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# LAKE SEVAN SHORELINE CHANGE ASSESSMENT USING MULTI-TEMPORAL LANDSAT IMAGES

**ABSTRACT.** Shoreline changes are important indicators of natural and manmade impacts on inland waters and particularly lakes. Man-induced changes in Lake Sevan water level during the 20th century affected not only the ecological status of the Sevan water but also near-shore areas. This article considers a long-term study of changes in Lake Sevan shoreline that occurred between 1973 and 2015. The Normalized Difference Water Index (NDWI) was applied to delineate the Sevan shoreline changes according to periods of lake water fluctuation from multi-temporal Landsat images and Historical changes in shorelines were analyzed with help of the Digital Shoreline Analysis System (DSAS) toolbox. Data obtained from the analysis have indicated that changes in the lake shoreline that occurred in different periods are similar to those in the lake water balance. Areas with the greatest shoreline changes have comparatively flat relief, so in the result of the lake water level raise vast forested areas were submerged. This study shows that application of multi-temporal spatial imagery and GIS methods can provide valuable information on time-and-space changes in the Sevan shoreline. Such information is important for monitoring Lake Sevan shoreline and nearshore changes.

**KEY WORDS:** Multi-temporal Landsat images, shoreline delineation, shoreline change, Lake Sevan

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## INTRODUCTION

Shoreline is the line between water and land. Shoreline changes are the best visible indicators that give information about changes in lake water and surrounding environment. However, geographical position of a shoreline

should be considered in the view of temporal resolution and time scale used when assessing changes. Shorelines delineation and assessment of multi-year changes allow visualizing shorelines and changes, getting a better understanding of causes, rate and effects of such changes (Boak & Turner, 2006).

The shoreline delineation methods include a coastal survey, GPS survey, aerial photography and satellite imagery (remote sensing (RS)). Each of these methods has its advantages and disadvantages. The choice of method should be based on the purpose and objectives of the research, spatial and temporal resolution of data, economic accessibility, and so on (Samanta & Paul, 2016). A RS-supported delineation of shorelines is important for erosion monitoring, shoreline areas management, flood prediction, evaluation of water resources, and so on (Bagli, Soille, & Fermi, 2004).

RS imagery and GIS are widely used for identification of inland water bodies, delineation of shorelines and coastlines of estuaries, lakes, reservoirs etc., for assessing changes on local, regional and global levels. One of best examples of application of RS for inland water bodies change detection on the global level is the work of Pekel et al. (2016), who used three million Landsat images (Landsat 5, 7, 8) between 1984-2015 for mapping the global surface water and changes in it (Pekel et al., 2016). Application of RS is an important tool supporting compilation the Pan-European coastline and lake database (Vogt et al., 2007). Agyemang et al. used Landsat images and GIS techniques to assess historical development of area of Lake Sevan from 1933 to 2005 (Agyemang et al., 2017).

There are many RS and GIS applications for coastline delineation in different regions of the world. Qiao et al. (2018) used declassified intelligence satellite images (CORONA) and Landsat images, for analyzing the 55-year shoreline changes in Shanghai (Qiao et al., 2018). Bai et al. (2011) applied Landsat images to assess the change of lake areas for the Central Asia region during 30 years (Bai et al., 2011). Oyedotun (2017) used historical maps and Digital Shoreline Analysis System (DSAS) to assess shoreline changes for the period of 1845-2010 and 1881-2010 respectively in St. Ives-Hayle Bay and Padstow-Camel Bay in Southwest England (Oyedotun, 2017).

Lakes are known to be more vulnerable to natural and anthropogenic impacts which affect both the quality and quantity of lake water and the surrounding environment (Aladin et al., 2005; Timoshkin et al., 2016; Babich et al., 2016).

Climate change and its consequences are among the important factors that impact on quantity and quality of water bodies, especially on inland waters. Because of climate change extremal weather conditions, such as floods and droughts became more frequent. As a result, water level in lakes and rivers fluctuate in more significant ranges. As for the lake Sevan, according to "First National Communication of the Republic of Armenia on Climate Change" reduction of annual river flow by 15%, and increase of evaporation from the surface of Lake Sevan by 13-14% is expected (Dokulil, 2014) (Ministry of Nature Protection of the Republic of Armenia, 1998).

Thus, shoreline delineation of individual lakes and detection and assessment of changes in such water bodies are essential on the local and regional scale. As an example: El-Asmar et al. (2013) applied Landsat images for Burlus Lagoon between 1973 and 2011 (El-Asmar, Hereher, & Kafrawy, 2013). Du et al. (2014) used Landsat 8 OLI images to map surface water bodies in the Yangtze River basin and the Huanghe River basin in China (Du et al., 2014). Landsat images were used in Armenia's neighbouring countries, too. Thus, in Iran, Alesheikh et al. (2007) applied RS methods for studying Lake Urmia shoreline changes (Alesheikh, Ghorbanali, & Nouri, 2007).

For this research, the RS method with application of Landsat images was selected as the most appropriate for Lake Sevan because Landsat images have longest retrospective data series, are free of charge, give periodic information, have a reasonable spatial, temporal and radiometric resolution. Due to these advantages, Landsat images are widely used in various studies as well (Feyisa et al., 2014; Wulder et al., 2016).

The importance of this research can be ensured by the several reasons: (i) the study object is Lake Sevan. The one of the largest alpine lakes in the world and the biggest freshwater reservoir in Armenia and the South Caucasus, the Sevan has a huge ecological and economic importance for the whole of the region, (ii) dramatic shoreline changes caused by dramatic drop in the lake water level in the result of manmade intervention were triggered in the 1930s. At present, lots of ecological problems emerged as a result of short-sighted management decisions, establishing an ecological monitoring system with a RS component is required, (iii) this study is an exceptional experience for Armenia and for the whole of the South Caucasian region in application of RS methods and GIS technologies and particularly the Digital Shoreline Detection System (DSAS) for determining the shoreline and its modifications over a long period of time (1973-2015).

A similar research in region was implemented in Turkey by Duru (2017) who used remote sensing data (Landsat imagery) and DSAS tool for the assessing shoreline displacement for Lake Sapanca between 1975 through 2016 (Duru, 2017). However, the present research is unique as it involved combination of these methods for a much more bigger water body – Lake Sevan.

## MATERIALS AND METHODS

### Study Site

Lake Sevan (40°23'N, 45°21'E) resides in Gegharkunik region in Armenia at an altitude of 1900 m a. s. l. Sevan is Armenia's largest water body and the largest freshwater resource for the whole of the South Caucasian region.

