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Research Article

Sediment Yield Analysis in Tahtaköprü Dam Basin

Şerife Pınar Güvel[1*], Mehmet Ali Akgül[2], Hakan Aksu[3]

[1*] General Directorate of State Hydraulic Works, 6th Regional Directorate, Department of Information Technologies, Adana, Turkey, (ORCID: 0000-0002-3175-5938), spinar.guvel@dsi.gov.tr

[2] General Directorate of State Hydraulic Works, 6th Regional Directorate, Department of Information Technologies, Adana Turkey, (ORCID: 0000-0002-5517-9576), mali.akgul@dsi.gov.tr

[3] Samsun University, Faculty of Aeronautics and Astronautics, Department of Meteorological Engineering, Samsun, Turkey, (ORCID: 0000-0003-4686-7446), hakan.aksu@samsun.edu.tr

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Abstract

The determination of the volume of water to be stored is one of the most important criteria for dam and pond planning and operation. This amount is calculated locally prior to planning studies, and a bathymetric map is created following water storage in the reservoir. Because of sedimentation during the operation period, the volume of the reservoir decreases over time, and this situation appears as a problem in the operation of the water structure. In this study, the reservoir storage volume changes and reservoir sediment accumulation rates between the locally produced map before the construction of Tahtaköprü Dam and the hydrographic survey maps prepared during operation period were investigated by using GIS modules. It was determined that the decrease in the storage volume of the dam reservoir at the maximum water level by 9.15% and at the minimum water level by 51.90% was due to sediment accumulation. The effect of the changes in the land cover and forest area in the basin on reservoir sedimentation was examined and it was found that land cover and forest area in the basin have reduced sediment accumulation in the reservoir. Furthermore, sediment thickness change was mapped to compare the decrease in the storage volume capacity of the reservoir at the maximum water level and at the minimum water level by comparing the digital elevation models of 1962, 1980 and 2014 to support the decision-makers on determining reservoir operation rules in order to benefit water resources effectively within the scope of sustainable management of water resources.

Keywords: Geographic information system, sediment accumulation, Tahtaköprü Dam, water resources management.

Tahtaköprü Baraj Havzasında Sediment Verim Analizi

Öz

Baraj ve göletlerin planlanmasında ve işletilmesindeki en önemli kriterlerden bir tanesi depolanacak su hacminin tespitidir. Bu miktar planlamadan önce yersel olarak, baraj ve gölet su tutulmasından sonra ise batimetrik harita yapılarak hesaplanmaktadır. İşletme süresince, baraj rezervuarına gelen sedimentasyon kaynaklı olarak bu hacim zamanla azalmakta, bu durum su yapısının işletilmesinde sorun olarak karşımıza çıkmaktadır. Bu çalışmada, Tahtaköprü Baraj rezervuarında baraj inşaatından önce hazırlanan yersel harita ile hidrografik harita yapım yılları arasında rezervuar depolama hacmi değişimi CBS modülleri aracılığı ile hesaplanmıştır. Baraj rezervuarında depolama hacminde maksimum su seviyesinde %9,15, minimum su seviyesinde %51,90 oranında azalmanın sediment birikiminden kaynaklandığı belirlenmiştir. Havzadaki arazi örtüsü ve orman alanındaki değişimlerin rezervuar sediment birikimine etkisi incelenmiş ve arazi örtüsü ve orman alanlarının rezervuardaki sediment birikimini azalttığı tespit edilmiştir. Ayrıca sürdürülebilir su kaynakları yönetimi kapsamında su kaynaklarından etkin olarak yararlanabilmek için, rezervuar işletme kurallarının belirlenmesinde karar vericileri desteklemek amacıyla, maksimum ve minimum su seviyelerinde rezervuar depolama hacimlerindeki azalmanın kıyaslanması için, 1962, 1980 ve 2014 yılları sayısal arazi modelleri karşılaştırılarak sediment kalınlık haritaları hazırlanmıştır.

Anahtar Kelimeler: Coğrafi bilgi sistemi, sediment birikimi, Tahtaköprü Barajı, su kaynakları yönetimi.

