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Research Article / Araştırma Makalesi

Comparison of bathymetric maps with different spatial resolutions for reservoir operation

Rezervuar işletmesi için farklı mekansal çözünürlüklere sahip batimetrik haritaların karşılaştırılması

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Abstract

The volume of water stored in the reservoir of a dam is the main determinant of the operational efficiency of the facility. As a result of sediment accumulation in a dam reservoir, the volume of water in it decreases, and bathymetric maps should be produced periodically to detect such changes. In this study, the bathymetric map of Seyhan Dam Reservoir with a spatial resolution of 10 m produced in 2019 was used. Using the actual bathymetric map, 13 bathymetric maps of different resolutions with spatial resolution between 20 m and 500 m were produced, and using these maps, the elevation-volume tables that form the basis of the dam operation were extracted. The correlation between these tables and the actual elevation-volume tables was analysed and the linear regression coefficients (K) were calculated between 0.99 and 0.74, mean absolute errors (MAE) between 1.67 and 81.10, Nash-Sutcliffe efficiency coefficients (NSE) between 1.00 and 0.76, and percentage biases (PB) between 0.66% and 37.35%. For models with a resolution between 20 m-100 m, K values were 0.99-0.95, MAE 1.67-13.99, NSE 1.00-0.995 and PB 0.66%-5.72%, but after 100 m, K 0.95-0.74, MAE 13.99-81.10, NSE 0.995-0.763, PB 5.72%-37.35%. By using the bathymetric map with a resolution of 100 m, the elevation-volume table to be used in dam management can be produced with a 95% approach and the number of points used in the model corresponds to 1% of the number of points on the real map. In view of the considerable expense associated with the production of a bathymetric map, it is anticipated that the results of the study, which will facilitate the preparation of bathymetric maps at optimal resolutions, will serve to inform future research by reducing the cost, labor, and time requirements of regular and/or urgent measurements.

Keywords: *Bathymetric Maps, Reservoir Operation, Seyhan Dam*

Öz

Bir barajın rezervuarında depolanan su hacmi, tesisin işletme verimliliğinin temel belirleyicisidir. Baraj rezervuarında sediment birikimi sonucu su hacmi azalır ve bu tür değişiklikleri tespit etmek için periyodik olarak batimetrik haritalar üretilmelidir. Bu çalışmada, 2019 yılında üretilen 10 m mekansal çözünürlüğe sahip Seyhan Barajı Rezervuarı'nın batimetrik haritası kullanılmıştır. Gerçek batimetrik harita kullanılarak, mekansal çözünürlüğü 20 m ile 500 m arasında değişen, farklı çözünürlüklerde 13 batimetrik harita üretilmiş ve bu haritalar kullanılarak baraj işletmesinin temelini oluşturan yükseklik-hacim tabloları çıkarılmıştır. Bu tablolar ile gerçek yükseklik-hacim tabloları arasındaki korelasyon analiz edilmiş ve doğrusal regresyon katsayıları (K) 0.99 ile 0.74 arasında, ortalama mutlak hatalar (MAE) 1.67 ile 81.10 arasında, Nash-Sutcliffe verimlilik katsayıları (NSE) 1.00 ile 0.76 arasında ve yüzdelik sapmalar (PB) %0.66 ile %37.35 arasında hesaplanmıştır. Çözünürlüğü 20 m-100 m arasında olan modellerde K değerleri 0.99-0.95, MAE 1.67-13.99, NSE 1.00-0.995 ve PB %0.66-%5.72 iken, 100 m sonrasında K değerleri 0.95-0.74, MAE 13.99-81.10, NSE 0.995-0.763, PB %5.72-%37.35 olarak bulunmuştur. Çözünürlüğü 100 m olan batimetrik harita kullanılarak, baraj yönetiminde kullanılacak yükseklik-hacim tablosu %95'lik bir yaklaşımla üretilebilmekte ve modelde kullanılan nokta sayısı gerçek haritadaki nokta sayısının %1'ine denk gelmektedir. Batimetrik harita üretiminin yüksek maliyeti göz önüne alındığında, batimetrik haritaların optimum çözünürlükte hazırlanmasını kolaylaştıracak olan bu çalışma sonuçlarının, düzenli ve/veya acil ölçümlerin maliyet, iş gücü ve zaman gereksinimlerini azaltarak gelecekteki araştırmalara katkı sağlaması beklenmektedir.

Anahtar Kelimeler: *Batimetrik Haritalar, Rezervuar İşletmesi, Seyhan Barajı*

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1. Introduction

The most important criterion in operating works of a dam reservoir is to identify the reservoir storage capacity. Bathymetry survey and bathymetry mapping in reservoirs are carried out in specified periods in order to calculate the water volume storage capacity in a reservoir which is decreased in time because of sediment transport across rivers from drainage basins.

As technology develops, maps are now being produced using the airborne Lidar method, instead of echosounder. Pan et al. [1] conducted a study of shallow water bathymetry and seagrass mapping in Redfish Bay, near Corpus Christi, Texas, USA. A comparison was made between a bathymetric map generated using hyperspectral data and a bathymetric map generated using airborne lidar data. The conclusion drawn was that both methods were effective in estimating sea depths.

