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SEDIMENTATION ANALYSIS ON SEYHAN DAM RESERVOIR USING LONG TERM BATHYMETRY DATA

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Keywords

Seyhan Dam,
Seyhan River Basin,
Bathymetric Survey,
Reservoir Operation

Abstract

In this study, sedimentation in the Seyhan Dam reservoir was investigated by analyzing a long-term bathymetric survey dataset. The focus was on understanding how reservoir capacity changes impact reservoir operation rules. The findings revealed that sedimentation from the main branch of the Seyhan River has largely stopped since the construction of the Çatalan Dam, but sedimentation from the Çakıt branch continues. Furthermore, the study observed changes in the upper basin between 1990 and 2018 based on the CORINE Land Cover (CLC) dataset. The forest area increased from 23.71% to 24.36%, and water bodies expanded from 0.3% to 0.9%. This increase in forest and water bodies contributed to a reduction in sediment flow into the Seyhan Dam reservoir. The researchers used regression analysis and found a high correlation (R^2=0.96) between water storage capacity changes and time (in years) at a 67.5-meter water level in the Seyhan Dam Reservoir. Overall, the study's results suggest that the decrease in sediment entering from the main branch of the Seyhan River has significantly improved the sedimentation issue.

UZUN DÖNEM BATİMETRİ VERİLERİ KULLANILARAK SEYHAN BARAJ REZERVUARINDA SEDİMANTASYON ANALİZİ

Anahtar Kelimeler

Seyhan Barajı,
Seyhan Nehir Havzası,
Batimetrik Ölçüm,
Baraj İşletmesi.

Öz

Bu çalışmada Seyhan Barajı rezervuarındaki sedimantasyon durumu uzun vadeli bir batimetrik ölçüm veri seti analiz edilerek araştırılmıştır. Çalışmanın odak noktası, rezervuar kapasitesi değişikliklerinin rezervuar işletme kurallarını nasıl etkilediğini anlamaktır. Bulgular, Seyhan Nehri'nin ana kolundaki sediment birikiminin Çatalan Barajı'nın inşasından bu yana büyük ölçüde durduğunu, ancak Çakıt kolundaki sediment birikiminin devam ettiğini ortaya çıkarmıştır. Ayrıca çalışmada, CORINE Arazi Örtüsü (CLC) veri setine dayanılarak 1990 ile 2018 yılları arasında üst havzadaki değişiklikleri gözlemlenmiştir. Orman alanı %23,71'den %24,36'ya, su kütleleri ise %0,3'ten %0,9'a yükselmiştir. Orman ve su kütlelerindeki bu artış, Seyhan Barajı rezervuarına sediment akışında azalmaya katkıda bulunmuştur. Araştırmacılar regresyon analizini kullanarak Seyhan Baraj Gölü'ndeki 67,5 metre su seviyesinde su depolama kapasitesi değişiklikleri ile zaman (yıl) arasında yüksek bir korelasyon (R^2=0.96) bulmuştur. Genel olarak bu çalışmanın sonuçları, Seyhan Nehri'nin ana kolundan giren sediment miktarının azalmasının, sedimantasyon sorununu önemli ölçüde iyileştirdiğini göstermektedir.

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SEDIMENTATION ANALYSIS ON SEYHAN DAM RESERVOIR USING LONG TERM BATHYMETRY DATA

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Highlights

- Investigation of reservoir sedimentation using long-term bathymetry data
- Investigation of impact of reservoir sedimentation on operation rules
- Estimation of reservoir capacity changes in future planning works

Purpose and Scope
In this study, a long-term bathymetric research dataset including 2019 bathymetry measurements were used to evaluate the sedimentation in the Seyhan Dam reservoir. The emphasis was on understanding how changes in reservoir capacity affect reservoir operation rules.

Design/methodology/approach
GIS is a powerful tool in this study for evaluating and maintaining the reservoir's bathymetry data, allowing for more effective and informed reservoir management and sedimentation analysis decisions.

Findings
This study examined the sedimentation in the Seyhan Dam reservoir using the long term bathymetric sırvey dataset within the scope of reservoir capacity changes and its impacts on reservoir operation rules. The results of this study will contribute operation-maintenance works of Seyhan Dam in terms of cost and labour savings.

Originality
An investigation of the impact of reservoir sedimentation on operation rules was conducted using 2019 bathymetry survey data of the Seyhan Dam reservoir.

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1. Introduction

Over the past 4,500 years, dams have been constructed with the primary goal of storing excess water from rainy seasons to be utilized during dry periods, maintaining the fundamental purposes of reservoirs intact (Estigoni et al., 2014). Among the critical factors influencing dam operation rules is the impact of sedimentation on reservoir water storage capacity. Monitoring the reduction in water storage capacity is crucial to ensure the fulfillment of water demands. For this purpose, bathymetry mapping has been employed to assess the current storage capacity in reservoirs and to study the effects of sedimentation on their capacity.

Diaconu et al. (2019) emphasized that determining the bathymetric properties of rivers, lakes, and reservoirs enables the identification of areas experiencing sedimentation or erosion. Over the years, bathymetric surveys and mapping have been extensively conducted to gather information about the bottom surfaces of reservoirs (Szatten et al., 2018; Sandoval-Erazo et al., 2018; Oladosu et al., 2019; Lopes and de Araújo, 2019), oceans, and sea floors (Weatherall et al., 2015), as well as rivers (Bandini et al., 2018; Legleiter et al., 2018), lakes (Gopakumar and Takara, 2009; Cross and Moore, 2014; Maina et al., 2019), coastal areas (Salameh et al., 2019), and other water bodies. These efforts aim to investigate water depths, changes in underwater topography, sediment accumulation, and potential environmental impacts. Traditional manual measurement techniques were initially used in these investigations. However, with the progress and advancements in measurement technologies for bathymetry mapping, echo sounders have been widely employed in bathymetric surveys for many years. Recently, remote sensing technology has also emerged as a valuable tool in bathymetry mapping alongside conventional techniques (Poliyapram et al., 2017; Akgül et al., 2018; Casal et al., 2020; Wang et al., 2022). For instance, Saito et al. (2021) studied sedimentation rates in a reservoir section in Viçosa, Brazil, for the years 2010, 2012, and 2016 using single-beam bathymetric survey techniques. In a separate study, Güvel et al. (2021a) investigated the feasibility of using remote sensing data to determine bathymetric water depths in the Berdan Dam reservoir.

Sedimentation is regarded as one of the most significant challenges for river ecosystems (Obialor et al., 2019). Understanding the impact of reservoir sedimentation on dam functions is crucial to safeguarding the dam's lifespan and operational processes. Mueller et al. (2010) emphasized that erosion and sedimentation must be taken into account when analyzing and implementing long-term strategies for land use planning and water management. The study of sedimentation in dam reservoirs has become a prominent research topic due to its adverse effects on the original capacity of the dam and the rules governing reservoir operation. The trapping of sediment by a dam reservoir leads to problems of sediment accumulation and a loss of water storage capacity in the reservoir. Estimating the sedimentation rate and the useful operation period of a reservoir can be achieved using the trap efficiency approach (Garg and Jothiprakash, 2008). However, there have been some limitations in using trap efficiency to predict reservoir sedimentation (Mulu and Dwarakish, 2015). Given that stored water volume serves various purposes such as water supply, energy production, and irrigation, monitoring temporal and spatial changes in a reservoir becomes essential for effective operational planning. Regular monitoring of reservoirs enables the assessment of the amount and distribution of sediment trapped within the reservoir, as well as the decrease in storage capacity. Determining sediment distribution is crucial for analyzing its effects on hydraulic structures, ensuring dam safety, and adhering to reservoir operation rules. Accumulation of sediment near water intake structures and changes in the bottom topography can have adverse effects on operational efficiency. Schleiss et al. (2016) highlighted the significance of considering reservoir sedimentation during the early planning phases of dam and reservoir design. By addressing sedimentation concerns proactively, better design strategies can be implemented to mitigate its impacts on reservoirs and their functions.