[*] Corresponding Author: spinar.guvel@dsi.gov.tr

1. Introduction

Sustainability in water resources planning and management works is a necessity to meet the needs of future generations. The commissioning of engineering projects by using new technologies are of great importance for efficient use of water due to the necessity caused by the rapid increase in the world's population and global climate change effects. Only 2.5 % of the 1,4 billion km^3 of water in the world is in the form of fresh water (DSİ, 2018). Water resources data whether obtained by measurements and observations on ground or remote sensing techniques can be used for assessment of spatial and temporal changes. Reliable databases are capable of, not only providing geographic analysis results but also able to generate future projections to support decision makers at water management policies. In recent years, analysis based on georeferenced data give reliable results in natural resources management. Some of preference reasons for using the Geographic Information System (GIS) are easy access to data, graphical representation possibilities, facilitating assessment of temporal and spatial properties of historical data, and the ability to integrate with many other applications. In recent years paper maps are transferred in to GIS environment by georeferencing tools and digitization processes. By integration of computer-aided design based projects into information systems, generation of high accuracy digital models is commonly available in computer environment today. GIS technologies have been used in hydrology for many different areas such as surface flow estimations, groundwater quality mapping, flood mapping etc. (Cebe and İnan, 2020; Soyaslan and Hepdeniz, 2020; Hazır et al., 2016).

Dam projects need large amount of investment and also engineering and construction works. In order to keep the benefits at the highest level, bathymetric measurements are carried out to monitor the reservoir storage capacities during the operation of the dams. Bathymetric measurements also effect dam operation policies and have great importance in terms of dam safety. The volume of the stored water in a dam can be estimated by using bathymetric maps.

Study of bathymetric measurements in the GIS allows for the investigation of changes in the bottom topography of reservoir areas, the determination of accumulated sediments transported by rivers from the upper basin and the determination of sedimentation increase in the total storage volumes.

As regards to its importance on dam operation and recent developments on GIS technology, many studies were conducted on bathymetric assessment of reservoir sedimentation. Reservoir sedimentation was investigated in Seyhan Dam reservoir (Güvel and Yurtal, 2020), in Berdan Dam reservoir (Güvel at al., 2017), in Aswan High Dam reservoir (El-Sersawy, 2005). The level-area-volume relation was calculated by using bathymetric measurements in the Ruiru reservoir (Sang et al., 2017).

The changes in the reservoir storage capacity between 1981 and 2009 in Altınapa Dam reservoir were investigated using bathymetric and topographic data, the results showed that the reservoir storage capacity decrease by 12.4% in a period of 28 years due to sediment accumulation, and the storage volume decreased by 33.4% comparing the storage volume of 2009 with the storage volume of 1967 when the dam was built (Ceylan et al., 2011). The changes in the storage capacity of the Veľká Kolpašská reservoir for 123 years (1889-2012) were examined and the land cover changes in the coastline for 63 years (1949-2012); and found that the deposited sediment in 123 years reduced the storage capacity by 7.23% (Kubinský et al., 2014). Bathymetric study and volumetric analysis were presented for Suleja Dam in Nigeria, the decrease in surface area, volume and water depth was examined considering the dam design information and detected a decrease in volume of 3,6 x 10^6 m^3 (Samaila-Ija et al., 2014).

Volume and sediment deposition rates in the reservoir for 2011 on the Torata River in the Andes of Peru were calculated with TIN (Triangular Irregular Network) and IMP (Insertion of Mesh Points) methods by using topographic data and bathymetric measurements, the results were compared both proportionally and by mapping (Estigoni et al., 2014). Three-dimensional model of the Kainji Dam reservoir was prepared which is put into operation in 1968 and located on the Niger river in Nigeria, reservoir volume and flow direction were determined (Ehigiator et al., 2017). Sediment distribution in the Ujjani Dam reservoir in India was investigated by evaluating two empirical methods, and compared the volume-height graphs of the reservoir with the original values (Tukaram et al., 2016). Sedimentation in the Hasanlar Dam reservoir was examined by using bathymetric data, GIS and remote sensing techniques, it was stated that the storage loss between 1974 and 1999 was 24% in the reservoir active volume and 26% between 1974 and 2014 (Darama et al., 2019). Sediment accumulation volume was investigated to define the sedimentation regime and to calculate the reservoir life in the Kalimanci Dam reservoir which was built in 1969 in Macedonia for the period between 1969 and 2013 (Mincev et al., 2019). SWAT (Soil and Water Assessment Tool) model has been used to evaluate sedimentation at Vaigai Reservoir in India (Ninija Merina et al., 2019).

