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Application of GIS to Determine Storage Volume and Surface Area of Reservoirs: The Case Study of Buyuk Karacay Dam

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Abstract

Geographic Information Systems (GIS) are widely used in hydrological studies. Digital Elevation Model (DEM) was generated by using topographic map of Buyuk Karacay basin. This map can be used to determine basin characteristics, stream network, storage volume of reservoirs and surface area of the storage volume. In this study, Buyuk Karacay Dam which is still under construction in Hatay province of Turkey was chosen for the case study. Reservoir storage volume for the dam was estimated using the Ripple method. Procedures to determine storage volume according to the crest elevation are described. The maps of flow accumulation, flow direction, drainage network and surface area of storage volume maps were generated from DEM using Ilwis 3.6 GIS software and elevation-volume and elevation-area graphics were presented. According to Ripple method, dam reservoir storage capacity was found as 84 hm^3, in this capacity, estimated crest elevation was 360 meters from elevation-volume graphic and water surface area at the same storage capacity estimated to be 2.64 km^2 using elevation-area graphic. GIS application provides useful information for water manager and planners. Water storage capacity and water surface area can be analyzed for different dam locations easier than reservoir surveys method to find the most suitable location for the dam construction.

Key words: Buyuk Karacay Dam, Geographic Information Systems, Ripple method, Storage capacity

INTRODUCTION

The increase in water demand has necessitated to construct dams to store water. The current interest in reservoir systems is mainly from their utilization for irrigation, hydro-electric power, fishing, flood control etc. Dams are considered not only as a water resources system but also they are important in water resource planning and management.

The amount of water which can be stored in a reservoir is called reservoir capacity or storage capacity. However, this quantity is based on how much water is inflowing to and out flowing from the reservoir. The existing techniques for estimating reservoir capacity estimates include direct (reservoir surveys) and indirect methods (use of topographical maps). Field surveys to estimate water volume and surface areas of reservoirs, apparently are labor intensive and time consuming, and hence estimation of surface water resources of a basin at appreciable costs. Geographic Information Systems (GIS) has widely used in hydrological studies. GIS are simply processing, analysis and presentation of spatial data (1). These functionalities will enhance the feasibility and reliability of the decision making process in applications of the indirect methods.

The advantages of using DEM within GIS are to generate flow direction, flow accumulation, flow path, slope, aspect, elevation, and drainage network maps faster and accurately in comparison to the common classical cartographic methods (2).

To address this challenge an attempt has been made in this study to determine dam crest elevation for a appropriate reservoir storage capacity and water surface area by application of Geographic Information Systems (GIS). Ripple method (mass curve method) is one of the main procedures to be used to determine storage capacity, approximately. The crest height is calculated through the use of the results from the Ripple method. The GIS can be used easily to apply these calculations in determination the volume of storage in front of the crest of the dam. GIS also can be used to quantify changes in water volume of reservoirs (3).

Sattari et al. (4) used three different methods to determine irrigation reservoir capacity in East Azerbaijan, named Yalgiz Agac Dam. They found that dam capacity with Ripple method was 13.1 hm^3, with sequent peak algorithm was 6.86 hm^3, and with non-linear optimization was 6.19 hm^3.

Moore et al. (5) reported that widespread use of digital elevation map depending on developments in GIS technology accelerated hydrological and environmental research studies. The storage capacity was established for one or more different dam height and can be calculated by using the spatial information analysis on GIS.

Choong-Sung Yi et al. (6) used location analysis methodology to select the most suitable site for small hydropower plants in the upper part of the Geum river basin, in Korea. They applied Geo-spatial information system in location analysis and found six potential small hydropower plant sites.

This paper demonstrates the application of GIS as a decision support tool to calculate the amount of water volume and surface area of water volume for an appropriate dam crest height in the basin of the Buyuk Karacay Dam.

MATERIALS AND METHODS

In this study, Buyuk Karacay Dam basin is selected because of its data availability. The site of the reservoir is under construction near Antakya city of Turkey. Total basin area is of 99.6 km^2 in the southern part of the Hatay region, Turkey, at about 39^o 10' 00'' - 39^o 22' 00'' North and 34^o 39' 00''- 34^o 45'' 30' East. (7) Location of site was given in Figure 1.