Miyamoto et al. [2] examined the local distribution of large Gorgonian Corals in the southern Emperor Submarine Mountains in the open seas of the North Pacific using bathymetric maps at different spatial resolutions. The investigation revealed that bathymetric data with resolutions of 100 m and below yielded superior performance in determining coral distribution, as compared to data with resolutions ranging from 25 to 800 m. This finding emerged from the analysis of six distinct bathymetric maps.

The creation of bathymetric maps is not limited to the cartography of oceans, seas, and lakes; the production of such maps is also undertaken for rivers and canals. Kangsabanik et al. [3] conducted a study on the Rangafala Channel in the Port of Kolkata, India. Utilising echosounders, the researchers examined bathymetric maps from 2007, 2012, 2017 and 2018, thereby ascertaining the stability of the channel and the absence of any discernible shifts.

Güvel et al. [4] used GIS techniques to assess the quantity of sedimentation in the Berdan Dam reservoir. Utilising bathymetry maps from 1961 to 2003, the findings indicate that prior to the year 2003, there was a 32% reduction in reservoir storage volume at minimum reservoir operation elevation, 12% reduction at normal reservoir operation elevation, and 4% reduction at maximum reservoir operation elevation.

Pınarlık et al. [5] conducted a study on the Çorum Dam, located in the Yeşilırmak basin in northeastern of Türkiye, using bathymetric maps dated 1977 and 2014. A comparison of the two maps revealed that the dam had lost approximately 79.6% of its dead volume, and 14.58% of its total volume. It was determined through calculated analysis that, in the absence of requisite measures being implemented, the dam's dead volume would reach capacity within a decade. Nowadays, the production of bathymetric maps involves the utilisation of satellite imagery [6-9] and unmanned aerial vehicles [10]. The monitoring of reservoir areas and investigation of temporal and spatial changes were facilitated through the utilisation of satellite images [11-13].

In the event of natural disasters, such as floods, landslides, earthquakes, or mining operations, or road construction works within the drainage area of dam reservoirs, it is imperative to conduct a thorough examination of the amount of solid material flowing the dam reservoir. The aim of this study is to determine the appropriate resolution for bathymetric maps, which require specialized measurement and production, are more costly and time-consuming than terrestrial data, as long as the required precision is achieved. To this end, elevation-volume tables, a key criterion for dam operation, were calculated from bathymetric maps produced at different resolutions and the relationship between them was examined.

Given that the production process of bathymetric maps is a costly undertaking, including expenses related to labour and time, as well as considerations regarding climatic conditions, it is imperative to ensure the production of bathymetric maps at an appropriate resolution. The results of this study is of pivotal significance as it facilitates the expeditious, cost-effective, and labour-intensive preparation of bathymetric

measurements, both for routine measurements and urgent scenarios. Furthermore it impacts the number of point readings necessitated for the production of bathymetric maps.

2. Material and Method

2.1. Study Area

The Seyhan Dam Reservoir, which is selected as the study area, is located in the south of Türkiye. The Seyhan Dam is characterised by a drainage area of 19,254 km^2. The Seyhan Dam Reservoir is operational since 1956 with the aims of irrigation, energy production, and flood control. The elevation of the dam crest is 72.70 meters, with a total height from the foundation of 77 meters. The normal water surface level is 67 meters and the reservoir volume at normal water surface level is 865,420 hm^3. The dam reservoir is the water resource of the irrigation area of the Lower Irrigation Plain [14-15]. The location of the study area is given in Figure 1.

