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Detection of the Bathymetry and Shoreline of Terkos Lake-Turkey Using Digital Image Processing and GIS

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ABSTRACT

Bathymetry can be defined as the study of water depth, in other words, it is the topography of the bed of sea, ocean and lake floor. In this study, the bathymetry of Terkos Lake, northern Istanbul, Turkey is prepared using field work points and remote sensing data. More than 70,000 eco-sound points are collected; manipulated and entered to GIS geodatabase in order to create the bathymetric map, digital image processing for remote sensing data is also used to produce the map. The shoreline of the lake is detected using Iso Cluster unsupervised classification tool in spatial analyst arc tool from the most recent satellite image captured by Landsat 9 in 25th of March 2022. ARCGIS geodatabase is built in order to create a 0.5m interval bathymetric contour lines showing the bathymetry of the Terkos Lake bed. The Lake level, surface area, water volume curve for the lake are drawn using the results of lake water budget analysis. Results show the possibility of using remote sensing data as an aid to assist in field work related to the production of bathymetric maps. These maps give an indication to decision maker for the amount of sediment in the lake. Water bodies data bank also provides a dynamic database of related measurements as surface area, water volume knowing the water level.

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تحديد الخط الساحلي واعماق بحيرة تيركوس - تركيا باستخدام المعالجة الرقمية للبيانات ونظم المعلومات الجغرافية

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الملخص

قياس الأعماق هو دراسة عمق قاع البحار والمحيطات أو قاع البحيرة تحت الماء، وبعبارة أخرى، فإن قياس الأعماق هو ما يعادل التضاريس او ارتفاع سطح الارض. في هذه الدراسة، تم إعداد قياس الأعماق في بحيرة تيركوس، شمالي إسطنبول-تركيا باستخدام القياسات الحقلية وبيانات التحسس النائي. جمعت أكثر من 70,000 نقطة سونار خلال العمل الحقلي ثم عولجت هذه البيانات وأدخلت الى قاعدة بيانات في نظام المعلومات الجغرافية لغرض انشاء خارطة الأعماق، كذلك انتجت الخارطة باستخدام عمليات المعالجة الرقمية لبيانات التحسس النائي. تم اكتشاف الخط الساحلي باستخدام التصنيف غير الموجّه في أداة المحلل المكاني من أحدث مرئية قمر صناعي التقطها لاندسات 9 في 25 مارس 2022. تم بناء قاعدة البيانات الجغرافية ARCGIS من أجل إنشاء الخطوط الكنتورية بفترة 0.5 متر توضح قياس الأعماق في بحيرة تيركوس. تم رسم مخطط ارتفاع منسوب الماء في البحيرة مع المساحة السطحية ومنحنى حجم المياه للبحيرة باستخدام البيانات الناتجة من الموازنة المائية للبحيرة. أظهرت النتائج إمكانية استخدام بيانات التحسس النائي كمساعد للبيانات الحقلية فيما يتعلق بإعداد خرائط الأعماق للمسطحات المائية لتعطي فكرة عن كمية الترسبات في البحيرات، كما يوفر بنك بيانات المسطحات المائية أيضا قاعدة بيانات ديناميكية للقياسات ذات الصلة مثل مساحة السطح وحجم المياه مع معرفة مستوى المياه.

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Introduction

The term "bathymetry" or submarine topography means the depths and shapes of underwater terrain which means beds or floors of water bodies of the oceans, rivers, streams, and lakes (Ehigiator, 2017). Bathymetric maps are similar to the topographic maps, where contour lines are drawn to present the shape and elevation of land. Remote sensing data and geographic information system (GIS) databases present an effective and a high-quality output in dealing with the water resources problems. These databases offer a powerful software that can manage a large amount of data by collecting them in a bank in a small storage size. (Panwar and Kumar, 2015.). Bathymetric maps are normally produced in order to support safety for sub-surface navigation; it usually shows the seafloor shape or terrain as contour lines called isobaths (Tzouramanis, 2021).

More than 40% of the world's most important lakes' bathymetry has not been studied yet, thus their water volumes were calculated approximately (Shiklomanov and Rodda, 2003). The importance of studying the bathymetric data for the water bodies was increased because of its role in the studies of the effect of sediment change in the floor and leakage from the lakes, as well as the effect of climate change on the environment.

