IRSTI 70.03.05, 89.57.35 https://doi.org/10.26577/JGEM.2024.v75.i4.6

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ACCURACY ASSESSMENT OF DETERMINING THE AREAS OF SMALL LAKES BASED ON REMOTE SENSING DATA

Small lakes are important elements of the ecosystem, especially under conditions of climate change and active water use. Studying their condition is of key importance for understanding the water balance and biodiversity of the region. This study compares remote sensing techniques for small lakes using Landsat-8, Sentinel-2, Planet and unmanned aerial vehicle (UAV) data.

The aim of the work is to determine the most effective approach for monitoring lake conditions by analyzing the accuracy of different methods and indices. The methods used include the analysis of multispectral data such as NDWI, MNDWI and AWEI, which allow the distinction between aquatic and non-aquatic objects. The scientific significance of the study lies in assessing the potential of modern remote sensing technologies for detailed monitoring of ecosystem changes. Practical significance of the work consists in providing recommendations for sustainable water resources management and development of adaptation strategies.

The research methodology included processing satellite data of different resolutions, accuracy verification using UAV reference data, and application of spectral indices for water surface mapping. Results showed that high-resolution imagery (PlanetLab data) most closely matched field observations. The spectral indices NDWI, MNDWI and AWEI showed different accuracy depending on data characteristics and lake features. The analysis confirms the effectiveness of an integrated approach using high-resolution data and spectral indices for monitoring the condition of small lakes. The practical value of the study lies in optimizing the monitoring of water bodies and maintaining their ecological sustainability.

Key words: Remote sensing, small lakes, spectral indices, accuracy assessment.

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ЖҚЗ деректері бойынша шағын көлдердің аудандарын анықтау дәлдігін бағалау

Кіші көлдер экожүйенің маңызды элементтері болып табылады, әсіресе климаттың өзгеруі және суды белсенді пайдалану жағдайында. Олардың жағдайын зерттеу аймақтың су балансы мен биоәртүрлілігін түсінудің кілті болып табылады. Бұл зерттеу Landsat-8, Sentinel-2, Planet спутниктері мен ұшқышсыз ұшатын аппараттардан (ұшқышсыз ұшу аппараттарынан) алынған деректерді пайдалана отырып, шағын көлдерді қашықтықтан зондтау әдістерін салыстырады.

Жұмыстың мақсаты әртүрлі әдістер мен көрсеткіштердің дәлдігін талдау арқылы көлдердің жағдайын бақылаудың ең тиімді әдісін анықтау болып табылады. Қолданылатын әдістер NDWI, MNDWI және AWEI сияқты су және су емес нысандарды ажырата алатын мультиспектрлік деректерді талдауды қамтиды.

Зерттеудің ғылыми маңыздылығы экожүйе өзгерістерін егжей-тегжейлі бақылау үшін қазіргі заманғы қашықтықтан зондтау технологияларының мүмкіндіктерін бағалауда жатыр. Жұмыстың практикалық маңыздылығы су ресурстарын тұрақты басқару және бейімделу стратегияларын әзірлеу бойынша ұсыныстар беру болып табылады.

Зерттеу әдістемесі әр түрлі ажыратымдылықтағы спутниктік деректерді өңдеуді, ҰҰА-дан алынған анықтамалық деректерді пайдалана отырып, дәлдікті сынауды және су бетін картаға түсіру үшін спектрлік индекстерді қолдануды қамтыды.

Нәтижелер жоғары ажыратымдылықтағы кескіндердің (PlanetLab деректері) далалық бақылауларға ең жақын сәйкестік екенін көрсетті. NDWI, MNDWI және AWEI спектрлік индекстері деректер сипаттамаларына және көл ерекшеліктеріне байланысты әртүрлі дәлдіктерді көрсетті.

Талдау шағын көлдердің жағдайын бақылау үшін жоғары ажыратымдылықтағы деректер мен спектрлік индекстерді пайдалана отырып, кешенді тәсілдің тиімділігін растайды. Зерттеудің практикалық құндылығы су объектілерінің мониторингін оңтайландыруда және олардың экологиялық тұрақтылығын сақтауда жатыр.

Түйін сөздер: Қашықтықтан зондтау, кіші көлдер, спектрлік көрсеткіштер, дәлдік бағалау.