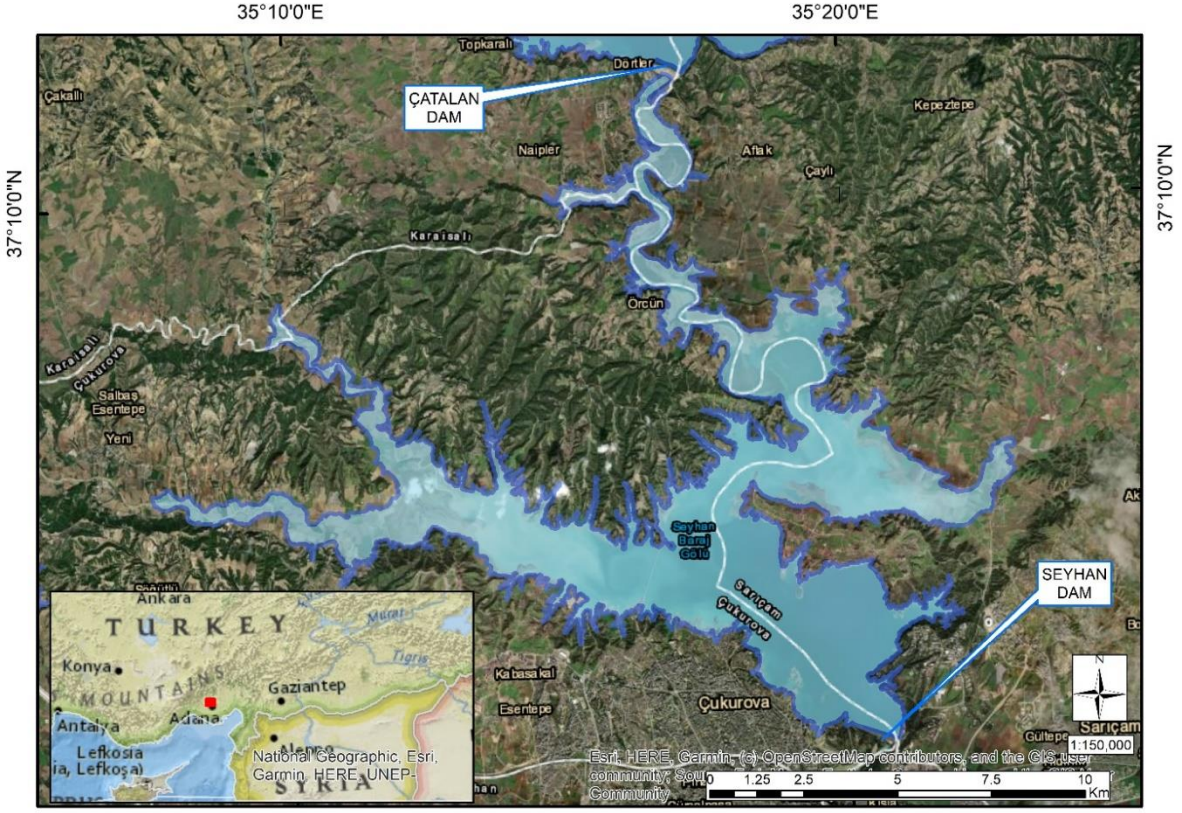


Figure 1. The location of the study area

2.2. Bathymetry Data

The bathymetric maps of the Seyhan dam reservoir was produced using an echosounder, with the surveys being conducted in August and September of 2019 [13]. Seyhan Dam Reservoir bathymetry surveys were conducted on a period of 41 days, with daily data points ranging from 5,994 to 19,339. The mean value recorded was 13,499, with a total of 553,461 points being measured. The bathymetric map of Seyhan Dam Reservoir is given in Figure 2.

2.3. Method

The flow chart of the study, which illustrates the methodology employed to produce 13 bathymetric maps of varying resolutions from the 2019 bathymetric map of the Seyhan Dam Reservoir, the process of generating and comparing elevation-volume tables from these maps, and the stages involved in the process, is depicted in Figure 3.

