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ORIGINAL PAPER

Gis-multi criteria decision analysis-based land suitability assessment for dam site selection

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Abstract
In this study, the appropriate areas were determined to select the most suitable dam sites within the borders of Sivas/Turkey with the help of Geographic Information System (GIS) according to the Analytical Hierarchy Process (AHP) method, which is one of the multi-criteria decision-making (MCDM) methods. Nine criteria (elevation, slope, distance to roads, rainfall, lineament density, distance to residential areas, land use/land cover, soil types and stream density) were used for dam site selection. The CR (Consistency) value was calculated as 0.054 for the criteria considered in the selection of the dam site within the scope of the AHP method, and this value showed that the results obtained were consistent and acceptable. The suitability categories revealed by the dam site selection suitability map created with the method were represented by 5 different classes "very high (12.70%)," "high (20.63%)," "medium (25.43%)," "low (25.11%)" and "very low (16.12%)." Most of the dams currently operating in Sivas province (64.63%) were in the "high" and "medium" level of suitability, while the majority of the planned dams (57.14%) were represented by the "low" class of suitability. The dam site selection suitability mapping obtained as a result of the study is a very important tool in terms of providing resource data to decision makers for regional water resources management and sustainable development.

Keywords Dam site selection · Analytical hierarchy process · Geographic ınformation system

Introduction

Future water scarcity is a global concern (Shahraki, 2019). Therefore, it is of great importance to discover new water resources or to find more effective ways to manage water, especially with the rapid development and population growth in industry and agriculture. In arid and semi-arid regions with low annual rainfall, water supply is a critical responsibility of local governments and water management is a serious need (Shahraki, 2019). The need to build dams is increasing in issues such as drinking water supply, irrigation, water resources efficiency, drought control system, and the impact of this construction can be social, environmental and economic (Altınbilek, 2002).

One of the most important components of water resources management is dam location determination (Pohekar and Ramachandran 2004). The selection of the most suitable site for dam construction is one of the most complex and controversial decisions in water supply management (Noori et al. 2018, 2019). An optimal site selection can increase the safety of the reservoir and groundwater regeneration in a region, while a bad site selection can negatively affect this situation. Selecting an unsuitable area for the dam site can cause detrimental effects such as adverse biophysical, socio-economic, and geopolitical effects, often through the loss of ecosystem services provided by fully functioning water systems (Fearnside, 2016; Mulatu et al. 2018).

The dam site selection is usually made by traditional methods such as traditional decision-making techniques or based on political interests (Jozaghi et al. 2018). Recently, remote sensing (RS), geographic information systems (GIS), and machine learning (ML) techniques have emerged as some of the most suitable approaches for dam site selection. Accordingly, advancement in satellite

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and computational power has increased the opportunity to manage different hydrological parameters and terrain features (Kumar et al. 2008). Combining spatial information with different advanced numerical, factual and decision-making strategies such as RS and GIS, fuzzy logic, analytical hierarchy process (AHP), Boolean logic, weighted overlay analysis, multi-criteria evaluation techniques, and artificial intelligence have found widespread application in dam site selection (Kumar et al. 2008).

Various studies are required to determine the optimal dam location. Decision making in this field is a complex procedure because this issue is related to different qualitative and quantitative criteria. Therefore, MCDA methods can be used to solve this problem. MCDA includes a group of traditional and special techniques that can assist decision makers in dealing with the difficulties they face while simultaneously handling large amounts of complex information (Baban and Wan-Yusof, 2003). GIS and MCDA are effective tools for spatial analysis and decision making (El-Shirbeny and Abutaleb, 2018). The most widely known MCDA methods are simple additive weight, ideal point method, AHP and fuzzy logic. MCDA is one of the branches of operations research that investigates decision-making problems under certain decision criteria (Pohekar and Ramachandran, 2004). GIS, which can integrate big data layers, is a computer-based system that processes attribute data as well as spatial data, where geographic information is a key feature (Shad et al. 2017). GIS-integrated MCDA techniques help decision makers choose between alternative solutions in determining suitable areas for the construction of dams, taking into account many criteria (Belton and Stewart, 2002). This type of decision making uses a set of criteria rather than just one optimal evaluation criteria (Pohekar and Ramachandran, 2004).

AHP is an effective multi-criteria decision-making technique used to solve decision problems in various fields. The AHP approach is an effective tool for systems analysis and solves decision problems by reducing complex decisions to a series of pairwise comparisons (Tung and Tang, 1998). In addition, AHP includes an effective technique to control the consistency of the decision maker's evaluations, thus reducing the bias in the decision-making process (Abdullah et al. 2018). GIS-based AHP and other MCDA methods are widely used in dam site selection to highlight key factors affecting dam site suitability (Yasser et al. 2013; AlJubaely et al. 2016; Othman et al., 2020). Many methods are mentioned in the literature to determine whether an area is suitable for dam site selection using the multi-criteria method (Table 1).

In the literature, there are many studies on dam site selection based on the GIS-AHP method. This studies include the applications of the similar method in different regions. This study is important in terms of presenting a method for evaluating the suitability criteria that contribute to the suitability level of the dam site at the regional scale (study area) and supporting other studies in the literature on this subject. The aim of this study is to determine suitable areas for dam site selection in Sivas province by using GIS-based AHP approach. The objectives taken into account to achieve the aim of the study are: (1) to evaluate and map the criteria that are effective in dam site selection, (2) to create a suitability map by applying AHP and weighted analysis, and (3) to identify suitable areas for dam site selection. In addition, The Receiver Operating Characteristic (ROC) curve was

Table 1 Studies on dam site selection and techniques used

Utilized technique	Study area	References
Weighted overlay In Arcgıs	Bachok, Kelantan	Rahman et al. (2021)
AHP	Semi-arid region of Mozambique	dos Anjos Luís and Cabral, (2021)
RS and GIS	Imo state, Southeastern, Nigeria	Ajibade et al. (2020)
RS and GIS	Greater Zab river in northern Iraq	Noori et al. (2019)
GIS and machine learning approach	Sharjah-UAE	Al-Ruzouq et al. (2019a, b)
AHP and TOPSIS techniques	Sistan and Baluchestan province, Iran	Jozaghi et al. (2018)
GIS with AHP	Mbeere North, Embu County-Kenya	Njiru and Siriba, (2018)
AHP	Abnahr dam, Iran	Esfahani et al. (2018)
RS and GIS	Tabuk city-Philippines	Abushandi and Alatawi, (2015)
MCDM	Harsin/Iran	Minatour et al. (2015)
Multi criteria evaluation (MCE) in the GIS	Kal Ajy basin	Safavian and Amani, (2015)
AHP	Harsin city-Iran	Yasser et al. (2013)
GIS, fuzzy logic and AHP	Debub district in Eritrea	Tsiko and Haile, (2011)
Weighted overlay analysis	Bakhar watershed of Mirzapur district, Uttar Pradesh, India	Kumar et al. (2008)
GIS-AHP	Sivas-Turkey	This study

prepared by using the suitability categories of the dam site suitability map and the dams existing in the study area, and the accuracy of the dam site suitability map was analyzed.