Many researchers have studied this field, and a number of empirical equations have released by Stump, *et al*. (2003) and Su, *et al*. (2008); another complex algorithm was produced by Lyzenga (1978, 1981), Lyzenga, *et al*. (2006) and Philpot (1989). After reviewing these researches and the required parameters which varied from location to another, it's not easy to create the bathymetric maps. The procedure is adopted according to Stumpf (2003) and Jagalingam (2015) because of the flexibility in dealing.

Study Area

Istanbul's drinking water requirement is met by a total of seven basins, four of them in the European side of Istanbul, while the other three in the Asian side. Terkos Lake is one of Istanbul's most important surface water supplies; it is located on the European part of Istanbul provinces, around 40-50 kilometers north of Istanbul. The lake coordinates are 41' 20" north and 28' 34" east, as shown in Fig. (1). The lake level is in between -1 and +4.5 meters above sea level depending on seasons of consumption. This lake reserves 200 million m^3/year of freshwater around Istanbul, with a potential to hold 25% of the city's consumption water.

Terkos Lake is a man-made lake in the small village of Durusu in Istanbul's ctalca district. The Turkish State Hydraulic Works developed the project on Terkos Lake, which was completed in 1971 and put into service at that time. It is the normal domestic water supply project for Istanbul Governorate western section. It is 40 kilometers from the northwestern part of Istanbul's city center. The maximum depth is 11 meters and the elevation is roughly 4.5 meters above mean sea level. The total area is approximately 39 km^2. Figs. (2 and 3) show the average monthly water level variation and available volume from January 1, 2000 to December 31, 2017. (Ahmed, *et al*. 2017).

Terkos Lake has a great interest by many researchers in many studies because of its strategic importance in supplying fresh water for a large part of Istanbul city. Maktav, *et al*. (2002) monitored for 14-years the coastal erosion by the multitemporal satellite sensor data for the barrier between the lake Terkos and the Black Sea. Bayram, *et al*. (2013) studied and monitored the land use and land cover of the basin that feeds the lake. Terkos Lake is formed as a pond and isolated from the Black Sea shore by a 700-meter strip, the lake's freshwater has no link to the sea. A number of streams feed the lake, with the Istrance Creek being the most important. 619 km^2 is the area of the drainage basin. Terkos basin which supplies approximately 25% of drinking water needed in Istanbul is an important vegetation area, it has been entitled under preservation on accounts of being a nature preservation area, natural site area and wild life preservation area according to the international criteria (Balcik, 2010). Inevitably, the quality of the water basins has deteriorated considerably as a result of increased population and uneven urbanization in Istanbul during the last 20 decades. All safeguards taken and strict laws and regulations implemented were insufficient to protect the water basins from pollution (Çodur, 2004).

Shoreline Extraction

Bathymetric data determination is critical for near-shore activities and hydrological research such as coastal engineering, sedimentary processes, and hydrographic surveys. Remote sensing data has offered waterbodies measurements with a large coverage, low cost, and quick solution (Mohamed, *et al*., 2016). Band 5 Near Infrared (NIR) of Landsat 9, LC09_L1TP_180031_20220325_20220325_02_T1 was used for the purpose of lake shoreline extraction, the wavelength of (NIR) band is 845 to 885 nm which emphasizes biomass content and shorelines (Kalther and Itaya, 2020) (Table 1).

