46 %	80.51 %	81.34 %	31.7	31.7	32.0	39.4
Erhai lake	41.81 %	49.74 %	44.40 %	49.6	57.5	51.4	118.7
Chenghai lake	83.18 %	85.34 %	83.66 %	40.3	41.4	40.6	48.5

Table 2: Accuracy assessment of the lake shoreline extracted from Sentinel-2 images.

Lake name	Pixel coincidence (%)			Length of the extracted shoreline (km)			Reference shoreline length (km)
	AWEI	MNDWI	NDWI	AWEI	MNDWI	NDWI	
Dianchi lake	81.71 %	79.06 %	76.12 %	126.3	122.3	117.7	154.6
Fuxian lake	81.15 %	92.18 %	65.05 %	72.7	82.5	58.2	89.5
Yangzonghai lake	94.70 %	94.41 %	82.94 %	30.4	30.3	26.7	32.1
Xingyun lake	90.09 %	94.05 %	84.40 %	32.4	33.8	30.3	35.9
Qilu lake	91.61 %	96.11 %	86.49 %	36.1	37.9	34.1	39.4
Erhai lake	84.46 %	77.34 %	71.94 %	100.2	91.8	85.4	118.7
Chenghai lake	90.17 %	92.88 %	85.37 %	43.8	45.1	41.4	48.5

5 Conclusions

Based on the comparative analysis of lake shoreline extraction accuracy using remote sensing data with different spatial resolutions and various water indices, this paper achieves the following conclusions:

(1) The medium-resolution remote sensing data is suitable for rapid monitoring of the area change of large-scale lakes with regular shorelines and low vegetation coverage, but shows insufficient accuracy and blurred boundaries for complex shorelines or intricate terrain. Increasing the spatial resolution of remote sensing data can significantly improve the accuracy of lake shoreline extraction, particularly in areas with dense vegetation or complex shoreline topography.

(2) Different remote sensing water indices demonstrate significant variations in applicability. NDWI is sensitive to water bodies but prone to vegetation interference, leading to lower accuracy in vegetated areas. MNDWI reduces vegetation and soil interference by incorporating the short-wave infrared band, improving shoreline extraction accuracy in vegetated zones. AWEI effectively suppresses shadow noise, demonstrating superior adaptability in complex environments and enhancing extraction accuracy in shaded areas.

The shoreline morphology and complex geographic settings of the key plateau lakes in Yunnan Province can significantly affect shoreline extraction accuracy. Therefore, it is essential to integrate multi-source remote sensing data with ground-based monitoring technologies to establish a multi-scale lake shoreline monitoring system. This integrated approach enables real-time and precise monitoring of lake dynamics, which is of great significance for ecological conservation and management of plateau lakes in Yunnan Province.

This study only used winter remote sensing data, which limits the analysis of seasonal and interannual variations in lake shorelines. Future research could integrate multi-seasonal and long-term datasets to clarify seasonal dynamics driven by monsoon precipitation and human activities.