Materials and methods

Study area

The province of Sivas is located in the upper Kzlrmak Region in Central Anatolia. The province, which is Turkey's second biggest after Konya and covers 27.386 km2, is situated between 36 and 39o east longitudes and 38o and 41o north latitudes (Fig. 1). Sivas province has a plateau shape, with valleys between single mountains or mountain groups, hills and sunken plains. The summer of Sivas is short, hot and dry, while its winter is long, very cold and snowy. Sivas is considered the coldest province in Central Anatolia. Sivas is characterized by large and sharp changes in temperature between summer and winter, and even between night and day. The temperature may reach 40 °C in the summer and − 33 °C in the winter. The study area typically exhibits a structure rising from the city center to the north-northeast and south-southeast. The research area's elevation above sea level ranges from 581 to 3012 m.

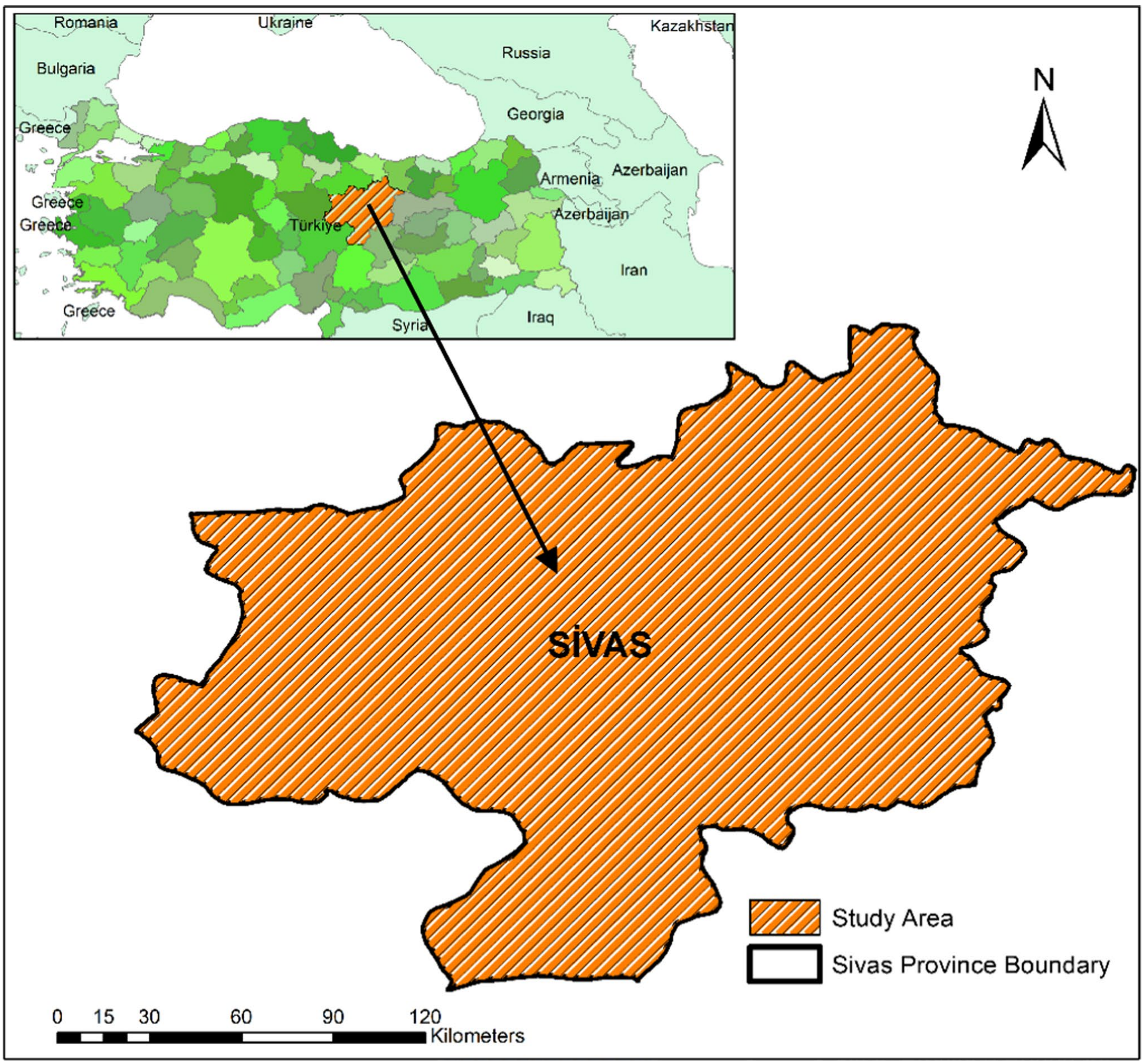

Fig. 1 Location of study area

With a length of 250 km and a width of 50 km, the Sivas Basin is between Erzincan and Kayseri in a NE-SW orientation. It is a sedimentary basin that has a variety of rock types, including metamorphic, magmatic, and ultramafic. These mostly consist of clastic, evaporite, and carbonate rocks that were deposited over various geologic eras. Raw elements required in industrial manufacturing, including as barites, halites (salt), and selestine, are found in evaporitic rock formations in the Hafik zone of Sivas. These elements may be found in abundance in the Hafik, Zara, and İmranlı zones, and their chemical makeup causes major agricultural and technical issues. Mineral reserves such as manganese, chromium, and iron can also be found in the area (Poisson et al., 1996).

In the study carried out by considering the temperature and precipitation data of at least 50 years of the study area; Karakuş and Güler (2022) revealed that annual and seasonal average temperature values increased, while precipitation values showed a decreasing trend. It is thought that these temperature and precipitation trends together with the drought may be effective in the planning and management of water resources for all areas such as energy, agriculture, industry and settlement, especially the natural environment in the coming years. From time to time, problems have started to be experienced in terms of quantity and quality of drinking, utility and irrigation waters in the study area. Sivas city center uses the 4 Eylül Dam as a surface water source and the Tavra Valley wells as a groundwater source for drinking and utility water supply. Due to population growth and drought, problems may be experienced in terms of both sources in meeting the drinking and utility water needs of Sivas city center. Other residential areas in the study area may also experience great problems in terms of drinking, utility and irrigation water, especially due to drought. The development of artificial water storage has become a necessity and a necessity in order to provide reliable water supply during periods when natural water potential decreases due to drought (World Bank, 2007). Based on this requirement and necessity, the location of the study area is of great importance in terms of dam location selection due to water scarcity that may occur in the coming years.

