



# Application of Remote Sensing and GIS Techniques for the Analysis of Lake Water Fluctuations: A Case Study of Ugii Lake, Mongolia

Amgalan Magsar<sup>†</sup>, Toru Matsumoto<sup>\*\*</sup>, Altanbold Enkhbold<sup>\*\*\*</sup> and Nandintsetseg Nyam-Osor<sup>\*\*\*\*</sup>

\*Faculty of Environmental Engineering, The University of Kitakyushu, Hibikino 1-1, Wakamatsu-ku, Kitakyushu-shi, Fukuoka 808-0135, Japan

\*\*Institute of Environmental Science and Technology, The University of Kitakyushu, Hibikino 1-1, Wakamatsu-ku, Kitakyushu-shi, Fukuoka 808-0135, Japan

\*\*\*Department of Geography, School of Art & Sciences, National University of Mongolia, Ikh Surguuliin Gudamj-1, P.O.X-46A/523, 210646 Ulaanbaatar, Mongolia

\*\*\*\*Institute of Geography and Geoecology of Mongolia, Baruunselbe 15-4, 4th Khoroo, Chingeltei district 15170, Ulaanbaatar, Mongolia

<sup>†</sup>Corresponding author: Amgalan Magsar; a-magsar@kitakyu-u.ac.jp

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## ABSTRACT

Ugii Lake is a freshwater lake located in the steppe region of Mongolia and is an important breeding and staging area for a wide variety of waterfowl. Remote sensing and geographic information system techniques were used to estimate fluctuations in the surface area and water balance of Ugii Lake. To estimate the changes in lake water balance, lake water fluctuations should be analyzed using the most accurate methods. A different water extraction technique was applied, and the results were compared with field surveys conducted in May, July, and September 2020. The lake surface area using both NDWI and MNDWI-1 showed a strong, positive correlation ( $R=0.93$ ,  $R=0.94$ ,  $p < 0.01$ ) with the water level of Ugii Lake. A topographic map of Ugii Lake was provided by the project (P2018-3568) conducted in August 2019 and used to estimate the volume of Ugii Lake in ArcGIS 10.1. This result was consistent with that of a previous study by JICA in 2005. Finally, the water balance of Ugii Lake was estimated, and the results proved that the influence of both surface and groundwater on Ugii Lake are valuable parameters, which are completely dependent on hydrological regime changes mostly due to local climate change in steppe regions. This study provides valuable insight into the most suitable water extraction methods for lakes in semi-arid steppe regions in Mongolia.

## INTRODUCTION

Lakes are essential components of the hydrological cycle, affecting many aspects of ecosystems and human activity. Lakes remain sensitive to natural changes and serve as an important proxy of global climate change and regional environmental variations (Mason et al. 1994). Lake area is an important indicator of climate change and is related to climatic factors that are critical for understanding the mechanisms that control changes in water levels (Kang et al. 2015). The water of most inland lakes in arid regions is supplied by seasonal snowmelt water and rainfall. As a result, these lakes are sensitive to the volume of water flowing into the lake and evaporation loss from their surface (Bai et al. 2011). In Mongolia, global warming occurs more rapidly than the global average. The time taken for the accumulated snow to disappear has advanced by approximately one month in our study area, which is evidence of the impact of climate change on hydrological processes. Due to changes

in precipitation and temperature, the hydrological regime of the surface water body is likely to be affected, especially in semi-arid regions. Several studies have examined the dynamics of climate and hydrological systems in semi-arid regions of Mongolia. Significant decreases in river discharges have occurred in the past three decades, while the annual precipitation has remained relatively stable (Dorjsuren et al. 2018). Ugii Lake is surrounded by the small mountains of eastern Khangay, which is a steppe zone area in terms of climate and landscape. The water level of Ugii Lake is influenced by the surface and groundwater flow of the Orkhon, Tamir, and Khugshin Orkhon Rivers (Batchuluun 2021). Ugii Lake was first registered as an International Ramsar Convention site in 1998 and is an ecologically important lake located in the semi-arid region of Mongolia.

In recent years, the water level of Ugii Lake has fluctuated. Several environmental problems have occurred due to changes in the hydrological regime, local climate changes,

and increased human activities around the lake. Sumiya et al. (2020) concluded that the surface area of Ugii Lake has fluctuated by 10 percent in the last three decades because of global warming.