Sedimentation in the Tri An HEPP (Hydroelectric Power Plant) reservoir located in the Dong Nai basin in Vietnam was investigated by using land use factors in the basin; as a result of the study, it has been determined that the reservoir sedimentation will increase by 8-9% annually as a result of a 10% decrease in forest areas (Loi, 2020) The effects of climate and land use changes on hydrological processes and sediment yield in the Be river basin in Vietnam was assessed by using SWAT (Soil and Water Assessment Tool); as a result of their study, they found that deforestration increases annual flow by 1.2% and sediment load by 11.3% (Khoi and Suetsugi, 2014). The changes on water discharge and sediment load of Feiyun River into the sea in China were analyzed by using observation data of runoff and sediment at Xuekou station, which is the main control station, in the main channel; as a result a good peak-valley correlation was found between the two (Lu et al., 2017). In the study conducted by İmamoğlu (2020), the relationship between morphometric features and erosion in the Alaca Stream Basin was investigated.

In this study, the storage volume capacity changes and sediment distribution in the Tahtaköprü Dam reservoir were investigated between 1962 and 2014 within the scope of water resources management. The reservoir area map locally prepared before the construction of the Tahtaköprü Dam reservoir, bathymetric survey maps of 1980 and 2014 of the reservoir were used to generate reservoir digital elevation models and to calculate the total storage capacity volume.

2. Material and Method

2.1. Material

The reservoir area of Tahtaköprü Dam has been selected as the study area. Tahtaköprü Dam is located in northeast of Hassa in Hatay City, in the southern part of Turkey, was constructed on Karasu River, was put into operation in 1977 (Figure 1). Tahtaköprü Dam was built for irrigation and energy purposes; during the rehabilitation of the dam, crest was raised 9 meters. Tahtaköprü Dam characteristics are given in Table 1.

Table 1. Tahtaköprü Dam characteristics

Characteristics	**Data**
River	Karasu river
Dam type	Earth fill
Purpose	Irrigation and energy
Date put into operation	1977
Crest elevation	417,00 m

In this study, standard topographic maps produced by photogrammetric method in 1962 by General Directorate of Mapping and bathymetric survey maps prepared in 1980 and in 2014 by State Hydraulic Works were used. ArcGIS software was used to analyse digital elevation models of Tahtaköprü dam reservoir area in GIS environment.

