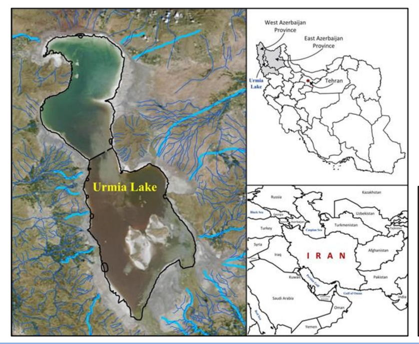

Water Research Institute

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Deriving and Evaluating of Urmia Lake bathymetry and stage curve for shallow lake using Remote sensing data

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Abstract

Urmia Lake as a significant water body in Iran has been shrinking since the late twentieth century and its area has dramatically decreased. Deriving physical information such as volume, area and their changes are very crucial for applying any survival plans and modeling. The main objectives of this study are firstly, studying the bathymetry of Urmia Lake with using Landsat-LDCM satellite image and in situ measurement data. A polynomial model was developed to predict the water depth in Urmia Lake area with the input series of reflectance values from blue, green, red and NIR bands of the Landsat images. Meanwhile on 12 April 2013 of the sampling sites from actual depth measured were taken on the same date. Also, using a large archive of Landsat imagery, a counter of equivalent elevation was established for deriving the bathymetry of desiccated areas by mapping the edges of the lake and finally assembled with bathymetry derived from polynomial model. In-situ depth measurements were used to evaluate resultant derived bathymetric map. This comparison shows reasonable agreement between the Landsat-derived depths and those measured in the field with RMSE of 0.27 cm and R^2=0.91. The maximum and mean depths measured were 4.9 and 11 m respectively. Results indicate that about 64 salt deposition has occurred during the last two years. Secondly, to make stage curves of lake, multi-temporal changes of water body have been derived from Landsat, MODIS and AVHRR satellite image sets since 1972. In this regard, the area of Urmia Lake at different level was estimated base on object oriented and pixel base classification using 78 satellite images. Finally, stage curve (volume-area- level relations) was derived from bathymetry map.

Introduction

Researchers believe that establishing an integrated water management plan budget is much more essential and practical than the other approaches. In fact, the only way to establish balance between demands for human use and ecosystem requirements is setting up a comprehensive water management program which takes into account all elements of the basin's water. In May 2010 under the United Nations Development Program, the integrated management plan of Urmia Lake was established (Sima and Tajrishy 2013). Based on this plan it is need to import 3.1 km^3 of water annually to the lake in order to keep its water level at the minimum ecological level of 1274.1 m. To implementation of this comprehensive plan and the information of the lake bathymetry and the rate of sedimentation are more essential. The bathymetry maps provide invaluable information in establishing an integrated water management program, both for deriving an appropriate volume- area- level curve and salt balance equations. It is inevitable to preserve the main ecological features of Urmia Lake affecting lake restoration. Indeed, detailed analysis of lakes requires volume estimation due to high effect of this physical information on the hydrological and hydraulic conditions. The main objective of present study is to estimate the Urmia Lake bathymetry using convenient and quick method and new Landsat-8 satellite images. Finally, extracted bathymetry map used for extract the high precision volume- area- level curves. To accomplish this objective, first, Landsat-8-LDCM satellite image with concurrent in situ measurements were used by applying a multiple regression equation with reflectance in blue, green, red and near infrared bands of Landsat-LDCM satellite imagery. The accuracy of the image-derived water depths will be estimated by comparison with in situ data measured by shipboard echo sounder. Then after, a combination of pixel and object oriented image classification methods were used to delineating the area of lake at different level. Finally, the volume- area- level relations of the lake were developed by combination of bathymetry, area and level of lake.