Data

In this study, 9 criteria (elevation, slope, distance to roads, rainfall, lineament density, distance to settlement areas, land use/land cover, soil type and stream density) were used to determine the most suitable areas in terms of dam site selection within the provincial border of Sivas. These criteria are based on previous studies (Ahmad and Verma, 2017; Shao et al., 2020; Qureshi, 2010; Odiji et al., 2021; Al-Ruzouq et al., 2019a, b; Ettazarini, 2021; Fathi et al., 2019; Balkhair and Ur Rahman, 2021; Faisal and Abdaki, 2021) and the most commonly used criteria in dam site selection in line with expert opinions (Table 2). Digital Elevation Model (DEM) with a spatial resolution of 30 m was used to obtain the elevation and slope criteria (ESRI, 2017). Lineament structure of the study area was obtained with the help of Catalyst Professional software using Landsat 8-OLI satellite image (PCI, 2021). The lineament density data of the study area were gathered by analyzing the line density tool in the Spatial Analysis tool of ArcGIS 10.8 software.

The distance criteria to roads and settlements were obtained by analyzing the road and settlement data obtained from the 1/100,000 scale environmental plan provided from the Ministry of Environment, Urbanization and Climate Change (Turkey) with the help of the Euclidean Distance tool of ArcGIS 10.8 software (ESRI, 2017). In order to determine the annual average rainfall criteria of the study area, first of all, the annual average rainfall data of the study area between the years 1990–2020 were obtained from the Meteorology Directorate (Sivas/Turkey) in Excel (.xlsx)

Table 2 The criteria used in the selection of the dam site and the features of the criteria

Criteria	Data	Data source	Data format	Analysis
Elevation	DEM	USGS	Raster layer	–
Slope	DEM	USGS	Raster layer	Slope
Distance to roads	Highway	EUM/landscaping plan (Ankara/Turkey)	Vector-line layer	Euclidean distance
Rainfall	Rainfall	Meteorology department (Sivas/Turkey)	Excel (xlsx)	Inverse distance weighting (IDW)
Lineament density	Landsat 8-OLI	USGS	Raster layer	Line density
Distance to settlement	Settlement area	EUM/landscaping plan (Ankara/Turkey)	Vector-polygon layer	Euclidean distance
Land use/land cover	Land use/land cover	CORINE (European union)	Vector-polygon layer	Feature to raster
Soil type	Soil	MFAL (Ankara/Turkey)	Vector-polygon layer	Feature to raster
Stream density	DEM	USGS	Raster layer	Line density

DEM Digital Elevation Model, *USGS* United States Geological Survey, *EUM* Environment and Urban Ministry, *CORINE* Coordination of Information on the Environment Program, *MFAL* Ministry of Food, Agriculture and Livestock format. These rainfall data were mapped using the IDW (Inverse Distance Weighted) tool in ArcGIS 10.8 software, and rainfall criteria data for a 30-year time period were obtained. DEM data were used to obtain the river density criteria. With the help of the hydrology extension of the ArcGIS 10.8 software, stream data of the study area were obtained by performing operations such as filling the gap, determining the flow direction, calculating the flow accumulation and defining the flow network on the DEM data. In addition, stream data were analyzed with the help of the line density tool in the Spatial Analysis tool of the software and the stream density criteria of the study area was obtained. In order to reveal the relationship between the existing and planned dams in the study area and the river flow degrees, a thematic map showing the degree of stream flow was obtained by reanalyzing the obtained river data with the help of the hydrology extension of the ArcGIS 10.8 software (ESRI, 2017). While the land use/land cover (LULC) criteria were obtained within the CORINE program, the soil types criteria were obtained from the Ministry of Food, Agriculture and Livestock. The cell size was stored in raster data format with a size of 10 m x 10 m by converting all the provided data, after preprocessing, to a common map projection (UTM 37 N, ED50) and data format (Fig. 2). ExtAHP 2.0 software was used to determine the relative weight values of all the criteria used in the study, and ArcGIS 10.8 software was used to obtain the raw and classified maps of all criteria and the dam site selection suitability map based on the AHP method.

Methods

The flowchart of the method to be applied in the study is shown in Fig. 2. The method applied in this study generally consists of 4 stages: (i) data acquisition, (ii) conversion of data into GIS data format, (iii) determination of suitable areas for dam site selection based on GIS-based AHP method, (iv) accuracy analysis. It is very important to choose the criteria to be used in the selection of the most suitable areas for the dam site and to design the database. The database design was carried out based on the literature information stated in Sect. 2.2. During the data acquisition phase, Remote Sensing data (elevation, slope, stream density, lineament density) along with digital maps (distance to roads, land use map, soil types map) and other data (rainfall data) were obtained from related sources (Table 2). Remote