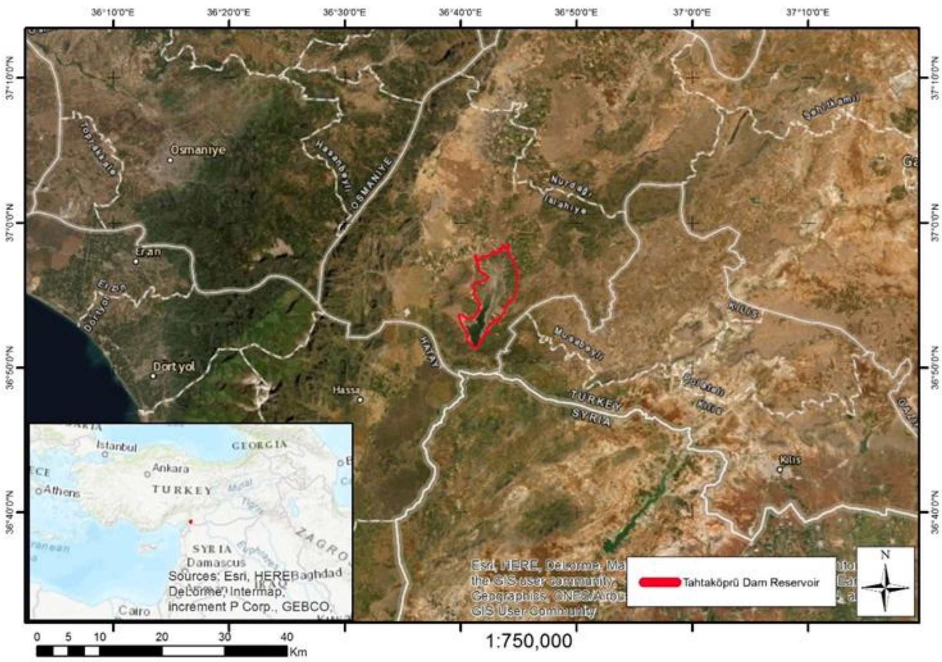

Figure 1. The location of Tahtaköprü Dam

2.2. Method

Estimation of sediment volume accumulated in a dam reservoir during operation period can be obtained by using consecutive hydrographic maps. The distribution of sediment accumulation in dam reservoirs can be determined by comparing the hydrographic maps of the monitoring years in GIS environment. The amount of sediment load is estimated at planning stage of the dam, and these values are taken into account in determining the dead storage of the dam. Bathymetric maps are prepared using depth measurements to examine bottom topography in reservoirs. The storage capacity of a reservoir may change due to the sediment flow carried with rivers from upper basin to the reservoir due to various environmental factors during operation works of the dam, the sediment accumulation effects cause changes in storage volume capacity. Changes in dam storage capacity have significant implications for dam operation rules. Reservoir volume-level-area tables prepared in planning activities, tables updated with monitoring studies, sediment accumulation maps are evaluated within the scope of operation policies by the dam operation-maintenance units. A basic flow chart of the study is given in Figure 2 for better understanding of the methodology as presented in Burgan and Aksoy (2018).

Digital elevation models of Tahtaköprü Dam reservoir were generated by TIN interpolation in GIS environment by using the photogrammetric map prepared in 1962 before the construction of the dam and the bathymetric maps of 1980 and 2014 (Figure 3). Digital elevation models were used to calculate the differences in storage volume in the reservoir at maximum and minimum operation levels (Figure 3).

