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Yarı-Kurak Bölgelerde Rezervuar Yeri ve Kapasitesinin CBS ile Analizi

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Özet

Coğrafi Bilgi Sistemleri (CBS), akarsu ağı ve alt havza (SWS) sınırlarının belirlenmesi gibi su havzalarının hidrolojik özelliklerini tanımlamak için kullanılabilir. Yarı-kurak bölgelerde, althavzaların rezervuar hacmi ve kapladığı su yüzeyi alanının tahmininde, su depolama yerinin ve depolanacak mevcut su potansiyelinin bilinmesi önemlidir. Bu çalışmada, CBS ortamında Sayısal Yükseklik Modeli (SYM), Türkiye'de Asi nehri havzası içindeki alt havzalara uygulanmıştır. Topografik açıdan dar, derin vadiler, ekolojik, çevresel ve jeolojik açıdan uygun olan aynı zamanda mevcut su verimi dikkate alınarak 13 potansiyel rezervuar yeri, bulunmuştur. Uygun olmayan rezervuar yerleri ise, jeolojik oluşum, yüksek verimli orman ve tarım alanları ve yerleşim yerleri dikkate alınarak belirlenmiştir. Belirlenen alt havzaların % 50 , % 80 ve % 90 olasılık havza su verimi potansiyelleri, Turc yöntemi kullanılarak hesaplanmıştır. Drenaj ağı, depolanan suların haritaları, yükseklik-hacim ve yükseklik alan grafikleri, Entegre Arazi ve Su Bilgi Sistemi (ILWIS) 3.7 kullanılarak oluşturulmuştur. Su depolama kapasitesi açısından, dört rezervuar yerinin uygun olduğu tespit edilmiştir. Aynı zamanda CBS ile uygun rezervuar yerleri, su depolama potansiyelleri ve su yüzeyi alanları kısa zamanda elde edilmiş ve haritalanmıştır. Bu çalışma ile havzalarda uygun rezervuar yerlerinin ve su depolama hacimlerinin belirlenmesinde ön fikir verme açısından CBS kullanımının önemli ve yararlı olduğu anlaşılmıştır.

Anahtar Kelimeler: Coğrafi Bilgi Sistemleri (CBS), Turc yöntemi, Rezervuar yeri, Ilwis, Asi Nehri Havzası

Reservoir Location and Capacity Analysis Using GIS in Semi-Arid Region

Abstract

Geographic Information Systems (GIS) can be used to identify hydrological characteristics of watersheds such as stream network and extraction of sub-watersheds (SWS). Estimation of volume and water surface area of reservoirs in SWS is essential to know the amount of potentially available water, storage location and storage capacity in semi-arid regions. In this study, Digital Elevation Model (DEM) in GIS environment was applied to SWS within the Orontes river basin in Turkey. Thirteen potential reservoir construction sites were found by considering mainly narrow, deep valleys, minimum ecological and environmental disturbance, high elevations, a watertight reservoir area, no geological hazards, and potential of water yield. Non-suitable reservoir locations were determined by considering geological formation, high productive forest and agricultural areas and settlement. Potential water yield for extracted SWS at 50%, 80% and 90% probabilities were determined using the Turc Method. Stream network, surface area of stored water maps, elevation-volume and elevation-area graphics were generated by using Integrated Land and Water Information System (ILWIS) 3.7. Four reservoir locations were determined to be suitable in terms of water storage capacities. By applying the GIS approach, a large area can be precisely surveyed within a short period of time and this study will be beneficial for the future capacity analysis of reservoirs in the watersheds.

Key words: Geographic Information Systems, Turc method, Reservoir location, Ilwis, Orontes River Basin

INTRODUCTION

Construction of water reservoirs for supplying irrigation water in drought period is the most viable way to overcome bottlenecks in agricultural production in semi-arid regions. Simple and economical water storage structures have been built to provide agricultural irrigation, drinking water, flood control, fisheries, and recreational purposes.

Determining a suitable location for the water reservoirs depends on many factors that need to be studied in detailed. In the last decade, the rapid advances in computer technology and the widespread use of Geographical Information Systems (GIS) become essential tools for analysing optimum reservoir locations [1,2]. GIS are simply process, analyses, and presentation of spatial data [3].