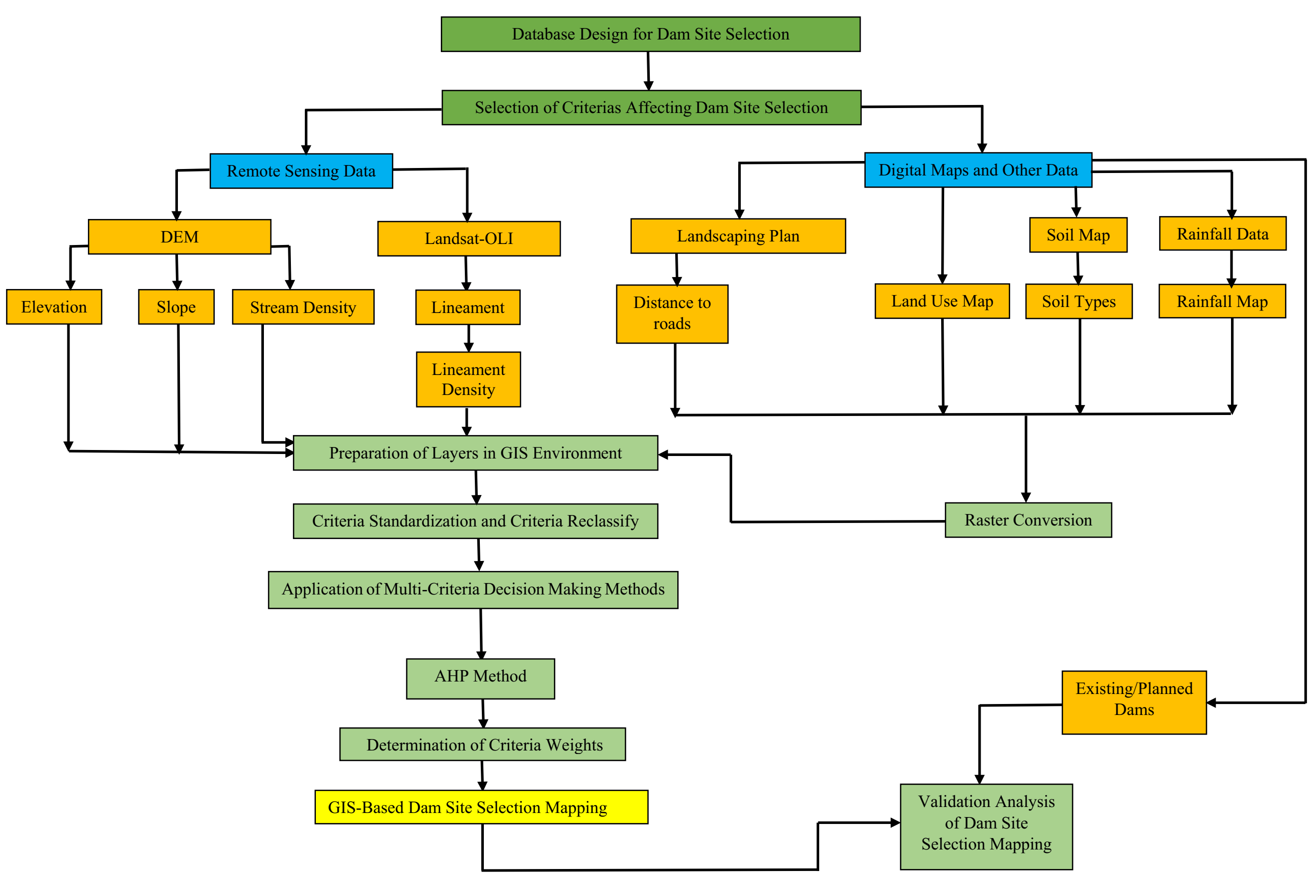

Fig. 2 Flowchart of the method used in the study

Table 3 Size classification of dams (Robinson, 2006)

Category	Storage (m^3)	Elevation (meter)
Small dam	< 1,234,000 and ≥ 61,600	< 12.5 and 5 ≥ 7
Intermediate dam	≥ 1,234,000 and < 61,675,000	≥ 12.5 and < 30.5
Large dam	≥ 61,675,000	≥ 30.5

Sensing data are in raster data format, and digital maps and other data in vector data format have been converted to raster data format. All data in raster data format were made ready for analysis in the GIS environment. All criteria were classified according to the efficiency levels in the selection of dam site, and the criterion standardization process was carried out. With the GIS-AHP integration, all criteria were evaluated and a dam site suitability map was obtained. In the last stage of the method, the locations of the existing/planned dams in the study area and the dam site suitability map were evaluated together and an accuracy analysis was carried out. This study identified only medium and large potential dams. Table 3 shows that, according to size and height, dams can be classified as small, medium, and large.

Dam site selection suitability analysis

The selection of the best suitable site for the dam is one of the particularly important decisions in water supply management (Minatour et al., 2015). Because an optimal choice for the dam site can improve a region's water supply security and groundwater regeneration. However, dam construction is very expensive and has long-term environmental impacts. Therefore, choosing the most suitable site for the dam can provide significant cost savings (Minatour et al., 2015). GIS-supported site selection methodology combines multi-criteria decision-making methods based on evaluation criteria (hydrological/hydrogeological, environmental, social, technical/economic) and spatial analysis tools provided by GIS (Kontos et al., 2005).

Analytic hierarchy process(AHP)

MCDM methods are tools that enable the best selection among multiple and simultaneous criteria (Saaty, 1980). AHP is a widely used MCDM tool (Chakhar and Martel, 2003). AHP is a decision aid that can provide relevant information to assist the decision maker in choosing the best alternative (Bodin and Gass 2004), or ranking a range of alternatives (Singh and Nachtnebel, 2016). It is one of the easily applicable Multi-Criteria Analysis (MCA) tools that includes the stages of selecting decision options and evaluation criteria in general, obtaining performance criteria for the evaluation matrix, converting them to proportional units, weighting the criteria, ranking or scoring the options, making a sensitivity analysis and finally making a decision (Singh and Nachtnebel, 2016).

The application of AHP is based on three basic principles: (i) Identifying the problem and establishing a hierarchy, (ii) constructing a comparative decision-making preference matrix, and (iii) determining factor weights. AHP uses pairwise comparison of criteria to determine which criteria are more important than other criteria (Saaty, 1980). In AHP, each factor is compared as a pairwise value using the pairwise comparison method, and relative values are evaluated according to the degree of importance among themselves according to the criteria in Table 2. Finally, a paired comparison matrix is created (Saaty, 1980).

Different factors have different importance levels in the selection of potential dam site (Chezgi et al., 2016). Therefore, the importance of each parameter was determined in this study as well. For example, geology is the main consideration in dam site selection, but the importance of different geological factors varies. In dam site selection, geological formations are more important than the distance to a fault line (Drobne et al., 2009).

Step 1: Determination of weights.

The MCDM is affected by factors of varying importance. Thus, the importance of each factor is weighed and ranked when defining the decision maker's preferences (Drobne et al., 2009). Pairwise comparison/AHP developed by Saaty (1980) was used in this study. Pairwise comparison compares each factor with all other factors. In the Saaty method, the main eigenvector of the square reciprocal matrix of the pairwise comparison between two criteria is used to calculate the weights of the factors (Drobne et al., 2009). Table 4 shows the explanation of the rating between the two factors with a continuous nine-point scale (Saaty, 1980).

Step 2: Pairwise comparisons' consistency.

Pairwise comparison accuracy is measured by calculating the consistency ratio (CR) (Eq. (1)), which is used to evaluate the relative weight of each factor. CR is a ratio between the Consistency Index (CI) and the Random Index (RI). Comparison between criteria is acceptable when the CR is less

Table 4 AHP pairwise comparison scale (Drobne et al. 2009)

Importance level	Meaning
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extremely importance

than 10%; otherwise, the CR allows the comparison with be re-evaluated (Noori et al. 2019).

$$CR = \frac{CI}{RI} \quad (1)$$

Depending on the matrix order, the RI can be found in the specific table. Table 5 shows the RI value according to the number of factors.

CI is calculated using Eq. (2).

$$CI = \frac{\lambda max - n}{n - 1} \quad (2)$$

Here, λmax (Major Eigen value) = (Weight1*S1 + Weight2 *S2 + Weight3*S3 + ...); n = number of criteria.

After CI is calculated, the CR equation is applied. If the result is less than 10%, it can be said that pairwise comparisons are acceptable. If this value is greater than 10%, the pairwise comparisons are inconsistent. In this case, the whole process has to be repeated from the beginning (Colak et al. 2020; Chakraborty and Banik, 2006).