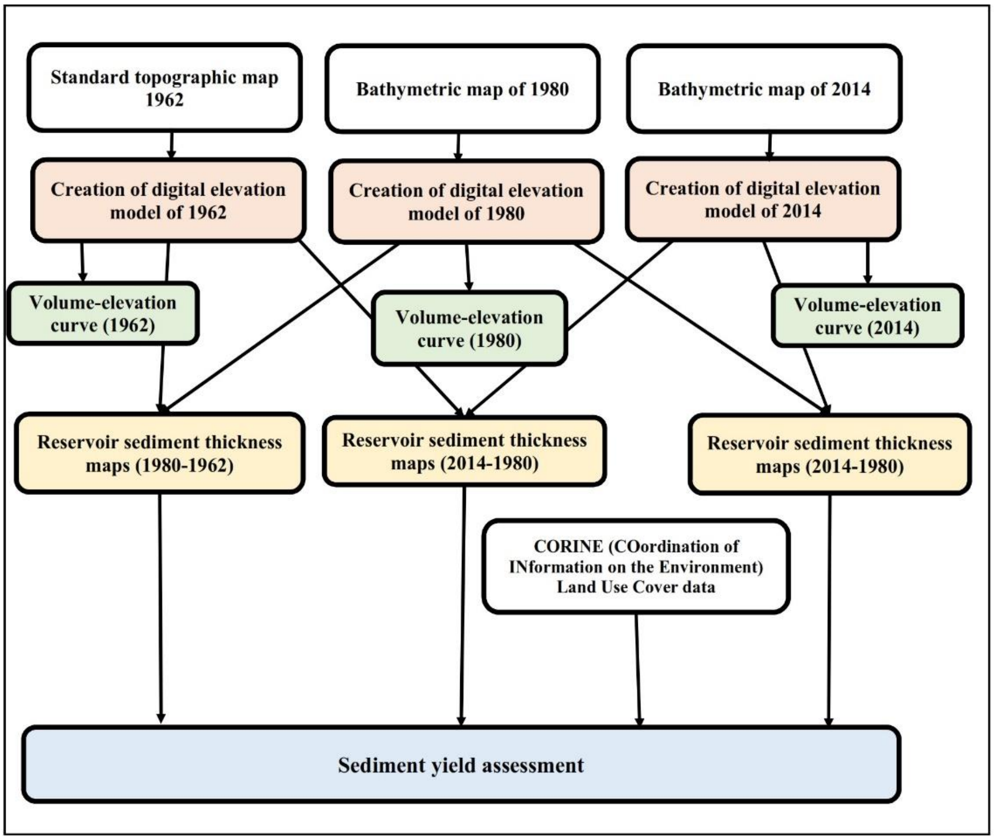

Figure 2. Flow chart of sediment yield assessment

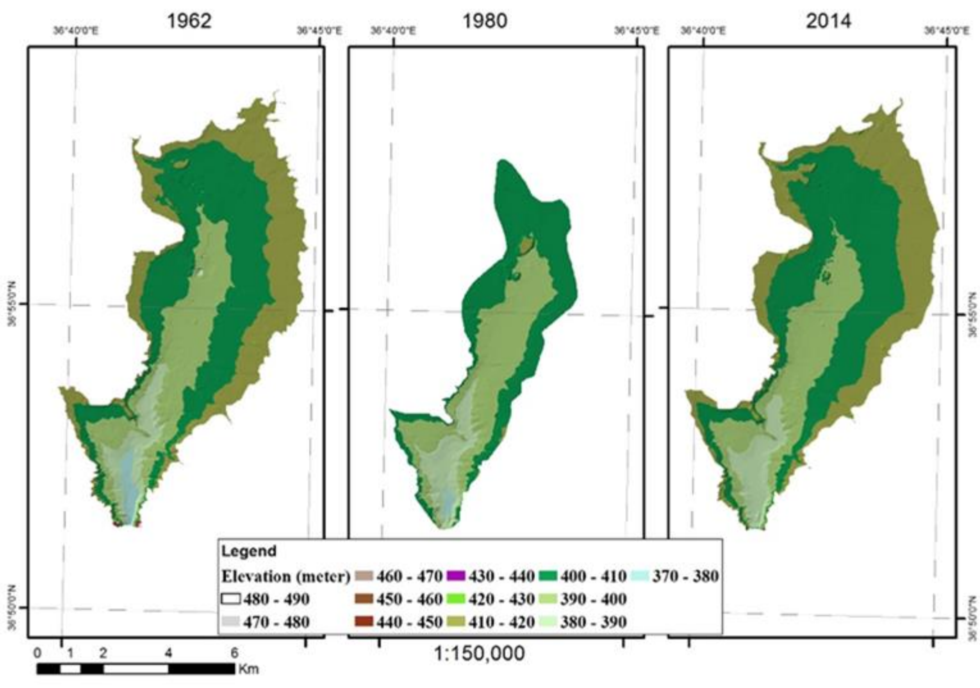

Figure 3. Tahtaköprü Dam digital elevation models

3. Results and Discussion

The same elevation and height information for all three models are shown in the same colour in Figure 3. Because survey area of the bathymetric map prepared in 1980 in Tahtaköprü Dam reservoir area was narrower than the survey areas of other measurement years, the maps showing the sediment accumulation in 1980-1962 and 2014-1980 were limited to this map boundary and the sediment thickness maps were prepared with this boundary.

It is seen by examining digital elevation models in GIS environment that the light blue colour representing elevations of 370-380 meters in the 1962 model decreased over time in 1980 and 2014 models in Figure 3, in other words, elevation values increase and sediment accumulation occurred by time. Similarly, the spatial changes of elevation between three years can be seen comparing the models given in Figure 3. The volume-level graph calculated through GIS analysis modules is given in Figure 4. When the storage volumes in 1962, in 1980 and in 2014 corresponding to 388 meters which is the minimum operation level of the reservoir are examined, it is determined that the maximum amount of sediment reaches into the reservoir before 1980. Compared the change between 1980-1962, it is seen that less sediment came between 1980 and 2014 (Figure 4).

