PlanetScope Imagery-based Monitoring of Annual and Seasonal Dynamics of Lakes in Tbilisi, Georgia

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Abstract: Lakes have special aesthetic and recreational value in Tbilisi, especially in recent years, as the demand for residential areas near water bodies and the load on the surrounding landscapes have increased. Monitoring small-area water bodies requires high spatial and temporal resolution images. For more precise research, the PlanetScope imagery (3 m) provides excellent data. We recorded the annual and seasonal dynamics of the lake area extent of four lakes in Tbilisi using PlanetScope optical satellite images. The changes observed in the NDVI and NDWI based on the four-season images in ArcMap 10.8.2 for the period of 2017–2023 revealed an interesting trend. Despite the increasing severity of droughts in Tbilisi over the last 30 years, Turtle Lake, which is located hypsometrically high and surrounded by forest landscapes, is the most resistant to annual and seasonal changes. Didi and Patara Lakes, located in steppe landscapes, were particularly vulnerable to changes. Lisi Lake exhibited a similar trend. Changes in lakes located in steppe landscapes have a special seasonal character, and therefore, a noticeable decrease in water level coincides with the summer dry season (August-September). In addition to natural conditions, land use changes are also important. Active development is underway near these lakes. The alarming dynamics of the lake area extent of these lakes confirm that research is important in future conservation decisions for these lakes and their ecosystems.

Keywords: lakes; monitoring; RS; PlanetScope; Tbilisi

1 Introduction

Inland lakes are important sources of fresh water resources. In addition, urban lakes are given recreational value, and in addition to their aesthetic value for the city's population, they often perform alternative health functions. Urban lakes are affected by many factors. Along with climate change, stress is increased by industry and domestic consumption linked to the growth of the city's population and related urban processes.

Urban lakes are usually small in size and relatively vulnerable to lake area changes and eutrophication processes. In parallel with the development of remote sensing, many opportunities have appeared for monitoring lake ecosystems (Niroumand-Jadidi and Bovolo 2021) and the biophysical processes occurring within them (Worqlul et al. 2020, Pham-Duc 2024). For countries such as Georgia, the use of open access data has additional importance. For example, with the spatial expansion of Tbilisi, the capital of Georgia, the demand for new residential areas increased, and Tbilisi actively began to develop around the lakes in the city (Tsitsagi et al. 2022). Unfortunately, data on the conditions of the lakes in Tbilisi is scarce and less accessible. Several aerial photographs were taken in Tbilisi in the past, but unfortunately, they were either panchromatic or in the visible spectrum. However, in parallel with the expansion and development of the city, we have significant statistical data that we will use in future urban planning.

The aim of this study was to determine the seasonal and annual changes in the extent of the lake area in Tbilisi using PlanetScope images.

2 Materials and methods

Tbilisi is located in eastern Georgia and is distinguished by its varied terrain, climate and landscapes. There are several natural and artificial lakes within Tbilisi. In a specific study, the following natural lakes in Tbilisi were considered: Didi Lake (Figure 1A), Patara Lake (Figure 1A), Lisi Lake (Figure 1B) and Turtle Lake (Figure 1C).

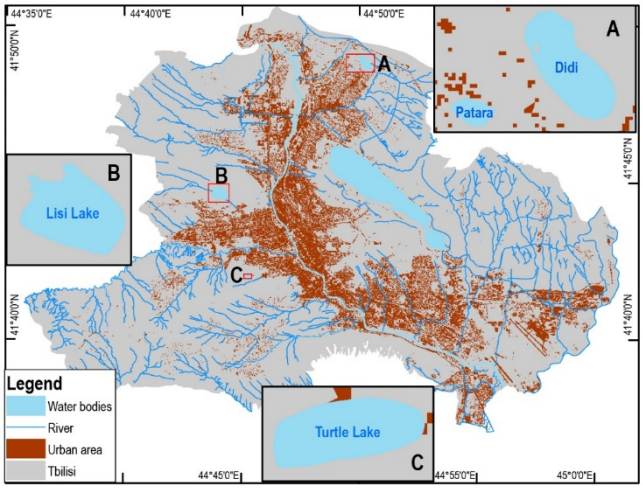

Figure 1. Study area, Tbilisi, Georgia.

Didi Lake (another name Gldani Lake) is located in the north of the city at 546 meters above sea level. The lake is mainly fed by rain and snowmelt water. The level of eutrophication in this region is quite high. There is also Patara lake nearby. Lisi Lake is located in the western part of the city 624 meters above sea level. Lisi Lake is fed by rain, snowmelt and underground water. The area around the lake is a popular place for city residents. Turtle Lake is located in the southern part of the city 686 meters above sea level. Turtle Lake is of landslide origin and is a favorite vacation spot for the population.