Numerous bathymetric surveys conducted worldwide have identified significant decreases in reservoir storage capacities (Rowan et al., 1995; Güvel et al., 2017; Darama et al., 2019; Shiferaw and Abebe, 2020; Ugwu et al., 2021; Güvel, 2021; Güvel et al., 2021b). Moreover, in recent years, researchers have increasingly utilized remote sensing data for bathymetry mapping and sedimentation assessment (Jagannathan and Krishnaveni, 2021; Skariah and Suriyakala, 2021).For instance, Taruya and Fuji (1997) conducted a study on reservoir sedimentation in irrigation dams in Japan, analyzing field data from 53 high dams. Estigoni et al. (2014) focused on the Lobo Reservoir in Brazil to investigate the impact of using different techniques to calculate water volume and reservoir sedimentation. In Australia, Cooper et al. (2018) explored the useful life of the Burdekin Falls Dam and discovered that over 24 years, 65 million m^3 of sediment had accumulated in the reservoir. Sun et al. (2022) examined reservoir sedimentation in the Lancang reservoirs using empirical models and theoretical methods. They found that by 2019, the storage capacity loss in the Manwan and Jinghong reservoirs reached 51.4% and 1.54%, respectively. In Indonesia, Mardwiono et al. (2022) conducted a study on the sediment management of the Sengguruh Reservoir and Sutami Reservoirs. They evaluated that the storage capacity of the Sengguruh Reservoir could increase by 9.45% through flushing and dredging activities, along with the construction of a storage pond and an additional intake guide wall. Additionally, they assessed that dredging efforts at a volume of 400,000 m^3/year could enable the utilization of the Sutami Reservoir for the next 135 years. Overall, these studies emphasize the importance of monitoring reservoir sedimentation and employing various techniques to assess and manage sediment accumulation for the effective operation and longevity of reservoirs (Güvel and Yurtal, 2020; Özşahin, 2023).

Estimating sediment yield is crucial for research on reservoir sedimentation (Kothyari and Jain, 1997). Sediment yield variations in river basins can be influenced by natural and/or human-induced factors. In recent years, numerous methods have been developed and utilized for research purposes in sediment yield estimation (de Araújo and Knight, 2005; Jain et al., 2010; Vemu and Pinnamaneni, 2012, Dutta, 2016; Colman et al., 2018; Chalise et al., 2019; Abdul Razad et al., 2020; Patil et al., 2021; Ayele et al., 2021; Billi and Spalevic, 2022). These methods play a significant role in understanding and quantifying the sediment load in river basins, which is essential for managing and planning reservoirs and other water-related projects.

The Seyhan River Basin is located between 36° 30' and 39° 15' northern latitudes and 34° 45' and 37° 00' eastern longitudes in the southern part of Türkiye. The Ceyhan River Basin is to the east of the basin, the Konya and Berdan Basins are to the west, and the Develi Basin is to the north. It extends to the Mediterranean sea in the south. Seyhan Dam sediment yield is stated as 126.82 m^3/km^2/year (DSİ, 2014). The Seyhan River basin stretches from high-elevation mountainous regions to the Lower Seyhan Plain, which offers fertile lands vital for agricultural irrigation and plays a significant role in agricultural production in Türkiye. Covering a vast area, the Seyhan River Basin spans 22,035 km^2. Reports from previous years (IECO, 1966; DSİ, 2014) have elaborated on water resources planning and development studies in the Seyhan River Basin. To address the region's irrigation, energy production, and flood protection needs, the construction of the Seyhan Dam began in 1953 on the Seyhan River in Adana Province, and the dam became operational in 1956. The Seyhan Dam's drainage area encompasses 19,254 km^2. However, climate change projections indicate that, until 2100, many parts of the Seyhan River Basin will confront water scarcity (Selek et al., 2016). This highlights the importance of prudent water resource management and the implementation of sustainable practices to address the potential challenges posed by climate change in the basin.

Over the years, the investigation of sedimentation and changes in the bottom profile of the Seyhan Dam reservoir since its operation has been a subject of interest for numerous researchers. Various techniques have been utilized to explore these aspects (İlter and Ağıralioğlu, 1987; Göğüş and Adıgüzel, 1991; Kırkgöz et al., 1992; Kırkgöz et al., 1993; Fakıoğlu, 2005; Güvel, 2007; Güvel and Yurtal, 2020). In particular, Güvel (2007) conducted a study in which the sediment accumulation and water storage capacity loss in the Seyhan Reservoir were investigated using a GIS (Geographic Information System) environment. The research was based on bathymetry measurements taken until 2005, and sediment thickness maps were generated as part of the investigation. Such studies are crucial for understanding the long-term changes in reservoir capacity due to sedimentation, helping in the management and planning of reservoir operations.

In this study, the focus was on investigating sedimentation in the Seyhan Dam reservoir from the perspective of sustainable management, utilizing a long-term bathymetry dataset. The researchers assessed deforestation activities in the upper basin and analyzed sediment transport in the Seyhan River and its tributaries. Furthermore, they evaluated sedimentation on water structures and sediment yield in the region. The primary goal of the study was to examine sediment accumulation and the actual changes in water storage within the Seyhan Dam reservoir over the past years. To achieve this, the researchers utilized bathymetry survey data collected between 1966 and 2019, within the context of reservoir operation activities. By analyzing this comprehensive dataset, the study aimed to provide insights into the sedimentation patterns and potential impacts on water storage capacity, facilitating informed decision-making for sustainable reservoir management.

2. Material and Method

2.1. Study Area and Data

The Seyhan Dam is a multi-purpose dam with 19,254 km^2 drainage area and is located on the Seyhan River in Adana City, situated in the lower reaches of the Seyhan River Basin in the southern part of Türkiye (Figure 1). Seyhan Dam has the purposes of irrigation, energy production, and flood protection. (Table 1). Çatalan Dam was built and put into operation at the upstream of Seyhan Dam for drinking water supply and irrigation purposes. The study area experiences a Mediterranean climate, characterized by warm and rainy winters, as well as hot and dry summers. The Seyhan River is formed by the confluence of two streams: the Zamantı Stream, which stretches for 317 km, and the Göksu Stream, which extends for 198 km. As it descends from the Taurus Mountains towards the Mediterranean, the Seyhan River is joined by several other streams, including Eğlence, Körkün, Üçürge, and Çakıt, which contribute to its flow.