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Оценка точности определения площадей малых озер по данным ДЗЗ

Малые озера являются важными элементами экосистемы, особенно в условиях изменения климата и активного водопользования. Изучение их состояния имеет ключевое значение для понимания водного баланса и биоразнообразия региона. В данном исследовании проведено сравнение методов дистанционного зондирования малых озер с использованием данных, полученных со спутников Landsat-8, Sentinel-2, Planet и беспилотных летательных аппаратов (БПЛА).

Целью работы является определение наиболее эффективного подхода для мониторинга состояния озер путем анализа точности различных методов и индексов. Используемые методы включают анализ мультиспектральных данных, таких как NDWI, MNDWI и AWEI, которые позволяют различать водные и неводные объекты. Научная значимость исследования заключается в оценке возможностей современных технологий дистанционного зондирования для детального мониторинга изменений экосистем. Практическая значимость работы состоит в предоставлении рекомендаций для устойчивого управления водными ресурсами и разработки адаптационных стратегий.

Методология исследования включала обработку спутниковых данных различного разрешения, проверку точности с использованием эталонных данных, полученных с помощью БПЛА, и применение спектральных индексов для картирования водной поверхности. Результаты показали, что снимки с высоким разрешением (данные PlanetLab) наиболее близки к данным полевых наблюдений. Спектральные индексы NDWI, MNDWI и AWEI продемонстрировали различную точность в зависимости от характеристик данных и особенностей озер. Проведенный анализ подтверждает эффективность комплексного подхода с использованием данных высокого разрешения и спектральных индексов для мониторинга состояния малых озер. Практическая ценность исследования заключается в оптимизации мониторинга водных объектов и поддержании их экологической устойчивости.

Ключевые слова: ДЗЗ, малые озера, спектральные индексы, оценка точности.

Introduction

Small lakes are an important object of water resources research, especially under conditions of climate change and active water use. The lakes of the Esil basin, located in the central part of the country, represent a unique ecosystem that plays a significant role in maintaining the biodiversity and water balance of the region.

Lakes play an important role in the hydrosphere and ecosystem, so studying their condition through remote sensing is of great importance for understanding changes in the environment. Small prairie lakes, especially saline and drainless systems, are very sensitive to climate change and human activities. These ecosystems face numerous threats including water diversion, pollution, resource exploitation, and invasive species (Beeton, 2002: 21-38; Jenny et al., 2020: 686-702; Gross, 2017: 43-46). In Central Asia, many endorheic lakes have experienced significant water level declines over the past century, with evaporation often exceeding precipitation

(Yapiyev et al., 2017: 14). Many lakes, especially those below 3,500 m above sea level, have shrunk, while some high-altitude lakes have expanded due to melting glaciers. (Huang et al., 2022). Human activities, including agriculture and dam building, have played a more significant role than climate change in altering lake water supplies (Huang et al., 2022; Li et al., 2011: 1216-1229). The future of small steppe lakes remains uncertain, requiring enhanced monitoring and analysis to develop appropriate adaptation and mitigation strategies. Various methods and technologies are used to monitor and study small lakes in the study region, including data obtained from unmanned aerial vehicles (UAVs) and optical satellites. UAVs provide the ability to obtain high-resolution multispectral images, which allows for detailed analysis of water bodies and the surrounding area.

Comparison of data obtained using UAVs and optical satellites allows us to evaluate the effectiveness and applicability of different methods for monitoring small lakes. Analysis of the set of information obtained from various sources helps to more accurately identify changes in the state of water resources and makes it possible to make informed decisions on their protection and management.

The purpose of this study is to compare two methods of data collection – using UAVs and optical satellites, to assess the state of small lakes in the Esil WMB and to identify possible differences in the results obtained. Conducting data analysis will help determine the most effective approach to monitoring and studying water bodies in this region, which in turn contributes to sustainable water management and the preservation of the ecosystem of small lakes.

Materials and methods

Modern satellite observation technologies make it possible to obtain high-quality data on lake surface characteristics, including water cover parameters, water temperature, phytoplankton content, and other factors. Research shows that remote sensing of lakes is actively used to monitor ecosystem changes, identify pollution, and assess freshwater resources.