The numerous advantages of DEMs [5-8] provide extraction of any watershed parameters with accuracy and details depend on their quality and resolution [9]. DEMs have widely used in hydrological modelling [10-14], to determine, slope steepness, flow direction, stream order, areas, boundaries, and outlets of SWS [2].

For identifying suitable location and calculating water storage capacity of reservoirs within a SWS, it is essential, (i) to determine water yields for SWS (ii) suitable outlet location of SWS (iii) amount of water can be stored in reservoir for different crest heights. These can be determined by surveying in details. However, intensive field data measurement and post data processing, often limit the frequency of these surveys. Alternatively, contouring and surface mapping within GIS environment provide accurate calculations of reservoir volume and water surface area. This significantly reduces financial burdens, time, and workload to calculate reservoir capacities. The capacity calculation enables to have range of reservoir volumes and surface areas of water for the different crest heights, in comparison to the traditional methods. This gives a prior knowledge of the resource availability for water operators to manage natural resources and hydraulic infrastructure in a sustainable manner.

This research proposes the use of GIS approach in order to calculate the volume and surface area of water at a given crest height for assessing the reservoir capacity and comparing the calculated water yields for SWS to find out suitable reservoir locations in semi-arid region in Turkey.

MATERIALS AND METHODS

The study was conducted in a small part of the Orontes river basin, covered 7959 km^2, in the southern part of Turkey. The location of the study area, covered 43 km^2 is given in Figure 1. Antakya is the largest city in the basin, with a population of 220000. Orontes River is the main river system, flowing from Syria trough the Amik plain and then discharging into the Mediterranean Sea. The Amik plain is located in the middle of the basin and its flat lands have great potential for crop production.

Four different soil types have been classified in the basin: podzolic soil, brown forest soil, alluvial soil and terra rossa. Alluvial soils in the basin are of fine texture, impermeable, and low hydraulic conductivity. Study area is a mountainous region. Gradient ranging from 5% to 90% and the average slope of the study area was 25% [15].

Region has typical Mediterranean climate, mild and rainy in winter months, and hot and dry in the summer months. Average annual precipitation and temperature in the basin area are 1210 mm and 18^{o}C, respectively. More rainfall has fallen in spring, especially in the months of April and May. Serinyol Meteorological Station (SMS) that is the closest to the study area has only temperature and recipitation data available, evaporation data was obtained from Antakya Meteorological Station (AMS) and given in Table 1.

The ILWIS 3.7 academic version of GIS software [16] was used for the automated reservoir volume and surface area of water calculations and hydrologic analyses. Flow chart of study was given in Fig. 2.