Morphologically, Lake Sevan is divided into two basins– Big and Small Sevan. Its surface area is 1278.13 km<sup>2</sup>, according to the data as of January 1, 2017 (Hydrological regime of Lake Sevan, 2017). In natural conditions Sevan covered an area of 1416.km<sup>2</sup> at an altitude of 1915m a.s.l.

28 rivers empty into the lake and only one river, the Hrazdan, runs out of it, due to which Sevan is a freshwater lake.

The main inflow sources of the lake water balance are water inflow from rivers, water inflow from the Vorotan-Arpa-Sevan tunnel, groundwater flow.

Main outflow components are the Hrazdan river, evaporation from the water surface, water discharge, groundwater outflow (Ogannesian, 1994).

It is necessary to give a brief history of the so-called “Sevan Problem” to understand dramatic changes that took place in Lake Sevan from the 1930 onward. At the beginning of XX century it was decided to use centuries-old resources of the lake for energetic and agricultural needs. The result has been a drop in the lake water level, eutrophication of the lake, activation of erosion processes and so forth. (Pavlov et al., 2010).

The fluctuation of Lake Sevan water level can be divided into three main periods:

I. 1933 – 1981. A drop of lake water level associated with exploitation of centuries-old water resources and a water level drop by almost 18.8m.

II. 1981-2002. Relative stabilization due to Arpa-Sevan tunnel was put into operation in 1981 and annually conveying more than 200 mln. m<sup>3</sup> of River Arpa water to Lake Sevan.

III. From 2002 onward. A raise of lake water level in 2002. Since then, water balance has been mainly positive and the water level has been rising steadily. This is mainly due to Vorotan-Arpa tunnel was put into operation in 2004 and the inflow of additional 165 mln. m<sup>3</sup> of water to the Sevan annually. To have the lake ecosystem stabilized and prevent its further pollution, it is planned to increase Sevan water level to 1905m by 2013 after massif clean-up of shoreline zones from trees and other sources of pollution (Law of RA on Lake Sevan-<https://www.arlis.am/>) (Lake Sevan drainage basin planning project, 2013).

One should mention an intermediate period related to mismanaged release of the Sevan water for energetic needs in the 1990s during the energetic crisis in the country.

Since the early 1930s, the lake water level has been changing with different intensity (fig. 1) mainly due to overuse of century old resources of lake, and to a lesser degree due to climate change. As a result, shoreline changes have been affecting the ecological status of Lake Sevan and nearshore area. This all makes it urgent to study the shoreline changes and effects these produce on the nearshore belt (Babayan et al., 2013; Baghdasaryan, Abrahamyan, & Aleksandryan, 1971).

## Data collection

### Remote sensing data

Landsat images applied in this study are provided in Tab. 1. Landsat imagery used for shoreline delineation was selected for August or days as close to August as possible to avoid seasonal fluctuations of lake water because it is in August when the river inflow to Lake Sevan is minimal. Images which are used to verify the accuracy of the results are selected as close as possible to January 1, which corresponds to the data of the measurements of the lake water level and the surface area (Hydrological regime of Lake Sevan, 2017).

This research employs Landsat imagery in open access through USGS online service (USGS-<https://earthexplorer.usgs.gov/>); Landsat TM, Landsat 8 OLI data are available in the World Geodetic System (WGS84) Datum and are projected using Universal Transverse Mercator system (USGS-<https://landsat.usgs.gov>).

National Aeronautics and Space Administration (NASA) provides images which have already been geometrically corrected and orthorectified to the so-called Landsat Level 1 (L1T) (Gutman et al., 2013). All Landsat images used in this research are Level 1 products from Landsat Collection 1. All images besides Landsat 1 MSS for 1973, correspond to Tier 1 category and are eligible for time series analysis. Image-to-image registration accuracy threshold is Root-Mean-Square-Error (RMSE)  $\leq 12\text{m}$  (LANDSAT COLLECTION 1 LEVEL 1, 2017). For the image-to-image registration, Landsat 5 TM for 1985 was selected as a basic image. This image was georeferenced using a topographic map for 1984.

### Ancillary data

Hydrological data – inflow and outflow components of water balance for the period of 1927-2015 necessary for this research were obtained from published sources and reference material published by the Service of the Hydrometeorology and Active Influence on Atmospheric Phenomena

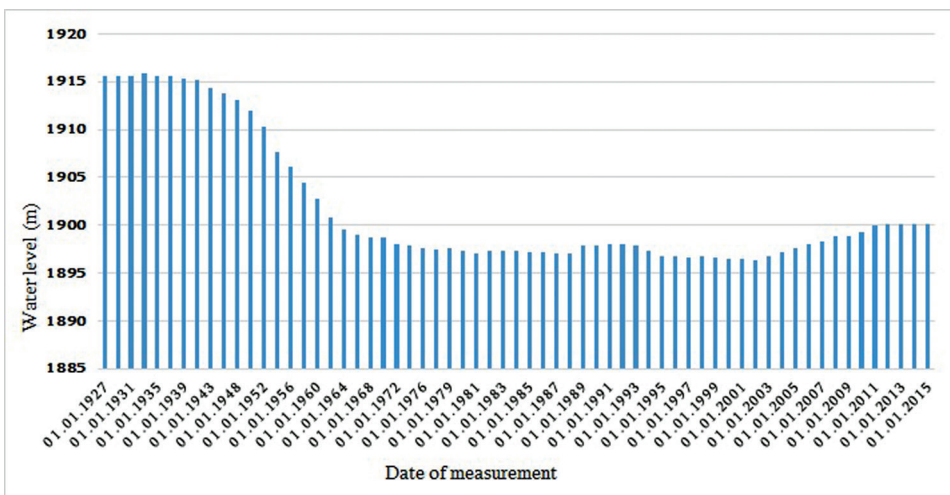


Fig. 1. Changes in Lake Sevan water level from 1927 to 2015

SNCO , Ministry of Emergency Situations RA (hereafter referred to as the Service) (Hydrological regime of Lake Sevan, 2017; Papikyan, 2011).

“Sevan” national park provided a GIS database on land use (protected areas, forested areas, species composition of trees and bushes, etc.) of Lake Sevan nearshore sites (“Sevan” national park- <http://sevanpark.am/>).

## Methods

The shoreline delineation and shoreline change assessment methodology used in this research is given in Figure 2 and is discussed in detail below.

### Shoreline delineation

The most applicable RS methods for water objects identification and classification and shoreline detection include classification (supervised and unsupervised) and spectral signature feature analysis, which in turn is divided into single-band and multi-band methods (Li et al., 2013).