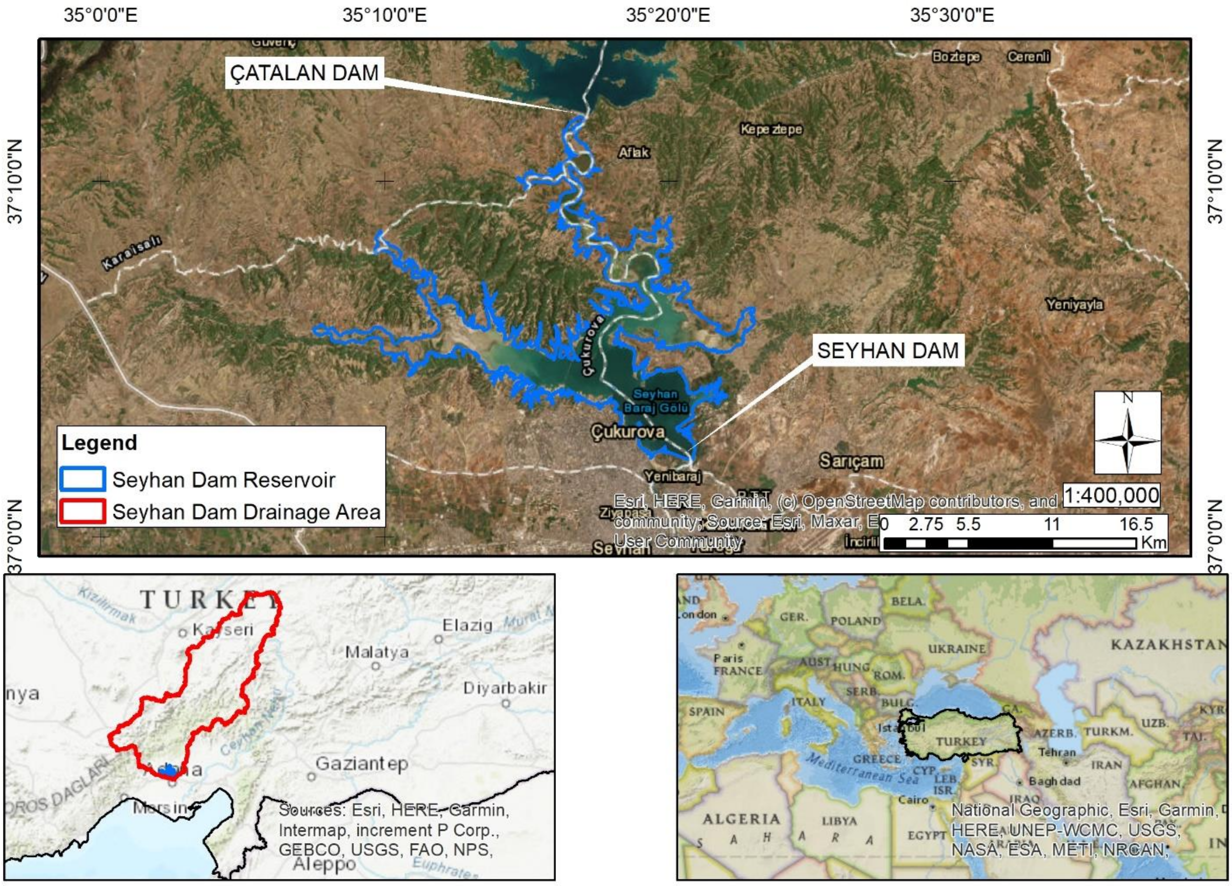

Figure 1. The Location Of Seyhan Dam in Türkiye

Table 1. Characteristics Of Seyhan Dam (DSİ, 2014)

CHARACTERISTICS	DATA
River basin	Seyhan
Purpose	Irrigation-Energy production-Flood control
Drainage area	19254 km²
Type	Earthfill
Dam crest elevation	72,70 m
Dam crest length	1949 m
Installed capacity	54 MW
Date put into operation	1956
Stage	Operational

The Çukurova Plain, with its fertile lands, plays a vital role in contributing to the economic development of the region through agricultural production. Located downstream of the Seyhan Dam, the plain benefits from the water resources managed by the dam. To support and enhance agricultural activities on the plain, the Lower Seyhan Plain Irrigation project was developed in previous years. This comprehensive project comprises four stages. The construction of the first, second, and third stages was completed in 1968, 1975, and 1984, respectively. As of 2022, the fourth stage has been put into operation, further enhancing the irrigation and drainage capabilities of the region. As the demand for water in irrigation has increased over time, rehabilitation planning studies have been initiated (DSİ, 2022). These efforts aim to optimize water usage, ensure sustainable irrigation practices, and meet the growing water needs of the agricultural sector in the region. By continuously improving and managing the irrigation and drainage systems, the authorities seek to promote efficient and sustainable agricultural development in the Lower Seyhan Plain.

The storage capacity of the Seyhan Dam reservoir has been continuously monitored, given its significant role in water resources management as a multi-purpose dam. The monitoring results have been instrumental in establishing operation rule curves, which are essential for effectively managing the reservoir's water levels and releases. Bathymetric mapping has played a crucial role in assessing the reservoir's storage capacity and sediment accumulation over time. The first bathymetric map of the Seyhan Dam reservoir was prepared in 1966, providing valuable insights into the initial state of the reservoir (Güvel, 2007). Subsequent bathymetric mapping studies were conducted at various intervals to track changes in the reservoir's bottom profile and sedimentation patterns. The most recent bathymetric mapping of the Seyhan Dam reservoir was carried out in 2019, providing up-to-date information on the reservoir's current storage capacity and sediment distribution. This continuous monitoring and mapping process has contributed to informed decision-making in reservoir management and sustainable utilization of water resources for various purposes, including irrigation, energy production, and flood protection.

The reservoir's storage capacity and sedimentation analysis are crucial for understanding and maximizing the benefits provided by the Seyhan Dam Reservoir. To achieve this, reservoir monitoring works have been carried out through bathymetric surveys. Over the years, bathymetric surveys of the Seyhan Dam Reservoir have been conducted at regular intervals to track changes in its bottom profile and sedimentation levels. The surveys were performed in the years 1966, 1971, 1976, 1980, 1986, 1991, 2005, and 2019, providing valuable data at different time points. Field investigations for bathymetric maps are typically conducted during the summer months due to favorable weather conditions. For this study, the researchers utilized the standard topographic map of the Seyhan Dam reservoir area before the construction of the dam, alongside all the bathymetric maps of the reservoir. These comprehensive datasets were used to assess and analyze the updated sedimentation status in the reservoir. By comparing the bathymetric data from different periods, the study aimed to gain insights into the sediment accumulation and changes in the reservoir's storage capacity over the years. This information is essential for effective reservoir management and planning to ensure the sustained benefits of the Seyhan Dam Reservoir.

In this study, changes in forest areas in the upper river basin of the Seyhan Dam were investigated using data from the Coordination of Information on the Environment (CORINE) Land Use Cover. Specifically, the researchers utilized CORINE Land Cover (CLC) data from multiple years, including 1990, 2000, 2006, 2012, and 2018. The CORINE Land Cover data is an essential resource for monitoring and analyzing land use and land cover changes across Europe. The data is publicly available and can be accessed from the Copernicus Land Monitoring Service website (https://land.copernicus.eu/pan-european/corine-land-cover). By using the CLC data for different periods, the study aimed to understand how forest areas in the upper river basin of the Seyhan Dam have changed over the years. Such information is crucial for assessing the impacts of land use changes on the environment, especially to water resources and reservoir management in the region.

2.2. Method

Estimating reservoir capacity loss resulting from sediment deposition can be achieved through the use of bathymetric maps. Using bathymetric maps, the volume of water stored in a reservoir at each elevation is calculated in GIS environment, and the difference between the two amounts is assessed as the sediment accumulation volume. Over the years, various methods, including traditional and advanced techniques, have been employed in the bathymetry mapping of dam reservoirs. In the case of the Seyhan Dam reservoir, traditional methods were predominantly used in the past to generate bathymetric maps. However, with advancements in technology and surveying techniques, new approaches have been adopted in the most recent measurements and mapping processes. These modern methods likely offer enhanced accuracy, efficiency, and data resolution, providing more detailed insights into the sedimentation patterns and changes in the reservoir's storage capacity. By utilizing both traditional and advanced approaches in bathymetry mapping, researchers and reservoir managers can obtain a comprehensive understanding of sedimentation trends make take more informed decisions related to reservoir operation and sediment management. This combination of techniques ensures a holistic assessment of the reservoir's condition and facilitates effective planning for sustainable reservoir management.

Making bathymetric maps of the reservoir bottom topography is the most reliable way for assessing sediment deposition in dam reservoirs. Because some of the sediment entering the reservoir is moved downstream of the dam, estimating the basin sediment yield and the sediment in the dam reservoir based on sediment yield is more challenging. Bathymetry map creation, on the other hand, is an expensive engineering task. If monitoring studies are delayed, it will have an impact on the present volume elevation table and dam operation activities.

Geographic Information System (GIS) is a powerful decision support tool that is utilized for data management and analysis, streamlining the decision-making process and increasing efficiency. GIS-based approaches have been widely employed in various research fields, including science, to aid in decision-making processes (Malczewski, 2006; Gharbia et al., 2016; Shaikh et al., 2021; Bwambale et al., 2022; Hagos et al., 2022; Xing et al., 2022). By creating digital models of spatial and temporal changes on the Earth's surface, GIS enables the evaluation of model outputs to address problems and make informed decisions.

The use of GIS techniques allows researchers and managers to study alternative scenarios in planning and management processes, leading to significant savings in labor, time, and costs. The computer-based systems offer the capability to analyze and visualize data in a spatial context, facilitating better understanding and decision-making.