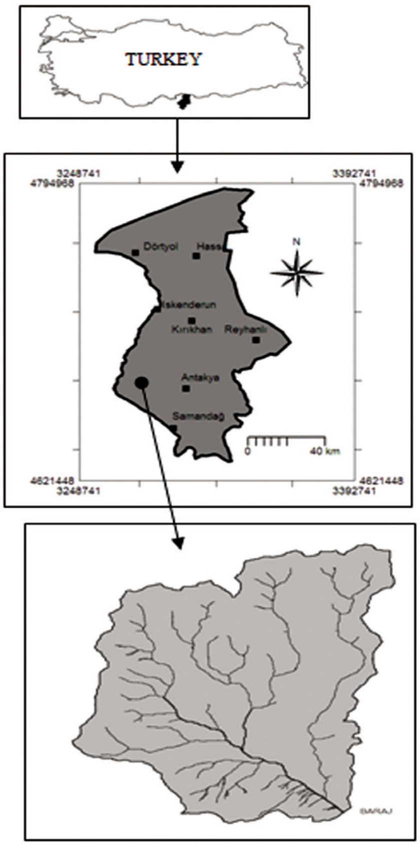

Figure1. Location of the study area

In the study area, climate is mild and rainy in winter months. The late summer is hot and dry. More rainfalls in the region fall in the months of April and May in spring. The available data of temperature and precipitation obtained from the Directorate of Meteorology of Antakya (DMI). The mean monthly precipitation and temperature data was given in Table 1. that follows.

This paper used Ripple method to obtain water potential of the reservoir which can be stored. The estimated storage capacity as the first planning criteria was used to determine appropriate dam crest elevation using the GIS based algorithm.

In the Ripple method, the expected total demand for water (hydro-electric power, irrigation, domestic use of water natural life in stream) is expressed as a constant rate over time and then plotted as a straight line with the slope equal to the demand rate. This straight line is constructed tangent to the mass curve at the beginning of the drought period. A second, parallel line is constructed tangent to the mass curve at the lowest point during the drought period. The vertical distances between these two lines represent the storage needed to meet the demand during the drought period (8).

The required data to calculate the storage capacity of the reservoir is based on topographic map that contains spatial data. Spatial data was taken from 1:10000 scale topographic map. The topographic map was transferred to GIS projected in the UTM coordinate system. This map was used to generate DEM (Digital Elevation Model) through the DEM menu in the hydro-processing tool. The derived DEM was used with DEM-Hydro-processing module of Ilwis 3.6 GIS software (9), for basin delineation.

Calculation of the storage depth by subtracting the elevation of the DEM from the water surface elevation of the reservoir created by the dam, and then summing up the storage depths according to the cell and multiplying them by the area of the unit cell. This scheme was described in Figure 2.

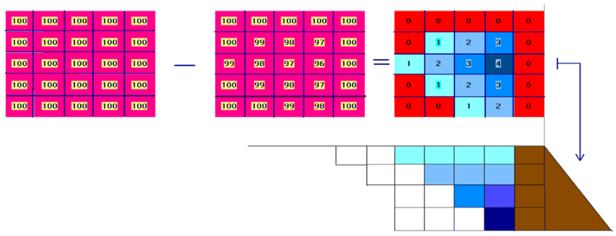

Figure 2. Conceptual scheme of calculating water volume

RESULTS AND DISCUSSION

Prediction of water volume

Water potential of the study area was determined using inflow and outflow data. Measured annual inflow data from 1978 to 1999 used to generate mass curve. Demand line was generated from total outflow that including for hydro-electric power, irrigation, domestic use of water natural life in stream.

Table 1. Mounthly precipitation and temperature

Months	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Precipitation (mm)	128.7	139.2	112.1	34.3	41.4	7.9	0.5	0.7	3.3	39.0	119.7	134.3	761.1
Temperature(°C)	8.0	9.6	13.0	17.1	20.9	24.5	26.8	27.3	25.5	20.6	13.0	9.4	17.7