Mapping lake areas using remote sensing (RS) images is key for detecting changes in the size of lakes and understanding the relationship between lake variations and climate change. RS is a rapidly growing technology that provides low-cost and reliable information for environmental changes at local, regional, and global scales, providing long-collected repeatable and even real-time data (Melesse et al. 2007). Various water indices have been applied to extract surface water bodies from the surrounding land using RS imagery based on their spectral characteristics (Acharya et al. 2019, Herndon et al. 2020, Liu et al. 2016, Zhai et al. 2015). The accuracy of the surface water extraction method is important for the estimation of lake water fluctuation and to understand the impact of hydrometeorological factors on lakes in semi-arid regions. The objectives of this study were to apply the most common water index ratios in the multi-spectral RS water identification method, which includes the normalized difference vegetation index (NDVI), normalized difference water index (NDWI), modified normalized difference water index-1 (MNDWI-1), and modified normalized difference water index-2 (MNDWI-2), to extract the lake surface area, to verify with *in-situ* measured data, and to suggest the most suitable method for surface water extraction in semi-arid regions of Mongolia. Furthermore, the extracted surface area and topographic map of Ugii Lake are proposed to estimate the changes in the water balance of the lake.

## MATERIALS AND METHODS

### Study Area

According to the climate zone classification by Jambaajamts (1989) in Mongolia, Ugii Lake is located in the sub-humid-cool zone, 1332 m above sea level. Sumiya et al. (2020) reported that Ugii Lake was formed by the meandering of the Khugshin Orkhon River, which is a unique surface inflow into the Ugii Lake. The outlet is located northwest of the inlet and joins the Orkhon River after 7 km (Schwanghart et al. 2008). For numerous years, the outflow river (Narini Gol) has been dry, and it only becomes an issue when the water level of Ugii Lake reaches a certain level. Ugii Lake is 7.4 km long, 5.3 km wide (mean width 3.4 km), and covers an area of 25.7 km<sup>2</sup> with a maximum depth of 15.3 m and a mean depth of 6.6 m (Tserensodnom 2000). More than half of the lake is less than 3 m deep. The lake has a shoreline of 24.7 km and carries a water volume of approximately 0.171 km<sup>3</sup> (Fig. 1). The mean annual temperature is approximately -2°C, and the mean annual precipitation ranges from 250 to

300 mm, with the majority of the precipitation occurring in June, July, and August.

## MATERIALS AND METHODS

### Field Survey

The field survey was conducted three times in May, July, and September 2020 using a Garmin eTrex10 handy GPS. The measured coordinates were used to calculate the lake surface area using ArcMap 10.1.

### Data Collection

**Hydrological station data:** Discharge of Khugshin Orkhon River was obtained from the Ugii Lake gauging station between 2002 and 2019. Daily lake water level data was obtained from Ugii Lake Hydrological Station (~102.77°E, 47.75°N) between 2002 and 2019. Global daily precipitation gridded data (102.71°-102.82° E, 47.74°-47.79° N) with a spatial resolution of 0.5° latitude by 0.5° longitude from the Global Precipitation Climatology Centre (GPCC) was obtained from the Physical Science Laboratory (PSL) at the National Oceanographic Atmospheric Administration (NOAA) from their website (<https://psl.noaa.gov/>). Daily evaporation data for Ugii Lake was compiled from previous research (Magsar et al. 2020) between 2002 and 2019 in order to estimate the water balance of Ugii Lake. A topographic map of Ugii Lake was provided by the literature.

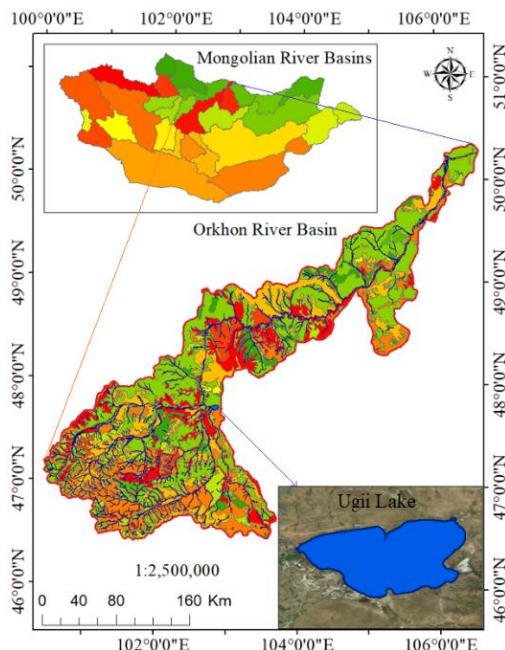


Fig. 1: Location of the study area.