A single-band method is based on selection of bands and thresholds, which show a water-to-land transition in a more precise way. A multi-band method is based on band ratio or on spectral indices. This method provides more precise information as it is based on the analysis of signature differences between

water and other surfaces. In the case of a simple band ratio, the ratio of one of visible bands, e.g., green, and NIR is calculated. On a productive image reflective properties of water objects are expressed stronger as compared to non-water objects (Qiao et al., 2012).

A spectral index most frequently used for detecting water bodies and assessing shoreline changes is Normalized Difference Water Index (NDWI) derived by McFeeters (1996). NDWI ranges from -1 to 1, where water has values above 0 and non-water objects have values below 0 (McFeeters, 1996). Later Xu (2006) proposed a Modified Normalized Difference Water Index, where MIR band is used instead of NIR band. According to Xu (2006), MNDWI as compared to NDWI is more acceptable for water bodies with larger amounts of built-up land on the background in nearshore sites, since it can effectively reduce and/or remove noise resulted from built-up land, bare soil and vegetation (Xu, 2006). Nonetheless, as the research advanced, all the above-mentioned methods were employed in order to find the most appropriate method for Lake Sevan.

DSAS is applied for assessing changes in shoreline position along the whole of the lake in selected time intervals between 1973 to 2015 (1973-1985, 1985-1990, 1990-1995, 1995-2002, 2002-2015 (the selection of time slots was based on Lake Sevan water level change periods and RS data availability).

**Table 1. The applied Landsat images and their properties**

RS data	Date	Resolution, m	Geometric RMSE model, m
Landsat 1MSS	July 13, 1973	80	17.159
Landsat 5 TM	August 21, 1985	30	4.666
Landsat 5 TM	September 20, 1990	30	4.587
Landsat 5 TM	September 02, 1995	30	4.261
Landsat 5 TM	December 20, 2001	30	6.473
Landsat 5 TM	August 04, 2002	30	4.102
Landsat 5 TM	December 16, 2010	30	6.604
Landsat 8 OLI	January 12, 2015	30	9.264
Landsat 8 OLI	September 09, 2015	30	7.001

As an example of a single-band method application, the NIR band was selected due to better absorption by water and reflection by vegetation and land. As a threshold value for water and non-water bodies, 0.1 is selected based on the values of visual differentiation between water and non-water on a space image histogram. Thus, reflectance values  $> 0.1$  and  $< 0.1$  indicate land and water, respectively.

The Green/NIR band ratio is used to define the lake shoreline as an example of the band ratio method. In this case, a threshold value=1 is selected for water - non-water differentiation. Values  $> 1$  and  $< 1$  correspond to water and land, respectively. For NDWI and MNDWI, the aforesaid threshold value=0 was selected. The accuracy of shoreline delineation method was assessed through Root Mean Square Error.

### Shoreline change assessment

In order to implement Lake Sevan shoreline change assessment a DSAS tool developed by the United States Geological Survey (USGS) was used. This tool computes rate-of-change statistics for a time series of shoreline data. The statistics are represented by Net Shoreline Movement (NSM), which shows a distance between the oldest and youngest

shorelines for each transect. End Point Rate (EPR) denoting NMS divided into the number of years elapsed and showing the “velocity” of shoreline change, whereas Shoreline Change Envelop (SCE) is the distance between the shorelines farthest and closest to the baseline (Himmelstoss, 2009).

### RESULTS AND DISSCUSION

#### Shoreline delineation and accuracy assessment

It should be stressed that the all the shoreline delineation methods tested when conducting this research gave good results. However, the best results were achieved when applying NDWI, and it was the reason for which subsequent shoreline delineation for all dates was conducted using NDWI alone. (Fig. 4 a-e). Correlation of data of surface area of Lake Sevan provided by Service (Table 2) (Kireev, 1933) with surface area data derived using NDWI gives (shows) RMSE value of 8.15.

Analysis of GIS database provided by “Sevan” national park shows that almost 1900 ha of forests (trees and shrubs) were watered as a result of Lake Sevan water level rise between 2002-2015 as the main water level rise took place on that period.

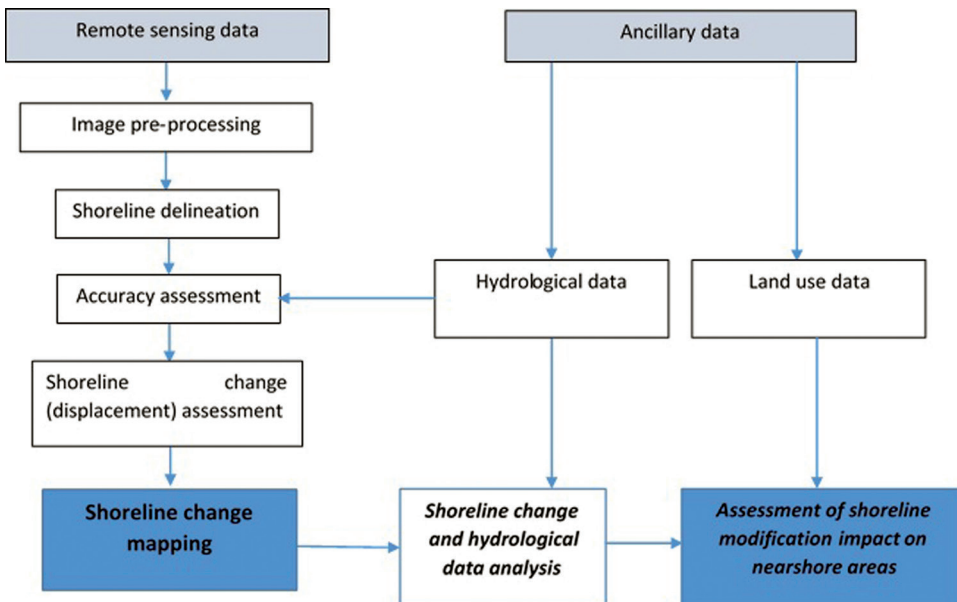


Fig. 2. A summarized methodology of delineation of shorelines and assessment of their spatiotemporal changes



**Table 2. The area of Lake Sevan according to Service and NDWI**

Date (Space image/Service)	Area, sq.km (Service)	Area sq.km (NDWI)
23.12.2001/01.01.2002	1236.2	1231.13
16.12.2010/01.01.2011	1272.8	1263.32
12.01.2015/01.01.2015	1274.99	1265.83

**Total shoreline change analysis for each time period**

The onshore baseline shapefile was created at a distance of 200 m from the last shoreline position (2015). The selected transects spacing was 300 m for the whole of the lake. All the transects which intersected the shorelines more than once, were manually deleted in order to avoid computational errors, a confidence interval being set within 90%.