Satellite remote sensing is an effective method for mapping and monitoring small lakes and wetlands, providing valuable data for climate studies and water resources management. Remote sensing techniques have been widely used to monitor lake areas and assess accuracy in various regions, including steppe and permafrost. Various methods using different satellite sensors have been used to estimate lake area. Recent advances in satellite technology, including Landsat 8 and the upcoming Sentinel missions, are increasing the ability to assess various water quality parameters over a wider range of lake sizes (Olmanson et al., 2015: 111-140). The integration of Landsat and MODIS datasets combined with water surface definition indices like Normalized Difference Water Index (NDWI) and Modified Normalized Difference Water Index (MNDWI) has helped to improve the increased accuracy of lake map visualization (Zhang et al., 2017: 742-772; Buma et al., 2018: 1-24). Integrated multi-sensor methods combining optical and radar datasets have been developed to estimate lake surface area and changes in water level and volume (Chipman, 2019: 158). The accuracy of lake area estimates is affected by spatial resolution, spectral characteristics, and satellite data processing techniques (Lyons et al., 2013:7887-7905). Recent advances in satellite technology and data availability have increased the ability to monitor lakes worldwide, especially in remote regions such as the Tibetan Plateau (Gao, 2015: 147-157; Jawak et al., 2015: 196-213). Precision assessment methods, including statistical experiments and systematic sampling methods, have been developed to evaluate area measurements and detect changes. (Sun et al., 2004: 189-202). These methods provide valuable information on the impacts of climate change and water management. Modern advances in satellite technology and data availability make it possible to monitor lakes worldwide, even in the isolated region of the Tibetan plateau (Gao, 2015:147-157; Javak et al., 2015:196-213). Methods have been developed to accurately estimate areas and their variations using statistical experiments and systematic sampling (Sun et al., 2004:189-202). They provide important information on climate change impacts, consequences and water management under such conditions.

Remote sensing techniques are an effective tool for monitoring changes in lake area, providing important data on the impact of climate change. The satellite families of Landsat, MODIS and SPOT/VEGETATION and others have been applied to estimate lake area (Chipman, 2019; Zhang et al., 2017; Xu et al., 2012; Ma et al., 2007). Various calculated water indices, including NDWI, MNDWI and AWEI, show high accuracy in distinguishing between aquatic and nonaqueous environments (Zhang et al., 2017; Buma et al., 2018). And the combination of satellite imagery with altimetry data can track changes in lake water volumes. These approaches have been successfully applied to lake monitoring in regions of Mexico, Egypt, and China (Tapia-Silva et al., 2018; Chipman, 2019; Ma et al., 2007). Mapping accuracy depends on the choice of data and methods, and results depend on variables such as spatial resolution, temporal coverage, and regional characteristics (Zhang et al., 2017:742-772; Xu et al., 2012:792-796; Gao, 2015:147-157).

The Esil water management basin (WMB) is located within the North Kazakhstan, northern part of Akmola and a small part of Karaganda oblasts of Kazakhstan. Its area is 237,226 km² and the main water body is the Esil River, which is 2,450 km long and has a catchment area of 177,000 km². The main tributaries of the river include the Kalkutan, Zhabai, Terisakkan, Akkanburlyk and Imanburlyk. The river flow is regulated through the Astana (Vyacheslav) and Sergeevskoye reservoirs. The basin territory is also characterized by a significant number of lakes, among which there are both large water bodies and small steppe lakes. Lakes play an important role in maintaining the biodiversity and hydrological regime of the region (Mukasheva, 2019: 50-54).

In this study, three lakes with different water mirror area were selected for detailed study (Figure 1).

Lake Zhamankol (53°50’45.186’’ N, 68°34’41.823’’ E) is located to the west of Zagradovka village in Yesil district of North Kazakhstan region. In the south-western part of the reservoir there are mountains. The lake has an open water surface and its bottom is covered with silt. The maximum depth is 2.9 meters, the water’s edge mark is 152.7 meters above sea level. The water surface area is 3.36 km². The water body is drainless and is currently not used. In this study, 3 lakes with different water mirror area were selected for detailed study.

Lake Kumdykol (53°55’44.443’’ N, 66°13’37.705’’ E) is located 22.5 km southwest of the village of Kairankol in the Timiryazev District of North Kazakhstan Oblast. Its maximum depth is 3.1 m, and the water’s edge mark is 163.3 m above sea level. The water surface area is 7.37 km². The lake is drainless, belongs to flat water bodies and is fed mainly by precipitation and melt water. The reservoir is used for fishing.