Methods

1.Bathymetry mapping

There are several methods for remotely sensing water depths and reservoir bathymetry. Optical bathymetry methods (passive remote sensing imageries) and RADAR based techniques (active remote sensing imageries). Optical bathymetry method (includes airborne and space-borne hyper/multi spectral imageries) is based on this principle that the total reflected energy of electromagnetic waves from a water column (including the water surface, the water body and the sea bottom) varies with the water depth. Although passive optical systems are limited in depth penetration, and constrained by water turbidity, the use of such satellite data could be the only possible way to reliably map water Algorithms for the mapping of water depth.

- **wave spectrum analysis at different water depth**
- **analysis for deriving the water depth**

The radiation reached to the space sensor is inversely proportional to water depth. A model conducted using two or more different bands (in the multi-spectral images as well as Landsat satellite images) and assumes a constant reflection at the bottom.

$$Z = A_0 + A_1B_1 + A_2B_2 + \cdots + A_nB_n$$

By comparison the reflectance of each 9 optical bands of LDCM sensor, four bands with the highest correlation between the reflectivity and observed water depth were selected (2,3,4 and 5).

$$Z = 0{,}868 + (50{,}1 \times r_2) - (4{,}46 \times r_3) - (39{,}04 \times r_4) - (37{,}02 \times r_5)$$

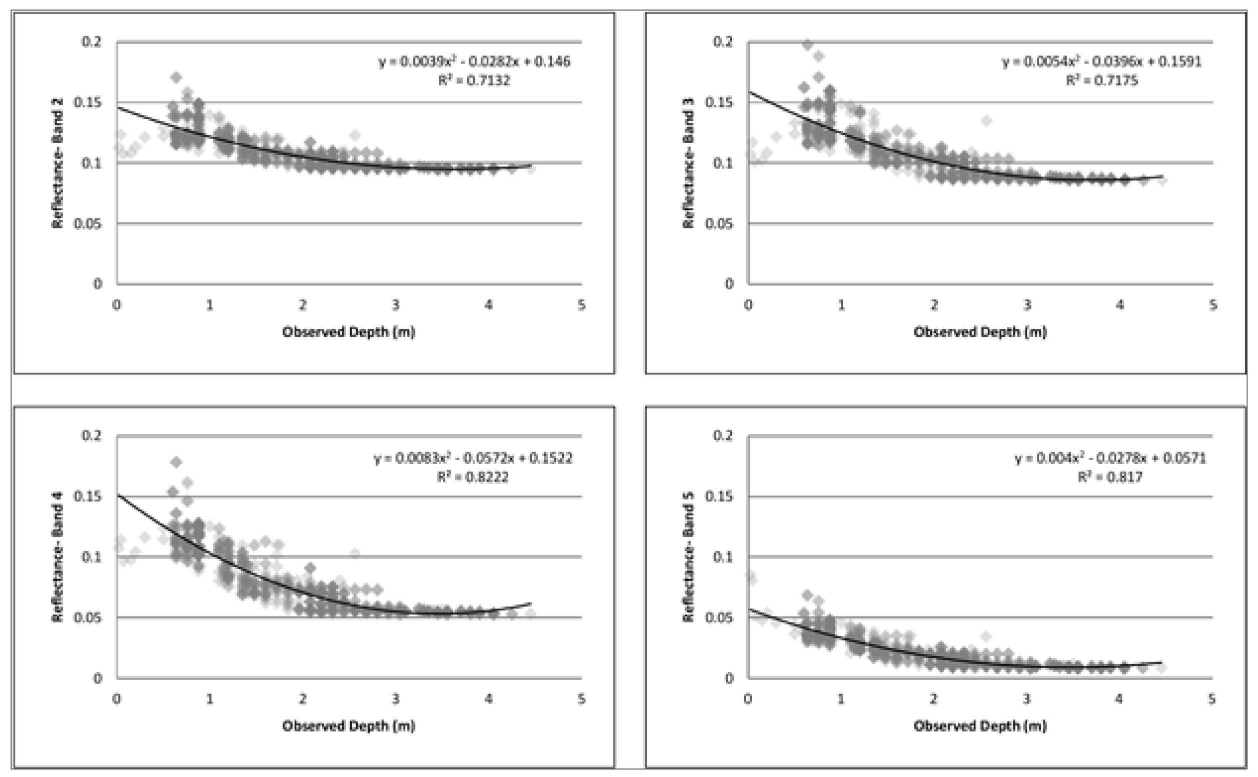

Fig1:Relation between Landsat-8- LDCM bands reflectance and lake depth measured in the field