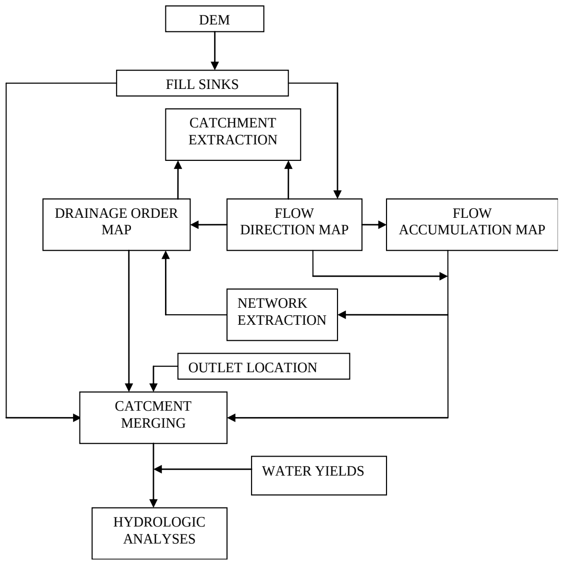

Figure 2. Flow chart of the study

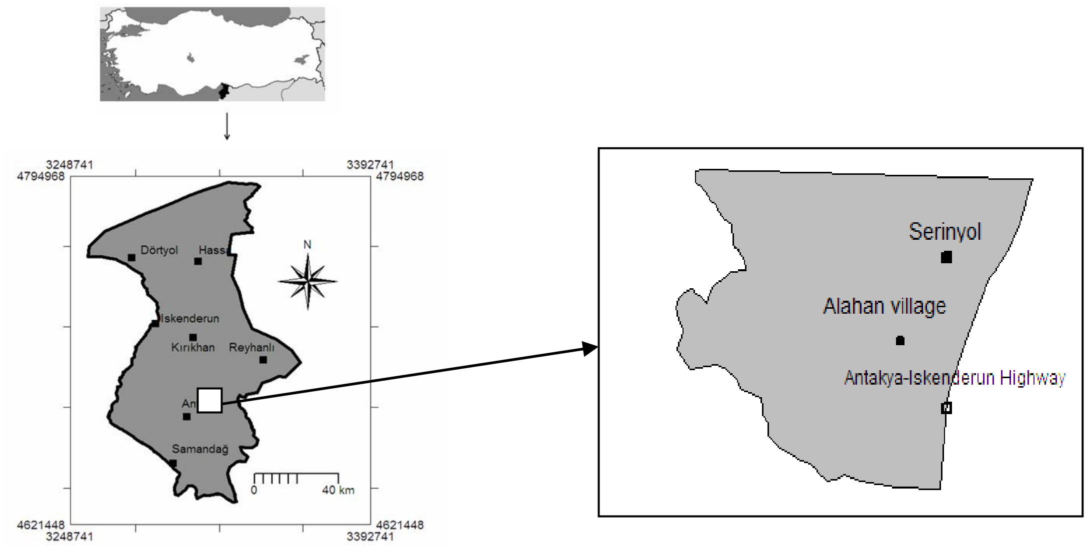

Figure 1. Location map of study area

Table 1. Averaged of precipitation, temperature and evaporation data of study area

Climatic data	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 (^{o}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
**Evaporation (mm)	50.0	61.6	94.7	125.8	164.6	203.3	236.1	231.7	198.3	142.0	81.3	46.0	1555.6

* Data from SMS
** Data from AMS

In this study, Turc method was used to determine water yields for each SWS. The annual water yield expressed in this method was reported by Shaw [17] as:

$$V = A.h.10 \quad (1)$$

where, V is the annual water yield (m^3 $year^{-1}$), A is the area of basin (hectare), h is the surface run-off depth that occurred in the watershed (mm $year^{-1}$).

The surface run-off depth is calculated as:

$$h = P - ET \quad (2)$$

where, ET is the evapotranspiration (mm $year^{-1}$) and P is the mean precipitation (mm $year^{-1}$).

ET is defined as:

$$ET = \frac{P}{\sqrt{0.9 + \left(\frac{P^2}{L^2}\right)}} \quad (3)$$

the correlation parameter L is described as:

$$L = A + 25T + 0.05T^3 \quad (4)$$

where, T is the mean annual temperature (^oC) and A is the watershed flow coefficient (0-300).

Calculated A value was 104.2 for the Orontes river basin [18]. In this method, temperature was adjusted as decrease 0.5°C every 100 meter from the sea level. Averaged elevations of SWS were calculated as follows [19].

$$H_a = \frac{H_1 + H_2}{2} \quad (5)$$

where, H_a is the averaged elevation of SWS (m), H_1 is the maximum elevation of SWS (m) and H_2 is the outlet elevation of SWS (m).

In the Turc method, precipitation at 50%, 80%, 90% probabilities were used to find probability of water yield in SWS as follow:

90 % probability of precipitation:

$$P_{90} = \overline{X} - 1.28(S_{n-1}) \quad (6)$$

80% probability of precipitation:

$$P_{80} = \overline{X} - 0.845(S_{n-1}) \quad (7)$$

50% probability of precipitation:

$$P_{50} = \overline{X} \quad (8)$$

where, $\overline{X}$ is the mean annual precipitation (mm) and S_{n-1} is the standard deviation.

A 10 m interval contour map was derived from the contour data obtained from topographic map. DEM was generated from contour map using interpolation module of ILWIS 3.7. with a grid size of 4m x 4m. DEM was used to generate flow direction map, flow accumulation map and stream order map. Boundaries and outlets of each SWS were extracted using these maps.