To estimate the seasonal and annual changes in the lake area extent, we used PlanetScope images orthoscenes that are geometrically corrected and scaled to surface-

reflectance radiance from the period 2017-2023. PlanetScope imagery has a spatial resolution of 3.7–4.1 m and is recorded in four bands (eight bands since March 2021) in VIS and NIR spectra (Qayyum et al. 2020). Figure 2 details the methodology used in the study. For the study, we selected cloudless images that included only one scene. To avoid bias, we created a mosaic of average monthly values from images of the appropriate detection quality for each month. PlanetScope has several limitations in addition to its high resolution, including limited access, image quality, short record, and lack of SWIR and TIR bands (Abderhalden et al. 2024).

Using selected scenes in ArcMap 10.8, we identified water based on the normalized difference vegetation index (NDVI) (equation 1), normalized difference water index (NDWI) (equation 2, which is one of the most widely used indices to classify water in satellite imagery (Huang et al. 2018)) and visual interpretation of each month's mosaic. The seasonal and annual changes in the lakes were determined using the obtained data. For the NDVI, the following thresholds were used: –1–0.25-water and >0.25–nonwater. For the NDWI, the following thresholds were used: < 0.3 - nonwater and >= 0.3 - water.

$$NDVI = \frac{B_4 - B_3}{B_4 + B_3} \quad (1)$$

$$NDWI = \frac{B_2 - B_4}{B_2 + B_4} \quad (2)$$

Where B4 is NIR, B3–red, B2–green bands of PlanetScope imagery.

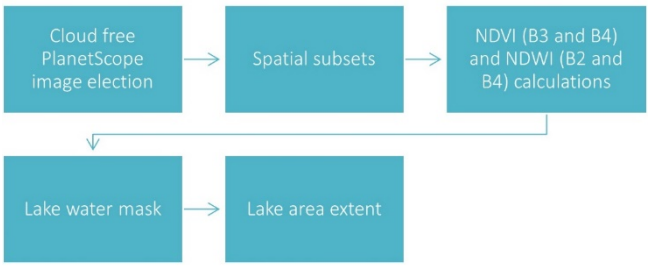

Figure 2. The methodology proposed in this study.

3 Results

According to the obtained results, the extent of lake area in Tbilisi changes according to season and year. Figure 3 shows that the average area of Big Lake was 31 ha in 2017, the average area of Small Lake was 2.8 ha, the average area of Lisi Lake was 42.6 ha, and the total area of Turtle Lake was 4 ha.

Figure 3 shows that these lakes are characterized by seasonal fluctuations. In the case of all four lakes, the low-water season coincided with late summer and early autumn (August–September), and the maximum area of the lakes occurred in late spring (May). It should be noted here that the seasonal fluctuations are most noticeable in the case of Great Lake and Lisi Lake, while in the case of the rest of the lakes, the seasonal changes are less noticeable.

Table 1 shows that the lake area changed during 2017–2023. Similar to the seasonal changes, the annual changes are more noticeable in the case of Didi Lake and Patara Lake. The area of Didi Lake decreased from 31.03 ha (2017) to 27.3 ha (2023). The area of Lisi Lake also experienced significant changes, from 42.6 ha (2017) to 38.6 ha in 2023.

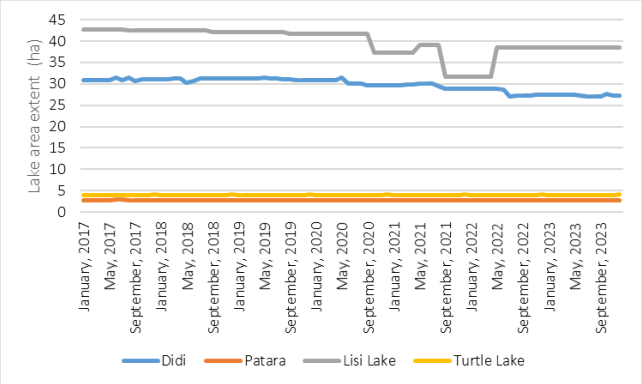

Figure 3. Lake area extent dynamic in 2017–2023 in Tbilisi.

In 2021, it even decreased to 36 ha. For Patara Lake and Turtle Lake, the lake area extent did not actually change during the research period.

Table 1. Lake area extent changes during 2017–2023.

Lake	Lake area extent (ha)						
	2017	2018	2019	2020	2021	2022	2023
Didi	31.04	31.09	31.11	30.27	29.50	28.01	27.27
Patara	2.8	2.69	2.68	2.70	2.71	2.72	2.72
Lisi	42.63	42.37	41.94	40.65	36.06	36.30	38.60
Turtle	4.02	4.18	4.02	4.02	4.02	4.02	4.02

4 Discussion

The purpose of this study was to analyze the seasonal and annual changes in the areas of natural lakes in Tbilisi. As the results showed, Didi Lake and Lisi Lake are the most vulnerable to environmental factors. In their case, we are dealing with the results of the combined effects of natural and anthropogenic factors. Both of them are located in the steppe landscape, and their surrounding areas are devoid of trees and mainly contain grass cover. Therefore, evaporation is high, which leads to the drying of shallow coastal areas. According to studies, the mentioned landscape is one of the most transformed within Tbilisi (Kharebava et al. 2024). Studies confirm that the temperature has increased in the last decade in Eastern Georgia (Elizbarashvili et al. 2017), and the intensity of drought is also increasing (Tatishvili et al. 2023), which in turn affects the loss of water in lakes.