2.Water surface area delineation

Different classification methods used to extract water surface area. These approaches can be divided into three categories: thresholding methods (such as NDWI (Normalized Difference Water Index) and NDVI (Normalized Difference Vegetation Index)), supervised/ unsupervised pixel based classification methods (such as maximum likelihood and minimum distance) and object oriented classification approaches. The presence of thin salt crusts covering layers of salt and bathing brine was confirmed through field observations. Methods that use the water absorption bands (IR and NIR wavelength) cannot detect such areas due to the bathing brine beneath thin salt crust.

Methods

In this study, Urmia Lake (based on the satellite images used) monitored within a 42 year time period (1972-2014). First, based on the thresholding approach (using NDVI and NDWI). The area of Urmia Lake were measured by AVHRR and MODIS images. Present indices have been frequently used for water body detection and estimating the area of lakes and reservoirs. Noted that NDWI is distinguished to be more appropriate in comparison with the other indices. Accordingly, this index was applied here for MODIS images, but for AVHRR images which don't include green band, NDVI was used. The accuracy of the aforementioned indices depends on the threshold value that considered for water extraction from the other land use areas. (Fig 2)

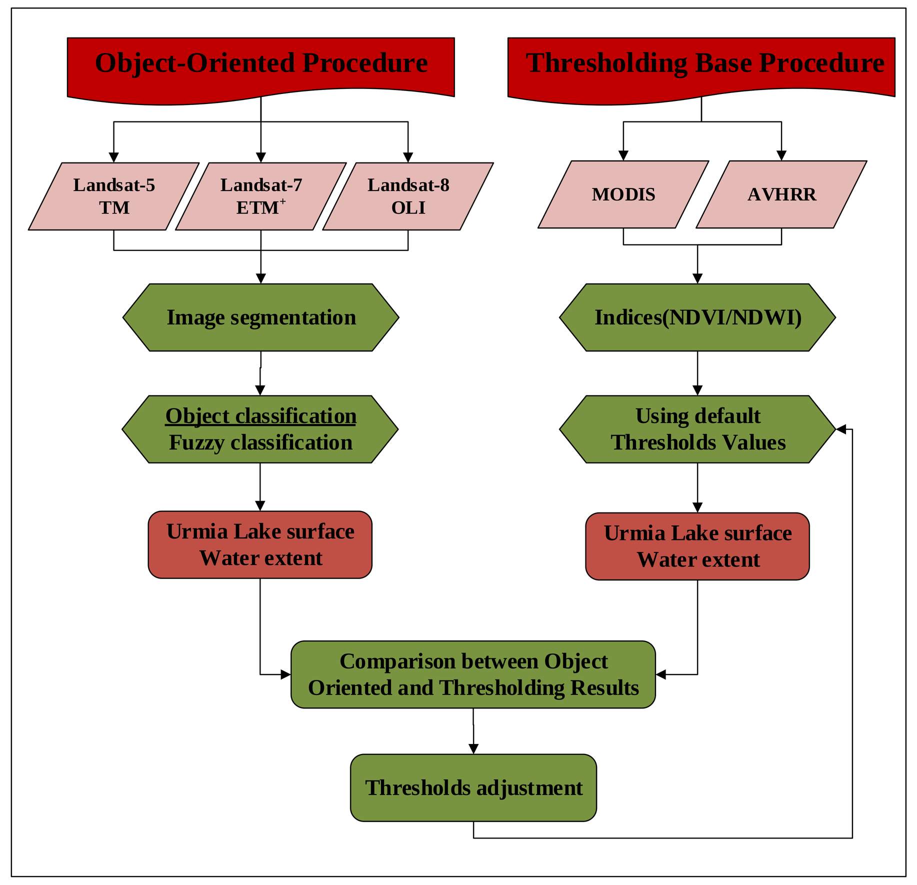

Fig2: Hybrid classification procedure to extract Urmia Lake surface water extent from salt lands and surrounding areas