The most suitable reservoir locations were selected by considering mainly narrow, deep valleys, minimum ecological and environmental disturbance, a high elevation, a watertight reservoir area, no geological hazards, and potential of water yield. Non-suitable reservoir locations were determined by considering high productive forest and agricultural areas and settlement.

RESULTS AND DISCUSSION

The required data to calculate the storage capacity of the reservoirs 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 through the DEM menu in the Hydro-Processing Tool in ILWIS. Thereafter, all sinks were filled, prior to the creation of the flow direction data. Such process would help eliminate any unwanted pits or sinks in the DEM that might produce erroneous flow direction. Digital Elevation Model (DEM) for study area is shown in Figure 3. DEM shows that the maximum elevation value is 1320 m and minimum elevation value is 93 m so that the study area is highly sloppy and hence more run-off is to occur.

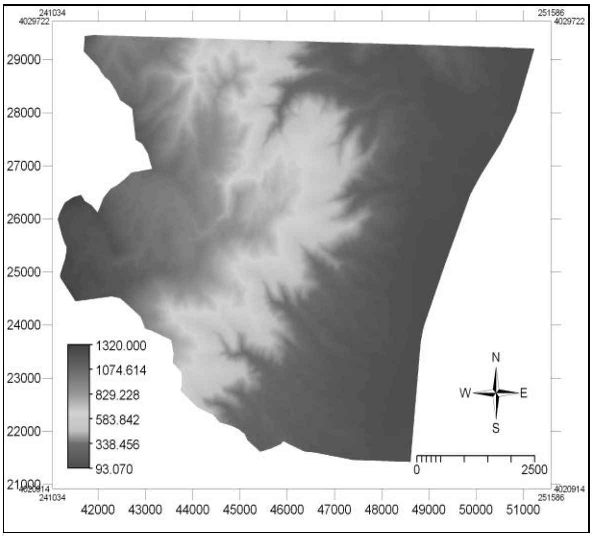

Figure 3. DEM of the study area

Flow direction (Fig. 4) and flow accumulation map were obtained from DEM. Stream network map has been generated from flow accumulation map by using extraction of stream network option of the ILWIS operations menu. Stream network map, water flow direction map and DEM used for preparation of drainage network ordering map. This map has been ordered using the Strahler's stream ordering method. It consists of maximum up to five order stream as shown in Fig. 5.