DSAS statistics NSM, EPR describe a change in shoreline from the first to the last date (1793-2015 in this case), whereas SCE describes the overall change in shoreline position. These statistics cannot fully reflect a real picture of shoreline changes because Lake Sevan shoreline changes on different time periods had different directions. In order to understand the cause of changes, DSAS was applied for each period of time and data were compared with hydrological data on water balance (Fig. 3a) (The Digital Shoreline Analysis System (DSAS) Version 4.0 - An ArcGIS extension for calculating shoreline change, 2009). The data of almost 750 transects for each period were analysed. Minimum and maximum transect lengths are given in Figure 3b, which corresponds to NSM for each of transects. As baseline location is selected "Onshore" in DSAS, negative values of NSM correspond to shoreline (water) movement towards land.

The period between 1973 and 1985 is selected because the first available Landsat image for Lake Sevan is for 1973 and the image of 1985 is the nearest available image to 1981 when intensive lowering of Lake Sevan water level stopped and a water level stabilization period started. The average annual water balance is negative for that period as seen

from Fig. 3a. As a result, shoreline moved towards the water.

The period between 1985 and 1990 was a lake water level stabilization period, when Arpa river water via the Arpa-Sevan tunnel was inflowing to Lake. Water balance was positive and as a result, shoreline moved towards the land.

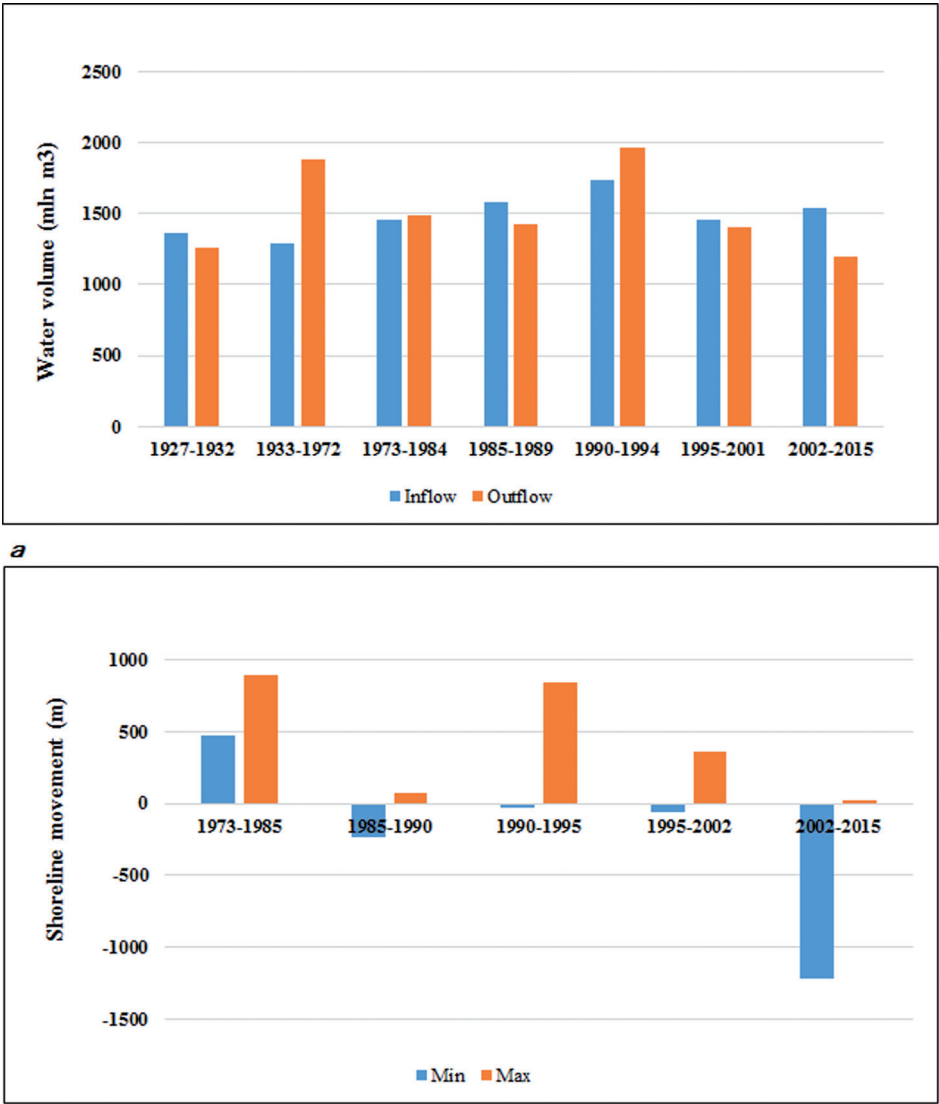
The period between 1990 and 1995 corresponds to that of energetic crisis in Armenia, when additional volumes of lake water released for energetic purposes resulted in water level lowering and subsequent shoreline movement toward the water.

According to the water balance data for the period of 1995-2002, water inflow slightly exceeds outflow but the shoreline moves in the opposite direction.

The last considered period is 2002-2015. 2002 corresponds to the beginning of Lake Sevan restoration consistent with the RA Government Program (World Bank Technical Paper, 2001) (Parliament-<http://parliament.am/legislation.php?sel=show&ID=1676&lang=arm>).

As a result, the water inflow to Lake Sevan has increased due to the operation of Vorotan-Arpa tunnel. As seen from Figure 3b, the absolute NSM value is higher in this period and the direction of the shoreline movement is towards land.

Besides, Fig. 3b shows that basic shoreline changes exceed 30 m – the pixel size of most of Landsat images used in this study. This is robust evidence of changes that occurred in shoreline positions, even if accounting for a problem of mixed pixels and misclassification.



**Fig. 3. The averaged values of water inflow and outflow for the period of 1927-2015 (a) and Shoreline changes for each period of time (1973-2015) represented by NSM (b)** (first two time periods in Fig. 3.a are included in order to visualize the lake water balance in natural conditions (1927-1932) and after water level lowering (1933-1972))

Shoreline change analysis for each region

Because of the variety of forms and complexity of relief of Lake Sevan and its shores, the shoreline changes are dissimilar in different parts along the entire shoreline. In the areas with relatively plane relief shorelines were changed significantly. Five regions were distinguished based on more significant changes. In those regions, DSAS was applied for a period of 1973-2015. For

the Regions 1 to 4 Onshore baseline and transect spacing 300 m were selected. Shoreline in Region 5 is more complicated and Onshore/Offshore baseline and transect spacing 50 m was set. In this case the confidence interval has also been set within 90%.