Step 3: Geometric mean

The geometric mean is a special type of mean where numbers are multiplied together as percentages from the values then root is applied to the numbers as described in Eq. (3) (Dong et al. 2010).

$$\text{Geometric Mean (G. M)} = \sqrt[n]{X1 * X2 * X3 * \ldots Xn} \quad (3)$$

where n represents the number of returns in the series, and X is a variable.

Criteria standardization and reclassification

Criteria standardization is known as a method that allows the relative weights of criteria to be adjusted. It is carried out by giving a number of numerical values (0–1, 0–5, 0–10 or 0–100) to the criteria. Criteria standardization is used to standardize and score the rank values of the sub-criteria for each criteria. With the standardization process, the original values are converted into common suitability values and it is ensured that one criteria scale is comparable with the other (Karakuş et al., 2020).

In this study, elevation, slope, distance to roads, rainfall, lineament density, distance to residential areas, land use/land cover, soil type and stream density criteria were divided into sub-criteria according to their suitability for dam site selection, and scores between 1 and 5 were given to each sub-criteria (Ettazarini, 2021; Balkhair and Ur Rahman, 2021). The scores of 5, 4, 3, 2 and 1 used in terms of dam site suitability correspond to the "very high," "high," "moderate," "low" and "very low" categories, respectively (Swain et al., 2020; Radwan et al.., 2019). The scoring made in the study and the criteria weighting process made with AHP were applied according to the literature we used as a source in this study (Shao et al., 2020; Qureshi, 2010; Ettazarini, 2021; Balkhair and Ur Rahman, 2021; Faisal and Abdaki, 2021) and the opinions of academics and experts on the subject. After the criteria weights, sub-units and values of those units were determined, thematic maps of the criteria were reclassified according to the effect level scores in the suitability mapping of the criteria given in Table 6 with the help of the Spatial Analyst module of the ArcGIS 10.8 program (Fig. 3). The dam site selection suitability map of the study area was obtained (Fig. 4) with the help of GIS-based AHP software by evaluating the geometric mean values based on expert opinions, which were determined in terms of the effect levels of classified maps and criteria in dam site selection suitability mapping.

Suitability index and weighted overlay

The most common method used in calculating the suitability index is the Weighted Linear Combination (WLC) method. WLC is a multi-criteria evaluation method in which suitability is determined according to the relative importance of the criteria (Jamshidi-Zanjani and Rezaei 2017). This method, which uses map algebra operations and cartographic modeling according to the weighted average of the criteria, can be easily applied and understood in the GIS environment (Chen et al., 2011). The mathematical formula of the suitability index, which is obtained by summing the product of the standard suitability scores of the criteria in the selection of the dam site and the relative importance weight of each criteria, is shown in Eq. 4 (Dos Anjos Luís and Cabral, 2021).

$$SI = \sum W_i x S_i \quad (4)$$

Here, SI = suitability index, Wi = weight of relative importance of criteria i, Si = standardized suitability score of criteria i, and n = Total number of criteria.

Different weights have been determined for different criteria, since not all factors have the same importance in determining dam site suitability areas. The suitability of an area for dam site selection depends on the determination of the best area from the potential areas determined by analyzing all the characteristics of the study area. In this study, the

Table 5 Average RI values (Saaty, 1980)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Table 6 Main criteria and suitability level used in dam site selection

Main criteria	Sub-criteria	Suitability value	Suitability level	Area (km^2)	Area (%)
Elevation (m)	581–1200	5	Very high	12.97	4.55
	1200–1478	4	High	79.55	27.93
	1478–1703	3	Medium	98.57	34.61
	1703–1991	2	Low	67.50	23.70
	1991–3012	1	Very low	20.13	7.07
Slope (degree)	0–6.30	5	Very high	115.70	40.63
	6.30–14.92	4	High	77.07	27.06
	14.92–24.21	3	Medium	46.04	16.17
	24.21–35.49	2	Low	29.38	10.32
	35.49–84.58	1	Very low	10.42	3.66
Distance to roads (km)	0–2.14	5	Very high	112.79	39.60
	2.14–4.28	4	High	90.29	31.70
	4.28–6.42	3	Medium	52.73	18.51
	6.42–8.56	2	Low	22.13	7.77
	8.56–10.70	1	Very low	6.86	2.41
Rainfall (mm)	445.58–500.73	5	Very high	24.39	8.56
	408.24–445.58	4	High	102.70	36.06
	372.60–408.24	3	Medium	110.79	38.90
	330.17–372.60	2	Low	32.72	11.49
	284.35–330.17	1	Very low	14.21	4.99
Lineament density (km/km^2)	0–0.17	5	Very high	95.04	33.37
	0.17–0.30	4	High	88.91	31.22
	0.30–0.47	3	Medium	56.88	19.97
	0.47–0.69	2	Low	31.29	10.99
	0.69–1.17	1	Very low	12.62	4.43
Distance to settlement (km)	1–17.10	5	Very high	146.43	51.42
	17.10–25.66	4	High	68.07	23.90
	25.66–34.21	3	Medium	43.37	15.23
	34.21–42.77	2	Low	18.36	6.45
	0–1	1	Very low	8.56	3.01
Land use/land cover	Barren land	5	Very high	155.30	54.53
	Water body	4	High	1.75	0.61
	Forest	2	Low	10.72	3.76
	(Settlement, agriculture, artificial areas)	1	Very low	110.88	38.93
Soil type	AS, RBS, BS, CS1	5	Very high	11.85	4.16
	LBS, HAS, HMGS	4	High	110.30	38.73
	GBPS	3	Medium	2.95	1.04
	LBFS, BFS	2	Low	107.75	37.83
	CS2, SAS	1	Very low	51.95	18.24
Stream density	1.12–1.79	5	Very high	19.46	6.83
	0.80–1.12	4	High	44.05	15.47
	0.55–0.80	3	Medium	69.93	24.55
	0.32–0.55	2	Low	94.88	33.31
	0–0.32	1	Very low	56.39	19.80

Soil Type Explanation: *HMGS* High mountain grassland soils, *LBS* limeless brown soils, *LBFS* Limeless brown forest soils, *BFS* Brown forest soils, *CS*2 Colluvial soils, *HAS* Hydromorphic alluvial soils, *GBPS* Gray brown podzolic soils, *RBS* Reddish brown soils, *SAS* Saline-alkaline soils, *CS*1 Chestnut soils, *BS* Brown soils, *AS* Alluvial soils