Index	Formulation	
NDVI	$\frac{NIR - R}{NIR + R}$	G: Green Band (0.50- 0.59 μm) R: Red Band (0.61- 0.68 μm) NIR: Near infrared band (0.78- 0.89 μm)
NDWI	$\frac{G - NIR}{G + NIR}$	

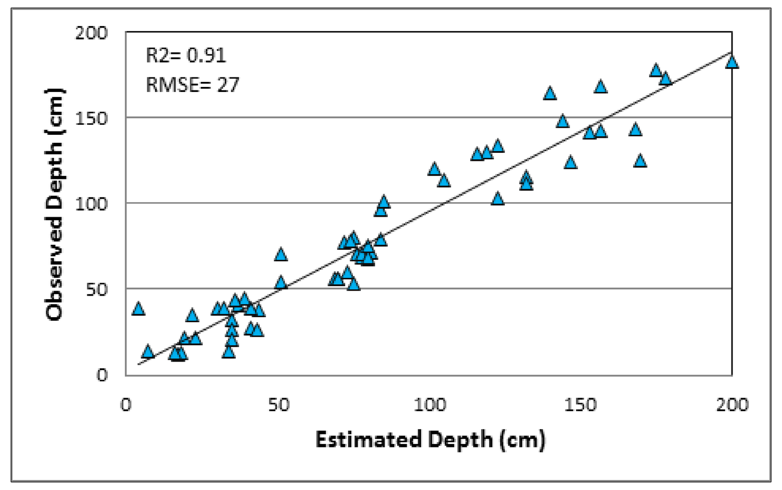

Fig3: Comparison between the Landsat image-derived water depth and the observed measurements (the 45-degree oblique line represents the perfect fit)

Results

1.Bathymetry map and its accuracy assessment

In this study, 170 independent in situ measurement points were used (measured by the shipboard echo sounder). The scatter plot of the image derived water depth and in- situ measured depths shows reasonable agreement between the Landsat-derived depths and measured ones in the field with RMSE (which represent the extent of variability in the estimated depth) of 0.27 cm and R2=0.91(Fig3). Although it is expected that the depth errors should be increased significantly when the water gets deeper, but the amount of error in present study does not comply with a particular spatial pattern.

After mapping bathymetry across the covered areas with water, equal elevations of lake margins were mapped with the Landsat iso-contours derived from classification methods (Object-Oriented and Thresholding classification). Indeed, for deriving the topographic properties of desiccated areas of Urmia Lake a classification method first used to determine the edge of exposed water body. The distance of these edges from the playa edge along the reference point (Golmankhane station) is measured and then interpolated to derive the bathymetry of these areas. The Landsat-derived bathymetric map of the Urmia Lake is shown in figure 4. The mean depth of Urmia Lake in comparison with its maximum water level (1278 m) is about 4.9 m. The deepest part is 1267 m at the upper part of the lake and the shallowest depth is 1278 m around the inner islands and marginal areas of the lake. The deepest part of the lake is located in the northern part and as one moves toward the southern part of the lake, the water depth is abruptly reduced around the Shahid Kalantary causeway. The maximum water depth in the northern and southern parts of the Urmia Lake is about 11 and 8.8 m respectively.

