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STUDYING THE DYNAMICS OF LAKE SEVAN WATER SURFACE TEMPERATURE USING LANDSAT8 SATELIITE IMAGERY

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Abstract

Lake Sevan being Armenia's largest freshwater reservoir has a vital economic, recreational and cultural importance to both the catchment area and the nation as a whole. At present the Sevan which has seen the dramatic - some 20m drop - in water level entailing grave ecological consequences to the whole of its ecosystem, is at the stage of recovery. Hence, it is very important to study basic parameters describing the ecological status of the lake, and their annual and seasonal dynamics. The Sevan water surface temperature (WST) is a key parameter which influences all ecological processes that occur in the Lake. Declining lake level has brought to reduction of water volume and consequently to earlier warming of lake water in spring and its earlier cooling in the fall. Besides, more frequent becomes the complete surface freezing of Lake Sevan. Remotely sensed imagery makes it possible to get immediate information on a regular basis about WST across the entire surface of lakes. The purpose of this particular research was to study the space and time dynamics of Lake Sevan WST using Landsat 8 satellite imagery. The advantage of Landsat8 images is a regular frequency of capturing and availability of another thermal band that helps reduce the atmospheric refraction-induced errors/deviations. This research involved Landsat imagery for 2000-2018. The images underwent preprocessing steps (radiometric calibration, atmospheric correction, normalization etc) and then Lake Sevan WSTs and their monthly and annual changes over the mentioned periods were derived using both thermal bands (b10, b11). The research confirmed the fact, that Lake Sevan surface completely or partly freezing with periodicity of 2-3 years, whereas before the water drop the periodicity was 15-20 years. The study of spatial distribution of WST data derived from remote sensing shows that the temperature data corresponds to the overall general picture of temperature for Lake Sevan. This research has indicated that remotely sensed images and Landsat 8 imagery in particular allow derive both WST data on a regular basis and retrospective data (since 2013).

Keywords: Remote sensing, Water surface temperature, Lake Sevan, thermal data.

1. INTRODUCTION

Lake water temperature is one of the most important physical parameters, which affects all the physical, chemical and biological processes of the water system. So, significant changes in water temperature can lead to serious environmental consequences (Ma et al., 2016).

Lake Sevan is the largest lake in Armenia and the largest reservoir of fresh water. As a large water body, lake acts as a huge heat insulator. In the summer months, Sevan absorbs heat, in winter transmits to the environment, softening the surrounding climate (Physical geography of the Armenian SSR 1971).

During 30-80s of the 20th century the water level in the lake was artificially reduced by almost 20 meters, and the volume of water decreased by about 40%. As a result, a number of environmental problems have appeared (water pollution, water blooms, changes in the species and quantity of flora and fauna, etc.). Since 1980s the process of lake restoration began, aimed at raising the level of water and the restoration of conditions close to natural. One of the consequences of lowering of water level was the change of the thermal regime of the lake.

The thermal regime of Lake Sevan is due to the high altitude position, considerable depth and intensive vertical mixing of the waters.

As a result of the water level lowering, lake water heats up faster in the spring-summer period and cools down faster in the autumn period. Before the lowering of water level, the heating period of Sevan was starting in May and ending in August. In the current conditions it begins in April and ends at the end of July. The process of shifting of heating period is accompanied by its acceleration. The heat content of the lake also decreased ($700*10^{12}$kkal before and $500*10^{12}$kkal after water level drop), as a result of which lake is covering completely with ice more often. Before the water level lowering, Lake Sevan was covering with ice every 15-20 years. Now the lake is covering with ice almost every 2-3 years (Ogannesian 1994).

Thermal remote sensing of lakes makes it possible to evaluate their thermal characteristics and is widely used for obtaining and mapping the WST. The main advantage of evaluating of WST by remote sensing is the simultaneous and rapid acquisition of spatial data (Hlevca et al., 2015).

The Landsat system provides Earth remote sensing data since 1972. Landsat 5 TM and Landsat ETM+ satellites thermal data was provided only in one infrared band. TIRS sensor of satellite LANDSAT 8 OLI/TIRS operating since 2013, provides data in two narrower ranges of the infrared spectrum (B10 - 10.6-11.2nm and B11 - 11.5-12-5nm), with a spatial resolution of 100m. The presence of two spectral ranges makes it possible to reduce inaccuracies due to the influence of the atmosphere, in obtaining surface temperatures (Riffler et al., 2015).