The case of Lisi Lake is interesting. The results show that its area decreased sharply in 2021 (from 40.6 ha (2020) to 36 ha (2021)), and in 2023, its area slightly increased again to 38.6 ha. This is because the area around Lisi Lake is one of the fastest developing areas in Tbilisi, and the high demand for residential areas is caused by the presence of the lake; accordingly, lake restoration measures were planned. Given the lake's previously unsatisfactory water quality (Grim et al. 2010, Jaiani et al. 2013), it is imperative to begin restoration efforts.

An interesting precedent is Patara lake, which is located in the vicinity of Didi lake, but unlike it does not show sharp annual fluctuations. The reason is that it is relatively deep

with a weakly separated coastline. As for Turtle Lake, it is located hypsometrically higher and is surrounded by forest, which reduces evaporation and water loss.

5 Conclusions

Although PlanetScope has a limited number of spectral bands, using the combination of NDVI and NDWI is an effective method for detecting variations in the extent of lake areas. The analysis of seasonal and annual changes in the area of lakes in Tbilisi confirmed that along with the impact of natural factors, anthropogenic intervention is also important, both in a positive and negative context. For example, the decrease in the area of Lisi Lake by 6.5 ha was caused by active construction processes in addition to natural factors. After the restoration measures were implemented, the area of the lake increased by 2.3 ha. The use of open access PlanetScope data for monitoring urban lakes is an alternative for Georgia at this stage, as there is no access to higher resolution data, despite the limitations involved. For example, due to the high level of eutrophication in the Didi Lake, automatic water masking was difficult, and manual delineation was necessary in certain areas. Similar and more detailed studies will play an important role in monitoring urban lakes in Tbilisi and making recommendations for restoration works.

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6 References

Abderhalden, J.M., Bly, K.K., Lappe, R., Andreassen, L.M., Rogozhina, I., 2024. Tracking rapid and slow ice-dammed lake changes through optical satellites and local knowledge – a case study of Tystigbreen in Norway. Journal of Glaciology.

Elizbarashvili, M., Elizbarashvili, E., Tatishvili, M., Elizbarashvili, S., Meskhia, R., Kutaladze, N., King, L., Keggenhoff, I., Khardziani, T., 2017. Georgian climate change under global warming conditions. Annals of Agrarian Science 15 (1), 17-25.

Grim, C. J., Jaiani, E., Whitehouse, C. A., Janelidze, N., Kokashvili, T., Tediashvili, M., Colwell, R. R., Huq, A., 2010. Detection of toxigenic Vibrio cholerae O1 in freshwater lakes of the former Soviet Republic of Georgia. Environmental Microbiology Reports 2 (1), 2-6.

Huang, C., Chen, Y., Zhang, S., Wu, J., 2018. Detecting, Extracting, and Monitoring Surface Water from Space Using Optical Sensors: A Review. Reviews of Geophysics 56.

Jaiani, E., Kokashvili, T., Mitaishvili, N., Elbakidze, T., Janelidze, N., Lashkhi, N., Kalandadze, R., Mikashavidze, E., Natroshvili, G., Whitehouse, C. A., Huq, A., Tediashvili, M., 2013. Microbial water quality of recreational lakes near Tbilisi, Georgia. Journal of Water and Health 11 (2), 333-345.

Kharebava, N., Nikolaishvili, D., Tsitsagi, M., 2024. Satellite-Based Analysis of Landscapes Transformation in Tbilisi, Georgia. Bulletin of the Georgian National Academy of Sciences 18 (1), 99-104

Niroumand-Jadidi, M., Bovolo, F., 2021. Water Quality Retrieval and Algal Bloom Detection Using High-Resolution Cubesat Imagery, in: ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences.

Pham-Duc, B., 2024. comparison of multi-source satellite remote sensing observations for monitoring the variations of small lakes: a case study of Dai Lai Lake (Vietnam). Journal of Water and Climate Change 15.

Qayyum, N., Ghuffar, S., Ahmad, H.M., Yousaf, A., Shahid, I., 2020. Glacial lakes mapping using multi satellite PlanetScope imagery and deep learning. ISPRS International Journal of Geo-Information 9 (10).

Tatishvili, M., Palavandishvili, A., Tsitsagi, M., Suknidze, N., 2023. The Big Data for Drought Monitoring in Georgia, in: Springer Proceedings in Business and Economics.

Tsitsagi, M., Kharebava, N., Nikolaishvili, D., Kupatadze, I., Gadrani, L., 2022. Tbilisi Through Time. Georgian Geographical Journal 1 (1).

Worqlul, A.W., Ayana, E.K., Dile, Y.T., Moges, M.A., Dersseh, M.G., Tegegne, G., Kibret, S., 2020. Spatiotemporal Dynamics and Environmental Controlling Factors of the Lake Tana Water Hyacinth in Ethiopia. Remote Sensing 12 (17).