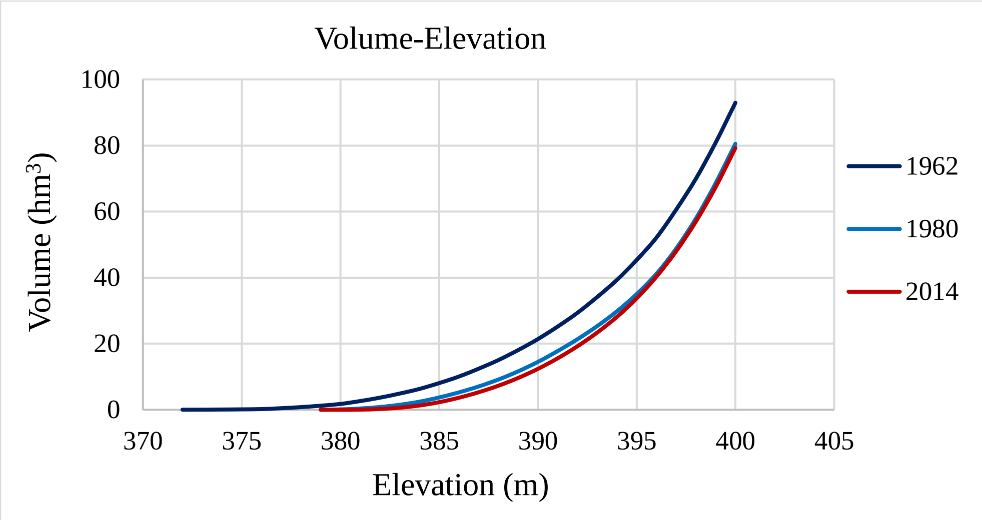

Figure 4. Tahtaköprü Dam volume-elevation curve

There were no sediment observations in the rivers in the Asi basin until 1958 (DSİ, 1958). Within the scope of the planning studies of Tahtaköprü Dam, 12 sediment samples were taken from the current observation station on the Karasu stream between November 1964 and February 1965, these samples were not found sufficient for sediment analysis, assuming an annual average sediment value of 200 m^3 per km^2 of the drainage area, it was estimated that 7.8 million m^3 sediment would arrive in the reservoir area in 50 years (IECO, 1966).

It can be seen by comparing digital elevation models between 2014 and 1962 that the amount of sediment coming into the reservoir in the intervening years was compatible with the values in the planning studies. The volume decrease in reservoir storage due to sediment accumulation is calculated as 9.15% in the maximum water level and 51.90% in the minimum water level as of 2014.

The sediment thickness maps were drawn by comparing the three digital elevation models in GIS environment; the maps showing the sediment deposition and distribution in pixels in the reservoir area are given in Figure 5. Sediment thickness maps of Tahtaköprü Dam (Figure 5) were evaluated in GIS environment.