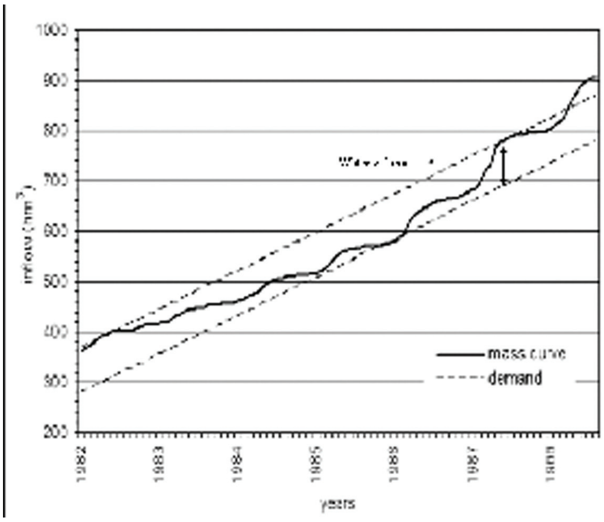

Figure 3. Water volume according to Ripple method

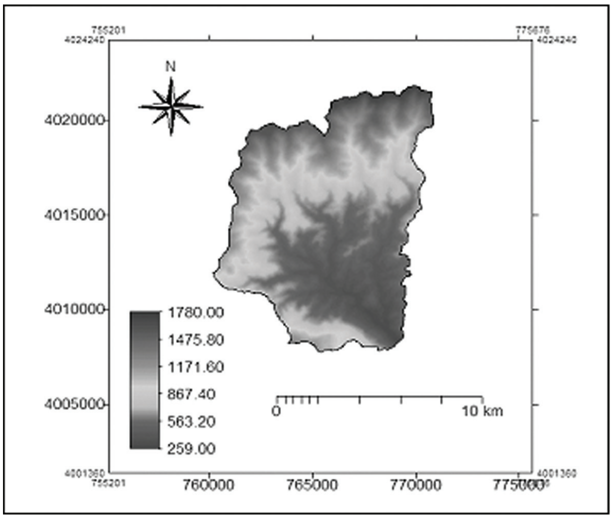

Figure 6. DEM of the study area

Maximum difference in mass curve and demand line gives the amount of water volume which can be stored based on inflow data of the study area. Maximum difference was obtained between 1982 and 1989 years shown in Figure 3. Water volume was calculated as 85 hm^3. Dam crest elevation was determined based on this prediction.

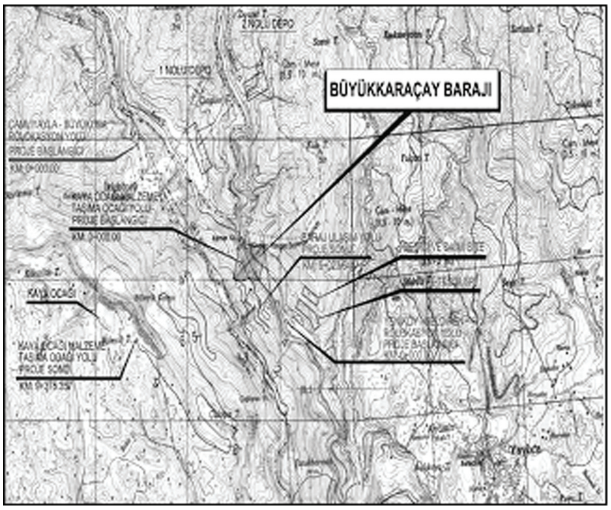

Figure 4. Topographic map of the study area

Digital Elevation Model

The contour map of scale 1:10000 of the study area was imported to Ilwis as shown in Figure 4. This map was digitized (Figure 5). Digitized topographic map was used in preparation of Digital Elevation Map (DEM) with cell size 5m x 5m as shown in Figure 6. DEM shows the maximum elevation value is 1780 and minimum elevation value is 259 so that the study area is highly sloppy and hence runoff is more.

Basin Delineation

The derived DEM was used with Hydro-process module of Ilwis for basin delineation. The possible sinks are performed for eliminating the unreasonable low elevation cells on the DEM with respect to the surrounding cells.

Boundary of basin, flow accumulation flow direction, drainage network and stream order maps were generated using DEM-Hydro processing module.

The flow direction of each cell obtained based on the relations between the neighboring cells. By the help of the flow direction map, the flow accumulation map was determined. In this map, flow accumulation value of a cell shows the number of the cells that will drain to this cell.