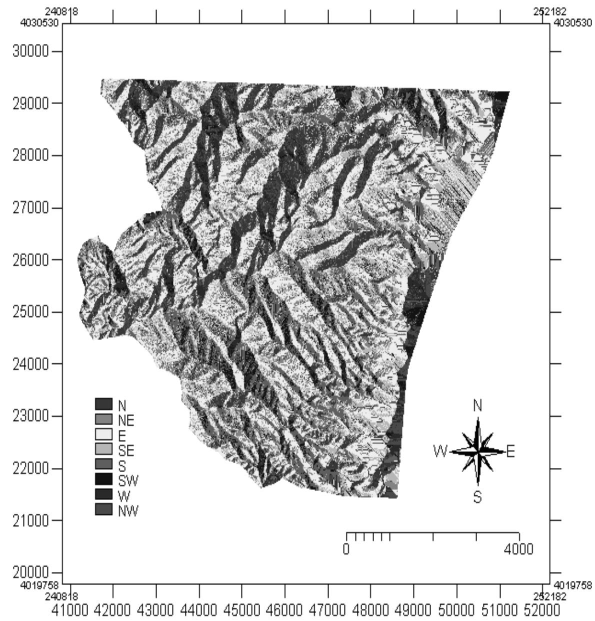

Figure 4. Flow direction map for the study area

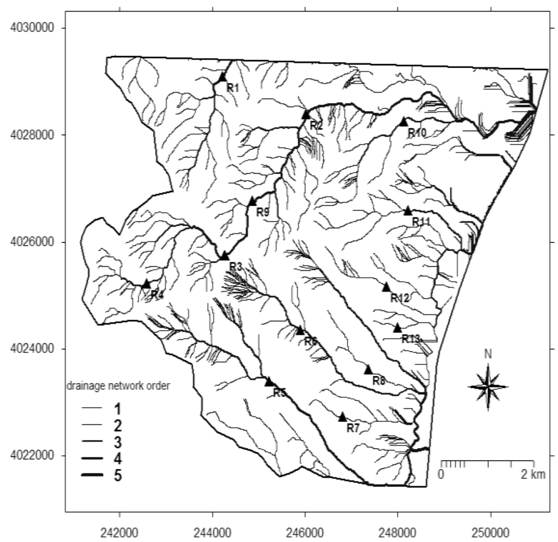

Figure 5. Reservoir locations and stream network order map

By using the integrated GIS tools in the computer program ILWIS, watersheds can be defined either by drawing them, by using an existing GIS layer or a DEM. In this study, SWS were extracted from DEM, also using flow direction drainage network and drainage order map. Extracted boundaries of thirteen SWS were shown in Fig. 6. The derived DEM was also used with DEM-Hydro-Processing Module of ILWIS 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.

Characteristics of SWS as follows; basin perimeter (m), basin area (km^2), the area of upper SWS (km^2), total flow length (m), drainage density (m/km^2), and the longest stream length (m) were calculated in GIS environment (Table 2).

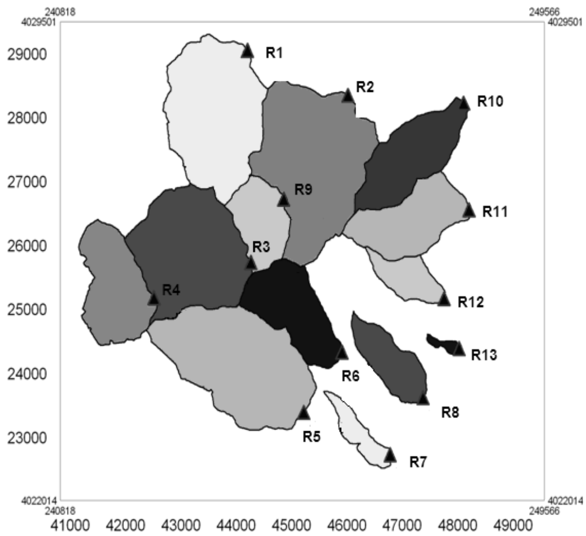

Figure 6. Reservoir boundaries of SWS

Stored water surface areas for each reservoirs were calculated using elevation heights sub-true loop with the iterator to the water will fill the field properly, other areas identified as false. Generated map of stored water surface areas shown in Fig. 7 and shown as 3D in Fig. 8.

Since, the crest location is already decided, storage capacity and surface area of water were 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 [20].

Elevation, number of cells and covered area at the same elevation were calculated by using the menu of the cross table calculation. Depth of the each cell was calculated as a difference between assigned crest elevations and cell elevations. Volume was calculated by multiplying of cell area and depth. Cumulative area and cumulative volume were determined cumulative menu of the table calculation module of the ILWIS.

For calculation of surface area of water, the point, which is lower than crest elevation, was taken and continued visiting recursively all those neighbors whose heights are less than crest elevation and were connected to the taken cell through other cells. Iteration menu was used to find out of this procedure. 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 crest heights of the reservoir.

Using this approach, graphics of elevation-reservoir water volume and elevation-water surface area have been generated for each SWS using cumulative area and cumulative volume values in ILWIS Graph Menu. Elevation-area and elevation-water volume graphics for reservoir number 5 were given in Fig. 9 and Fig. 10 respectively.