Despite already existing MODIS and AVHHR sensors are providing free data in two thermal bands twice a day, in this work Landsat 8 imagery were used, because its spatial resolution is more suitable for our study area (Lake Sevan) (Grim et al., 2013).

The aim of this work is to obtain the picture of spatio-temporal changes of Lake Sevan WST and assess the applicability of these images for study of Lake thermal regime.

1.1 Study area

Lake Sevan (40°23´N, 45°21´E) is a high-altitude freshwater lake. The mirror of the lake is at an altitude of 1900m above sea level. Morphologically Lake Sevan consists of the Minor Sevan (up to 90 m) and the relatively swallow Major Sevan (up to 40 m deep). Mean annual temperature for Lake Sevan is 5°C. The coldest month here is January, and the warmest month is August (Tepanosayn et al., 2017).

2. MATERIALS AND METHODS

To study spatio-temporal changes of Lake Sevan WST, LANDSAT 8 TIRS images were used for the period of 2013-2018. From about 110 images available for a given period, cloud free images, or images with minimal cloud cover were selected. Preprocessing of images included radiometric and atmospheric corrections, emissivity and temperature data acquisition with ENVI 5.3 software. Temperature data acquisition is based on Plank’s equation for absolute black body.

The atmospheric correction algorithm similar to the In-Scene Atmospheric Compensation algorithm (Johnson and Young 1998; Kealy and Hook, 1993).   In this paper presented the results of study for January and August, which correspond to the coldest and warmest time for this territory. Temperature data were taken from the images, according to two transects on Major and Minor Sevan (37 and 17 km respectively) (fig. 1). Data were taken from every 300m near shoreline and from every 700m in the central part.

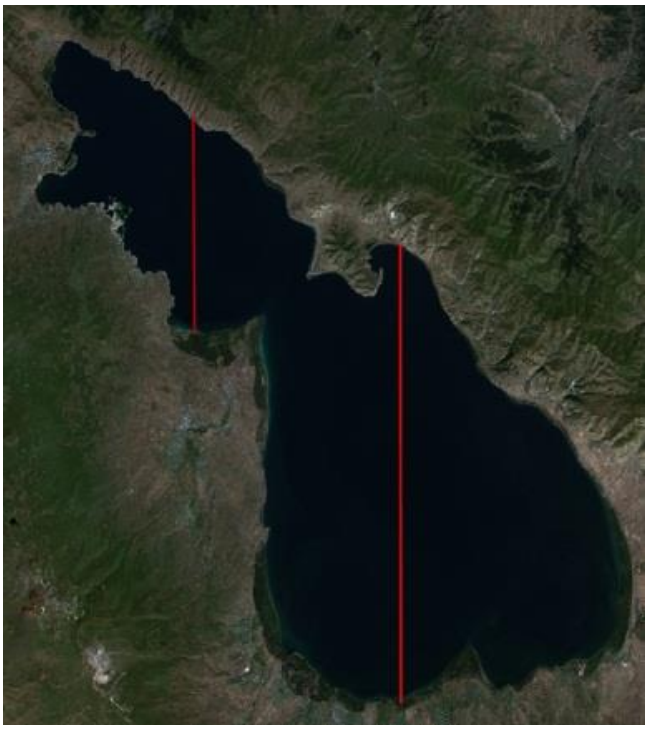


Figure 1. Transects in Major and Minor Sevan for thermal data

Temperature data for every year were compared to understand the spatial and temporal changes of temperature. The data of mean temperatures for Major and Minor Sevan also were compared.