The shores of Small Sevan are steeper than those of Big Sevan especially on sections where the shore is edged by steep slopes



of Areguni mountain range, and partly the western shore. So, lake water fluctuation does not cause more changes in shoreline in these areas. The shores near Lchashen village and town of Sevan (Region-1) and Gavaraget estuary (Region-3) are changed significantly. Changes in the eastern shore of Big Sevan and that located close to Artanish peninsula are not significant. The southern (Region-1) and western (Region-2) shorelines are changed significantly. The statistics of change rates are provided in Table 3.

Region 1 is a shoreline of almost 1400 km. As seen from Fig. 4a, the shoreline transformations in this region are similar to transformations of entire shoreline for the period of 1973-2015. As it can be seen from Table 3, the shoreline mean movement rate is  $2.26 \pm 0.15$  m/year for the period of 1973-2015. In the case of Lake Sevan, this figure cannot reflect the real picture of changes, because shoreline movements for different

periods had a different direction. DSAS gives statistics (in particular EPR and NSM) for the period of 1973-2015. The longest shoreline displacement for this period (NSM) is towards land and is almost 244 m. But the largest displacement of shoreline (SCE) – some 610 m - occurred between 2002 and 2015. Table 3 and Figure 4a show that shoreline movement direction is not the same for the entire region. In some parts of shoreline, there is a movement opposite to the main direction. The causes may be both cartographic errors and natural and manmade processes. In the case of Region 1, the main reason is the land assertion in the estuary of the Masrik river. Region 1 is on the territory of Gili reserves, and partly on the territory of Vardenis and Tsovak forests. In the result of a water level rise, part of these forests covering some 420 ha and consisting mainly of poplar and willow trees are completely submerged by the lake.

**Table 3. Statistics of Lake Sevan shoreline in different regions (segments) from 1973-2015**

Regions	Statistics	EPR (m/yr)	LMS (m/yr)	LRR (m/yr)	SCE (m)	NSM (m)
R-1	Min	-6.1	2.76	-5.18	172.22	-244.99
	Max	1.11	14.71	1.62	610.03	44.71
	Mean	-2.26	10.18	-1.16	376.22	-90.84
R-2	Min	-8.25	3.06	-4.76	174.4	-347.9
	Max	-1.04	19.82	0.04	755.77	-43.94
	Mean	-3.72	9.81	-1.56	454.11	-156.78
R-3	Min	-12.67	-0.96	-10.56	42.2	-534.13
	Max	-0.21	13.88	-0.15	691.94	-8.85
	Mean	-4.85	3.83	-3.66	328.22	-204.66
R-4	Min	-5.93	-1.87	-4.21	22.68	-250.06
	Max	-0.47	5.73	0.11	413.62	-19.79
	Mean	-2.9	2.87	-1.92	218.52	-122.28
R-5	Min	-15.75	-13.92	-13	6.95	664.15
	Max	0.87	19.73	4.57	814.8	36.59
	Mean	-2.53	2.65	-1.46	268.95	-106.88

Region 2 is an almost 7600 m long shoreline (Fig. 4b). The shoreline movement in this region reflects the movement along the entire shoreline for all periods. The mean shoreline movement rate between 1973 and 2015 is  $3.72 \pm 0.15$  m/year. From 1973 to 2015, shoreline maximum displacement is almost 348 m, but the longest change occurred between 2002 and 2015 - almost 755 m. This region is partly on the territory of Gavaraget sanctuary, and partly on the territory of Noraduz forest. Today, almost 100 ha of forested and sea-buckthorn –planted area is also submerged by the lake as a consequence of the Sevan water level rise.

Shoreline in Region 3 has almost 9200 m length (Fig. 4c). Mean shoreline movement towards land is  $4.85 \pm 0.15$  m/year from 1973 to 2015. From 1973 to 2015, shoreline displacement is almost 692 m. The longest displacement - some 534 m - occurred between 2002 and 2015. This region partly lies on the territory of Gavaraget sanctuary. It also occupies part of territories of Noraduz and Ajrivank forests. The area submerged by the lake is almost 160 ha, main submerged species being poplar, willow and sea buckthorn.

Region 4 has almost 3700 m length shoreline (Fig. 4d). The mean shoreline movement from 1973 to 2015 is  $2.9 \pm 0.15$  m/year. In this Region, the longest shoreline movement towards land (250 m) occurred between 1973 and 2015; the longest distance between these shorelines in this Region was recorded between 2002 and 2015. The mean and maximum movement from that point (SCE) is 218 and 413, respectively. This Region is on the territory of Sevan forest, where some 25 ha of poplar trees and sea buckthorn bushes are submerged by the lake.

Region 5 is the most complicated region (Fig. 4e). Shoreline in this region is very complex. Even transect spacing of 50 m instead of 300 m set for other regions could not give the real picture of this region. This region is on the territory of Norashen reserves. Its relief is flat and the shore rugged. In the Norashen reserves, there are three small lakes (black circled in Fig. 4e Region 5 a) (IRTEK-<http://www.irtek.am/views/act.aspx?aid=41347>).

DSAS cannot give the real picture of changes in this area even if it shows that shoreline maximum displacement is almost 815 m. As seen from the map of the Region, the shorelines of small lakes in this area are not always separated from Lake Sevan. Presumably, shoreline movement by 815 m is the perimeter of one of small lakes (upper left side) rather than the shoreline real displacement. Sources of error can be both differences in spatial resolution (80 m for 1973 and 30 m for 2015) and seasonal changes in water level. As soon as this area is flat, it can be affected by seasonal water level rising.

## CONCLUSIONS

The application of RS methods and particularly Landsat image-based delineation of shorelines using NDWI spectral index gives sufficiently reliable results for Lake Sevan. This method is used not only for shoreline delineation, but also for visualizing changes in Lake Sevan shoreline. Applying DSAS in its turn helps make statistical and quantitative spatiotemporal analyses of shoreline changes.

The shoreline change analyses show that these changes correspond to water balance changes. Because of different landforms, the consequences of shoreline changes are different along the whole length of shore. In the areas where the shore is edged by gentle slopes the shoreline displacement can even reach 600-700 m, on a steep slope edging areas shoreline changes being insignificant.

A water index NDWI is a reliable method for shoreline delineation, nonetheless in some cases DSAS calculations indicate some inconsistencies with the direction of the main shoreline course. Most of these are within one-pixel size (30 m) and are supposed to be cartographic or computational errors. In the larger areas, the causes can include natural phenomena as it was in the case of Region 1, or man-made impacts (sprawls, etc.).