Kishi Koskol Lake (53°17’26.766’’ N, 68°25’46.186’’ E) is located to the south of Antonovka village in Ayirtau district of North Kazakhstan oblast. The lake basin has an oval shape, slightly elongated from north to south. The catchment area is about 124.9 km², the water surface occupies 9.76 km². The maximum depth of the lake reaches 3.5 meters, the average depth is 2.97 meters. The water body belongs to the category of periodically waterlogged. The shores are monotonous, mostly low and gentle, with a sandy beach strip 10-15 m wide. The bottom is flat, saucer-shaped, and much of it is covered with silt. The lake is used for fishing and watering cattle.

In this work, medium and high resolution archival data from Landsat-8, Sentinel-2 and Planet satellites were used to update vector layers of the map base of the study area. Landsat-8 presents multispectral data in 11 spectral bands with resolution from 15 m to 100 m. Sentinel-2, in its turn, in 12 spectral bands with resolution from 10 m to 90 m.

However, for a more detailed study of morphometric characteristics of individual objects, higher resolution data are required. For this purpose, Planet satellite images with 3m resolution were used. Information about the used data is given in Table 1.

The extensive coverage bandwidth and the availability of a wide range of channels, in particular shortwave infrared channels, allow these satellites to be useful data sources for lake studies using different spectral indices. In previous studies by the authors (Iskaliyeva et al, 2024:117-130), different spectral indices for water surface determination were considered. As a result, MNDWI and AWEI indices were found to be the most accurate for water surface mapping.

Table 1 – Information on used aerospace data

Satellite	Resolution	Date	Month	Year	Path/Row	Cloud Cover	Source
PlanetScope	3 m	18	August	2021	242a, 2453, 2453	0%	Planet Labs
Landsat-8 OLI/TIRS	15/30 m	20	August	2021	157/023	0.7%	USGS
Sentinel-2A	10/20 m	18	August	2021	T42UVE	11.8%	ESA
DJI Phantom 4 pro	0.1 m	18	August	2021			In-situ works