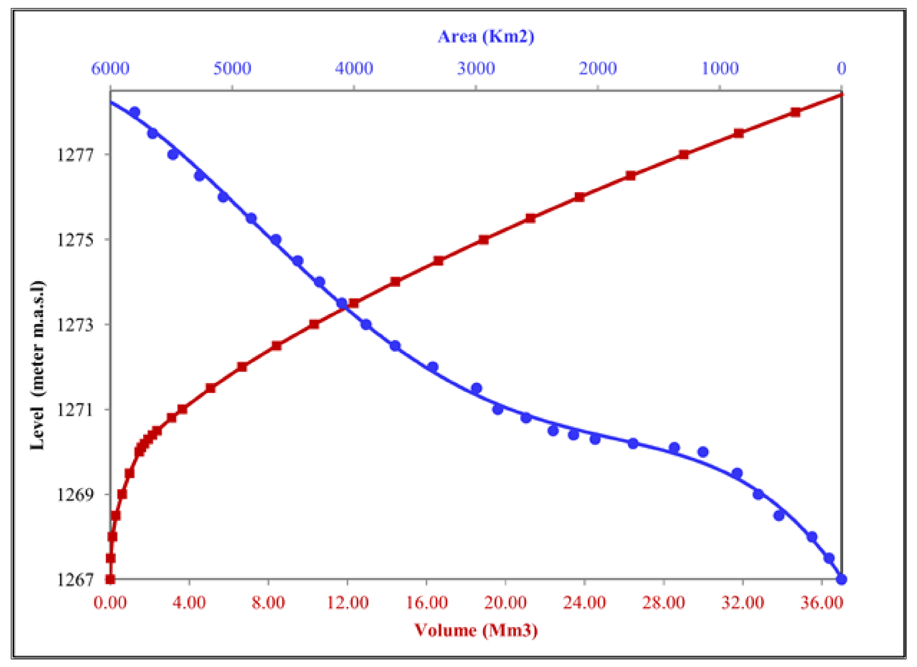

Fig6: Stage curve of Urmia Lake.

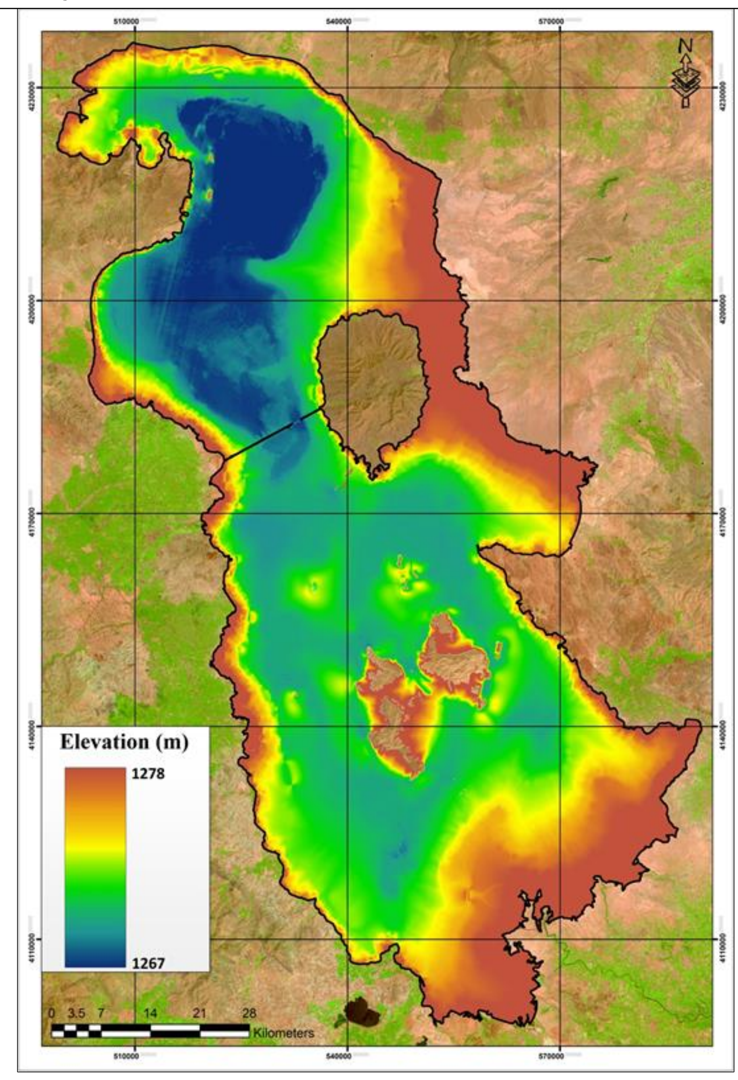

Fig4: Bathymetric map of Urmia Lake (derived from Landsat OLI image)