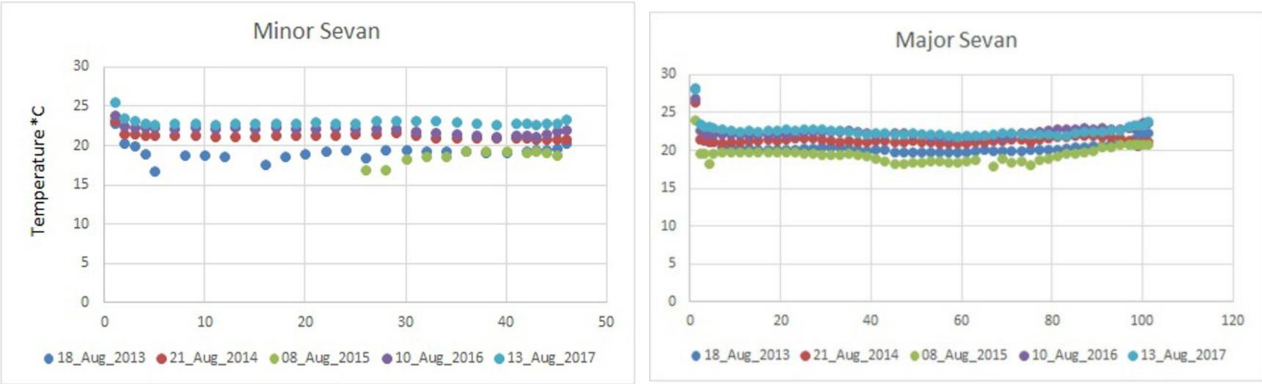
To study Lake freezing periodicity, in addition to LANDSAT 8 images LANDSAT 7 images also used, to obtain longer series of data (2000-2017). Ice cower on images was interpreted visually, and to confirm visual interpretation results Normalized Difference Snow/Ice Index was used for January 17, February 18, March 22, 2017. These images correspond to dates, when lake is free from ice (January 17) and covered with ice (February 18, March 22). Normalized-Difference Snow Index (NDSI) is a normalized difference of the visible and near-infrared or short-wave bands. It is used to map snow and ice [0,0]. For Landsat 8 image Green and SWIR bands were used:

$$NDSII = (Green - SWIR)/(Green + SWIR)$$

NDSII $\geq$ 0,4 is identifying ice or snow cower.

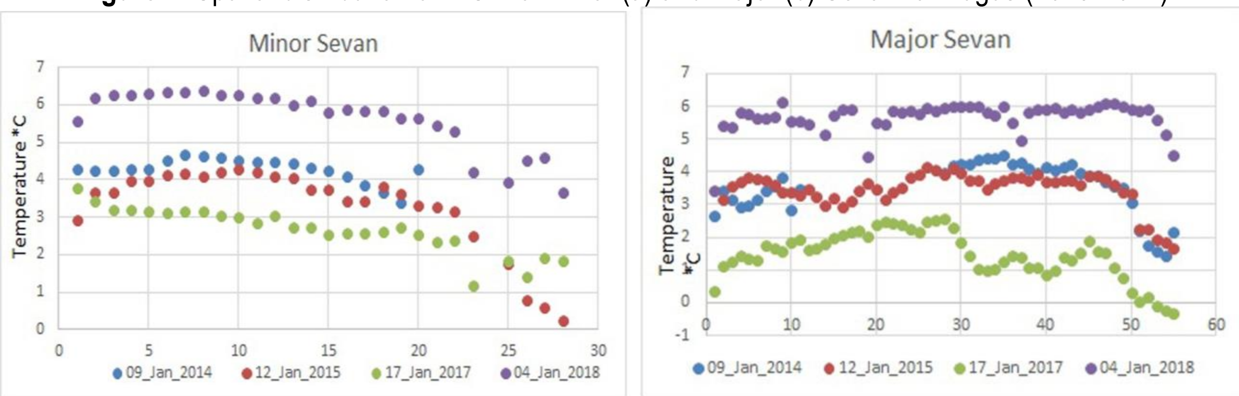
3. RESULTS AND DISCUSSIONS

The spatial distribution chart of the WST shows that in August the temperature is higher close to shore both for Major and Minor Sevan (Fig. 2). In January, on the contrary, the temperature is higher in the central part (Fig. 3). Besides, the comparison of mean WSTs shows, that in January the mean WSTs are equal in two parts of lake or higher in Minor Sevan than in Major Sevan, while in August mean WSTs of Minor Sevan are equal or lower than in Major Sevan (Fig. 4). This is probably due to the fact that Minor part of the lake is deeper than Major part and in the summer water heats up slower in deeper part of the lake, and in winter cools down slower.