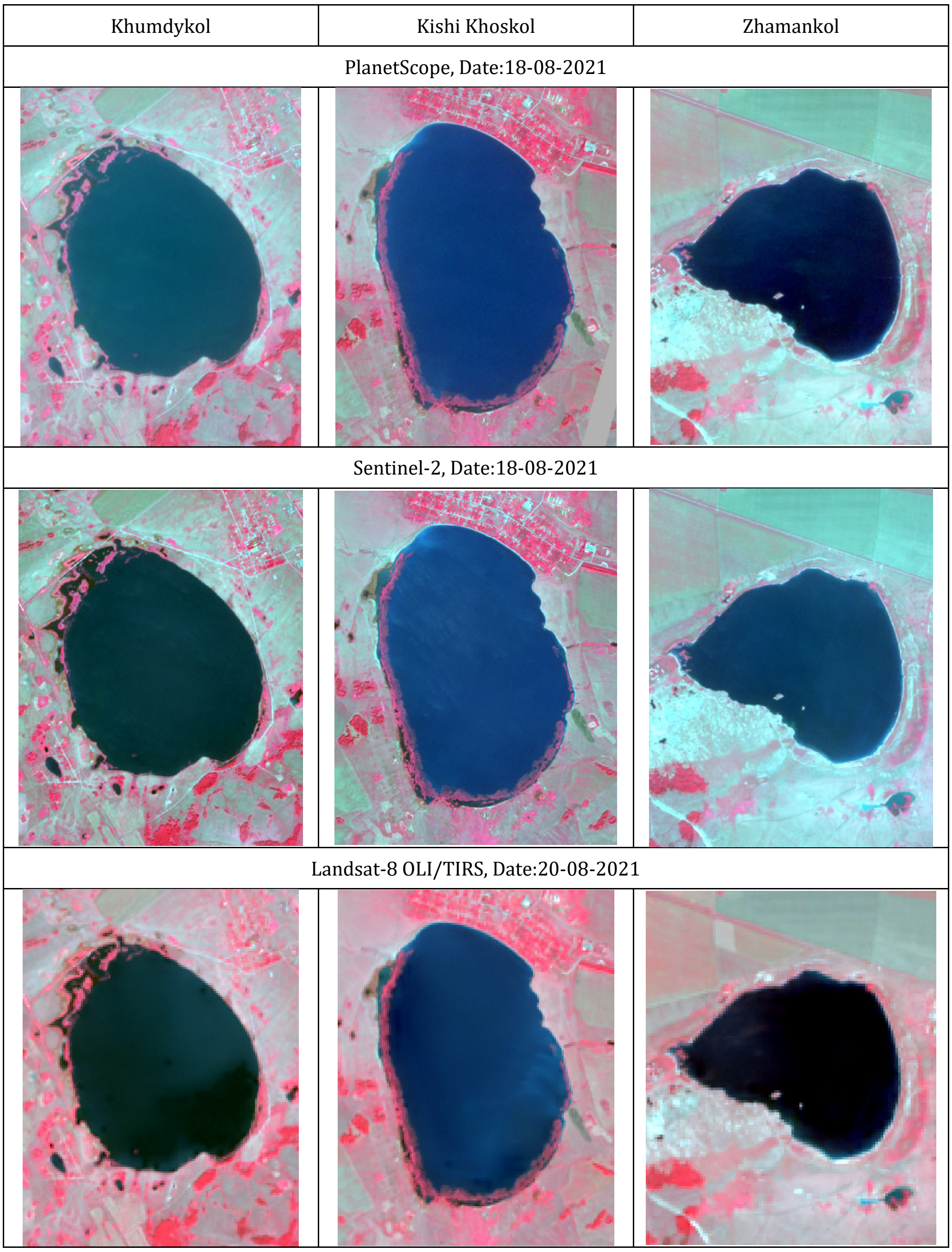

Figure 1 – Display of selected lakes on different satellite images

The modified normalized normalized difference water index (MNDWI) effectively distinguishes between water and built-up areas in satellite images (Xu, 2006: 3025-3033). This method utilizes the visible green (GREEN) and shortwave infrared 1 (SWIR1) spectral bands (Equation 1).

$$MNDWI = (GREEN - SWIR1)/(GREEN + SWIR1) \quad (1)$$

The Automated Water Extraction Index (AWEI) aims to improve the accuracy of land cover classification into water and non-water binary under different environmental conditions. This is achieved by using multiple spectral bands (blue, green, NIR, SWIR1 and SWIR2) and stabilizing the 0 threshold used to distinguish between water and non-water pixels by forcing non-water pixels below 0 and water pixels above 0 (Feyisa et al, 2014: 23-35). The lower index "sh" in the equation is introduced to effectively eliminate non-water pixels, including dark surfaces in urban areas, resulting in improved accuracy by removing shadow pixels (Equation 2).

$$AWEIsh = BLUE + 2.5 \times GREEN - 1.5 \times (NIR + SWIR1) - 0.25 \times SWIR2 \quad (2)$$

However, due to the fact that the lakes in question have swampy shorelines, a threshold of 0 may not always lead to the best waterbody extraction results (Xu, 2006: 3025-3033; Feyisa et al, 2014: 23-35; Guo et al, 2017: 5430-5445). Therefore, additional verification using reference information was carried out.

As a reference information were used the data of "Institute of Geography and Water Security" LLP from field observations obtained using DJI Phantom 4 UAVs. UAV allows to obtain data with resolution of 2-4 cm in different spectral ranges and provided quantitative and qualitative data on the lake surface.

Results and discussion

In this paper, the lakes of the Esil WMB were analyzed using satellite data with different resolutions. The used spectral indices also differ in their applicability depending on the characteristics of satellite data. Thus, due to the lack of short-wave infrared channel, only one of the three indices – NDWI – was applied to Planet satellite images. However, due to the high resolution, the results of Planet images processing were closest to the reference data from field observations (Table 2, Figure 2).

For Lake Zhamankol, the greatest discrepancy from the benchmarks is observed in Sentinel-2A data using MNDWI and AWEInsh indices (error 19.3%), which may be due to the low spatial resolution or peculiarities of the index itself.

For the study of Lake Khumdykol, NDWI shows the least discrepancy with field data (errors 0.41%), which may indicate its better adaptation for analyzing water bodies in this region.