Figure 5. Digitized topographic map of the study area

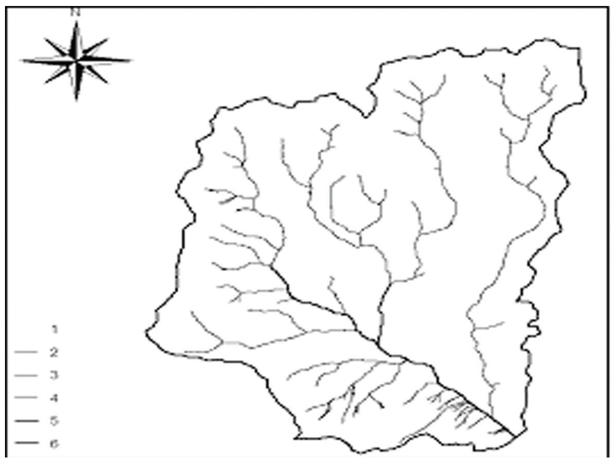

Figure 7. Stream network ordering map

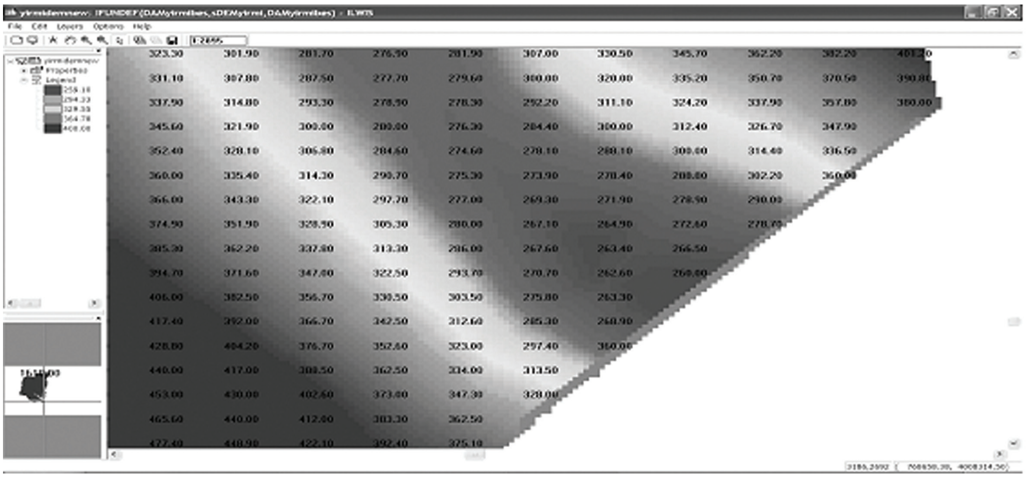

Figure 8. Combined of DEM and DAM map

Water drainage network map has been generated from flow accumulation map by using drainage network extraction option of the Ilwis operations menu. Stream network map, water flow direction map and DEM used for preparation of stream network order map. This map has been ordered using the Strahler's stream ordering method. It consists of maximum up to six order stream as shown in Figure 7.

Since the Dam location is already decided, storage capacity and surface area of water was calculated for different dam crest heights at the location of the dam. The graphics of reservoir water volume and elevation have been generated using Ilwis graph menu.

In this study, new raster map was created using value domain on the DEM called DAM. Cells on this map assigned as dam height at the dam location then these two maps were combined using following equation:

Demnew = IFUNDEF (DAM, DEM, DAM)

This means that if a cell in the map DAM is undefined, the value of the DEM is assigned; else the value was given in map DAM. Output map (Demnew) was shown in Figure 8.

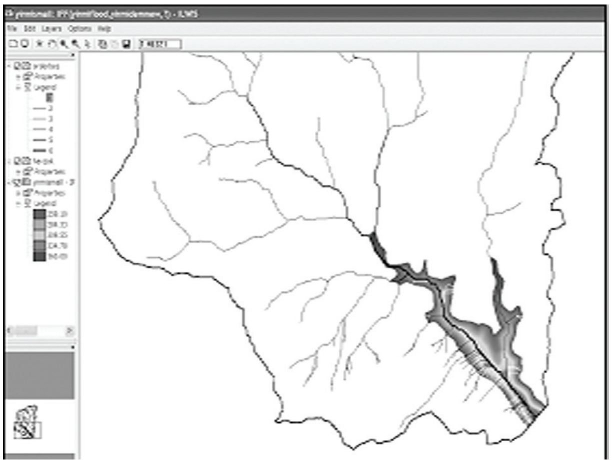

Figure 9. Output map of cross map

Another map was generated as the value under dam height assigned TRUE and others FALSE using bool domain. Iteration with propagation was used until there are no changes anymore in any of the pixel values. The output map was given in Figure 9. From the combined raster map, the number of cell filled with water is found.