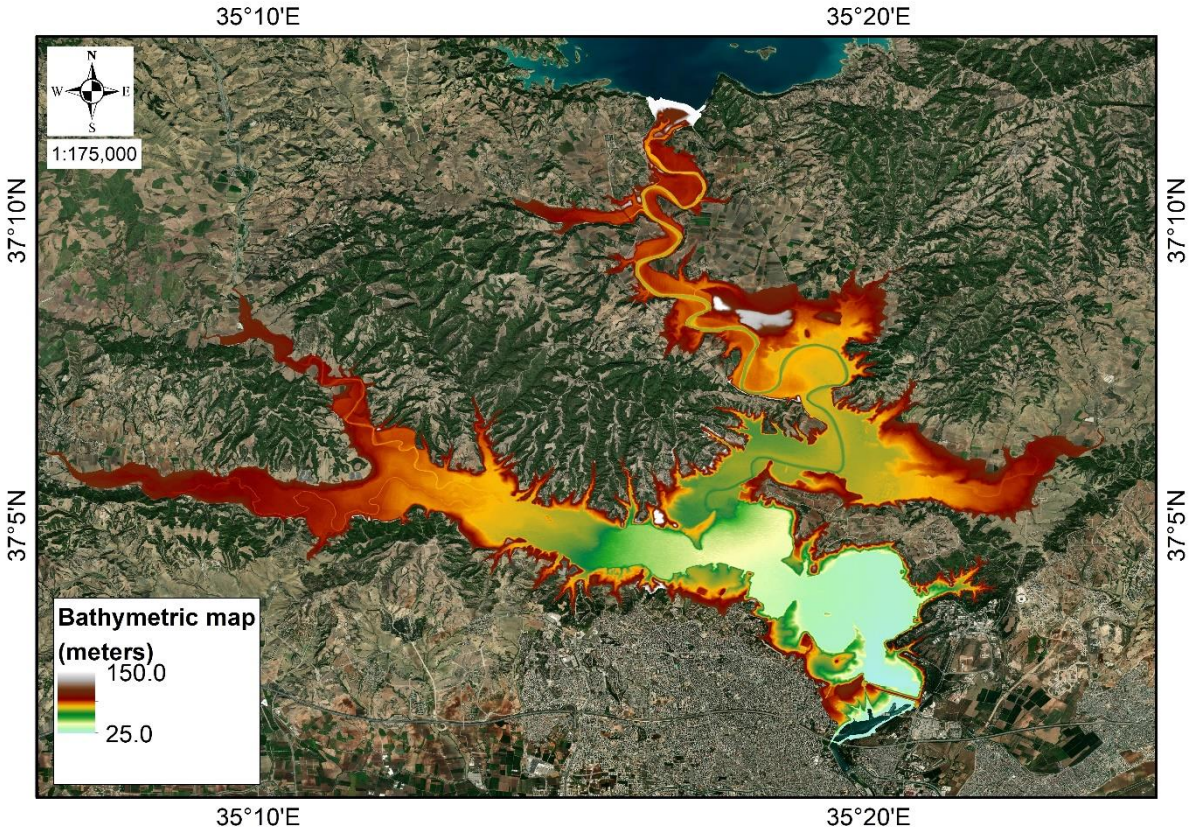


Figure 2. The bathymetry map of the Seyhan Dam Reservoir

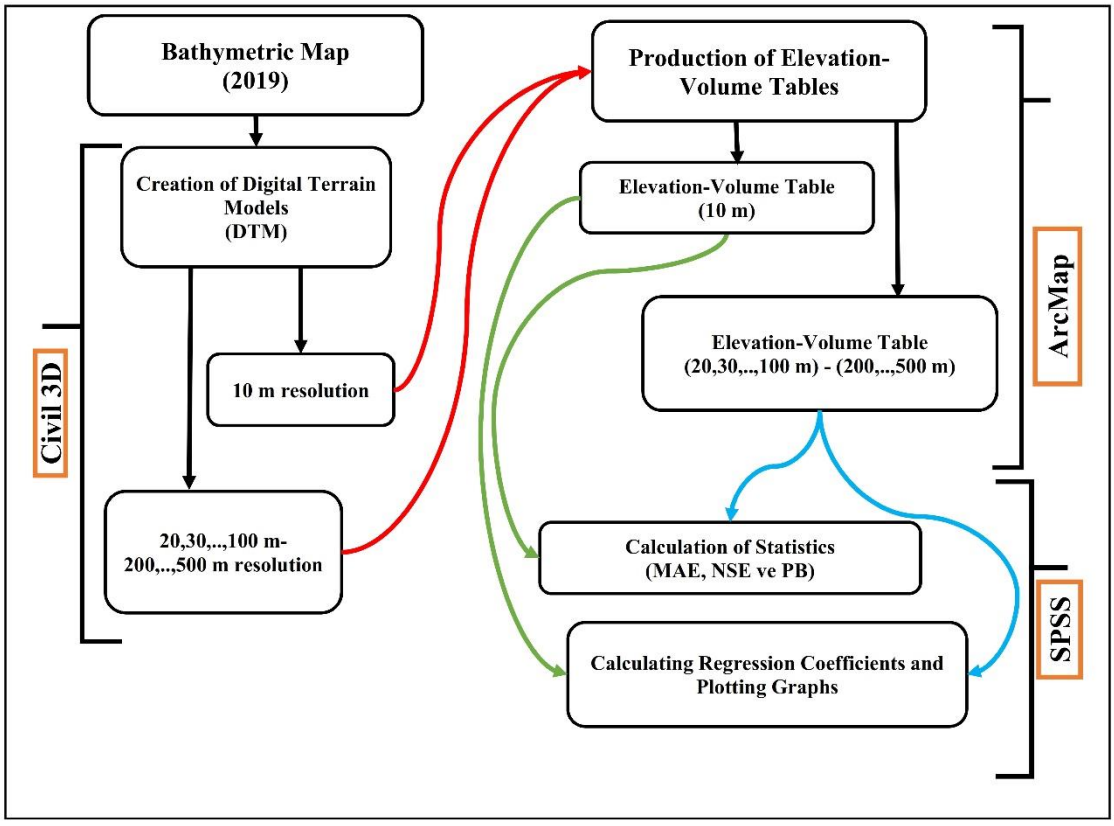


Figure 3. The flow chart of the study

2.3.1. Production of bathymetric maps and elevation-volume tables

A total of 13 bathymetric maps were produced using the 2019 bathymetric map of the Seyhan Dam Reservoir. These maps were produced using Autodesk Civil 3d software [16-17]. Nine of the maps were creayed with 10-meter intervals between 20 and 100 meters, and four were created with 100 meter intervals between 100 and 500 meters.

Elevation-volume tables for a total of 13 bathymetric maps were calculated using the 3D Analyst Tools within the ArcMap software [18].