Table 2. Characteristics of SWS in the study area

Res. No	SWS perimeter (m)	SWS Area (km^2)	Upper SWS (km^2)	Total flow length (m)	Drainage density (m/km^2)	The longest stream length (m)	SWS coordinate (UTM)
1	7881.78	3.48	3.48	18927.1	5429.3	2820.0	243610.25 N 4027961.55 E
2	9241.65	4.10	10.31	30525.2	7435.2	3238.3	245300.79 N 4027130.57 E
3	7848.01	3.28	5.09	21533.9	6547.3	3228.2	243154.95N 4025865.55 E
4	6032.92	1.80	1.80	8093.3	4492.6	1729.7	241875.45N 4025421.55 E
5	8386.33	3.75	3.75	31402.3	8363.8	3477.0	244106.45N 4024093.55 E
6	5888.28	1.63	1.63	17435.0	10699.8	2248.8	244979.45N 4024933.55 E
7	4454.09	7.93	7.93	3774.1	4756.8	1625.6	245769.26N 4022385.55 E
8	4485.49	9.26	9.26	2299.1	2480.7	1571.2	246740.45N 4024261.55 E
9	4465.75	1.11	6.20	5395.6	4840.2	1354.4	244460.85N 4026313.55 E
10	6351.38	1.77	1.77	11246.5	6350.4	3139.4	247139.12N 4027379.55 E
11	6049.05	1.70	1.70	8293.7	4876.9	2461.4	247139.58N 4026459.55 E
12	3201.0	4.61	4.61	4560.6	9886.0	1301.0	248002.45N 4025797.55 E
13	1569.46	0.82	0.82	470.0	5676.2	470.0	247762.62N 4024457.55 E

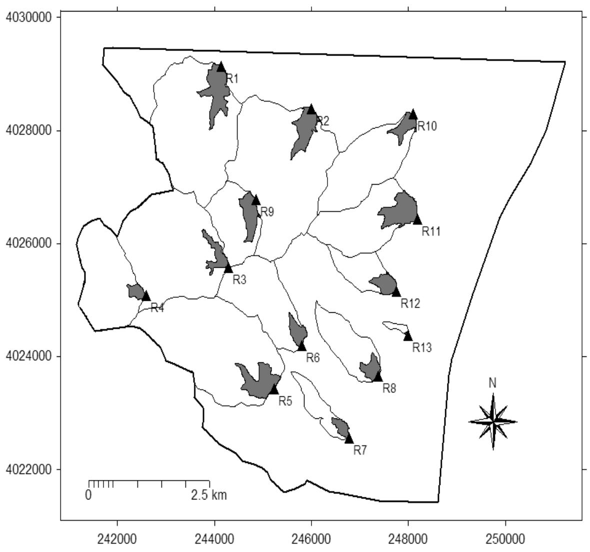

Figure 7. Reservoirs and stored water surface areas

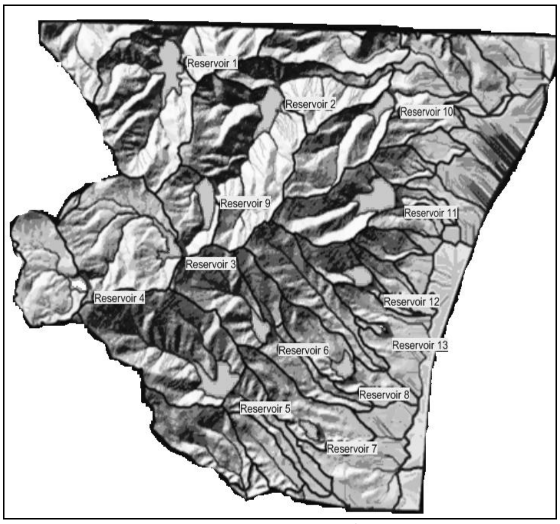

Figure 8. Reservoir and stored water surface areas (3D)

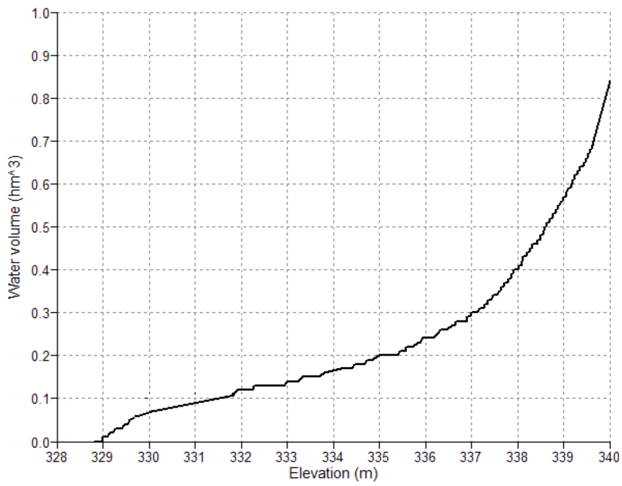

Figure 9. Water volume-elevation graphic for reservoir number 5.