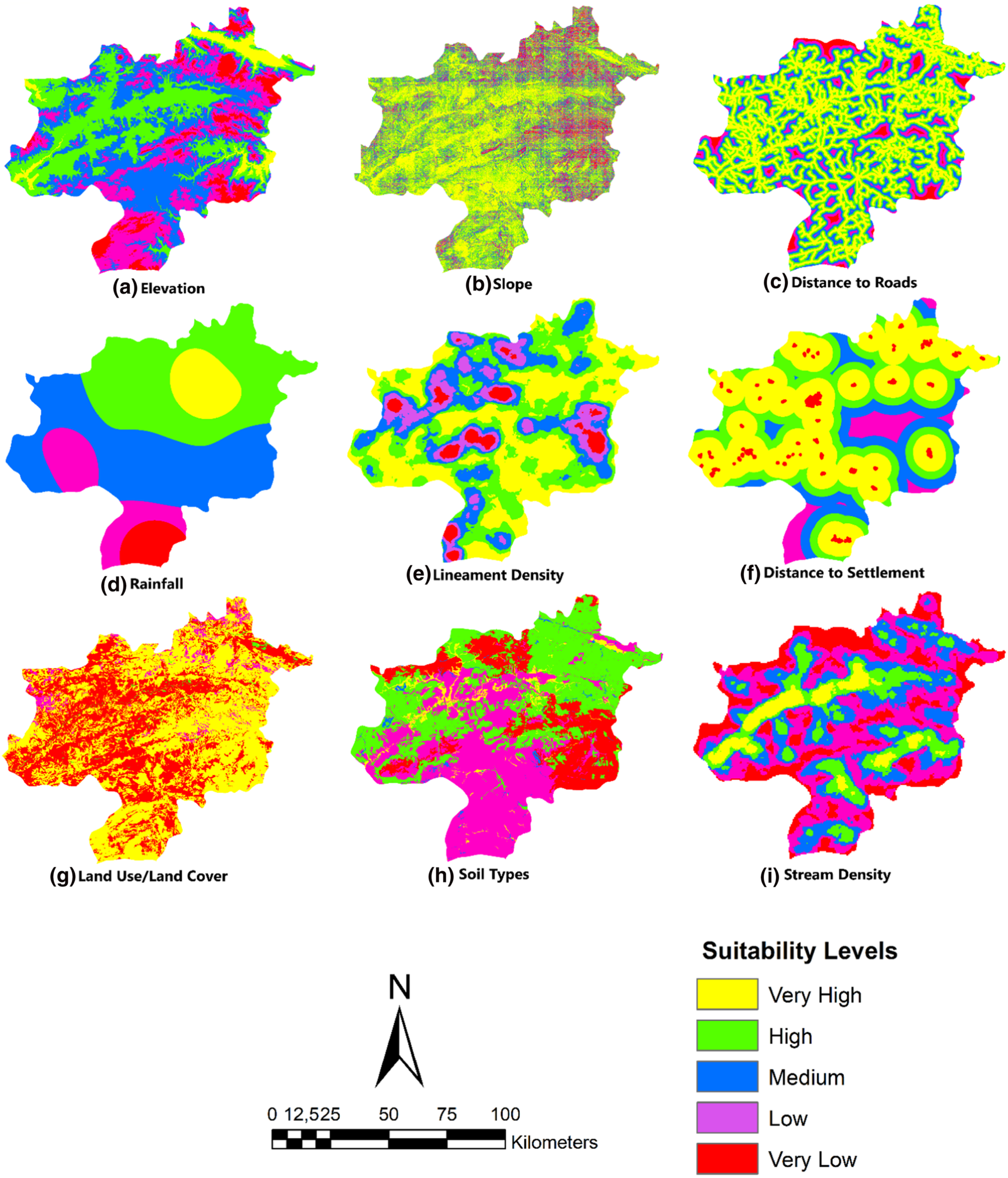

Fig. 3 Classified maps of standardized criteria for dam site selection

suitability index values and the suitability index map were obtained with the Raster Calculator tool in ArcGIS 10.8 software (weighted overlay) by analyzing raster maps created according to the relative weights of the criteria and the importance of the criteria in choosing the dam site (standard scores). High SI values indicated the most suitable areas for dam site selection (Barakat et al., 2017).