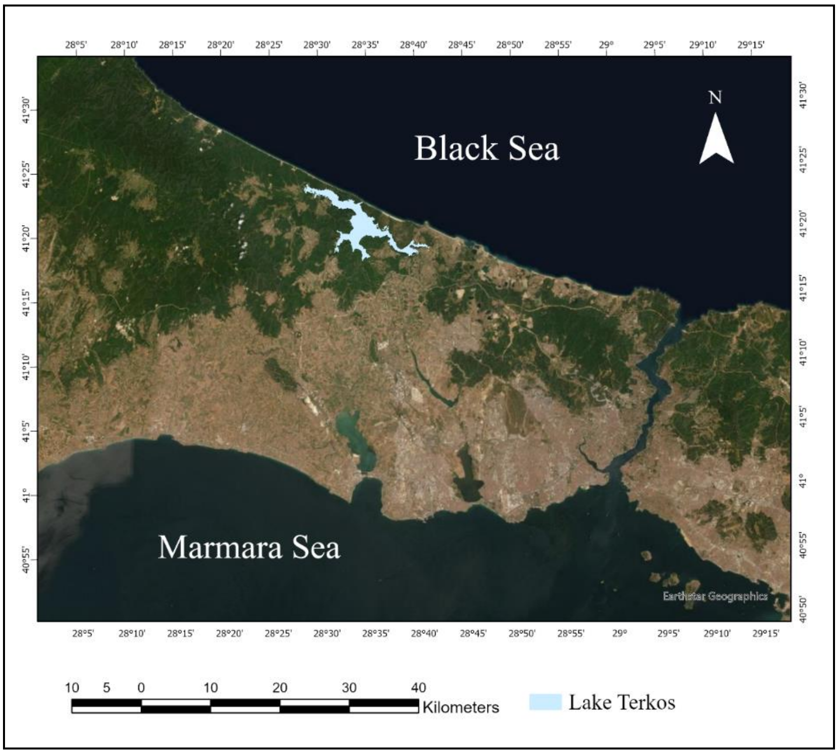

Fig. 1. The location of the study area

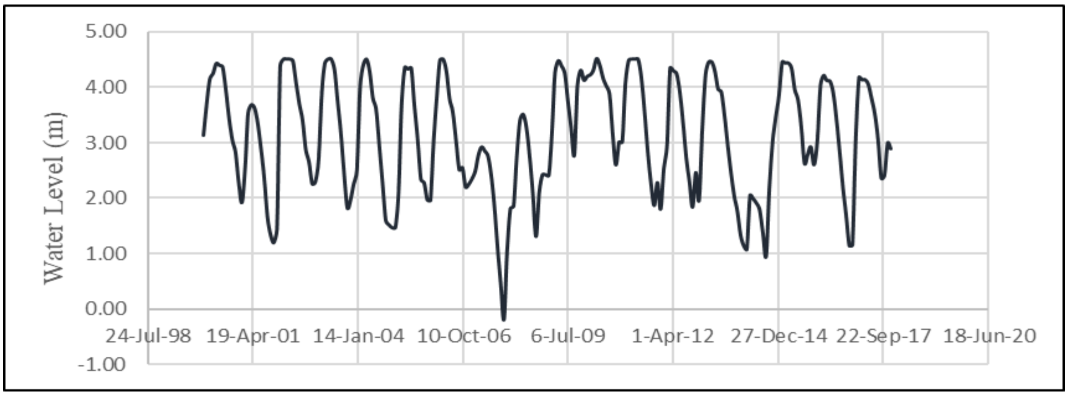

Fig. 2. Terkos Lake average monthly water level fluctuation

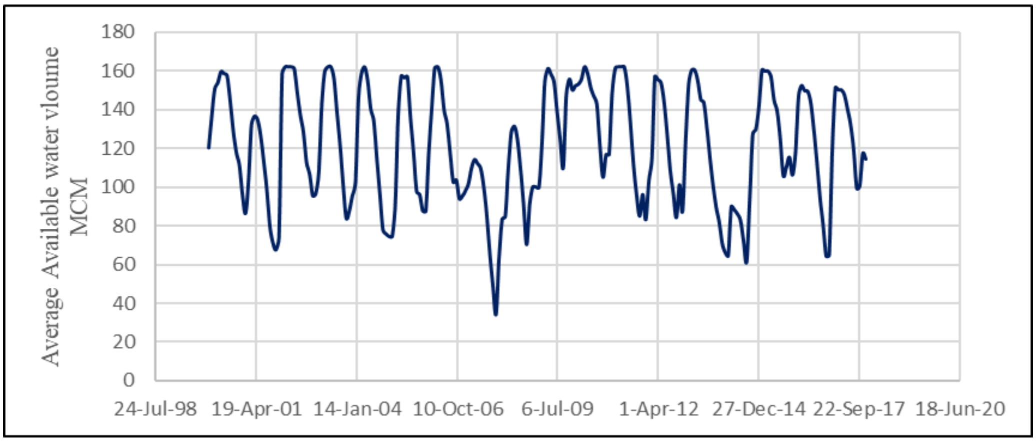

Fig. 3. Terkos Lake average monthly available water volume x10^{6} m^{3}

Iso cluster unsupervised classification under spatial analyst tool in ARCGIS pro.2.8.4 toolbox was utilized to isolate the water body from other classes, the water body was isolated then converted from raster format into polygon as a vector format using raster to polygon tool under conversion toolset in order to calculate the area of the water body automatically, the area of the lake surface is $(36.9119x10^6)$ m^2. The polygon then is converted into a line by data management tool; lake circumstance also can be calculated automatically and it is $(104.710$ $x10^3)$ m. (Fig. 4).

Table 1: Landsat 9 Operational Land Image (OLI) and Thermal Infrared Sensor (TIRS)

Band	Wavelength	Useful for mapping
Band 1 - coastal aerosol	0.43-0.45	Coastal and aerosol studies
Band 2 – blue	0.45-0.51	Bathymetric mapping, distinguishing soil from vegetation and deciduous from coniferous vegetation
Band 3 – green	0.53-0.59	Emphasizes peak vegetation, which is useful for assessing plant vigor
Band 4 – red	0.64-0.67	Discriminates vegetation slopes
Band 5 - Near Infrared (NIR)	0.85-0.88	Emphasizes biomass content and shorelines
Band 6 - Short-wave Infrared (SWIR) 1	1.57-1.65	Discriminates moisture content of soil and vegetation; penetrates thin clouds
Band 7 - Short-wave Infrared (SWIR) 2	2.11-2.29	Improved moisture content of soil and vegetation; penetrates thin clouds
Band 8 - Panchromatic	0.50-0.68	15-meter resolution, sharper image definition
Band 9 – Cirrus	1.36-1.38	Improved detection of cirrus cloud contamination
Band 10 - TIRS 1	10.60-11.19	100-meter resolution, thermal mapping and estimated soil moisture
Band 11 - TIRS 2	11.50-12.51	100-meter resolution, improved thermal mapping and estimated soil moisture