**Satellite remote sensing images:** RS is an effective technology for the monitoring of water resources. Both Landsat 5 TM and Landsat 8 OLI satellite RS imagery data was used to derive the surface area of the Ugii Lake. Since its inception on March 1, 1984, until its decommission on June 5, 2013, Landsat 5 has provided Earth-imaging data for approximately 29 years. Landsat-8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) satellite were launched in February 2013. Satellite data (pixel size of 30 m) was downloaded from the Earth Explorer at <https://earthexplorer.usgs.gov/>, which was developed by the United States Geological Survey (USGS). The differences in band range and resolution between the OLI and TM sensors are listed in Table 1.

**Satellite image processing and analysis:** Satellite images were preprocessed before conducting any analyses because they contained noise and digital number value offsets that result from the viewing geometry of the satellite, and the atmospheric depth due to the viewing angle of the sun’s incoming radiation (Alparslan et al. 2007). Landsat 5 satellite images were preprocessed with the radiometric calibration tool in ENVI 4.7, which converted the digital number (DN) images to top of atmosphere (TOA) reflectance.

The Landsat 8 images were also preprocessed using Equation (1) and Equation (2):

$$\rho\lambda' = M_{\rho} * Q_{cal} + A_{\rho} \quad \dots (1)$$

Where,

$\rho\lambda'$  TOA planetary spectral reflectance, without correction for solar angle,

$M_{\rho}$  Reflectance multiplicative scaling factor for the band,

$Q_{cal}$  Quantized and calibrated standard product pixel value in DN,

$A_{\rho}$  Reflectance additive scaling factor for the band.

TOA reflectance with a correction for the sun angle was denoted by:

$$\rho\lambda = \frac{\rho\lambda'}{\cos(\theta_{SZ})} = \frac{\rho\lambda'}{\sin(\theta_{SE})} \quad \dots (2)$$

where

$\rho\lambda$  TOA planetary reflectance,

$\theta_{SZ}$  Local solar zenith angle,

$(\theta_{SZ} = 90^{\circ} - \theta_{SE})$ ,

$\theta_{SE}$  Local sun elevation angle (degrees).

After the conversion of the scene center sun elevation angle provided in the metadata, the lake water surface was delineated using the most common water indices such as NDVI, NDWI, MNDWI-1, and MNDWI-2. Then, the surface area of Ugii Lake was calculated using ArcMap 10.1.

Table 2 shows the multiband indices used for water feature extraction in this study. NDVI is an index of plant greenness since plants absorb red light and reflect NIR. Its value ranges from -1 to +1. By contrast, water absorbed the majority of the NIR light; hence, NDVI could be used to delineate surface water features (Acharya et al. 2019). NDWI is one of the most commonly used water indices to detect surface water bodies and was first created by the green and near-infrared (NIR) spectral bands of Landsat TM, introduced by McFeeters in 1994. NDWI is designed

Table 1: Differences in band ranges and resolutions between the OLI and TM sensor.

№	Landsat 8 OLI (Gabr et al. 2020)			№	Landsat 5 TM/ETM+ (Zhai et al. 2015)			
	Band	Wavelength (µm)	Resolution (m)		Band	Wavelength [µm]	Resolution [m]	
1	Coastal aerosol (CA)	0.435–0.451	30 m	1	Blue	0.450–0.515	30 m	
2	Blue	0.452–0.512		2	Green	0.525–0.605		
3	Green	0.513–0.590		3	Red	0.630–0.690		
4	Red	0.636–0.673		4	NIR	0.775–0.900		
5	Near Infrared (NIR)	0.851–0.879		5	Mid Infrared (MIR)	1.550–1.750		
6	Shortwave NIR1 (SWIR1)	1.566–1.651		6	Thermal Infrared Sensor (TIRS)	10.40–12.50		60 m
7	Shortwave NIR2 (SWIR2)	2.107–2.294		7	MIR	2.080–2.350		30 m
8	Pan	0.500–0.680	15 m	8	Pan	0.520–0.900	15 m	
9	Panchromatic	1.363–1.384	15 m					

to: (1) maximize the reflectance of water by using green wavelengths, (2) minimize the low reflectance of NIR by water features, and (3) take advantage of the high reflectance of NIR by vegetation and soil features (Xu 2006). Xu noted that the threshold 0 was not an appropriate distinguishing feature and proposed the MNDWIs (Zhai et al. 2015).