2.3.2. Statistical analysis

The relationship between elevation-volume tables calculated from bathymetric maps produced at different resolutions was examined using statistical analysis. The analysis of the correlation data was undertaken using a range of comparative statistical measures, including the mean absolute error (MAE), the Nash-Sutcliffe efficiency coefficient (NSE), and the percentage deviation (PB). The calculation of these statistics is demonstrated in Formulas (1), (2), and (3).

$$\mathbf{MAE} = \frac{\mathbf{1}}{\mathbf{N}}\sum_{\mathbf{i=1}}^{\mathbf{N}}(|\mathbf{C_i} - \mathbf{G_i}|) \quad (1)$$

$$\mathbf{NSE} = \mathbf{1} - \frac{\sum_{\mathbf{i=1}}^{\mathbf{N}}(\mathbf{C_i}-\mathbf{G_i})^{\mathbf{2}}}{\sum_{\mathbf{i=1}}^{\mathbf{N}}(\mathbf{G_i}-\bar{\mathbf{G}})^{\mathbf{2}}} \quad (2)$$

$$\mathbf{PB} = \mathbf{100}\frac{\sum_{\mathbf{i=1}}^{\mathbf{N}}(\mathbf{C_i}-\mathbf{G_i})}{\sum_{\mathbf{i=1}}^{\mathbf{N}}\mathbf{G_i}} \quad (3)$$

In the formulae: G: Volume (10 m), $\bar{G}$: Volume (10 m) average, C: Volume (20-500 m),
N: Number of data pairs

The MAE is determined by dividing the sum of the absolute values of the differences between the real and predicted values in the data set by the number of samples. MAE values are contained within the interval from 0 to ∞. It is evident that as the value approaches 0, the performance of the system is enhanced. The utilisation of absolute values for the differences ensures that the positive and negative errors do not cancel each other out. The NSE statistic ranges from -1 to 1, measuring the ratio of the variance in the residuals to the variance of the observed values. An NSE value of 1 indicates a perfect match, whilst negative values signify a weak relationship [19].

The PB statistic is employed to evaluate the trend between predicted and observed data. It is evident that as the PB value approaches zero, the correlation between the predicted and observed data becomes increasingly stronger. Positive values indicate that the model underpredicts, while negative values indicate that the model overpredicts [20].

3. Research Findings and Discussion

Figure 4 presents a series of bathymetric maps, delineated at 13 distinct resolutions, ranging from 20-100 m at 10 m intervals to 100-500 m at 100 m intervals. These maps were derived from the 2019 bathymetric map of the Seyhan Dam Reservoir, utilising the aforementioned map as a foundation.

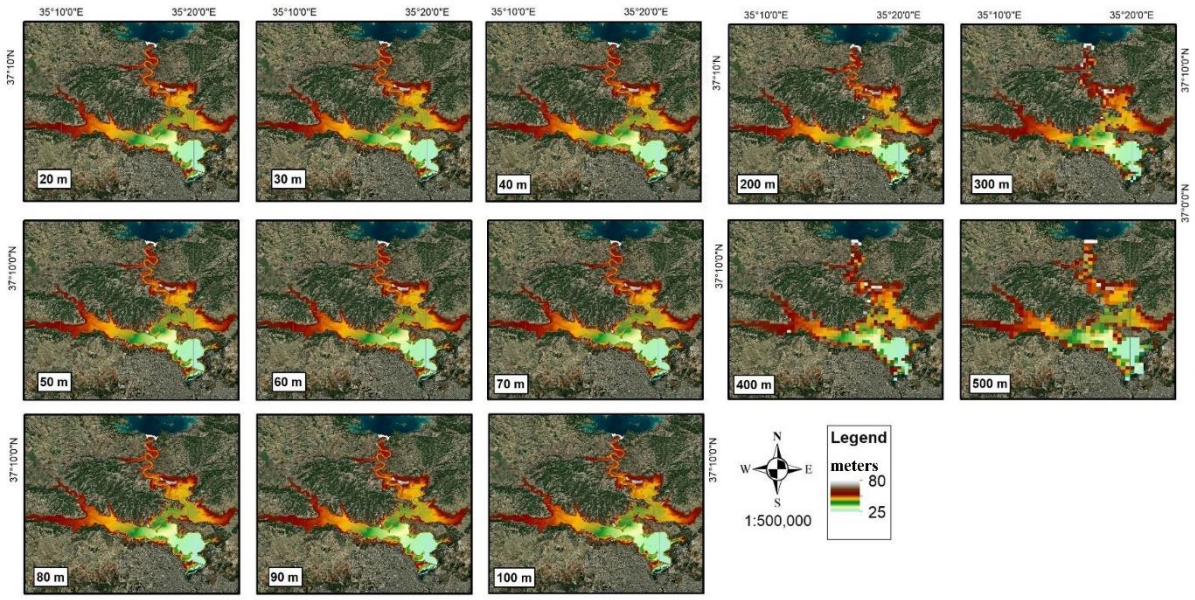


Figure 4. Bathymetric maps produced at different resolutions within this study

The generation of elevation-volume tables was achieved through utilisation of 13 bathymetric maps, employing ArcMap software. The regression between the actual volume was examined and the results are presented in Figure 5. A thorough examination of the graphs reveal that while the regression slope approximates 1/1 at 20-100 m resolution, it deviates from 1/1 at 200-500 m resolution.