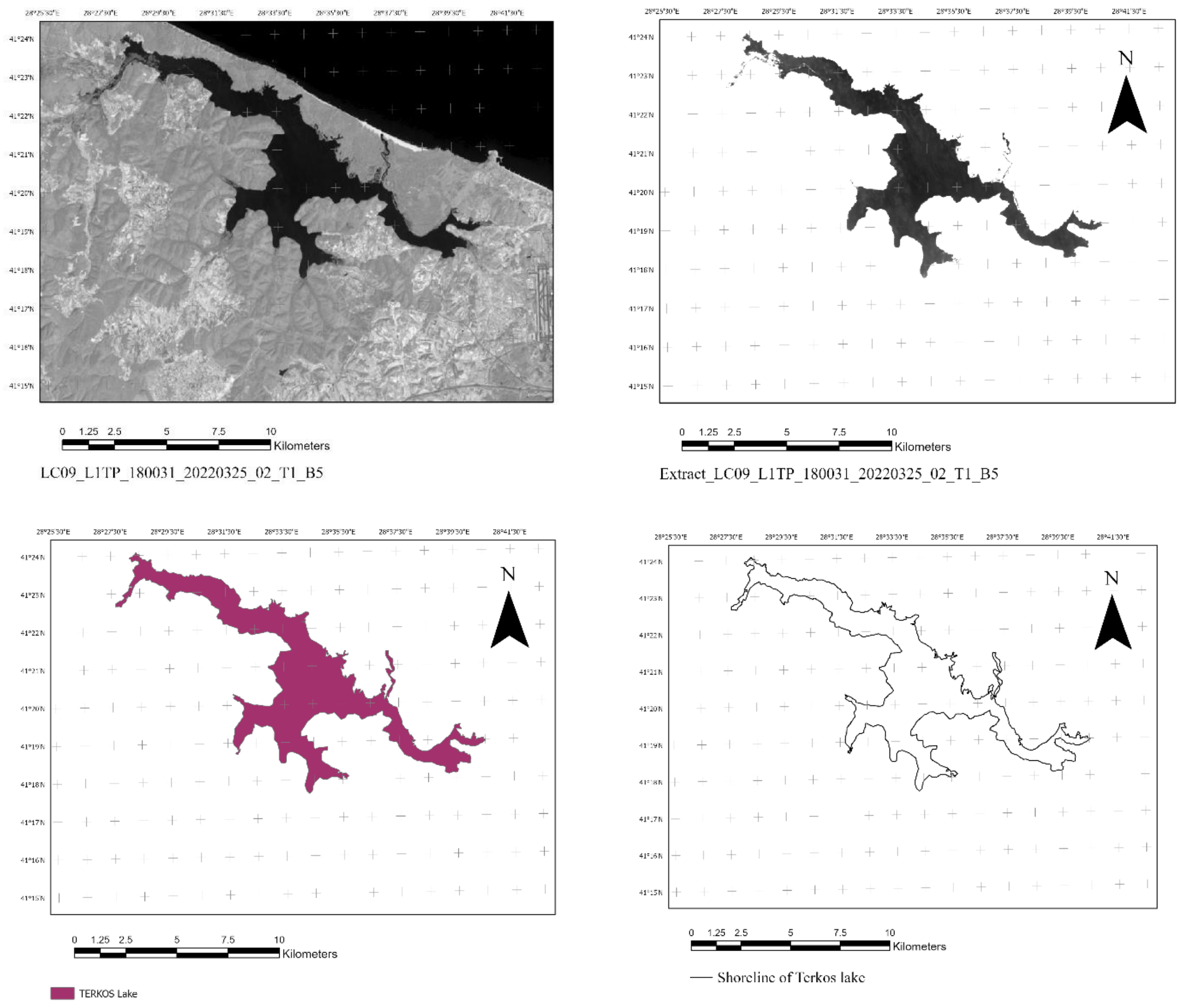

Fig. 4. Terkos Lake shoreline extraction

The Measurement of Bathymetry

Bathymetric data can be measured using a variety of ways, the first method which is rather old is the use of a pre-measured rope or cable; the rope then dropped to the side of a ship and the depth of water was determined by how far the rope could go. The problem with using a pre-measured rope is that the measurements may be erroneous owing to ship movement and currents during the measuring procedure. Furthermore, the rope can only measure one spot at a time which is limiting the amount of water that may be covered.

The difficulty of inaccuracy encountered while utilizing the pre-measured cable approach has been overcome by echo sounders, determining depth by employing the sounding or lead line as an instrument which was employed in the current study. Satellite images are also an approach that is professionally utilized nowadays, and the primary source of bathymetric data for the world's oceans is NOAA (National Oceanic and Atmospheric Administration).

In sounder system, while the ship travels it modifies the measurements to account for variations in depth. For the Terkos Lake, more than 70,000 sound point were used to create the underwater terrain of Terkos Lake. These points were collected by the Engineering Faculty in Istanbul Technical University-Turkey during the investigations related to the Canal Istanbul construction in April 2017. These data include the longitude, latitude and the depth of the lake. Surfer 16 is used to manipulate the data, the contour lines of the underwater terrain are created and drawn using these points.

Satellite Images have made it feasible to create maps that depict generic underwater characteristics across a vast region. According to Stumpf, (2003) and Jagalingam, (2015), the following equation has been used to determine the depth of the near shore coastal area:

$$z = m_1 \left[\frac{\ln\left(L_{obs}(Band_i)\right)}{\ln\left(L_{obs}(Band_j)\right)} \right] - m_0 \qquad (1)$$

Where, m_1 is a tunable constant to scale the ratio to depth, L_{obs} is a fixed constant for all areas, and m_0 is the offset for a depth of 0 m. The fixed value of n in Eq. 1 is chosen to assure both of that the logarithm will be positive under any condition and that the ratio will produce a linear response with depth. For the lake under study, green and blue bands of Landsat 9 in March 2022 have been used in order to determine the bathymetric mapping. The reason for applying blue and green bands in the coastal environment is that the radiance in the blue band which has a wavelength of (450 – 515 nm) decreases more rapidly with depth than radiance in the green band of (525 – 600 nm) (Fig. 5).