In the specific context of this study, the researchers utilized ArcGIS software to analyze bathymetric survey data of the reservoir within a GIS environment. The study's flowchart, as depicted in Figure 2, outlines the step-by-step approach taken to conduct the analysis and draw conclusions based on the GIS-based evaluations. The application of GIS in this study serves as a valuable tool in examining and managing the reservoir's bathymetry data, enabling more effective and informed decisions related to reservoir management and sedimentation analysis.

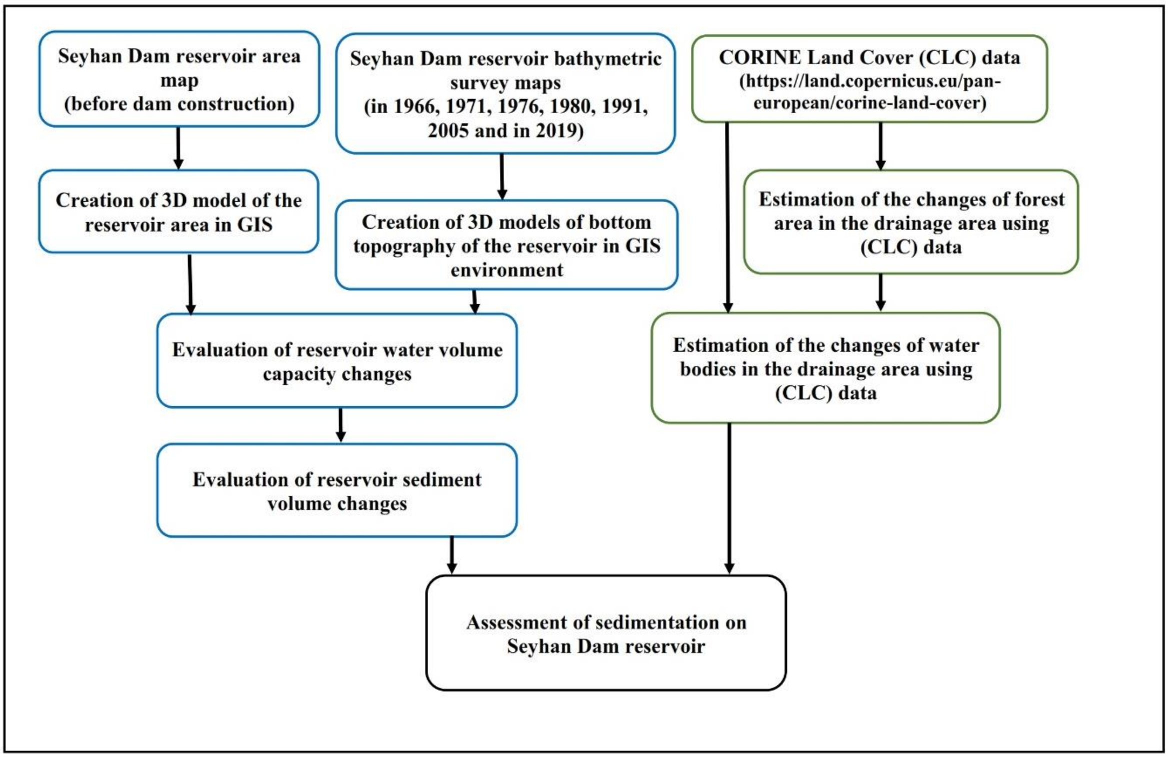

Figure 2. Flow Chart Of The Applied Methodology

3. Results and Discussions

In this study, the evaluation of changes in the Seyhan Dam reservoir's water storage capacity is conducted through a comparative analysis of volume-elevation data. The researchers compare the volume-elevation data of the reservoir before the dam's construction with the volume-elevation data obtained from bathymetric surveys conducted in the reservoir in previous years. To assess the sedimentation levels, the researchers analyze the volumetric difference at the same elevation data points. This difference represents the volume of sediment accumulated between the measurement years, and it is depicted in the graph of volume-elevation curves, as shown in Figure 3. By examining the volume-elevation curve in Figure 3, the sediment accumulation value between the pre-dam construction period and the years of the bathymetric surveys can be obtained. This information provides crucial insights into the changes in the reservoir's storage capacity over time due to sediment deposition.

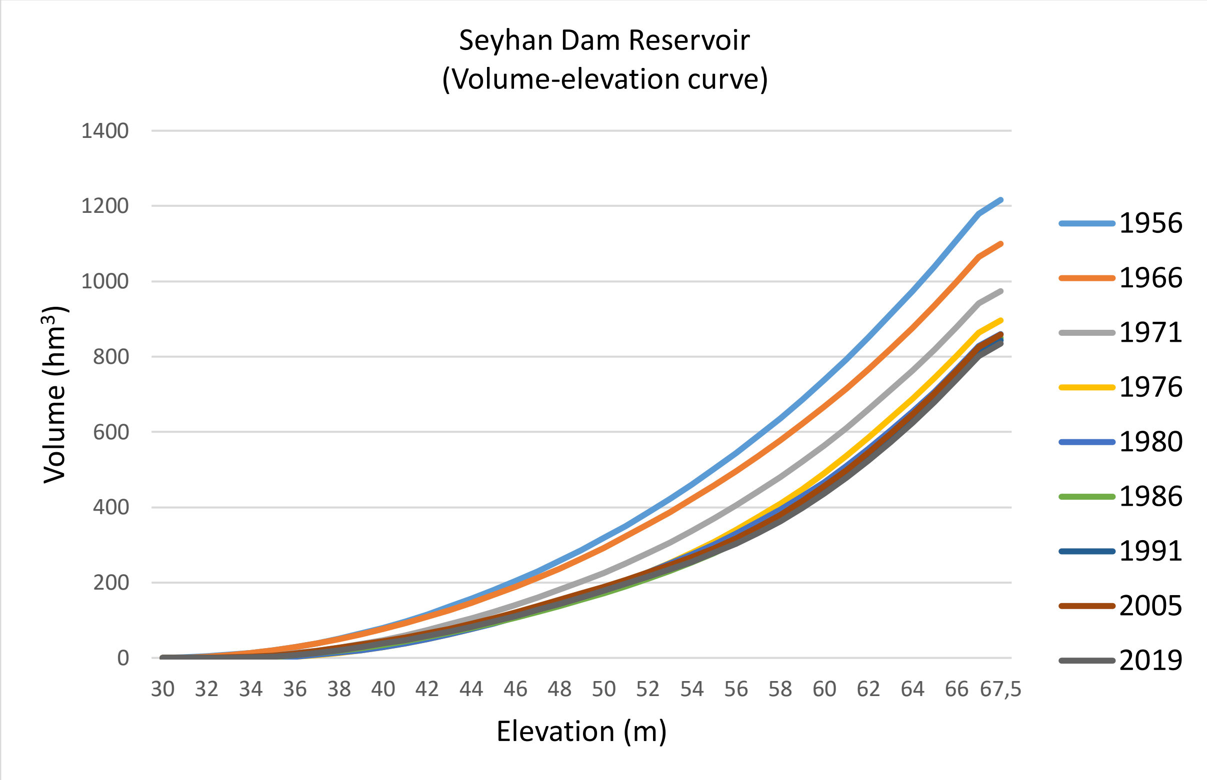

Figure 3. Seyhan Dam Volume-Elevation Curve

As depicted in Figure 4, the water storage capacity of the Seyhan Dam reservoir has experienced a significant and rapid decrease during the operation period, primarily due to the increase in sedimentation levels. However, the trend in sedimentation volume shows a tendency to become stationary as of the last three bathymetric surveys conducted up to 2019. The observed sedimentation patterns and the stability in sedimentation volume provide valuable insights for estimating future water and sediment volumes. Based on the formulation created by evaluating the results of bathymetric measurements, researchers and reservoir managers can develop predictive models to estimate future changes in water storage capacity and sediment accumulation in the reservoir.

As presented in Figure 4, the volume of the Seyhan Dam reservoir experienced a rapid change during the first 24 years after the dam's construction, primarily due to significant sediment accumulation. However, starting from 1980, there was a noticeable decrease in the rate of change in the reservoir volume over the last 39 years. Specifically, the change in the reservoir volume decreased by approximately 2.9% during this period. This finding suggests that the sedimentation rate has become more stable or slowed down significantly in recent decades, resulting in a relatively smaller impact on the reservoir's storage capacity compared to the earlier years.