Shoreline displacements, especially when occurring on larger territories, affect nearshore areas and the land use in Lake Sevan region. After Lake Sevan water level had lowered, water-free places were planted by trees and shrubs. However, since 2002 water level has been rising steadily, and these areas

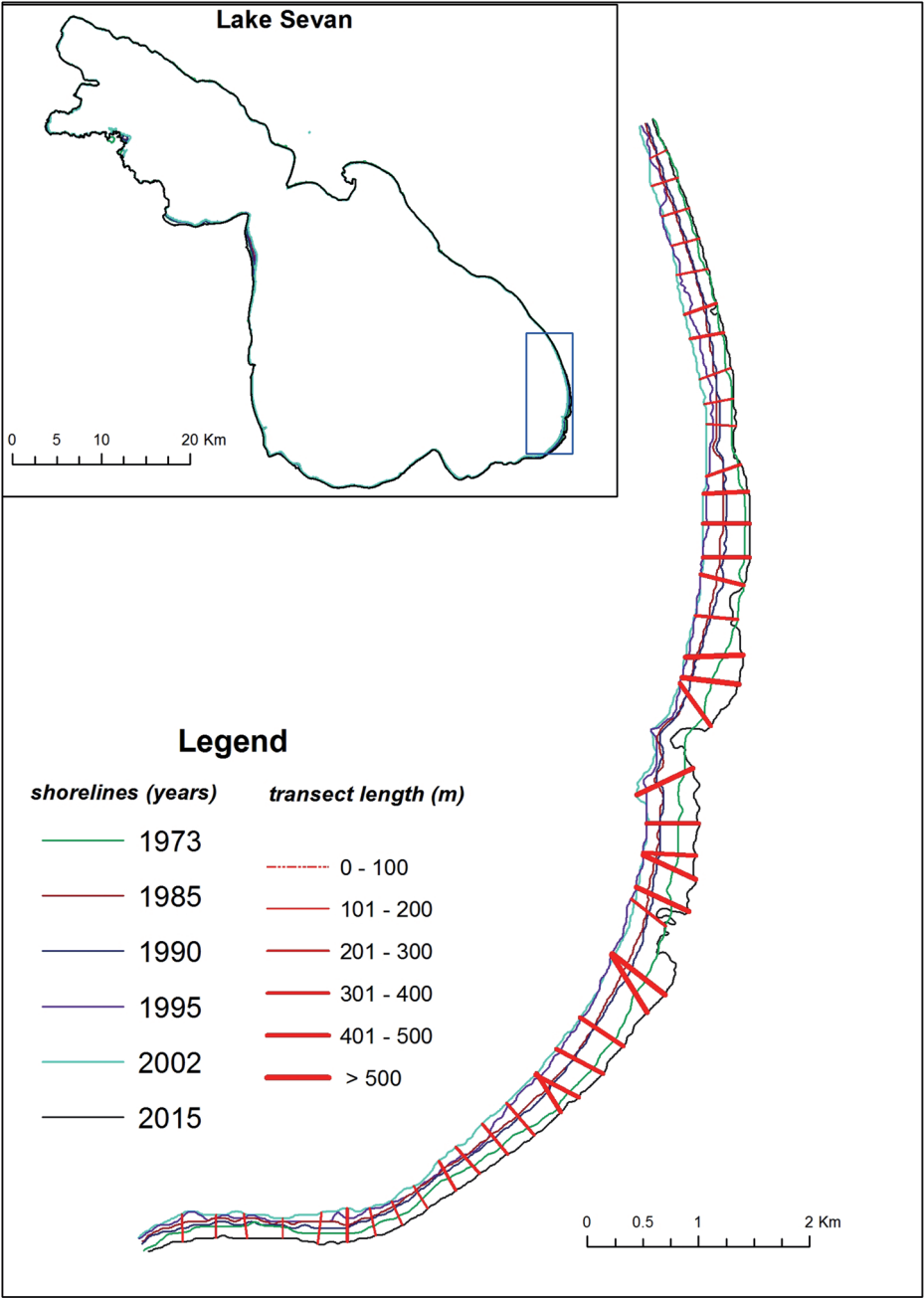


Fig. 4a. Lake Sevan with outlined Region 1, shoreline positions in each date and shorelines displacements