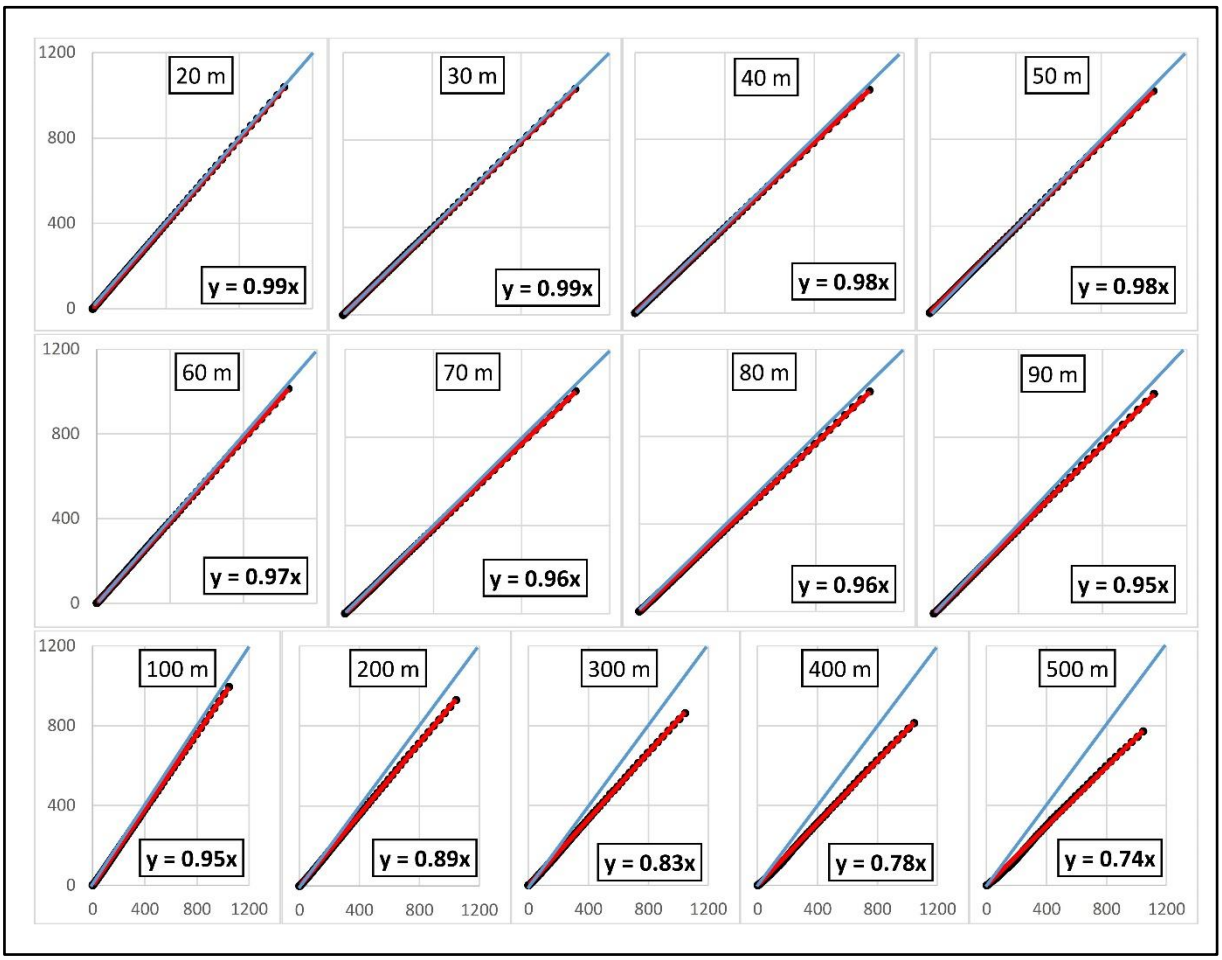


Figure 5. Regression graph between the actual volume and the generated bathymetric map volumes

In the statistical analyses, the methods given in Formulas (1), (2) and (3) were employed, and the results shown in Table 1 were obtained for the MAE, NSE and PB measures. The SPSS programme was utilised to calculate these statistics, as outlined in the study conducted by Huizingh [21].

Table 1. Statistical Results

Resolution (m)	MAE	NSE	PB (%)	K
20	1.67	1.000	0.66	0.99
30	3.07	1.000	1.22	0.99
40	4.72	0.999	1.88	0.98
50	6.52	0.999	2.62	0.98
60	8.75	0.998	3.55	0.97
70	9.99	0.998	4.07	0.96
80	10.74	0.997	4.39	0.96
90	12.95	0.996	5.34	0.95
100	13.99	0.995	5.72	0.95
200	32.11	0.972	12.77	0.89
300	44.77	0.927	21.24	0.83
400	59.02	0.863	30.02	0.78
500	81.10	0.763	37.35	0.74

The logarithmic graph of the relationship between the MAE and K values with changes in resolution is given in Figure 6. It was observed that the K value, in particular, decreased with increasing resolution after being 0.95 at 100 m resolution, and decreased further to 0.74 at 500 m resolution. The MAE value was determined to be 13.99 hm^3 at 100 m resolution and 81.10 hm^3 at 500 m resolution.