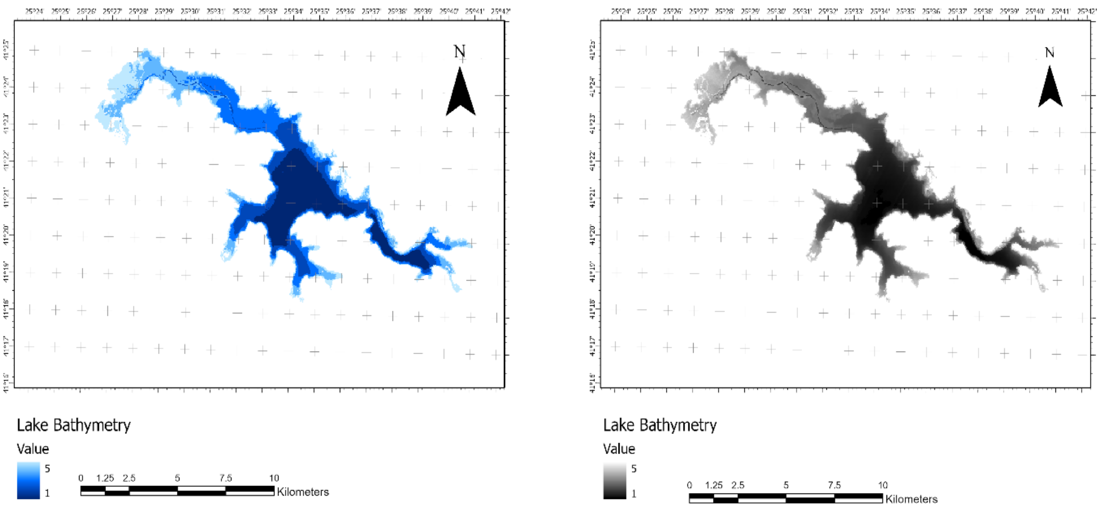

Fig. 5. Z values of the lake

The Measurement of Level, Surface Area, and Volume

Bathymetry maps are created by measuring the depths of the ocean. The maps show the form, size, and distribution of the underwater features in a great detail. Engineering, environmental, scientific, and marine geophysical researches are all benefit from bathymetry maps. False colors are used to depict various aquatic depths on the bathymetry charts. Lines connect the areas with identical ocean depths on the maps (Pereira, 2019). After determination of bathymetric maps and with the aid of the Lake level char, the surface area and the volume curve has been drawn as shown in Fig. (6), where this curve makes it easy to study the lake water budget at any time if the satellite image is available for that time by following the procedures in this paper. For example, for the image used for the extraction of the shore line (Band 5), the surface area was calculated automatically in the GIS geodatabase which was 36.91km^2; this area can be projected on the curve in Fig. (6) in order to estimate the lake level at that time and vice versa without going back to the study area. Physically, the lake level was 3.5m above mean sea level for this case. The water volume also can be estimated using the volume-elevation curve in the same figure and its release as 180 x 10^6 m^3.