Lake water fluctuations provide important information regarding the water balance of lakes in arid and semi-arid regions and are necessary to understand the conditions of local climate change, the hydrological regime, and the ecological status of important lakes.

The water balance of Ugii Lake can be expressed by Equation (3):

$$P - E + Y_{SI} \pm \Delta V - Y_{SO} = \Delta Y_{GW} \quad \dots (3)$$

Where,

$\Delta V$  - Changes of the lake volume,

P - Precipitation over the lake,

E - Evaporation over the lake,

$Y_{SI}$  - Surface inflow,

$Y_{SO}$  - Surface outflow,

$\Delta Y_{GW}$  - Groundwater change,

The topographic map of Ugii Lake and the lake depth measurement results were provided by the implemented project (P2018-3568) at Ugii Lake in August 2019 and used to estimate the changes in lake volume. The surface area of each depth was calculated using ArcGIS, and the volume of the lake was calculated using Equation (4):

$$V = \sum_{i=1}^n [(A_i - A_{i+1}) \times d_i] \quad \dots(4)$$

Where,

V - Volume of the lake,

A - Surface area,

d - Depth of the lake level,

n - Number of each water depth,

$i = 1, 2, \dots n$

## RESULTS AND DISCUSSION

According to the station data, the average annual water level of Ugii Lake fluctuated. The highest water level was observed in 2004 (3.53 m); however, the lake water level decreased gradually between 2004 and 2011. The lowest water level was observed in 2011 (1.79 m), which increased steadily until 2017 (3.23 m) and decreased by 0.63 m in 2018. Ugii

Lake has only one surface inflow to lake. The annual average discharge of the Khugshin Orkhon River was  $0.5 \text{ m}^3 \cdot \text{s}^{-1}$  in 2003, which was the highest level during the study period. Since 2003, the annual average discharge decreased gradually until 2011 ( $0.079 \text{ m}^3 \cdot \text{s}^{-1}$ ) and increased in 2016 ( $0.463 \text{ m}^3 \cdot \text{s}^{-1}$ ). The changes in discharge of the Khugshin Orkhon River are relevant to the fluctuation of the Ugii Lake water level (Fig. 2). In the case of Ugii Lake, water flows out from the lake on the northwestern side and joins the Orkhon River when the water level of the lake increases. However, due to fluctuations in the water level in recent decades, outflow rivers from lakes have dried out. Therefore, the amount of surface outflow from the lake could be excluded from further lake water balance calculations.

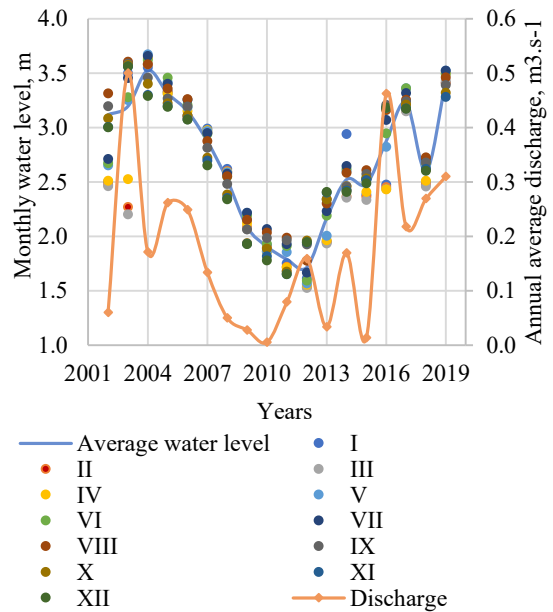


Fig. 2: Comparison of annual average discharge and monthly water level of Ugii Lake.