This observation of a reduced change in reservoir volume over time can have implications for reservoir management and future planning. It indicates that sediment management strategies and reservoir operation practices implemented in recent years may have contributed to mitigating the impact of sediment accumulation on the reservoir's storage capacity. Understanding these trends is essential for making informed decisions regarding reservoir management and ensuring its sustainable use for various purposes.

Based on the data presented, it was estimated that during the first 24 years after the construction of the Seyhan Dam reservoir, the total storage volume loss in the reservoir was approximately 1.22% per year. This indicates a relatively rapid decrease in the reservoir's storage capacity during the initial operational period, primarily attributed to sediment accumulation.

However, in the subsequent 39 years, the storage volume loss in the reservoir significantly decreased to approximately 0.074% per year. This reduction in the rate of storage volume loss indicates a slower sedimentation rate or improved sediment management practices during this period.

The comparison between the two periods highlights the effectiveness of sediment management efforts or changes in reservoir operations that have helped to reduce the impact of sediment accumulation on the reservoir's storage capacity in recent years. This information is valuable for reservoir managers and decision-makers as it provides insights into the historical trends of sedimentation and the effectiveness of mitigation measures taken over time.

It can guide future management strategies to ensure the sustainable utilization of the Seyhan Dam reservoir for various purposes.

Regression analysis was applied to obtain the correlation between water storage and years at 67.5 meter water level in Seyhan Dam Reservoir and found as,

$$y = -0.003\,x^3 + 0.4739\,x^2 - 24.292\,x + 1238.8 \quad (1)$$

The results of the regression analysis indicate a high correlation between water storage capacity changes and the bathymetric survey years in the Seyhan Dam Reservoir. The correlation coefficient (R^2) value of 0.96 suggests a strong positive linear relationship between the two variables.

Furthermore, the statistical significance of this correlation was assessed using a t-test, which indicated that the correlation is significant at the 0.05 significance level. This means that the relationship observed between water storage capacity changes and the bathymetric survey years is not likely due to random chance but is statistically meaningful and reliable.

The high correlation and its statistical significance indicate that the bathymetric survey years can be used as a valuable indicator for understanding and predicting water storage capacity changes in the Seyhan Dam Reservoir. This information can aid in reservoir management and decision-making processes to ensure the optimal and sustainable utilization of the reservoir's water resources over time.

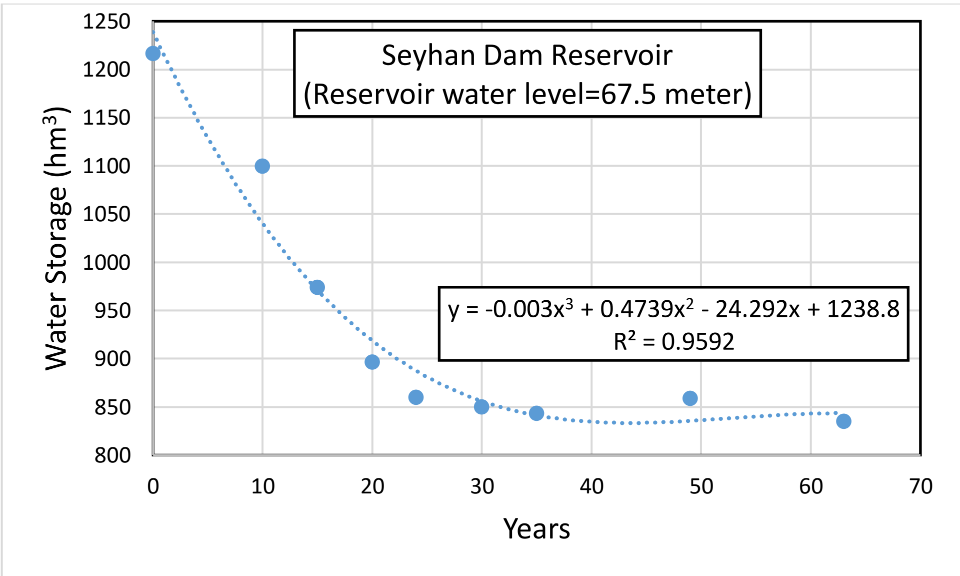

Figure 4. Water Storage Capacity Changes in Seyhan Dam Reservoir (Reservoir Water Level=67.5 Meter)

The investigation of changes in the reservoir storage capacity up to the dead volume upper elevation is depicted in Figure 5. The results show that the dead volume changes in the reservoir were estimated to be approximately 2.17% per year during the first 20 years after the dam's construction. In contrast, during the last 43 years, the dead volume changes in the reservoir were estimated to be significantly lower, at only around 0.022% per year.

Additionally, a regression analysis was conducted to determine the correlation between water storage and years at 49 meters water level in the Seyhan Dam Reservoir. However, the specific correlation coefficient value (R^2) resulting from this analysis was not provided in the given information. To fully interpret the correlation result, it is crucial to know the actual correlation coefficient value. This coefficient will indicate the strength and direction of the linear relationship between water storage and years at the specified water level in the reservoir.

$$y = -0.0012\,x^3 + 0.1876\,x^2 - 9.1312\,x + 300.17 \quad (2)$$

The regression analysis revealed a high correlation between water storage capacity changes and the bathymetric survey years in the Seyhan Dam Reservoir, with a correlation coefficient (R^2) value of 0.88. This strong positive linear relationship indicates that as the bathymetric survey years increase, the water storage capacity changes in the reservoir also tend to increase. The coefficient of determination (R^2) indicates that approximately 87.96% of the variability in water storage capacity changes can be explained by the changes in the bathymetric survey years.

Moreover, the statistical significance of this correlation was assessed, and it was found to be significant at the 0.05 significance level.

The high correlation and its statistical significance suggest that the bathymetric survey years are a robust indicator for understanding and predicting water storage capacity changes in the Seyhan Dam Reservoir. Based on the data from the last 6 bathymetric surveys, it is observed that sediment accumulation has significantly slowed down at the elevation of 49 meters, which is the upper dead volume elevation in the Seyhan Dam Reservoir. This finding suggests that sedimentation levels have decreased or become more stable in this particular region of the reservoir.

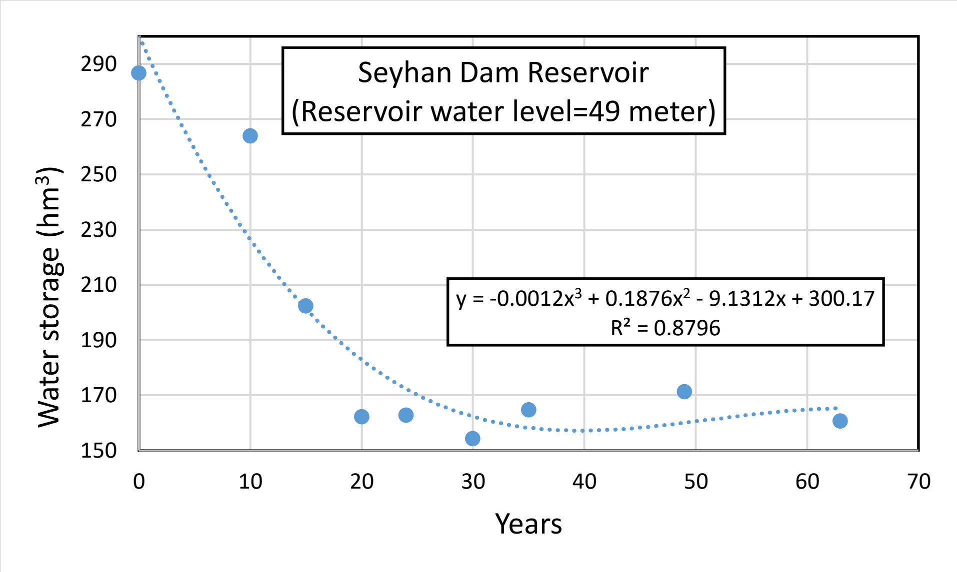

Figure 5. Water Storage Capacity Changes in Seyhan Dam Reservoir (Reservoir Water Level=49 Meter)

The slowdown in sediment accumulation at the upper dead volume elevation is a positive observation for reservoir management. It indicates that sediment management efforts or changes in reservoir operations have likely contributed to reducing the sedimentation rate in this part of the reservoir.