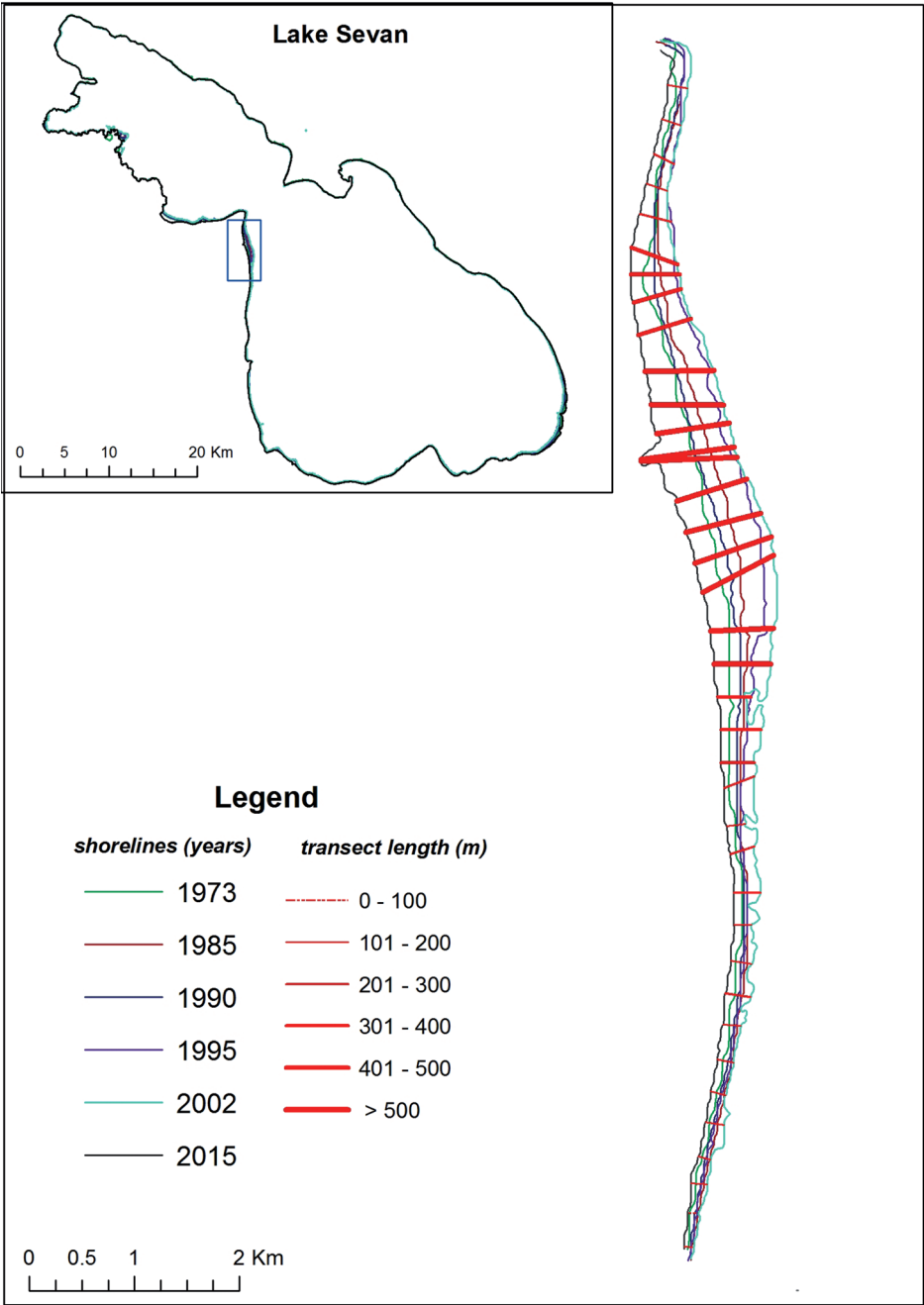


Fig. 4b. Lake Sevan with outlined Region 2, shoreline positions in each date and shorelines displacements

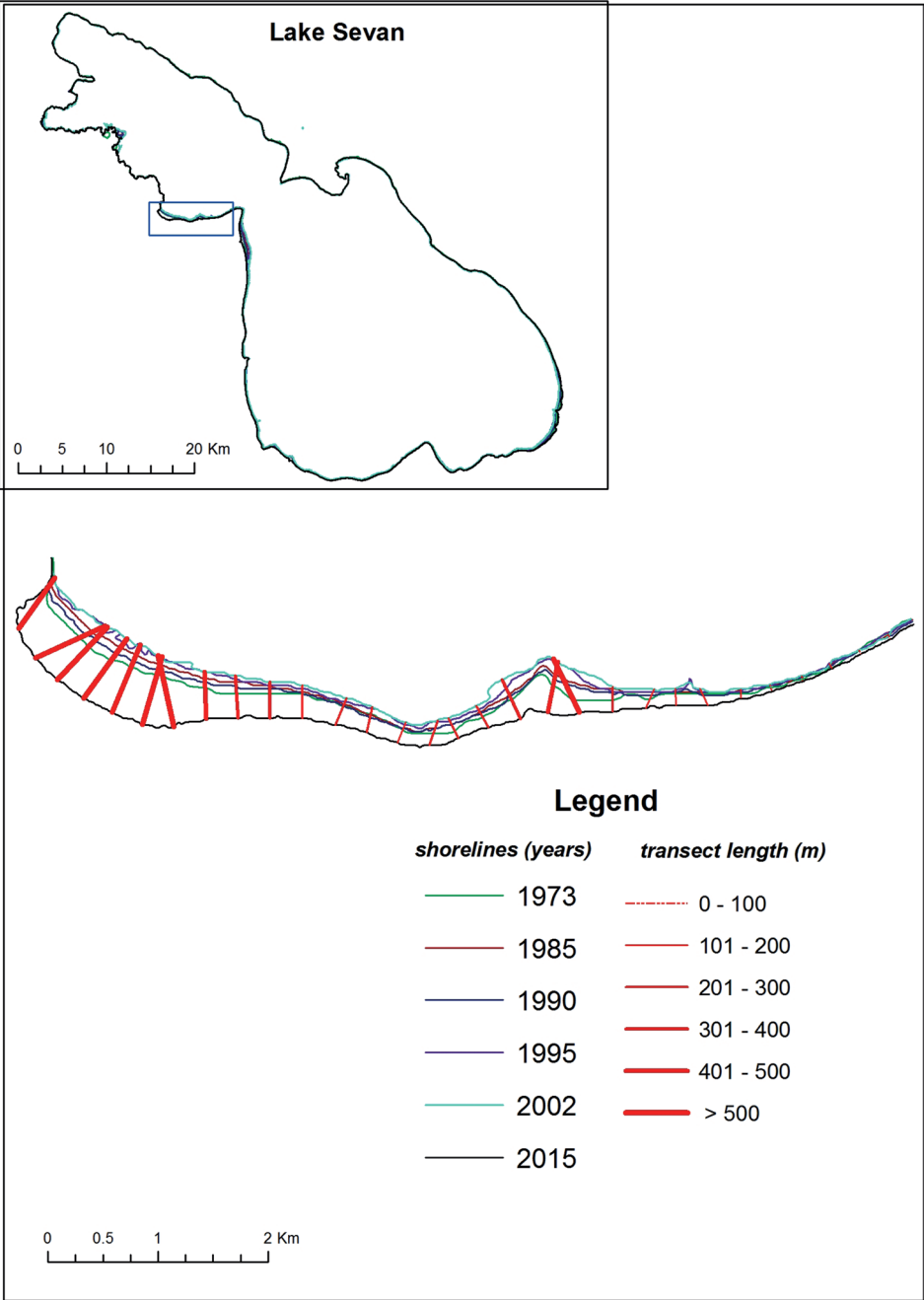


Fig. 4c. Lake Sevan with outlined Region 3, shoreline positions in each date and shorelines displacements