Results

2. Urmia Surface area change

The maximum surface area of Urmia Lake has been observed at the level of 1278 m with area of about 5732.2 km2. Based on our analysis it can be said that this area is the largest area which was observed during the past half century(Fig 5). Also, the minimum surface area of Urmia Lake is about 242.91 km2 which was observed at the level of 1268 m. This represent that the difference between the minimum and maximum surface area of Urmia Lake is about 5489.29 km2. On the other hand, the lake surface area decreased at a ratio of 95.7 % until 2013. Also the level of water has decreased to its lowest level in recent years (1268 m).

Given the water elevation data and concurrently surface areas, the area- level relationships can be derived for Urmia Lake. This relationship is displayed in figure 6. Also, a four number polynomial trend line can be well fitted to data with R2=0.99 as follows:

$$y = -4E - 14x^4 + 5E - 10x^3 - 2E - 0{,}6x^2 + 0{,}0042x + 1267$$

Where X is the water surface area in km2 and y is the water elevation in m.

3.Salt Deposition Monitoring

A new bathymetry map was derived based on the image acquired on Sep 2015 and the polynomial equation that has already been developed. It should be noted that at Sep 2015, the southern part of the lake was completely dry and therefore the methodology described in this study cannot be used for this section. Accordingly, the elevation changes were derived for the upper section of Lake. After deriving a new bathymetry map, the elevation change (sedimentation) of the lake was calculated by subtracting the bathymetry maps. Figure 7 shows the elevation change (sedimentation) of Urmia Lake bed from April 2013 to Sep 2015.

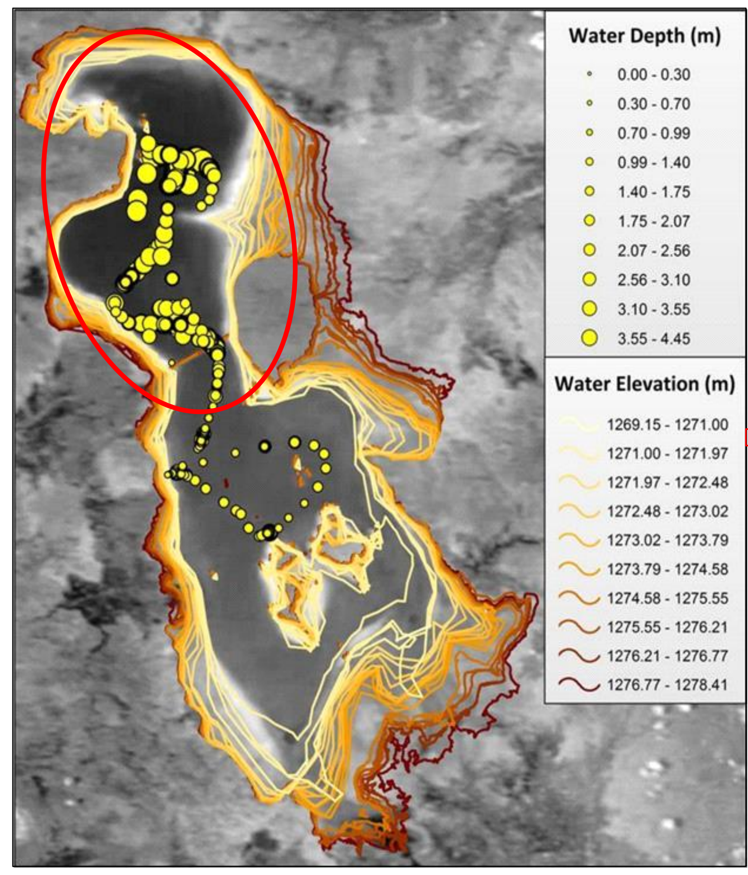

Fig5: Urmia Lake surface change detection at different water level during last 29 years (from 1984 to 2014).