### Estimation of Changes in the Surface Area of Ugii Lake Using Satellite Remote Sensing

**Field survey result:** Surface area and water level are interrelated parameters of lake morphometry. As mentioned above, data on the water level of Ugii Lake was available between 2002 and 2019. Therefore, above mentioned water indices were applied to estimate the lake surface area using the monthly RS images of both Landsat 5 TM and Landsat 8 OLI. To assess the extraction accuracy of the water indices, the length of the lake shoreline was measured three times between May and September 2020. Table 3 provides detailed information on satellite images and field survey dates.

Cloudless satellite images from paths 134 and 27 with 30 m resolution were collected, and each water index was estimated accordingly. The comparison between the water indices and *in-situ* measurements are shown in Table 4 and Fig. 3.

According to the estimated lake water surface area, both NDWI and MNDWI-1 had closer estimates than NDVI and MNDWI-2. A total of 68 satellite images were used to estimate the monthly lake water surface area using both NDWI and MNDWI-1 within the study period from May to October (2002-2019). The results of the estimated lake water surface area were compared with the water level data from the Ugii Lake station. Fig. 4 shows that the estimated surface area of the lake had a strong, positive correlation ( $R=0.93$ ,  $R=0.94$ ,  $p < 0.01$ ) with the water level of the lake. Therefore, the NDWI and MNDWI-1 methods are recommended for lake water extraction in steppe regions.

As shown in Fig. 5, the surface area of the lake changed slightly each month during the study period, increasing in August and September each year, which may contribute to the increases in both surface and groundwater discharge during the summer (rainy) season. From the beginning of November, the lake surface area was covered by ice with a thickness of 1–1.5 m during the winter season until mid-April. Once the snow and ice cover melted, the surface water discharge and lake water level increased depending on the amount of snow accumulated during the winter months.

Since 2016, changes in the surface area of the lake have steadily increased. The highest value of lake surface area was estimated in September of each year. Fig. 6 shows the difference between each year in September. Water flowed out from the lake when the lake surface area increased. Magsar et al. (2020) concluded that annual total evaporation from the lake mostly exceeds the total amount of precipitation since 1995. The summer precipitation consisted predominantly of total annual precipitation, the majority of which occurred during the months of July and August each year during the study period. The highest recorded monthly precipitation

was in July 2018 (113.25), which may have contributed to an increase in the lake’s surface area by 0.95 km<sup>2</sup> in the following month (August 27, 2018). The lowest recorded monthly precipitation was in July 2017 (26.45 mm), which may have contributed to a decrease in the lake surface area by 0.04 km<sup>2</sup> in the following month (August 01, 2017). As seen in Table 5, the surface area of Ugii Lake fluctuates each month. Depending on the weather condition, the surface area increases mostly in August and September.

**Estimation of the Water Balance of the Ugii Lake**

According to the results described in the previous section, the surface area of Ugii Lake had fluctuated, which is an indicator of changes in the local hydrological regime as a result of several factors, including local climate change. In

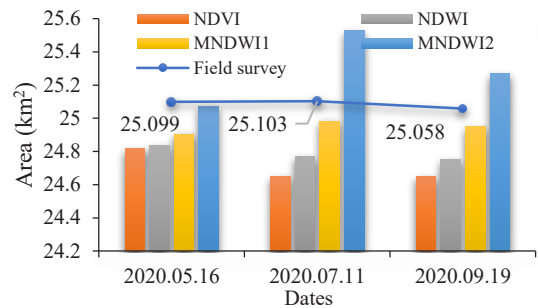


Fig. 3: Comparison of different water indices.

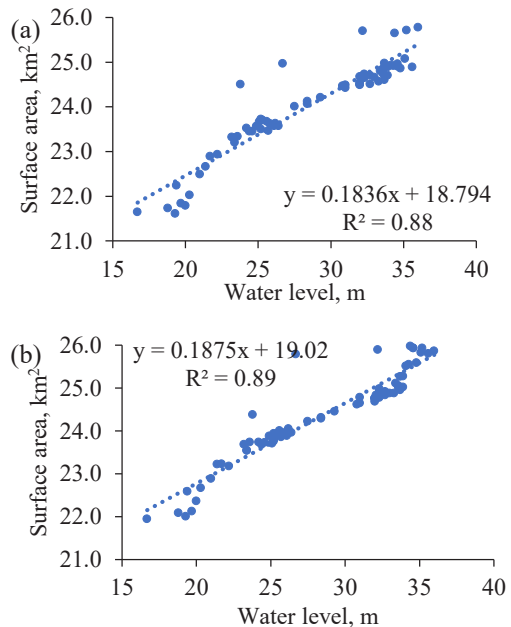


Fig. 4: Correlation between lake level and surface area (a) NDWI, (b) MNDWI-1.