Table 2 – Surface water area from each water index

Lakes	**Source \ Index**	**In-situ works**	**NDWI**	**MNDWI**	**$AWEI_{nsh}$**
		Total Surface Area (km²)			
Zhamankol	DJI Phantom 4 pro	3.36	-	-	-
	PlanetScope	-	3.86	-	-
	Sentinel-2A	-	3.88	4.01	4.01
	Landsat 8	-	3.77	3.89	4.00
Khumdykol	DJI Phantom 4 pro	7.37	-	-	-
	PlanetScope	-	7.38	-	-
	Sentinel-2A	-	7.34	7.94	7.89
	Landsat 8	-	7.22	7.48	7.88
Kishi Khoskol	DJI Phantom 4 pro	9.70	-	-	-
	PlanetScope	-	8.95	-	-
	Sentinel-2A	-	8.91	10.01	9.80
	Landsat 8	-	8.83	9.07	9.75

For Kishi Khoskol, Landsat 8 shows the lowest areas (8.83 km²), which is probably due to insufficient resolution (error 8.14%). The largest areas are shown by MNDWI from Sentinel-2A (10.01 km²), which is also due to the characteristics of the index, which is more sensitive to turbid water (error 3.2%), the most accurate result was shown by the AWEInsh index applied to Sentinel-2 data (error 1.03%).