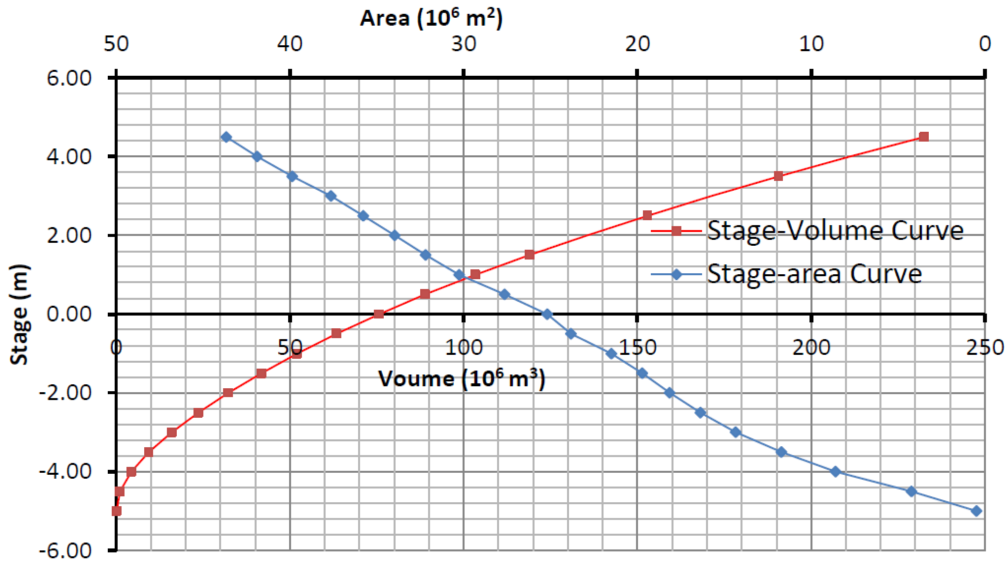

Fig. 6. Area-Elevation-Volume curve for Terkos Lake

Discussion and Conclusion

Bathymetric maps are important, it defines the habitat of animals and plants in oceans, seas, and lakes, among other water bodies. Bathymetry is also useful for seafarers who go by water since it keeps them safe. Bathymetry warns the globe about the impacts of changing weather patterns due to climate change. It forewarns scientists, for example, of rising sea levels and ongoing and future beach erosion. Bathymetric data are also employed in the management of fisheries and the establishment of maritime boundaries. Scientists can also use it to detect geo-hazards such as underwater landslides. Finally, scientists develop hydrodynamic models using bathymetric data.

In this study, the bathymetry of Terkos Lake was established using two ways: first, using the eco-sound field work, where more than 70,000 sonar points were used in order to create the bathymetric map shown in Fig. (7) depending on longitude, latitude and the measured depth of the points, added as an XY event layer in data management tool in ArcGIS database. Second method was relayed on digital image processing techniques for satellite images using green and blue bands properties shown in Fig. (5), while the produced map is shown in Fig. (8). Shoreline of the lake was isolated with the aid of remote sensing data and digital image processing depending on the sensor properties of near infrared ray as shown in Fig. (4). As it is clear from Fig. (7), the contour lines vary from -0.5m to 5.4m above mean sea level with an accurate 0.5m contour interval without any intersection, while on the contrary, Fig. (8) satellite images cannot recognize deeper than 1.5m. By comparing the two methods, it’s clear that the field work is much more accurate in term or producing this type of maps but still remote sensing data and GIS software analysis besides the lake hydraulic properties like water level, reservoir volume and surface area or stage curve relationship are effective tools for rapid bathymetric survey and map generation and it is better than nothing (Dost, *et al*., 2008).