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References

1. Adrian R, O'Reilly CM, Zagarese H, Baines SB, Hessen DO, Keller W, et al. Lakes as sentinels of climate change. Limnol Oceanogr 2009;54:2283–97.
2. Tan G, Yao S, Li L. Key technical problems and expected achievements in efficient use and protection of the resources of river and lake shoreline and inland river marshland. Adv Eng Sci 2019;51:1–8.
3. Du Y, Zhou C. Automatically extracting remote sensing information for water bodies. J Remote Sens 1998;2:264–9.
4. Guirguis SK, Raey MEE, Hussain M, Hassan HM. Technical note multi-temporal change of lake Brullus, Egypt, from 1983 to 1991. Int J Remote Sens 1996;17:2915–21.
5. Göksel Ç, Akyüz D, Kabdaşlı M, Balcik F, Seker D. Definition of sensitive areas in a lakeshore by using remote sensing and GIS. Fresenius Environ Bull 2004;13:860–4.
6. Yang Y, Zhang G, Hong C, Yan P, Ha S, Dong M, et al. Lake area variations in the Altun mountain national nature reserve 1970-2021. J Beijing Normal Univ Nat Sci 2024;60: 541–50.
7. Liu J, Tian B, Wu C, Ding Y, Gao P, Mu X. Analysis of lake area changes and driving factors in Nam Co and Selin Co from 1976 to 2021. J Salt Lake Res 2024;32:61–8.
8. Han S, Wang L. A Survey of thresholding methods for image segmentation. Syst Eng Electron 2002;24:91–4.
9. Chen W, Jing J, Li Y, Niu Z. Extraction of water information based on China-made GF-1 remote sense image. Resour Sci 2015;37:1166–72.
10. Li D, Wu B, Chen B, Xue Y, Zhang Y. Review of water body information extraction based on satellite remote sensing. J Tsinghua Univ Sci Technol 2020;60:147–61.
11. Xiong J, Wang S, Zhou Y. A sensitivity analysis and accuracy assessment of different water extraction index models based on ALOS AVNIR - 2 data. Remote Sens Land Resour 2010;22: 46–50.
12. Barton IJ, Bathols JM. Monitoring floods with AVHRR. Remote Sens Environ 1989;30:89–94.
13. Sun Z, Zhao Y, Chen J, Li G, Tan M. Application of object-oriented classification in extraction of impervious degree of urban surface. Sci Geogr Sin 2007;27:837–42.
14. McFeeters SK. The use of the normalized difference water index (NDWI) in the delineation of open water features. Int J Remote Sens 1996;17:1425–32.
15. Xu H. A study on information extraction of water body with the modified normalized difference water index (MNDWI). J Remote Sens 2005;9:589–95.
16. Feyisa GL, Meilby H, Fensholt R, Proud SR. Automated water extraction index: a new technique for surface water mapping using Landsat imagery. Remote Sens Environ 2014;140:23–35.
17. Liu S, Huang D, Wang J, Yu Z. Monitoring surface moisture changes using NDWI and extended indices: a case study of Suyahu reservoir. Hydro-Sci Eng 2024:103–14.
18. Liu S, Wu Y, Zhang G, Lin N, Liu Z. Comparing water indices for Landsat data for automated surface water body extraction under complex ground background: a case study in Jilin province. Remote Sens 2023;15:1678.
19. Bai K, Li Z, Zhang P, Wang Z, Zhao W, Lu H. Shoreline evolution of natural lakes in lake Dongting area based on multi-source remote sensing interpretation. J Lake Sci 2024;36:1537–49.
20. Yu Y, Zhang M, Qian S, Li D, Kong F. Current status and development of water quality of lakes in Yunnan-Guizhou plateau. J Lake Sci 2010;22:820–8.
21. Li Q, Wang Y, Li L, Zhang H, Wang B. Ecological restoration scheme of lake basins on the karst plateau based on natural solution: take nine lakes on the Yunnan plateau as example. Carsol Sin/Zhong Guo Yan Rong 2023;42:391–401.
22. Li S, Yu M, Li G, Ceng J, Chen J, Gao B, et al. Limnological survey of the lakes of Yunnan plateau. Oceanol Limnol Sin 1963;02:87–114.
23. Cundill SL, Meijde Mvd, Hack HRGK. Investigation of remote sensing for potential use in dike inspection. IEEE J Sel Top Appl Earth Obs Rem Sens 2014;7:733–46.
24. Zhai Y. Study on pollution of inflow rivers in the lake Erhai watershed and constructed wetland technology. Shanghai: Shanghai Jiao Tong University; 2012.
25. Li S, Zhou J, Wang J. Spatio-temporal LUCC and driving force in Fuxian lake watershed from 1974 to 2014. Remote Sens Nat Resour 2017;29:132–9.
26. Obata K, Wada T, Miura T, Yoshioka H. Scaling effect of area-averaged NDVI: monotonicity along the spatial resolution. Remote Sens 2012;4:160–79.
27. Trevisiol F, Mandanici E, Pagliarani A, Bitelli G. Evaluation of Landsat-9 interoperability with Sentinel-2 and Landsat-8 over Europe and local comparison with field surveys. ISPRS J Photogramm Remote Sens 2024;210:55–68.
28. González-Márquez LC, Torres-Bejarano FM, Torregroza-Espinosa AC, Hansen-Rodríguez IR, Rodríguez-Gallegos HB. Use of LANDSAT 8 images for depth and water quality assessment of El Guájaro reservoir, Colombia. J South Am Earth Sci 2018;82:231–8.
29. Sambandham VT, Kirchheim K, Ortmeier F, Mukhopadhaya S. Deep learning-based harmonization and super-resolution of Landsat-8 and Sentinel-2 images. ISPRS J Photogramm Remote Sens 2024;212:274–88.
30. Sun N, Zhu W, Cheng Q. GF-1 and Landsat observed a 40-year wetland spatiotemporal variation and its coupled environmental factors in Yangtze river estuary. Estuarine Coastal Shelf Sci 2018;207:30–9.

31. Guo Y, Senthilnath J, Wu W, Zhang X, Zeng Z, Huang H. Radiometric calibration for multispectral camera of different imaging conditions mounted on a UAV platform. Sustainability 2019; 11:978.
32. Sola I, García-Martín A, Sandonís-Pozo L, Álvarez-Mozos J, Pérez-Cabello F, González-Audícana M, et al. Assessment of atmospheric correction methods for Sentinel-2 images in mediterranean landscapes. Int J Appl Earth Obs Geoinf 2018;73:63—76.
33. Congalton RG, Green K. Assessing the accuracy of remotely sensed data: principles and practices. Boca Raton, Florida: CRC Press; 2009.