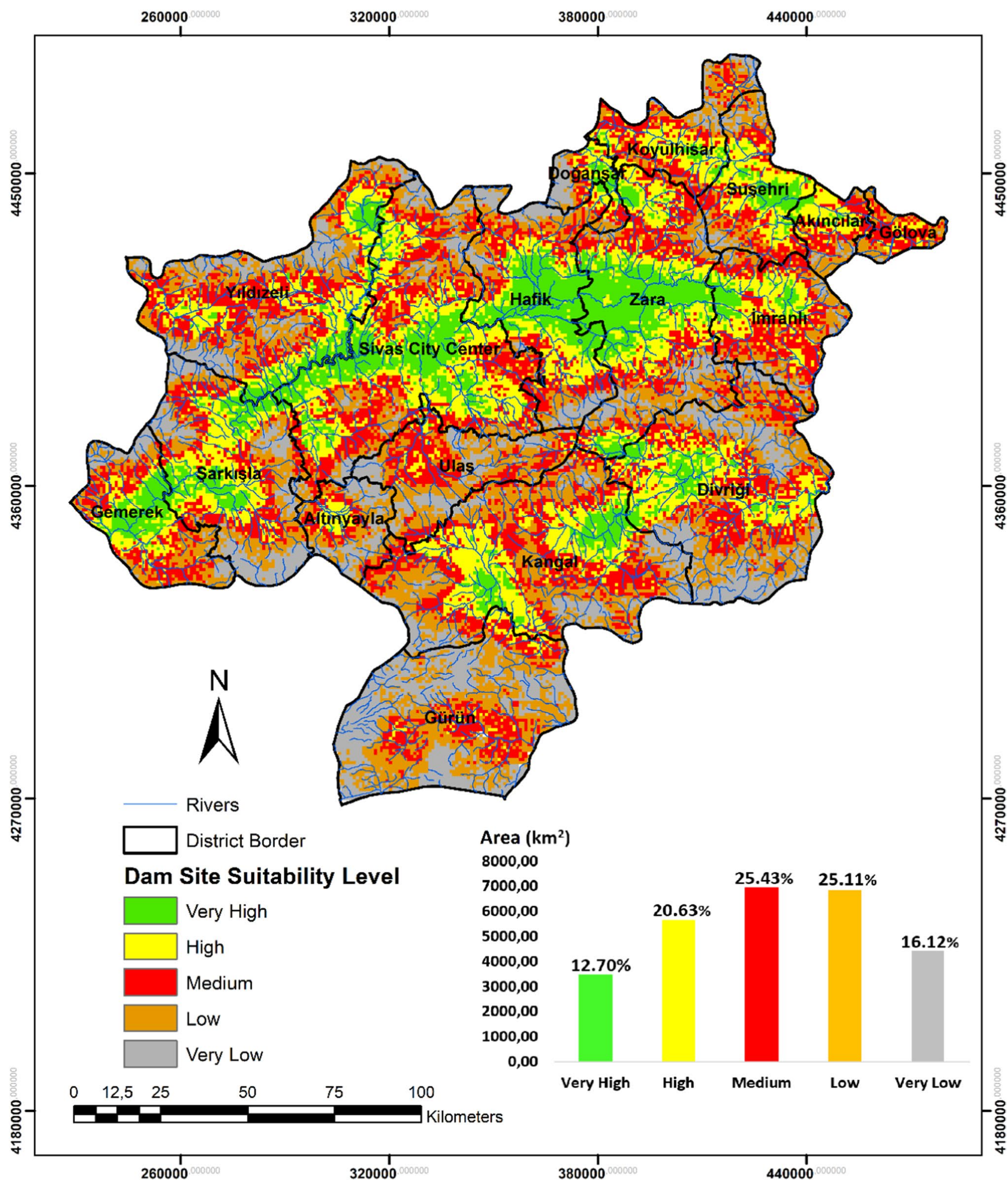

Fig. 4 Dam site suitability categories for the study area

Accuracy analysis

ROC curve method is used to evaluate the performance and accuracy of site selection results (Rahmati et al. 2019a). The ROC curve is a graph plotted between the sensitivity (on the vertical axis) and the "1-specificity" (on the horizontal axis) of a diagnostic test. Sensitivity is the proportion of correctly predicted events (dam site selection in this study), while specificity is the proportion of pixels that are not suitable for correctly defined dam site selection (Rahmati et. al., 2019b). Since the ROC curve is clear, comprehensive and visual, it is a widely used method for quantitative accuracy assessment (Tehrany et al., 2013). The basis of the ROC curve method is the true and false positive rates. Verification of site selection results can be performed using the area under the ROC curve (AUC) value. The AUC value depends on the comparison between the site selection suitability map obtained based on the analysis and the current locations of the relevant site selection (Rahmati et al. 2016). Sensitivity and specificity can be calculated with Eq. 5–6 (Rahmati et al., 2019a).

$$\text{Sensitivity} = \frac{\text{TP}}{\text{TP} + \text{FN}} \tag{5}$$

$$\text{Specificity} = \frac{\text{TN}}{\text{FP} + \text{TN}} \tag{6}$$

where; FP (false positive) and FN (false negative) are the numbers of pixels erroneously predicted, whereas TP (true positive) and TN (true negative) are the numbers of pixels that are correctly predicted.

The AUC value ranges from 0 to 1. A higher AUC value means a higher prediction performance, while an AUC value close to 0.5 indicates that the prediction is not better than a random prediction (Chung and Fabbri, 2003). Rahmati et al. (2019b) expressed the AUC values as 0–0.2 (very poor), 0.2–0.4 (poor), 0.4–0.6 (moderate), 0.6–0.8 (good), and 0.8–1.0 (excellent) in order to better understand the results.

Analysis of existing and planned dams

While the number of dams operated by the 19th Regional Directorate of State Hydraulic Works (Sivas/Turkey) in the study area is 22, the number of dams planned is 7 (URL1). In the study area, the river ranking map obtained by performing the "river ranking" analysis, the geographical reference points of these existing and planned dams and the suitability levels revealed by the suitability mapping of the dam location selection were matched. As a result of this overlay, the positioning accuracies of the existing and planned dams were analyzed.

Results and discussion

Reclassification of suitability criteria

Elevation

Elevation is an important factor in determining the best location of a dam, as it influences water accumulation and movement (Mura et al., 2018). In terms of the possibility of water accumulation, areas with low elevation values are the most suitable areas for dam construction, since groundwater as well as sedimentary waters have a higher potential to accumulate at lower elevations (Datta et al., 1996). It is generally accepted that mid-elevation areas are more suitable for dam construction, while lower and higher elevations are considered to show poor suitability (Wang et al., 2021).

Areas with an altitude range of 581–1200 m (with 5 points), which are in the "very high" category in terms of dam site suitability, cover 4.55% of the study area, and the areas in this elevation range are mostly seen in the east, west and northeast of the study area. Elevation values between 1991–3012 m (with 1 point), which are in the “very low” category in terms of dam site selection, are generally seen in the south and northeast of the study area, and the areas in this elevation range cover 7.08% of the study area (Table 6, Fig. 3a).

Slope

The slope factor, known as the topographic factor, significantly affects the water flow. High slope values cause water accumulation by increasing surface and groundwater flow rates (Al-Ruzouq et al., 2019a, b). Therefore, these slope values make the land more susceptible to flooding and sediment transport. The lower the slope, the higher the probability of water accumulation (Rahmati et al., 2019b). The slope is an important controlling factor as to whether dam construction is necessary to create a suitable habitat and also determines the energy and speed of the river. Therefore; the slope factor is closely linked to floodplain coverage and riparian materials (Njiru and Siriba, 2018). Therefore, the slope factor is closely linked to the floodplain coverage and riparian materials (Njiru and Siriba, 2018).

The slope of the study area varies between 0° and 84.5°. Figure 3b shows the slope classes of the study area divided into 5 main classes in terms of dam site suitability: Very high (0–6.30°), high (6.30–14.92°), medium (14.92–24.21°), low (24.21–35.49°) and very low (35.49–84.58°). Each class covers 40.63%, 27.06%, 16.17%, 10.32% and 3.66% of the study area, respectively.

Areas with a slope of 0–6.30° (with 5 points) cover the majority of the study area (40.63%), and these areas are the biggest potential areas in terms of dam site suitability. These areas were more distributed in the regions outside the eastern and northeastern parts of the study area. It is seen that the sloping areas (with 1 point) in the "very low" (35.49–84.58°) category in terms of dam location have the least areal value (3.66%) in the study area. These areas were mostly distributed in the eastern and northeastern parts of the study area. In general, there is the highest slope difference between the east and northeast of the study area and the other parts (Table 6, Fig. 3b).

Distance to roads

The distance criteria from the highway communication network are an important issue in the selection of the dam site (Ghazal et al., 2015). The proximity of roads and settlements to the proposed areas for the dam site will reduce the costs of water transportation (Othman et al., 2020). Roads have an important socioeconomic role in the population of the region by providing access to grass and water for animals. Existing roads near the proposed dam sites contribute significantly to reducing transportation costs (Hashim and Sayl, 2021). The evaluation range for the distance to roads criteria obtained with the help of the Euclidean distance tool varies between 0 and 10.70 km. In terms of dam site suitability, the 0–2.14 km range in the "very high" category (with 5 points) covers 39.60% of the study area, while the regions in the "very low" category between 8.56 and 10.70 km (with 1 point) form 2.41% of the study area. Regions between 0 and 2.14 km showed a homogeneous distribution throughout the study area (Table 6, Fig. 3c).