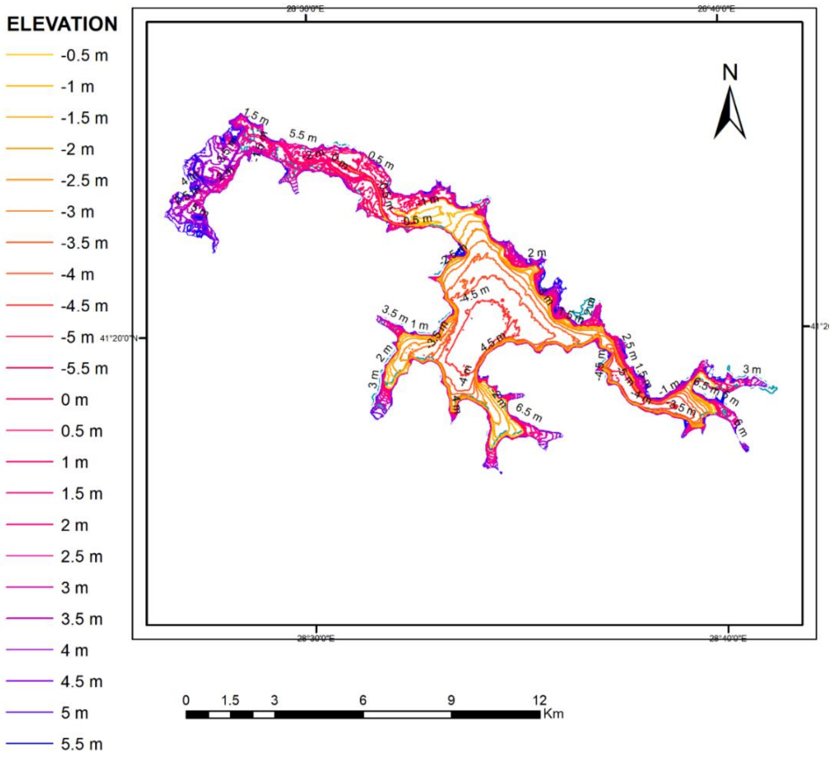

Fig. 7. The Bathymetry of Terkos Lake using field data

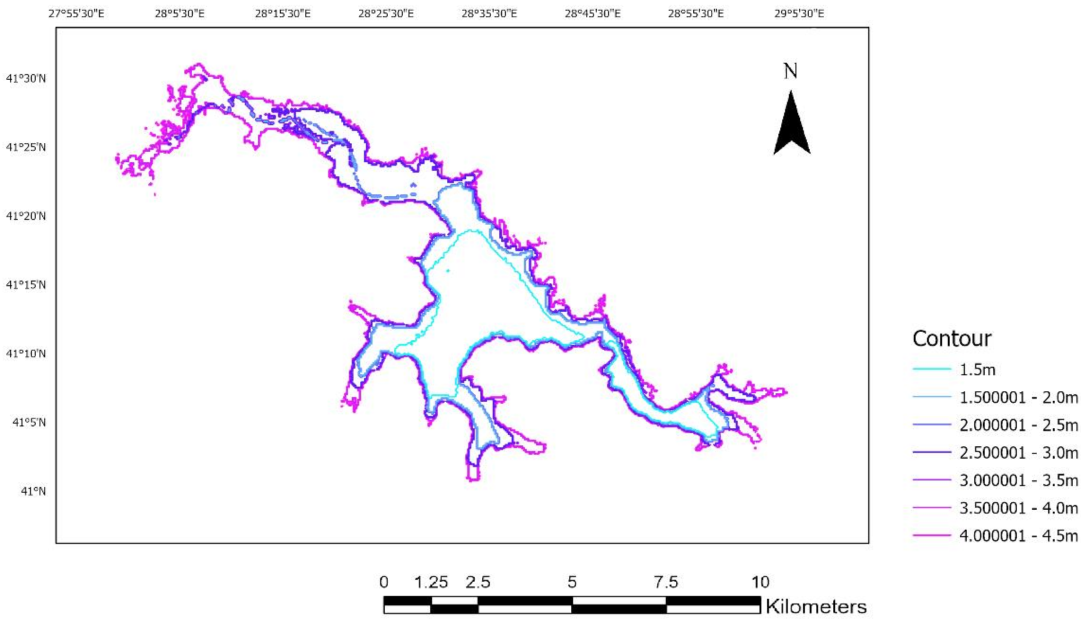

Fig. 8. The Bathymetric map of Terkos Lake using satellite Images

ARCGIS geodatabase was built for the studied lake. The area-elevation-volume curve for the lake was produced depending on water budget analysis for the lake, then this curve was combined with the bathymetric data in order to calculate the hydraulic parameters of the lake from the remote sensing data for anytime. By the above procedure, the hydraulic parameters of the lake like elevation or storage volume can be estimated easily and the lake will be monitored all the time in order to control water scarcity at the time of maximum consumption as well as to monitor the flood season water volume and level. During peak consumption seasons, the lake level reaches -1m under sea level (Ahmed, 2020). This will lead to another problem which is the intrusion for the salt water to the aquifer system, therefore, monitoring the lake periodically is very important. This problem is not less important than the problem of high rainfall or precipitations in the seasons that water is less withdrawn from the lake, till the lake level rises more than 4.5m, that may cause a malfunction in the work of the barrier that connects the lake to the Black Sea causing the loss of large quantities of water, especially since the rains in this region exceed sometimes 1000 mm.

The immediate and periodic monitoring for this kind of water bodies is extremely important due to its sensitivity for the citizen in the served area, especially with the global trend of sustainable development and conservation of natural resources. It is expected that more advanced equipment will be developed allowing for more accurate and precise underwater photography. As a result, individuals are better able to comprehend and appreciate the undersea environment. Tornadoes, hurricanes, and rising sea levels are just a few of the problems that will require education to solve. Bathymetry investigations will also continue to evolve as the environment changes. The current condition of affairs in terms of water contamination is really concerning. People, on the other hand, are more concerned with maintaining a healthy environment for humans and other living things. As a result of this issue, marine life may have a better underwater environment.

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