2a *2b*

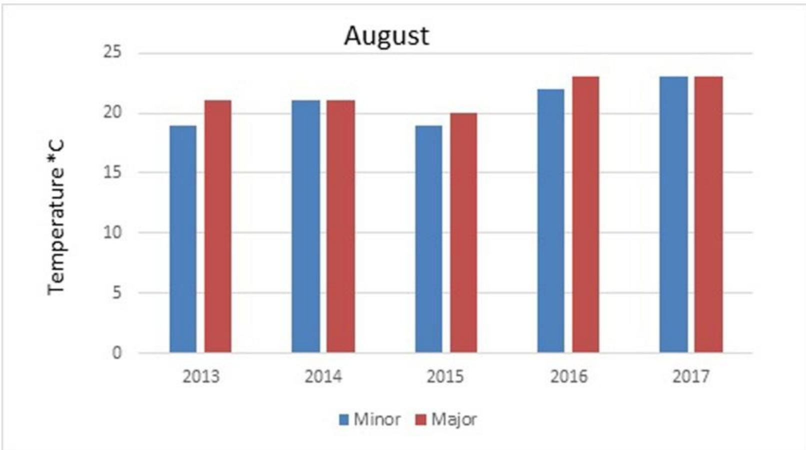
Figure 2. Spatial distribution of WST for Minor (a) and Major (b) Sevan for August(2013-2017)



3a *3b*

Figure 3. Spatial distribution of WST for Minor (a) and Major (b) Sevan for January (2014-2018)

4a



4b

Figure 4. Comparison of mean temperatures of Major and Minor Sevan for January and August

Visual interpretation of the images for 2000-2017 shows, that the lake was partly (mainly Major Sevan) frozen in 2000, 2002, 2007, while in 2008 and 2017 it was covered with ice completely. It should be noted, that in the study period the longest freezing period took place in 2017. From the image of February 2 we can see that the lake starts to freeze, on the image acquired on February 18 the Lake almost completely covered with ice. The images of March 6 and 22 show that in March it still was frozen completely. On March 29 image we can see that the ice is starts to melt. Because of the availability of cloud cover on further images, we couldn't keep track the complete ice-melting (fig. 4).

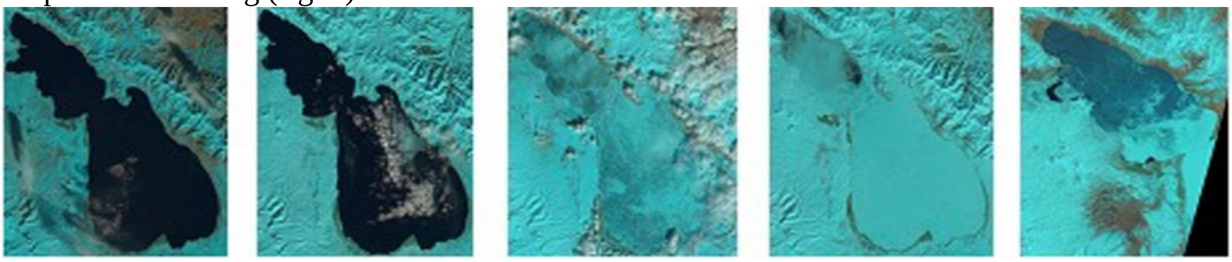


Figure 4. Ice formation and melting period on Lake Sevan from 17 January to 29 Match 2017

The comparison of statistical description for tree images NDSII presented on Table 1. The mean values for NDSII shows, that in February 18 and March 22 Lake Sevan was covered with ice.

Date	NDSIImin	NDSIImax	NDSIImean	StDev
17January 2017	0.13	0.56	**0.11**	0.02
18 February 2017	0.03	0.59	**0.52**	0.07
22 March 2017	-0.16	0.69	**0.57**	0.02

Table 1. Statistical description of NDSII

4. CONCLUSION

Study results show that in summer Lake Sevan WST is higher in more shallow parts of lake, while in winter it higher in deeper parts of the Lake. Also, the comparison of mean temperatures of two part of lake shows that the deeper part of lake is cooler in winter and vice versa it is colder in summer.

Application of NDSII index confirms the results of visual interpretation of spatial images, targeted to study the periodicity of freezing of Lake Sevan.

Although we hadn't have field data to validate our results acquired from satellite images, they confirm the results of resent investigations of thermal regime of Lake Sevan made using traditional methods.

The results show, that image series of LANDSAT, especially LANDSAT 8 can be used for studies of spatio-temporal distribution of WST of Lake Sevan.

Since LANDSAT images available after Lake Sevan water level lowering, so we have no opportunity to compare WST and thermal conditions of Lake before and after water level drop. But as far as lake is in restoration stage, we can use LANDSAT data to assess how the restoration actions impact Lake Sevan and its WST and thermal conditions.

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