Table 2: Multiband indices used for water feature extraction.

Multiband index	Equation	Water value	Reference
NDVI	$NDVI = (NIR - Red) / (NIR + Red) \dots (5)$	-	(Rouse et al. 1974)
NDWI	$NDWI = (Green - NIR) / (Green + NIR) \dots (6)$	+	(McFeeters 1996)
MNDWI	$MNDWI1 = (Green - SWIR1) / (Green + SWIR1) \dots (7)$ $MNDWI2 = (Green - SWIR2) / (Green + SWIR2) \dots (8)$	+	(Xu 2006)

Table 3: Details of Landsat 8 OLI images and field survey dates.

Field survey	Acquisition date	Landsat product ID	Path	Row	Resolution [m]
2020.05.16	2020.05.12	LC08_L1TP_134027_20200512_20200526_01_T1	134	27	30
2020.07.11	2020.07.15	LC08_L1TP_134027_20200715_20200715_01_RT	134	27	30
2020.09.19	2020.09.17	LC08_L1TP_134027_20200917_20201006_01_T1	134	27	30

Table 4: Comparison between *in situ* measurements and different water indices for estimating the surface area of Ugii Lake.

Field survey date	Area [km <sup>2</sup> ]	Satellite name	Acquisition date	Area [km <sup>2</sup> ]			
				NDVI	NDWI	MNDWI1	MNDWI2
2020.05.16	25.099	Landsat 8 OLI	2020.05.12	24.818	24.837	24.905	25.072
2020.07.11	25.103		2020.07.15	24.647	24.767	24.984	25.528
2020.09.19	25.058		2020.09.17	24.65	24.75	24.95	25.27

Table 5: Monthly average lake surface area fluctuation (km<sup>2</sup>) using MNDWI-1.

Years	Months					
	May	Jun	Jul	Aug	Sep	Oct
2002	-	25.79	-	25.04	24.83	24.61
2003	-	-	25.27	25.86	25.98	25.89
2004	-	-	-	25.81	25.55	25.51
2005	-	-	-	24.95	24.88	24.77
2006	-	-	-	24.83	24.69	24.78
2007	-	-	24.45	-	24.22	-
2008	-	-	-	23.88	23.73	24.38
2009	-	-	-	23.22	22.89	22.58
2010	-	-	-	22.67	22.12	22.08
2011	-	-	-	22.37	22.00	21.94
2012	-	-	23.34	23.38	23.46	-
2013	-	23.23	23.18	23.69	23.54	23.74
2014	-	23.89	23.96	23.86	23.68	23.73
2015	23.70	23.76	24.00	24.05	23.96	23.85
2016	24.29	-	24.65	24.76	24.76	-
2017	25.02	25.01	24.88	24.92	24.9	-
2018	24.82	24.76	24.98	25.93	25.93	-
2019	25.93	25.83	-	25.59	25.11	-

addition, the changes in lake water volume are interdependent on the hydrometeorological conditions.

As shown in Fig. 7, the lake water depth increased while the surface area of the lake decreased. For instance, the estimated lake surface area was 25.49 km<sup>2</sup>, 23.59 km<sup>2</sup>, and 21.71 km<sup>2</sup> at a depth of 0.5 m, 1 m, and 2 m, respectively (Table 6).

Based on the morphometric parameters of the lake, the volume of the lake in August, 2019 was estimated using Equation (4); (Table 6), the results of which were similar to those reported by JICA in 2005. The estimated surface area (2002-2019) and topographic map (August 2019) of Ugii

Lake were used to calculate the volume of the lake. During the study period, the volume of the lake decreased by  $0.6 \times 10^{-3}$  km<sup>3</sup>,  $1.4 \times 10^{-3}$  km<sup>3</sup>, and  $1.5 \times 10^{-3}$  km<sup>3</sup> in 2009, 2010, and 2011, respectively, compared to the data reported by JICA in 2005. Since 2013, the volume of the lake steadily increased until 2018, and then decreased by  $0.4 \times 10^{-3}$  km<sup>3</sup> in 2019, compared to the previous year (Table 7).