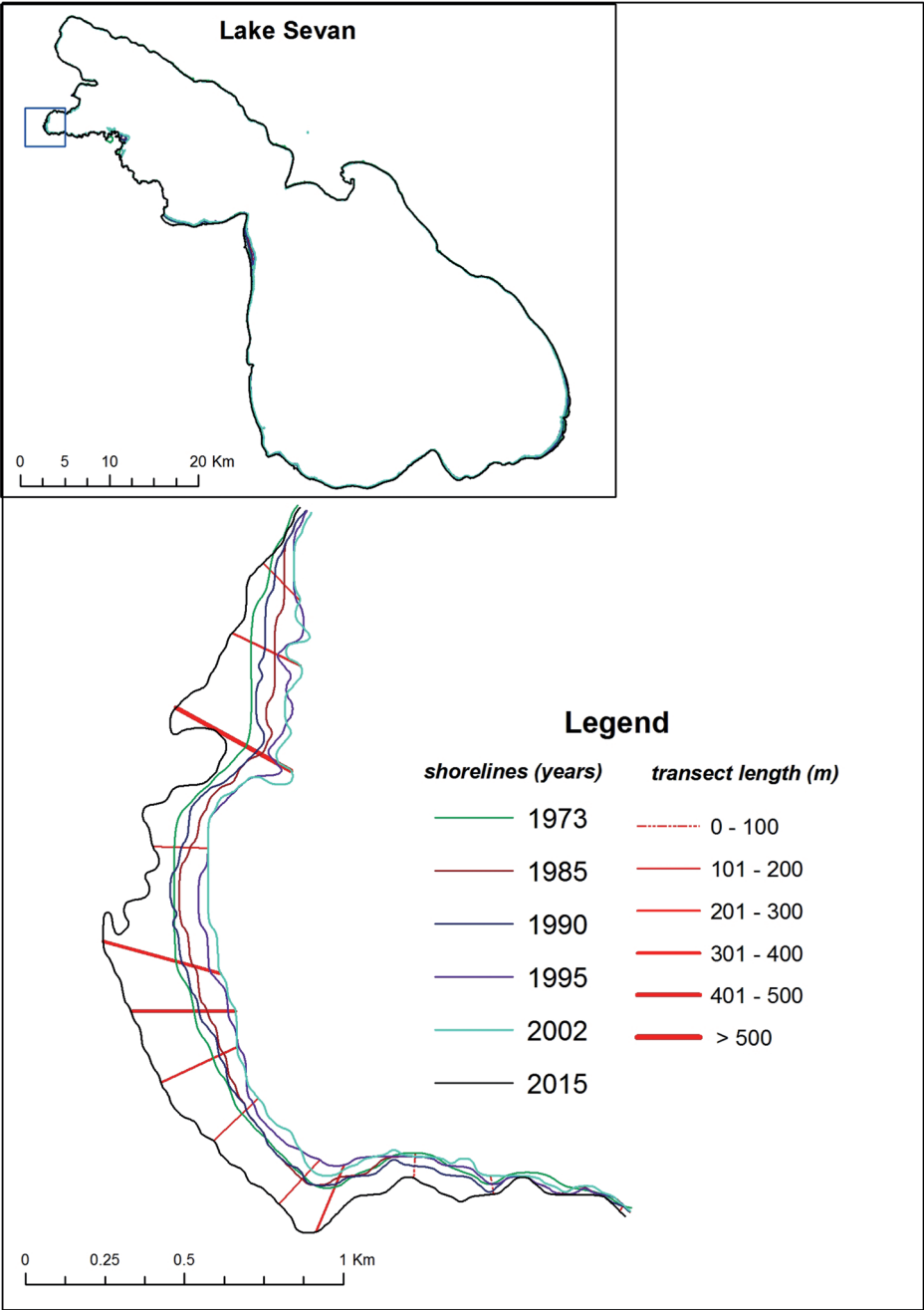
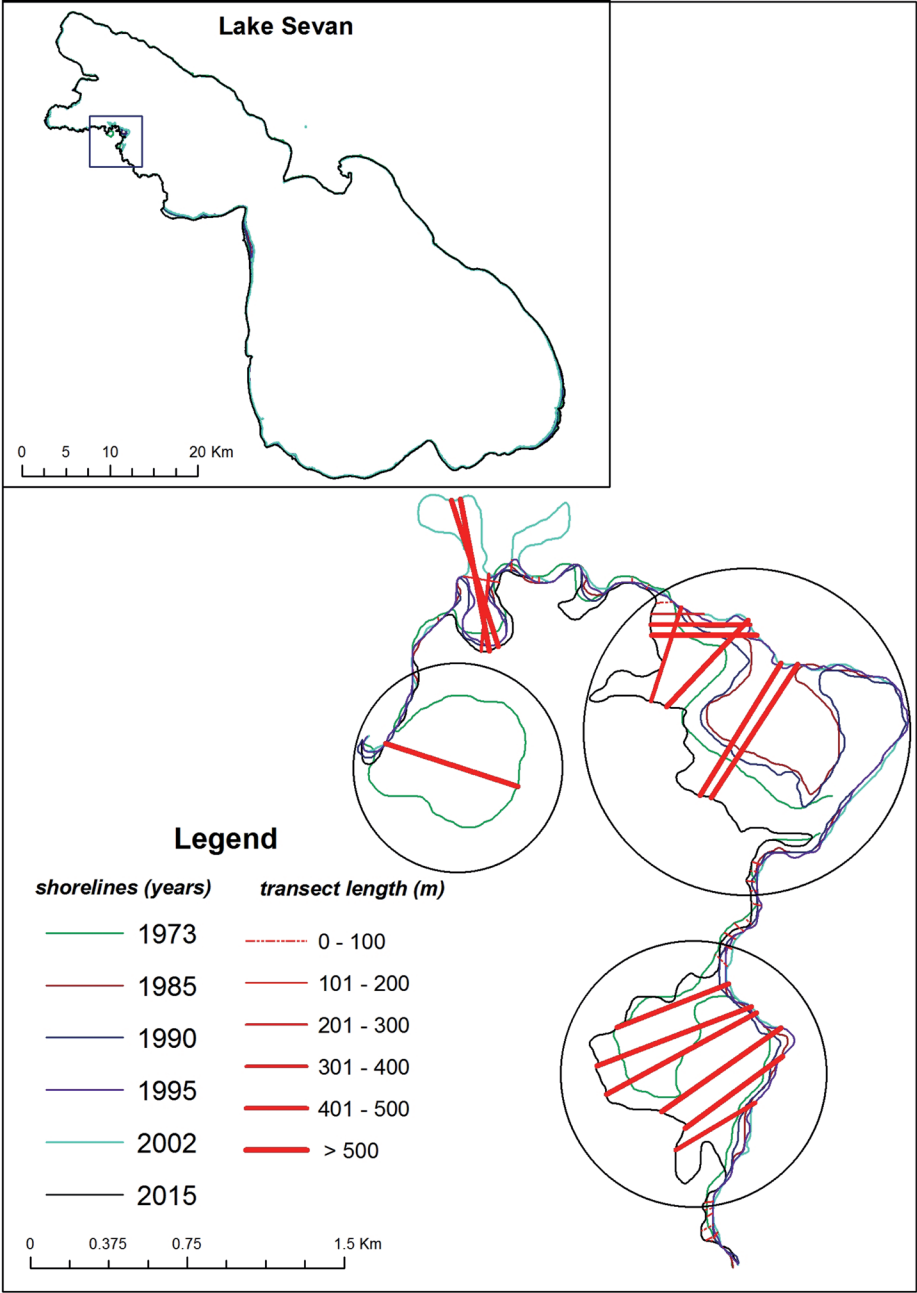


Fig. 4d. Lake Sevan with outlined Region 4, shoreline positions in each date and shorelines displacements



**Fig. 4e. Lake Sevan with outlined Region 4, shoreline positions in each date and shorelines displacements**

are submerged by the lake. To avoid further eutrophication of the lake in consequence of water level rise to the 1905 m it is necessary to properly clean nearshore areas.

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