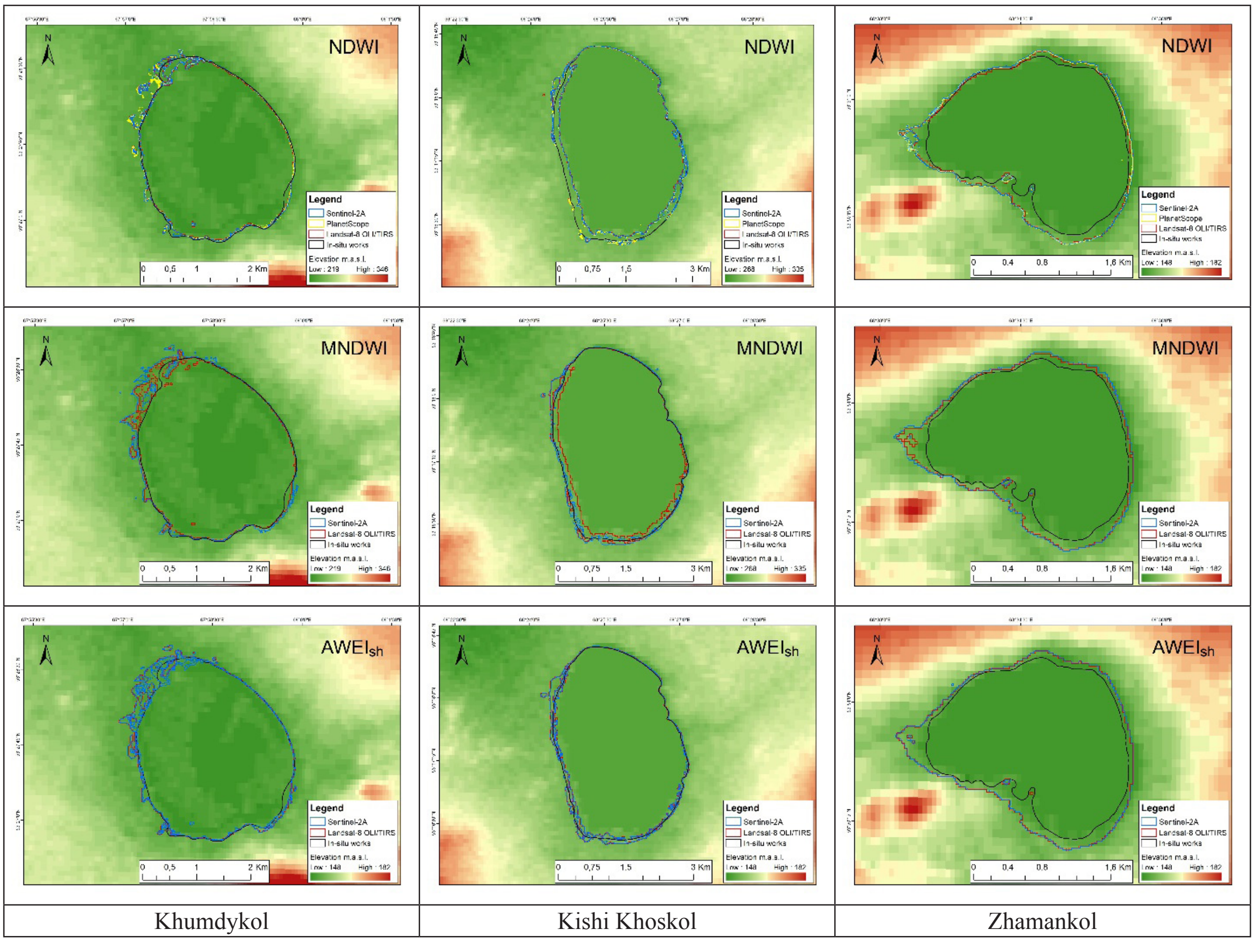

Figure 2 – Calculation of different water surface definition indices

Although MNDWI and AWEInsh indices were considered to be the most favorable indices for water body selection in earlier studies, in this paper they showed the best result only on the largest lake. This may be due to wetland and dense vegetation, hydrochemical indices of water bodies. In addition, increasing the areas and sizes of the study objects decreases the influence of spatial resolution of satellite data.

Remote sensing techniques have proven effective for mapping and monitoring small lakes and wetlands, offering valuable information on their dynamics and ecological importance. Studies have evaluated various methods for estimating lake area using satellite imagery, including density slices, classification trees, and feature extraction (Roach et al., 2012: 51). Landsat and MODIS data have been used extensively, with October identified as the optimal month for mapping lake area on the Tibetan Plateau (Zhang et al., 2017: 742-772). The combination of satellite altimetry and high-resolution imagery has shown promise in monitoring changes in lake volume (Baup et al., 2014: 2007-2020). For small water bodies, Sentinel-2 imagery has proven suitable for lakes larger than 350 m² (Freitas et al., 2019: 1-15). However, challenges remain in accurately measuring lake parameters, including boundary tortuosity and seasonal variation (Shahid et al., 2019: 1-6). Despite these challenges, remote sensing remains crucial for mapping and monitoring wetlands and small lakes, especially in poorly studied regions (Lyons et al., 2013: 7887-7905).

Various methods such as NDWI thresholding, ISODATA classification and K-means clustering combined with flood filling (KCFFM) have been applied (Ji et al., 2015: 327-334; Xu et al., 2021: 127180). KCFFM has shown high accuracy and stability, especially during ice periods (Xu et al., 2021: 127180). Studies have found significant correlations between lake characteristics and meteorological parameters, emphasizing the influence of climate on lake dynamics (Vakhnina et al., 20119: 178-182; Pshenichnikov, 2018: 45-53). Remote sensing has also been used to assess water balance and volume changes of steppe lakes (Magsar et al., 2021: 2051-2059).

Conclusion

This scientific paper is devoted to the study of lakes located in the Esil WHB using satellite data with different resolutions and spectral indices, namely NDWI, MNDWI and AweinSh. Remote sensing related methodologies have shown to be highly effective in delineating and identifying water bodies, especially when using high-resolution datasets comprising UAV data and Planet satellite imagery. These approaches ensured minimal variation from the reference data in the form of field observations of small lakes, allowing for more accurate delineation of shorelines and water surfaces.

The study confirmed that the choice of spectral index and input data with optimal spatial resolution has a significant impact on the accuracy of the results. The MNDWI and AWeinsh indices gave excellent results in regions with turbid water or wetland vegetation, while the NDWI index showed the highest level of accuracy for lakes with stable hydrological conditions. In addition, high-resolution satellite data were found to be more effective for small and medium-sized lakes, while medium-resolution data were more applicable to large water bodies.

The results obtained have significant potential for monitoring the dynamics and state of water bodies, as well as for improving water management systems. Prospects for further research include the development of more accurate algorithms based on machine learning methods, integration of satellite altimetry data for comprehensive analysis, and the study of relationships between climate change and water system dynamics.

Acknowledgement

This research was funded by the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. BR21882365).

Conflict of interest

There is no conflict of interest.

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Received: September 21, 2024
Accepted: November 20, 2024