As mentioned above, fluctuations in lake water are related to the hydrological regime. This is a primary indicator of local climate change, which results in the ecological condition of shallow lakes in the steppe region. As described earlier, the

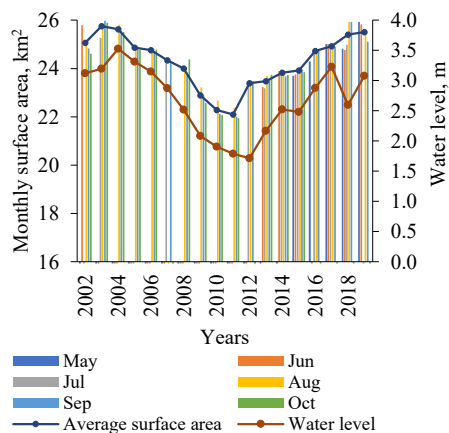


Fig. 5: Monthly fluctuations in surface area of the lake between 2002 and 2019.

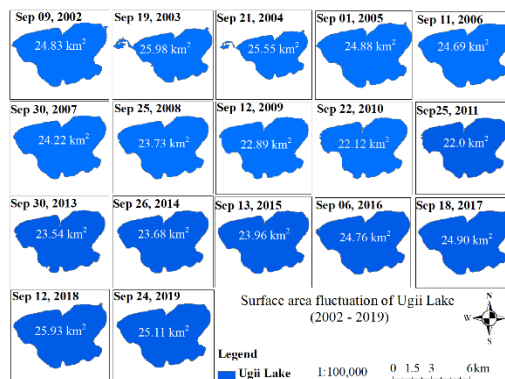


Fig. 6: Mapping of the surface area of Ugii Lake in September of every year between 2002 and 2019.

Table 6: The morphometric parameters of Ugii Lake (August 2019).

No	Reference lake depth [m]	Surface area of each depth [km <sup>2</sup> ]	Lake volume [km <sup>3</sup> ]
1	0.5	25.49	0.00095
2	1	23.59	0.00188
3	2	21.71	0.00362
4	3	19.90	0.00474
5	4	18.32	0.0056
6	5	16.92	0.0081
7	6	15.30	0.0141
8	7	12.95	0.01645
9	8	10.60	0.01248
10	9	9.04	0.01602
11	10	7.26	0.0196
12	11	5.30	0.01188
13	12	4.22	0.012
14	13	3.22	0.01833
15	14	1.81	0.0126
16	15	0.91	0.00825
17	15.3	0.36	0.00551
Total volume of the lake [km <sup>3</sup> ]			0.1721

water balance of Ugii Lake can be expressed by Equation (3). Based on available hydro-meteorological data, changes in the main parameters relating to Ugii Lake’s water balance were investigated, and it was estimated how these factors are linked to changes in the lake’s water volume.

The total amount of evaporation, precipitation, and surface inflow to the lake between the satellite acquisition dates of each September between 2002 and 2019, were compiled and used to derive the water balance of Ugii Lake (Table 8).

The volume of the lake was estimated at  $172.3 \times 10^3 \text{ km}^3$  in 2003 and 2018, which is the highest volume during the study period. As shown in Table 8, the annual total surface inflow was high, when the total amount of precipitation was closer to the amount of water evaporated from the lake.

For instance, the surface inflow was  $15.77 \times 10^3 \text{ km}^3 \cdot \text{year}^{-1}$ ,  $14.02 \times 10^3 \text{ km}^3 \cdot \text{year}^{-1}$ , and  $11.34 \times 10^3 \text{ km}^3 \cdot \text{year}^{-1}$  in 2003, 2016, and 2018, respectively, which resulted in an increase in the volume of the lake at the highest value. The

Table 7: Changes on volume of Ugii Lake in September between 2002 and 2019.