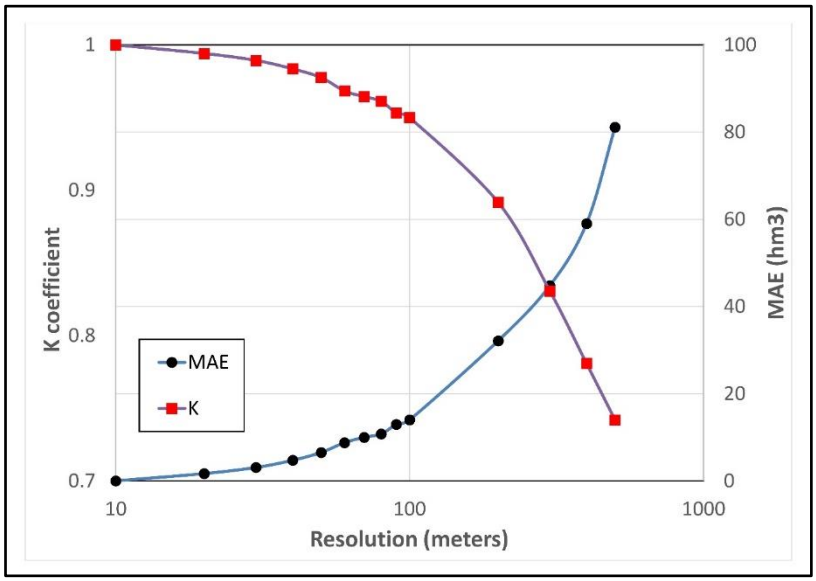


Figure 6. MAE and K coefficient graph

The logarithmic graph of the relationship between the resolution and the volume difference at normal reservoir operation level (67.00 m) is presented in Figure 7. When the graph of the differences between the actual reservoir volume at the normal reservoir operation level and the predicted reservoir volume is examined, it was found to be 4.83% at 100 m resolution, and this value increases to 25.14% at 500 m resolution.

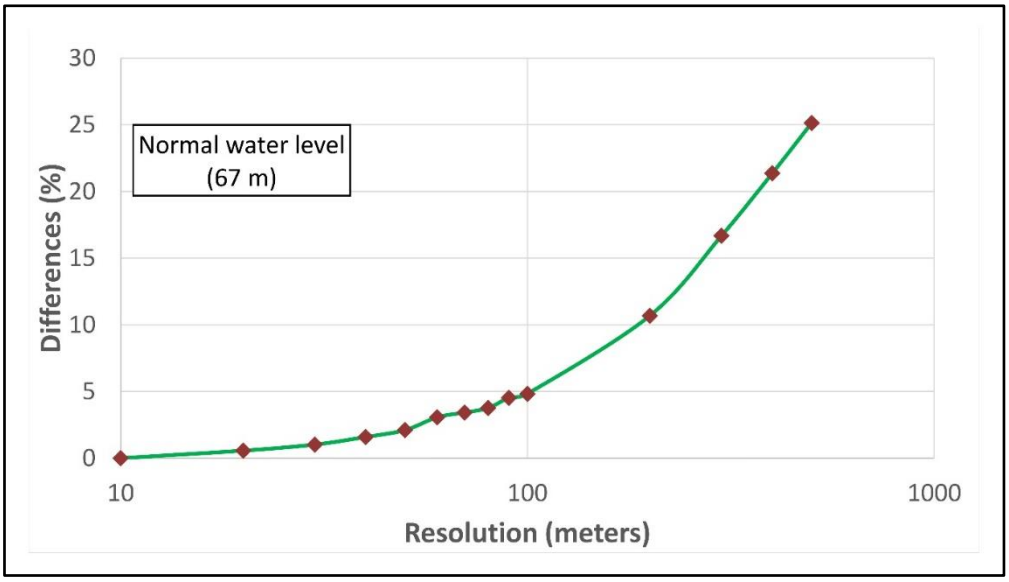


Figure 7. Volume difference (%) graph at normal water level

Upon examination of the analysis results from the bathymetric map, with a resolution of 100 m, it was found that, despite high percentage difference values due to low water volume, the difference was found to be 6.76% at the minimum reservoir operation elevation of 49 m, and 4.83% at the normal reservoir operation elevation of 67.00 m (Figure 8). The differences in volume were 11.42 hm^3 and 40.02 hm^3 at the minimum and normal reservoir operation elevations, respectively.