Understanding these trends is crucial for making informed decisions regarding sediment management strategies and ensuring the optimal utilization of the Seyhan Dam Reservoir's storage capacity. By focusing on areas where sedimentation has slowed down, reservoir managers can implement targeted measures to further mitigate sedimentation and optimize water storage for various purposes, such as irrigation, energy production, and flood protection.

In the study, the formulas (1) and (2) are used to represent specific water levels in the Seyhan Dam reservoir. These formulas likely provide mathematical relationships to estimate water levels at different stages of the reservoir operation based on various variables and factors.

To evaluate the necessity of conducting bathymetry measurements and to support planning studies for future research, it is recommended to perform regression analysis for each reservoir operation water level. This means carrying out separate regression analyses for different water levels within the reservoir's operational range.

Furthermore, such detailed regression analyses can aid in optimizing the frequency and timing of future bathymetric measurements, ensuring that resources are efficiently allocated to monitor critical areas of the reservoir and support effective planning studies for reservoir operation and sediment management.

The primary focus of the study is to investigate the impact of the increase in forest and land cover area on reservoir sedimentation accumulation. This is an important aspect as changes in land cover, especially forest cover, can influence sediment transport and deposition in the reservoir. Forests play a crucial role in stabilizing soil and reducing erosion, which, in turn, can affect sediment loads carried by rivers and streams that eventually reach the reservoir.

Additionally, the study aims to evaluate the impact of the increase in water bodies within the Seyhan River basin's drainage area. The presence of water bodies can influence sediment dynamics by altering flow patterns and sediment transport processes. Understanding the changes in water bodies and their potential influence on sediment accumulation is vital for predicting reservoir sedimentation and making informed decisions regarding reservoir management.

By considering both the increase in forest and land cover area and the changes in water bodies, the study seeks to provide a comprehensive understanding of the factors influencing sediment accumulation in the Seyhan Dam reservoir. This knowledge can support effective reservoir management strategies and sediment control measures, ultimately contributing to the sustainable utilization of the reservoir's water resources and enhancing its multiple benefits such as irrigation, energy production, and flood protection.

The CORINE Land Cover (CLC) data analysis between 1990 and 2018 reveals significant changes in water bodies and forest areas in the upper basin of the Seyhan Dam reservoir.

As shown in Figure 6, there has been an increase in forest area over the 28 years, rising from 23.71% to 24.36%. This indicates that the upper basin has experienced a positive trend in afforestation or reforestation efforts, which can have beneficial effects on sediment control and erosion prevention. Forests play a critical role in reducing soil erosion, stabilizing slopes, and enhancing water infiltration, which can lead to a decrease in sediment runoff into the river system.

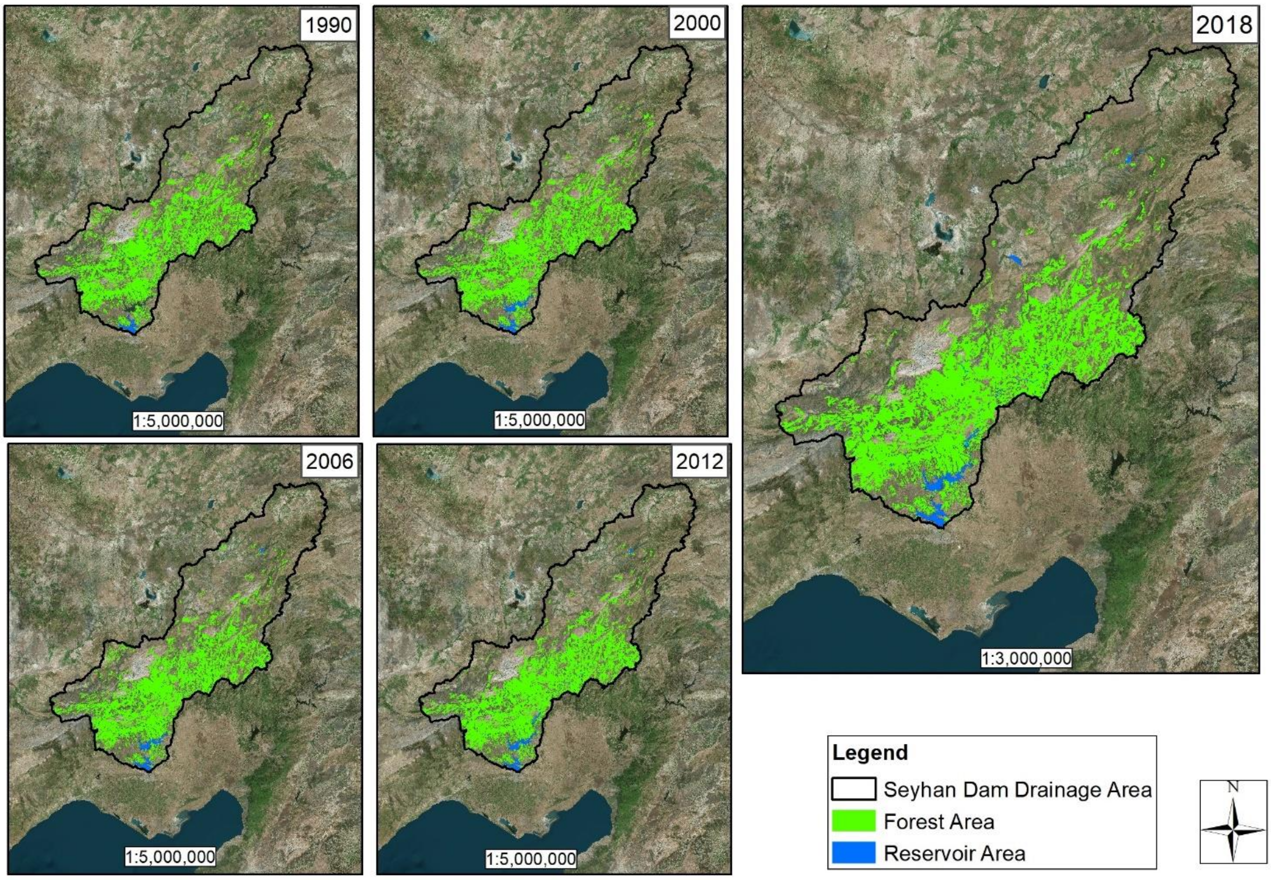

Figure 6. Seyhan Dam Drainage Area

Moreover, Figure 7 demonstrates a notable increase in water bodies within the upper basin during the same time frame. The water bodies' expansion from 0.3% to 0.9% suggests the creation or growth of natural or artificial water features in the region. The presence of water bodies can alter sediment transport patterns, potentially trapping sediment and reducing its transport downstream to the Seyhan Dam reservoir.