Table 2. A part of cross table of DEM and number of TRUE pixels

	yirmiflood	yirmismall	NPix	Area	depth	volume	cumarea	cumvol
True * 259.10	True	259.10	3	75	100.9	7567.5	75	7567.50
True * 259.20	True	259.20	5	125	100.8	12600.0	200	20167.50
True * 259.30	True	259.30	3	75	100.7	7552.5	275	27720.00
True * 259.40	True	259.40	12	300	100.6	30180.0	575	57900.00
True * 259.50	True	259.50	7	175	100.5	17587.5	750	75487.50
True * 259.60	True	259.60	14	350	100.4	35140.0	1100	110627.50
True * 259.70	True	259.70	10	250	100.3	25075.0	1350	135702.50
True * 259.80	True	259.80	24	600	100.2	60120.0	1950	195822.50
True * 259.90	True	259.90	6	150	100.1	15015.0	2100	210837.50
True * 260.00	True	260.00	59	1475	100.0	147500.0	3575	358337.50

DEM Cross Operation on this map was provided as number of TRUE cells and DEM elevation values. These values were derived from output of Cross Table. A part of the Cross Table was given in Table 2.

Graphics of reservoir water volume and elevation have been generated using Ilwis graph menu for Buyuk Karacay Dam. Elevation-area and elevation-water volume graphics were given in Figure10 and Figure 11 respectively.

From the combined raster map, the number of pixel filled with water was found. These pixels were multiplied by pixel area to obtained volume of water in each pixel. Water volume was calculated from cumulative of the pixels which filled water. For calculation of water surface area, the center point was taken and continued visiting recursively all those neighbors whose heights are less than the dam height and were connected to the center cell through other cells. The base case for this algorithm will be the boundary condition or finding the cell whose all non visited neighbors have heights more than the dam height.

Water volume was calculated with Ripple method as 85 hm^3. For this volume, dam crest elevation of 360 meters and water surface area of reservoir found to be 2.64 km^2. These graphs also give approximate water volume and surface area for different dam crest elevations.

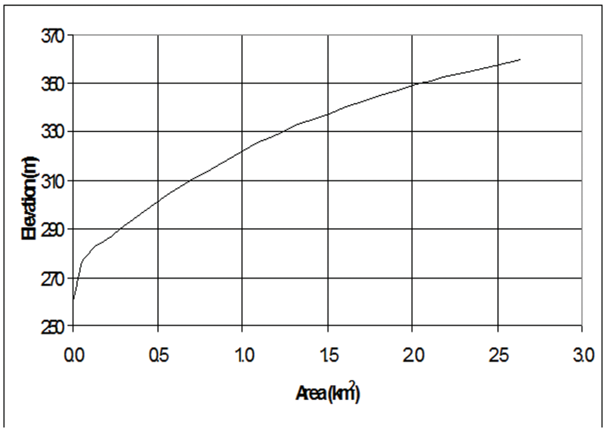

Figure10. Graph of elevation-area

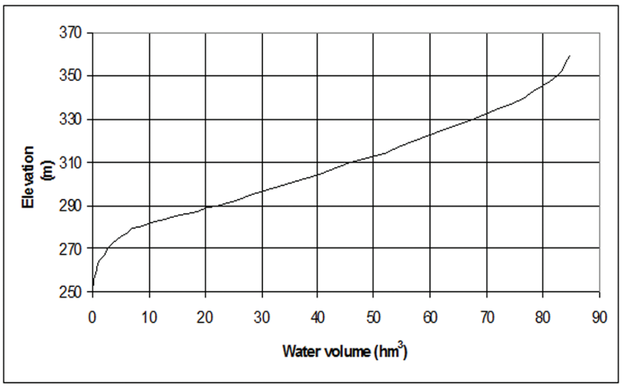

Figure 11. Graph of elevation-water volume

CONCLUSION

In this study, DEM map was used to determine basin characteristics, stream network, storage volume of reservoirs and surface area of the storage volume. These calculations can be done easily and quickly using GIS.

Drainage network and surface area of storage volume maps were generated using Ilwis 3.6 GIS software and elevation-volume and elevation-area graphics were presented. According to Ripple method, dam reservoir storage capacity found as 84 hm^3, in this capacity, the estimated dam crest elevation was 360 meters from elevation-volume graphic and the estimation of reservoir surface area was 2.64 km^2 from elevation-area graphic.

This application seemed to provide useful information for water managers and planners. Water storage capacity and water surface area can be analyzed for different dam locations easier than reservoir surveys method to find the most suitable location for the dam construction.

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