Years	[km <sup>2</sup> ]	[km <sup>3</sup> ]	[10 <sup>-3</sup> km <sup>3</sup> ]
2002	24.83	0.1717	**
2003	25.98	0.1723	1.3
2004	25.55	0.1721	0.171*
2005	24.88	0.1718	0.8
2006	24.69	0.1717	0.7
2007	24.22	0.1715	0.5
2008	23.73	0.1712	0.2
2009	22.89	0.1704	-0.6
2010	22.12	0.1696	-1.4
2011	22.0	0.1695	-1.5
2012	23.46	0.1710	0
2013	23.54	0.1711	0.1
2014	23.68	0.1712	0.2
2015	23.96	0.1713	0.3
2016	24.76	0.1717	0.7
2017	24.90	0.1718	0.8
2018	25.93	0.1723	1.3
2019	25.11	0.1719	0.9

Note: \* Reference value by JICA in 2005  
 \*\* Indicates no value

Table 8: Characteristics of the water balance of Ugii Lake.

Years	P	E	Y <sub>SI</sub>	ΔY <sub>GW</sub>	V	ΔV
	[10 <sup>-3</sup> km <sup>3</sup> .year <sup>-1</sup> ]			[10 <sup>-3</sup> km <sup>3</sup> ]		
2002	2.87	6.67	1.90	**	171.7	**
2003	7.07	7.97	15.77	14.27	172.3	0.6
2004	4.59	7.88	5.39	2.31	172.1	-0.2
2005	4.76	7.50	8.25	5.81	171.8	-0.3
2006	6.46	8.17	7.86	6.25	171.7	-0.1
2007	6.23	8.79	4.22	1.85	171.5	-0.2
2008	5.54	8.04	1.59	-0.62	171.2	-0.3
2009	3.99	7.85	0.88	-2.18	170.4	-0.8
2010	5.41	8.41	0.17	-2.03	169.6	-0.8
2011	6.49	7.31	2.50	1.78	169.5	-0.1
2012	6.97	7.83	5.01	2.65	171	1.5
2013	6.10	6.68	1.07	0.39	171.1	0.1
2014	6.40	8.33	5.34	3.31	171.2	0.1
2015	6.32	7.92	0.43	-1.27	171.3	0.1
2016	8.54	7.52	14.02	14.65	171.7	0.4
2017	6.38	8.61	9.15	6.82	171.8	0.1
2018	8.26	8.71	11.34	10.38	172.3	0.5
2019	6.08	8.29	7.31	5.50	171.9	-0.4

volume of the lake remained higher for the following year after increasing, and it was decreased because of the high amount of evaporation and decreased surface inflow to the lake for the following years. According to the estimated lake volume and Equation (4), it can be concluded that the fluctuation of Ugii Lake contributes to hydrometeorological parameters and groundwater flow. For instance, the surface inflow to the lake gradually decreased, and evaporation from the lake was higher than the precipitation between 2008 and 2010. However, the volume of the lake decreased slightly, which was not balanced. This imbalance was because the remaining changes in lake volume are fed by groundwater. Therefore, there is a need to study the potential groundwater of the Ugii Lake Basin in further studies.

**CONCLUSION**

The lake water surface area calculated using both NDWI and MNDWI-1 showed a strong, positive correlation (R=0.93, R=0.94, *p* < 0.01) with the water level of Ugii Lake. The accuracy of both NDWI and MNDWI-1 methods makes them feasible for lake water extraction in steppe regions. The estimated volume of Ugii Lake was consistent with that reported in a previous study by JICA in 2005. The water

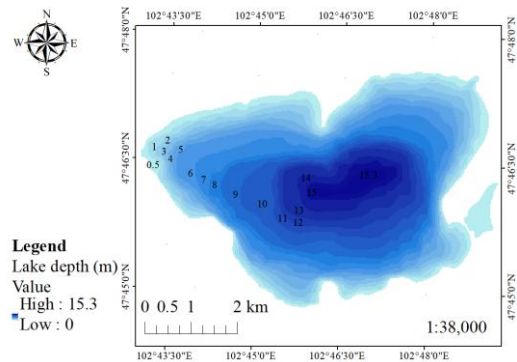


Fig. 7: Topographic map of Ugii Lake.

balance of Ugii Lake was calculated, and the results proved that the influence of both surface and groundwater on the water balance of the lake are valuable parameters, which can be seen from the difference between the estimated lake volume and the total inflow and outflow to the lake. This study provides valuable information on water extraction methods using satellite images that can be used for further studies, on the influence of climate change on the lakes of the steppe region in Mongolia.



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