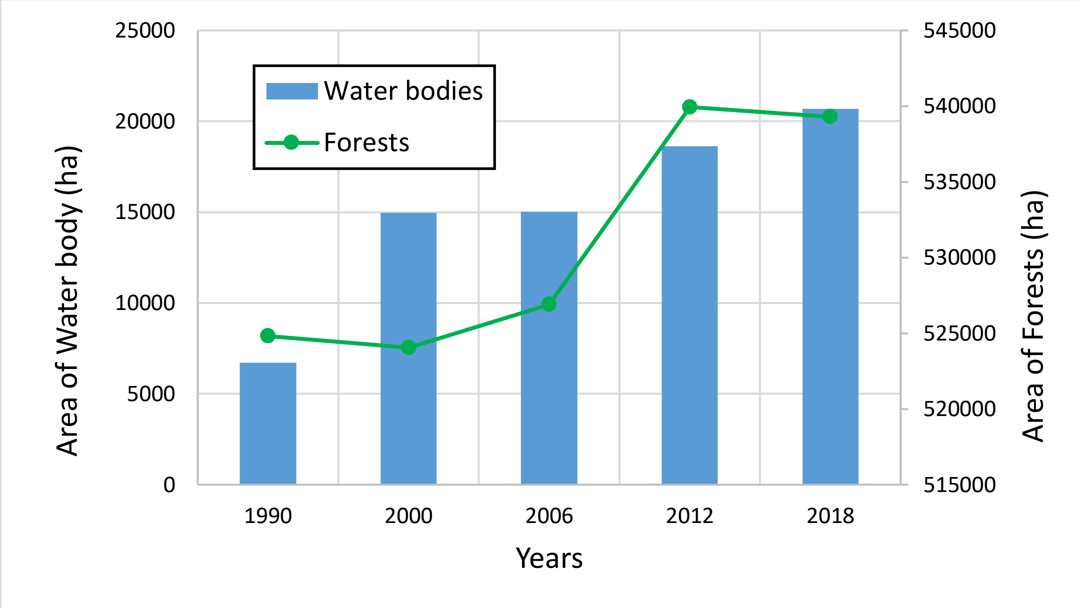

Figure 7. Water Bodies And Forests in Hectares in Seyhan Dam Drainage Area

The observed changes in forest areas and water bodies are crucial factors to consider when assessing sedimentation accumulation trends in the Seyhan Dam reservoir. These changes can have both positive and negative effects on sediment transport, and understanding their impact is vital for effective reservoir management and sediment control measures to ensure the sustainable utilization of the reservoir's water resources.

The previous studies have provided valuable insights regarding sedimentation patterns in the Seyhan River system (Fakıoğlu, 2005; Güvel and Yurtal, 2020). According to these studies, it was observed that sediment from the Çakıt Stream branch contributed significantly to sediment accumulation in the Seyhan Dam reservoir. This branch likely had higher sediment loads compared to the Seyhan main branch.

However, the construction and commissioning of the Çatalan Dam, located upstream, had a positive impact in reducing sedimentation from the Seyhan main branch. The presence of the Çatalan Dam likely acted as a sediment trap, preventing a significant amount of sediment from reaching the downstream Seyhan Dam reservoir.

The findings from these previous studies highlight the importance of understanding the sediment dynamics within a river system, particularly in multi-dam contexts. The interactions between different river branches and the presence of upstream dams can have varying effects on sediment transport and accumulation patterns. The study conducted in the Seyhan Dam reservoir provides valuable insights into the sediment accumulation and distribution over time. By comparing 3D models of the reservoir area before dam construction and the bathymetric survey years, the researchers were able to investigate spatial and temporal changes in bottom topography and sediment distribution, especially in the Çakıt Stream side.

At the 49-meter water level, it was observed that significant changes occurred along the Çakıt Stream branch and the reservoir area on this side (Figure 8). These changes were likely caused by high sediment transport from the upper basin side of Çakıt Stream, especially during the major flood disaster that occurred in the Seyhan River between 27 March and 6 April 1980 (DSİ, 1980). The flood event led to a large amount of sediment being transported from the Çakıt Stream branch into the reservoir, causing floor scours, slope collapses, and landslides.

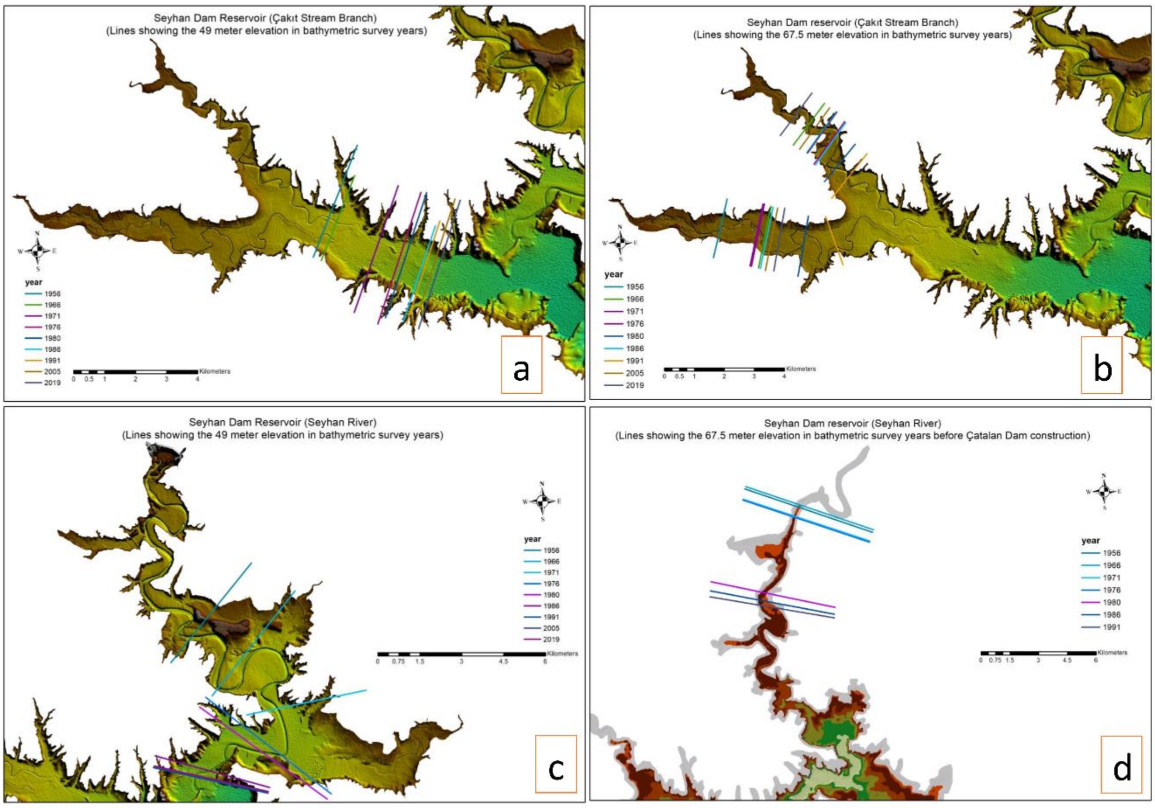

Figure 8. A- The Changes in Çakıt Stream Branch For 49 Meter Water Elevation, B- The Changes in Çakıt Stream Branch For 67.5 Meter Water Elevation, C- The Changes in Seyhan River Main Branch For 49 Meter Water Elevation, D- The Changes in Seyhan River Main Branch For 67.5 Meter Water Elevation Before The Construction Of Çatalan Dam.

However, after the construction of the Çatalan Dam, which was put into operation in 1997, the sediment accumulation and distribution in the Seyhan Dam reservoir were further investigated (Figure 9). Bathymetric measurements from 2005 and 2019 were used to evaluate the impact of the Çatalan Dam construction. Because these two maps were created after the Çatalan Dam was built, and it is necessary to have at least two maps for assessing the sediment effect. The results indicate that there were no significant changes in the Seyhan River main branch for the 49-meter and 67.5-meter water elevations in the years 2005 and 2019, respectively, after the construction of the Çatalan Dam. This suggests that the dam's presence likely acted as a sediment trap, reducing sediment transport downstream to the Seyhan Dam reservoir.