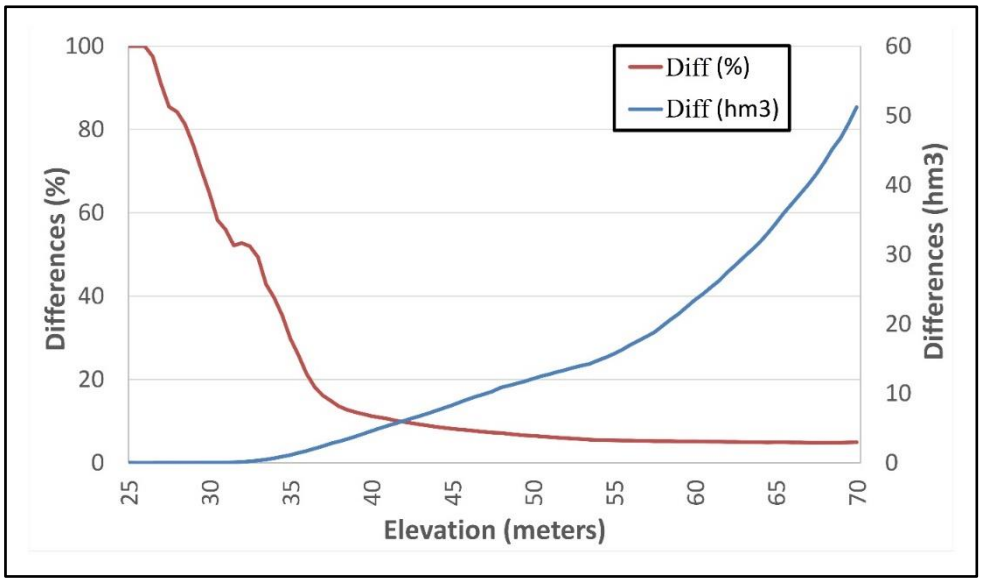


Figure 8. Graph of differences at 100 m resolution

Despite the negligible difference observed at low water levels, the percentage discrepancy is pronounced due to the negligible volume. Specifically, above the 42.00 m elevation, the difference decreases below 10%, and above 63.00 m elevation, it decreases below 5%. At minimum reservoir operation level of the Seyhan Dam Reservoir (49.00 m), the difference was found to be 6.76%, and at the normal reservoir operation level (67.00 m), the difference is 4.83%.

In bathymetric map production, as the distance between measurement points increases from a resolution of 20 meters to 500 meters, the map resolution decreases inversely. Considering the expense, the results will facilitate optimal map production, contributing to future research by reducing regular and urgent measurement costs, labour, and time.

Using a bathymetric map with a resolution of 100-meters, an elevation-volume table can be produced with 95% accuracy reducing a 100-day job to one. Given that this table can be produced expeditiously, it is considered to be unaffected by reservoir conditions or technical issues. As a 95% accurate table can be produced, it will also contribute flood and drought management works.

As the level of detail decreases, topographical features such as reservoir coastal trenches and narrow bays become obscured in the volume calculations of the reservoir. The absence of these details does not result in significant volumetric deficits in the calculation of volume, as illustrated in the graphs; however it can lead to minor loses. Furthermore, given that energy production planning is an ongoing issue, particularly in river basins with high sediment loads, this method facilitates the production of bathymetric maps on a semi-annual basis.

4. Conclusion

Bathymetry mapping studies, frequently employed in maritime navigation, underwater construction (e.g. ports and bridges), environmental research (e.g. underwater habitat) and underwater archaeology, are also utilised to detect and monitor sedimentation in dam reservoirs.

In this study, the 2019 bathymetric map of the Seyhan Dam reservoir was utilised to generate a series of 13 bathymetric maps, each characterised by distinct resolutions. The production of these maps involved meticulous delineation of the reservoir's bathymetry at intervals of 10 meters, ranging from 20 to 100 meters, and 100- meter intervals between 100 and 500 meters. The process of map generation was further complemented by the creation of elevation-volume tables, which were derived from the aforementioned maps. Despite the fact that the K value exhibited close values in models with a resolution ranging from 20 m to 100 m (0.99-0.95), MAE (1.67-13.99), NSE (1.00-0.995) and PB (0.66%-5.72%), it is evident that after 100 m, the K value ranged from 0.95-0.74, MAE (13.99-81.10), NSE (0.995-0.763), and PB (5.72% -37.35%).

At normal reservoir operation level (67.00 m), the differences between the actual reservoir volume and the volumes with a resolution between 20-100 m were between 0.57% and 4.83%, and between the volumes with a resolution between 100-500 m were between 4.83% and 25.14%. At the point of minimum reservoir operation level (49.00 m), the differences ranged from 0.83% to 6.76% across the 20-100 m range, and from 6.76% to 35.58% within the 100-500 m range. It was observed that the results were more successful when the reservoir water level and, by extension, the reservoir volume were higher.

In this study, utilising a 100-meter resolution bathymetric map, a 95% accurate elevation-volume table with an average of 13.99 hm^3 was found to be produced for dam operations. The number of points utilised in the model corresponds to 1% of the actual map. The Seyhan Dam Reservoir bathymetric map is characterised by its expedited production process, leading to a reduction in both costs and labour requirements. In the event that the objective of the bathymetric map is to produce an elevation-volume table for operational purposes, as opposed to highly precise work, a 100 meters resolution bathymetric map is adequate.

Author Contribution

Mehmet Ali Akgül: Methodology, Investigation, Data curation, Conceptualization, Visualization, Validation, Software, Formal analysis, Writing– original draft. Şerife Pınar Güvel: Methodology, Investigation, Visualization, Formal analysis, Data curation, Conceptualization, Writing– review & editing, Writing– original draft. All authors read and approved the final manuscript.

Conflict of Interest

No conflict of interest was declared by the authors.

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