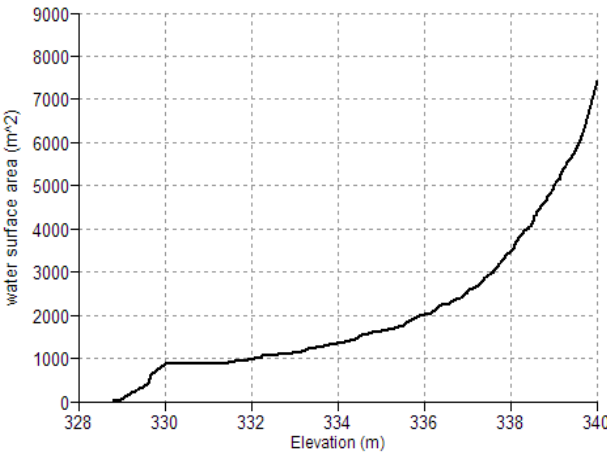

Figure 10. Water surface area-elevation graphic for reservoir number 5.

Table 3. Water yields and chracteristics of reservoirs

Res. No	SWS area (km^2)	Water yield (hm^3)			Outlet elevation (m)	Crest height (m)	Storage capacity (hm^3)	Area of water surface (m^2)
		50%	80%	%90				
1	3.48	0.972	0.586	0.414	584	19	0.604	4 880
2	10.30	2.450	1.419	0.975	308	35	0.169	25 088
3	5.08	1.520	0.933	0.668	868	20	0.595	11 520
4	1.80	0.575	0.358	0.260	1 080	22	0.368	5 568
5	3.75	0.933	0.546	0.378	329	10	0.567	4 960
6	1.62	0.385	0.223	0.153	328	11	0.229	2 432
7	0.45	0.091	0.050	0.033	183	5	0.087	3 744
8	0.92	0.182	0.101	0.067	157	5	0.178	5 840
9	6.19	1.608	0.952	0.664	623	23	0.584	4 064
10	1.77	0.370	0.207	0.139	189	6	0.395	7 008
11	1.70	0.364	0.205	0.138	171	7	0.385	3 104
12	0.65	0.127	0.070	0.046	185	5	0.144	1 584
13	0.08	0.016	0.089	0.059	132	4	0.017	2 619

For the reservoir number 5, water volume can be stored at 90% probability was calculated as 0.378 hm^3. In this volume, reservoir crest elevation and crest height were found 339 meters and 10 meters, respectively. At the same elevation, water surface area of reservoir found to be 4960 m^2.

These graphs also provide water volume and area of water surface for different crest elevations.

Calculated water yields for each SWS at 50%, 80% and 90% probabilities by using the Turch method and reservoir characteristics of SWS that were taken from graphics were given in Table 3.

According to Table 3, areas of SWS were found between 0.087 and 10.3 km^2 including areas of the upper SWS. The highest water yields were found for reservoir number 2 as 2.45, 1.41, and 0.975 hm^3 at 50%, 80% and 90% probabilities respectively. Also, reservoir number 2 had the highest SWS area and water surface area (0.025 km^2).

Outlet elevations of reservoirs changing from 132 to 1080 m and crest height of the reservoirs found minimum 4 m and maximum 35 m by considering the topographical conditions.

The water yields of each SWS can be compared with its storage capacity. Water yields at 50% probability in SWS were found to be higher than nine (Numbers 1-9)
SWS storage capacities of other reservoirs (numbers 10, 11, 12, 13) are not big. However, water yields at 90% probability in SWS provide enough water for reservoir numbers 2, 3, 9, and 13. Hence, these four reservoirs were found to be suitable in terms of storage capacities.

CONCLUSION

Developing the map information of the reservoirs and sub watershed hydrologic characteristics can be identified quickly and accurately by using GIS. The thirteen best possible reservoir locations were identified using GIS considering topographical, geological, environmental and hydrological criteria's. Water yields with 90% probability in SWS provide enough water for reservoir numbers 2, 3, 9, and 13. Economical criteria's and geological formations also must be considered for selecting the best reservoir locations. This study shows that GIS is highly applicable for reservoir planning.

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