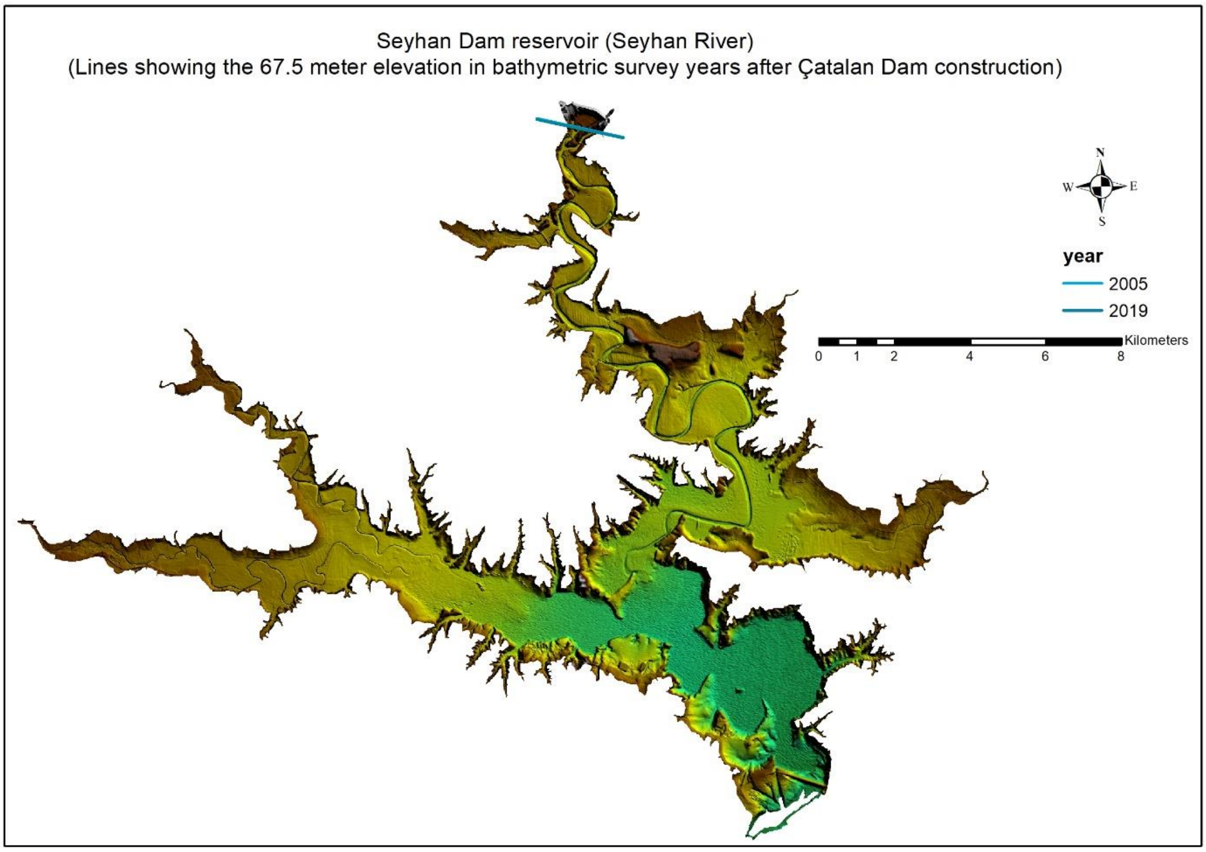

Figure 9. The Changes in Seyhan River Main Branch For 67.5 Meter Water Elevation After The Construction Of Çatalan Dam

Overall, the study provides important information on the effects of flood events and dam construction on sediment accumulation and distribution in the reservoir. Understanding these dynamics is crucial for effective reservoir management and sediment control strategies to ensure the long-term sustainability of the reservoir's water resources.

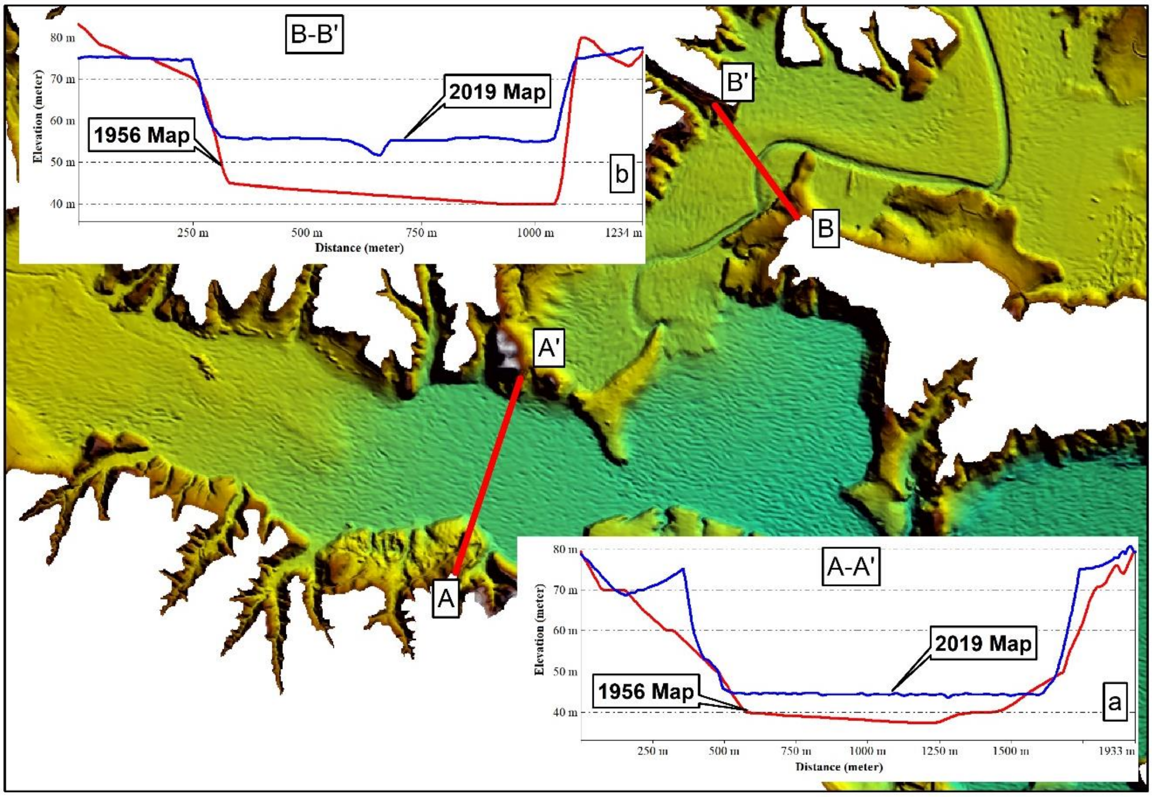

Figure 10. Sample Cross-Sections Showing Elevation Changes in The Seyhan Dam Reservoir Between 1956 And 2019.

Figure 10 depicts a sediment thickness map in Seyhan Dam Reservoir from 1956 to 2019 (with representative cross-sections in the model). To analyze areas of silt deposition and underwater erosion, representative cross sections were constructed. In order to investigate sediment deposition along the reservoir, 3D models of the reservoir area representing bathymetric years were also evaluated in GIS environment.

4. Conclusion

The findings from the investigation of storage capacity loss caused by sedimentation in the Seyhan Dam reservoir reveal important trends over time. The data indicate that in the first 24 years after the construction of the dam, the total storage volume loss was estimated at 1.22% per year, while in the last 39 years, this loss decreased to 0.074% per year. Similarly, the dead volume changes in the reservoir were estimated to be higher in the first 20 years (2.17% per year) compared to the last 43 years (0.022% per year).

Given the slowdown in sediment accumulation in the reservoir and the high cost and effort involved in preparing bathymetric maps, the study recommends using the formulas (1) and (2) to assess the necessity of bathymetry map production in the future. These formulas can provide valuable estimates of water storage capacity changes without the need for frequent bathymetric surveys, making the monitoring process more efficient.

Additionally, the study suggests evaluating the contribution of these formulas in planning studies before conducting bathymetric measurements. This approach can aid in decision-making and resource allocation for monitoring sedimentation in the reservoir.

The construction of the Çatalan Dam has had a significant impact in reducing sediment accumulation in the Seyhan Dam reservoir. This finding emphasizes the importance of considering upstream land and water management practices in sediment management strategies for the entire Seyhan River basin.

Furthermore, the increase in forest area and water bodies in the upper basin, as shown by the CLC data comparison between 1990 and 2018, is associated with a decrease in sediment flow into the reservoir. This highlights the positive role of forests and water bodies in mitigating sedimentation and underscores the significance of sustainable land and water management practices in the basin to ensure the long-term health of the reservoir and its water resources. The sedimentation should be monitored not only in dam reservoirs but also in streams concerning its impacts on environmental and social contexts.

Conflict of Interest

No conflict of interest was declared by the authors.

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