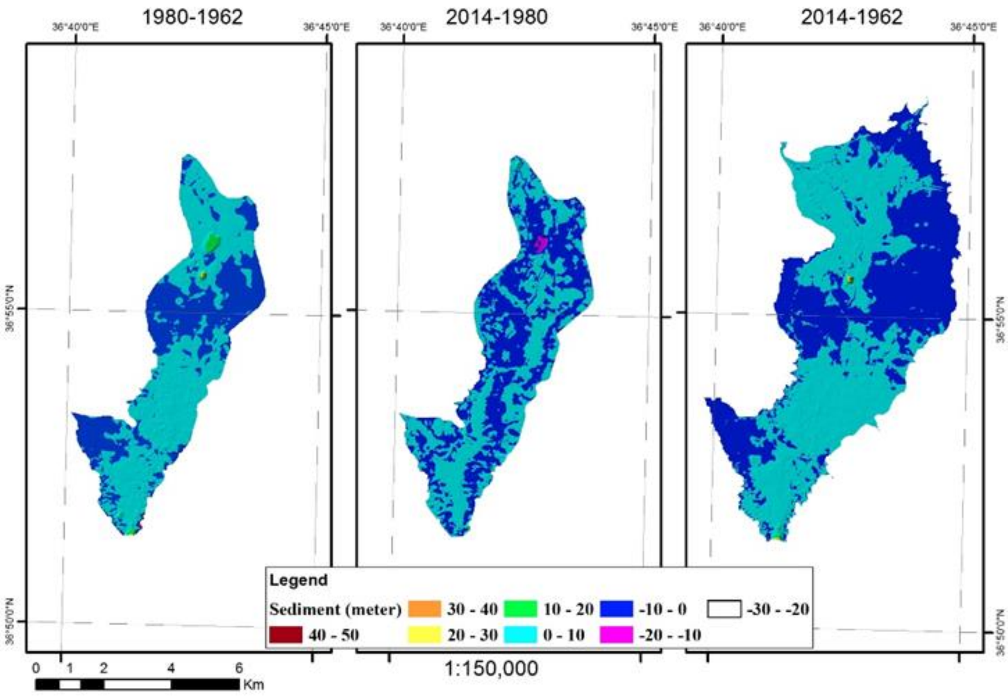

Figure 5. Tahtaköprü Dam reservoir sediment thickness maps

(a) Between 1980-1962, the sediment thickness was estimated as in the areas close to the dam body as approximately 3-4 m, while the sediment thickness in the middle parts of the reservoir ranged from 1.5-4.3 m; the sediment thickness at the upper parts of the reservoir was estimated as approximately 1-2 m.

(b) Between 2014-1980, the sediment thickness was estimated in reservoir area close to the dam body as approximately 1.4-2.6 m, while in the middle part of the reservoir the sediment thickness was estimated as 0.4-1.3 m, a decrease in elevation values between approximately 0.2-0.7 m was estimated in some areas. At the upper part of the reservoir, a decrease in the bottom elevations in the range of 0.2-1.0 m and sediment accumulation in the range of 0.2-1.2 m in some areas are estimated.

(c) Between 2014-1962, sediment thickness in areas close to the dam body was in the range of 3.5-5.5 m, while the sediment thickness in the middle parts was estimated about 2.7-3.0 m and there's a decrease in the bottom elevations of about 0.7-1.5 m. Sediment accumulation in the upper parts of the reservoir was estimated as 1.4-3.2 m and a decrease in bottom elevations between 0.3-1.6 m in some areas are estimated.

In this study, CORINE (COordination of INformation on the Environment) Land Use Cover data was used to detect the changes in land use, especially in forest areas, in the reservoir basin. As a result of the CORINE Land Use Cover (CLC) studies initiated in 1985, the first map was produced in 1990 and was updated in 2000, 2006, 2012 and 2018. CLC data has 44 different classes of land cover and this data has been obtained from https://land.copernicus.eu/pan-european/corine-land-cover .

With the examination of 1990 and 2018 CLC data, the forest area in Tahtaköprü drainage area is calculated as approximately 27% and 31% of the drainage area in 1990 and in 2018 respectively, the changes between 1990 and 2018 are given in Figure 6.