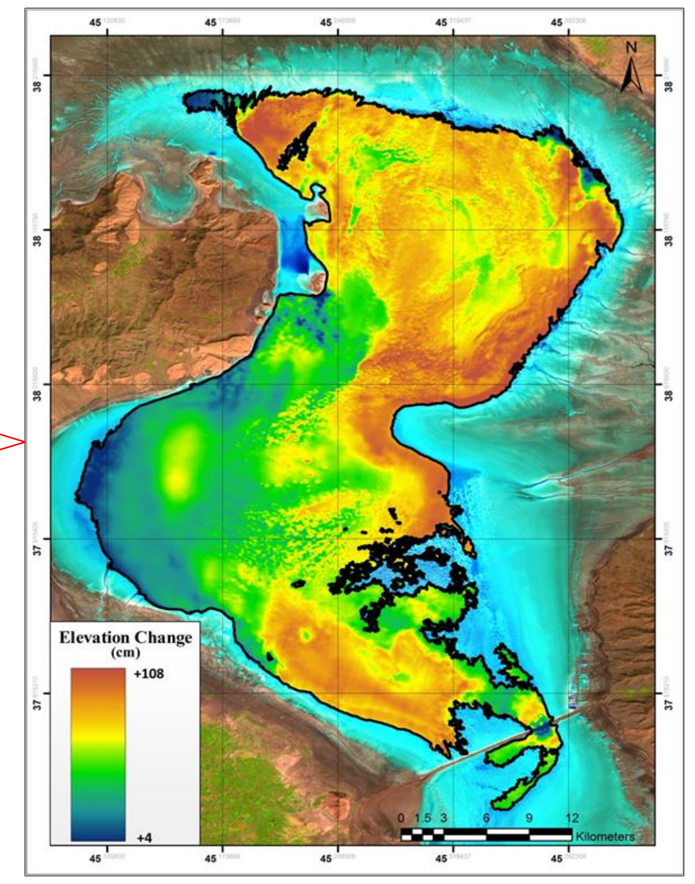

Fig7:Elevation change (sedimentation) map of Urmia Lake bed from April 2013 to Sep 2015.

Based on the obtained results, the sedimentation occurred about 4 to 108 cm during the past 2 years. According to figure 7 the lowest amount of sedimentation happened in western and southwestern part of the measured area but in the northeastern and central parts of the lake, sedimentation happened severely (about 70 to 90 cm). Generally, the average sedimentation of Urmia Lake is about 64 cm during the last two years.

Conclusion

Based on the Urmia Lake physiographic feature, this study developed and used a model that merges the reflectance bands with in situ measurements to simulate the lake's characteristics. We have used Landsat 8- LDCM image together with simultaneous ground truth data in the Urmia Lake to predict water depth from band reflectance using polynomial relation models.

The results indicated that a polynomial model did a good job in reporting observed water depths and accurately predicted the depth on May 2013. Subsequently, the results were used to generate a digital elevation model, which in turn was used to compute the fractional relations between water level, surface area and volume. Present method can be used for rapid bathymetric survey and map generation using existing satellite images at low coast. Also, present methodology and derived polynomial regression equation were used for salt deposition monitoring using new derived Landsat- LDCM image on Sep 2015.

After generation of bathymetry map, the stage curves were derived using multi-temporal water surface area delineation. These curves can be used to evaluate the lake water volume and area at different water levels and vice versa. These curves enable us to show the relationships between such variables.

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