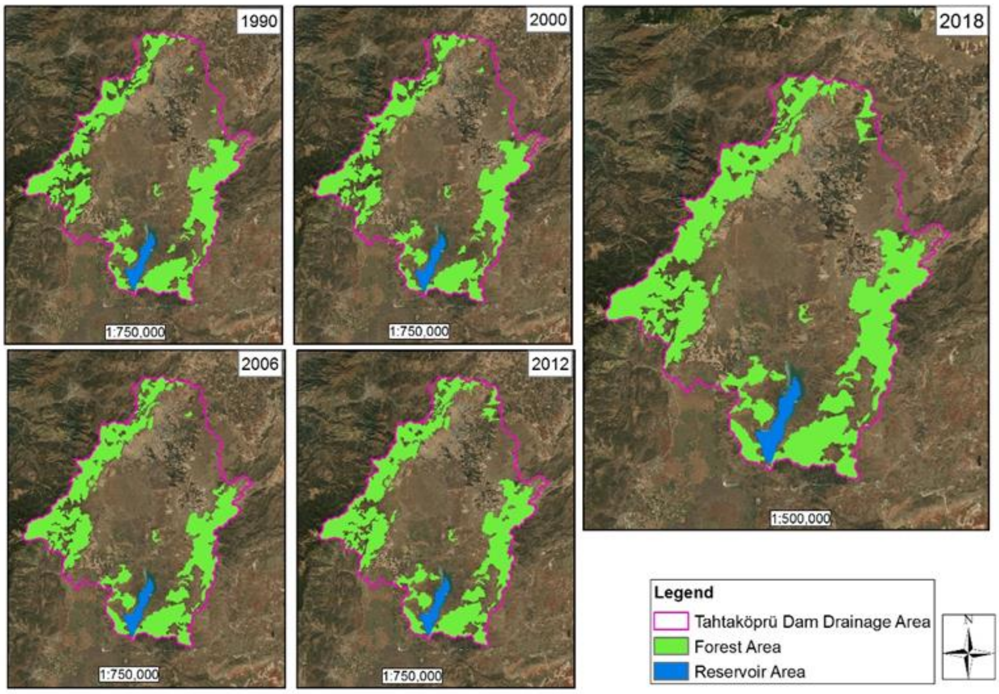

Figure 6. Tahtaköprü Dam drainage area

4. Conclusions and Discussion

In this analysis, sediment thickness maps were created in a GIS setting to display the distribution of sediment in the Tahtaköprü Dam reservoir and the spatial changes in sediment deposition between 1980-1962, 2014-1980, and 2014-1962. The decrease in the storage volume capacity of the reservoir due to sediment accumulation was calculated as 9.15% at the maximum water level and 51.90% in the minimum water level comparing the digital elevation models of 1962, 1980 and 2014.

Sedimentation is one of the main problems of sustainable water resources management practices. Due to the decreasing trends in surface water potential in some basins in Turkey (Selek and Aksu, 2020), it is important to monitor the storage volumes of dam reservoirs, especially at minimum operation level, within the scope of sustainable and effective management of water resources. Sediment accumulation in dead volume and active volume in a reservoir effects reservoir operation rules. Sediment distribution is also has to be monitored to determine its effects on the dam water intake structure to prevent sediment threat. The amount of water stored in a dam reservoir is used to meet the needs for such as agricultural irrigation, drinking water supply, industrial and energy production purposes. Monitoring sediment effects on the dam body have importance in terms of operation-maintenance works of dams.

It has been determined in GIS environment that the maximum sediment load was occurred in Tahtaköprü Dam reservoir before the year of 1980. The digital elevation models prepared within the scope of this study is ready to facilitate the analysis of temporal and spatial changes of sediment accumulation in Tahtaköprü Dam reservoir in future. Bathymetric survey data of the reservoir was used to visualize spatial distribution of sediment accumulation. The results of this study will support decision makers for reservoir operation policies. The importance of monitoring land cover data in basins and monitoring bathymetry of reservoirs by hydrographic surveys was stated. The results of this study are also expected to support future water-related facilities and projects in the basin. Sediment thickness maps may be used for decisions on sediment removal techniques and amount of sedimentation.

The effect of the increase in the land cover and forest area in the basin on the reservoir sediment was examined, and it was evaluated that the decrease in sediment coming into the reservoir after 1980, can be seen clearly in the volume-elevation graph of Tahtaköprü Dam, was due to the increase in the percentage of forest areas in Tahtaköprü Dam drainage area until 2018. It is seen by the analysis of CLC data of 1990 and 2018 that the forest areas in Tahtaköprü drainage area is approximately 27% and 31% of the drainage area respectively.

Sediment observation studies in Turkey has started since 1961 (DSİ, 2013). The data used in project designs in previous years were limited. With the technological developments in the field of data acquisition, it is possible to compare sediment values in projects design and actual conditions in current state. Digital elevation models and sediment thickness maps of reservoirs will be useful in determining operational policies of dams, and following up-to-date status of total, active and dead storage volumes of dams.

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