Rainfall

Rainfall is the primary source of runoff water recharge. Rainfall density and distribution are some of the prerequisites for designing a water collection system (Prinz and Singh, 2000). Rainfall density significantly affects the peak discharge of a river. The more rainfall in the region where the river is located, the higher the discharge density. The dam suitability potential of any region can be determined by the amount, density and distribution of rainfall in the form of rain (Zhao et al., 2019). Regions with high rainfall are suitable areas for dam construction (Al-Ruzouq et al., 2019a, b).

The Inverse Distance Weighted Interpolation Method (IDW) in ArcGIS 10.8 software was used to create the rainfall map of the study area. According to the rainfall map created with the method specified for the study area using the 30-year average total rainfall data between 1990 and 2020, the annual average rainfall values vary between 330.17 mm and 500.73 mm.

Lineament density

The high linearity density in a region is known as a reflection of the fact that the area contains many faults and abrupt changes in linear alignments that are not sufficient to store water. This is because water flows through faults or finds a different drainage channel along the line direction (Mugo and Odera, 2019). Fractures and joints in the earth increase the infiltration of the soil. Therefore, analysis of lineament density is important for mapping potential dam site areas. Areas with high lineament density are unsuitable for dam locations (Sayl et al., 2019).

Lineament density in the region is shown in Fig. 3e. Lineament density is very high in the northwest, east, south and parts of the interior (0.69–1.17). These areas, which were represented with 1 point in terms of dam site suitability, represented 4.43% of the study area. Areas with low lineament density in the range of 0–0.17 (with 5 points) showed a homogeneous distribution throughout the study area with a value of 51.42% (Table 6). These areas can be defined as suitable regions in terms of dam site selection, since they have a crack-free rock layer structure that provides longer water storage time.

Distance to residential areas

Distance to residential areas can be an indicator for the availability of experts, facilities and services for dam construction. In this way, the cost will increase as you move away from the residential area (Forziri et al., 2008). The presence of residential areas near the proposed dam sites greatly contributes to reducing water transport costs (Noori et al., 2019; Dos Anjos Luís and Cabral, 2021).

The residential areas distance criteria were scored and evaluated in terms of two aspects (environmental and cost) in the dam site selection. In order to prevent anthropogenic pollution risks that may arise from residential areas in terms of environment, areas between 0 and 1 km from residential areas were categorized as "very low (with 1 point)" and these areas represented 3.01% of the study area. Areas in the "very high" category between 1 and 17.10 km (with 5 points) cover 51.42% of the study area, while areas in the "low" category between 34.21 and 42.77 km (with 2 points) cover 6.45% of the study area. Areas in the "very high" category showed a homogeneous distribution throughout the study area (Table 6, Fig. 3f).

Land use

Land cover and land use are one of the most important criteria in selecting suitable sites for water collection (Kahinda et al., 2008). The hydrological response of river basins is affected by land cover/use change and rainfall. The land use criteria are an important parameter for flow assessment. This criteria, determining the changes in the flow characteristics of the basin under the influence of the land cover change, have an important place in the dam site selection. Land cover is associated with high runoff produced by rainwater due to higher infiltration in a given area, while low flows are associated with areas of vegetation (Kahinda et al., 2008). Vegetation, marsh and bare/rocky areas have high priority in dam site selection. Because there is a lot of human activity in residential areas, settlements have low priority in dam site selection (Ajibade et al., 2020). In particular, proposed areas for the construction of irrigation water dams should be near farmland to reduce the distances of farmers seeking water and the costs of transferring water from the reservoir to the farmland (Dos Anjos Luís and Cabral, 2021).

The land use type with the highest distribution in the study area is the areas in the "barren land (54.53%)" class (with 5 points), and these areas are in the "very high" category in terms of dam site suitability. Land use areas (barren land), represented by “5 points,” are found throughout the study area. These areas were mostly distributed in the southern and eastern parts of the study area. Areas in the category of "settlement, agriculture, artificial areas (industry-trade-transportation areas, mine-landfill-construction areas, non-agricultural green areas)" in the "very low" category (with 1 point) have a 38.93% distribution in the study area. These areas are mostly distributed in the inner and western parts of the study area (Table 6, Fig. 3g).

Soil type

Soil structure is an important factor in finding a suitable site for a dam. Different soils have different rates of swelling that affect the amount of runoff. Soil texture is very important for the dam foundation (Roy and Bhalla, 2017). Soil texture has an important place in the selection of dam site as it affects the infiltration as well as the amount of flow. Medium to fine textured soils are typically more suitable for the dam site because of their improved water retention. Clay soils have proven to be the best soil group for water storage and dam site selection due to clay's low permeability and water retention ability (Mbilinyi et al., 2007).

Due to their low permeability and higher water retention capacity, soil types AS, RBS, BS and CS1 were considered as suitable soil types in terms of dam site suitability. The soil types AS, RBS, BS and CS1 were represented by the “very high (with 5 points)” category in terms of dam site suitability. These soil types were distributed mostly in the northwest of the study area with a value of 4.16%. LBS, HAS and HMGS, which are the soil types with the highest distribution (38.73%) in the study area, are located more in the northeast of the study area, and these soil types are represented as "high (with 4 points)". CS2 and SAS, which were represented as “very low (with 1 point),” were considered as unsuitable soil types in terms of dam site suitability due to their high permeability and lower water retention capacity, and these soil types showed a distribution of 18.24% in the study area. These soil types are mostly located in the north and southeast of the study area (Table 6, Fig. 3h).

Stream Density

Stream density is the total length of runoff in the drainage basin and shows the proximity of the gaps of the water channels (Jamali et al., 2014). The suitability of the dam site location is directly proportional to the stream density due to its relationship with the surface flow and permeability. A high drainage density indicates a high groundwater probability and increased suitability for locating a dam (Pandey et al., 2011). Stream density is a very important factor for dam/reservoir function to provide the required runoff levels at different drainage network levels. In terms of dam site suitability; areas with high drainage density are known as areas with high potential compared to areas with low drainage (Luís and Cabral, 2021). First-order streams are generally considered to find suitable dam sites (Mohammed et al., 2019).

In the selection of dam site, areas with high stream density (1.12–1.79) (6.83%) have higher priority than areas with low river density (0–0.32) (19.80%). The regions where the Kızılırmak river is located, starting from the west of the study area and extending to the northeast and is the main river in the study area, are the regions with the highest stream density (with 5 points). In addition, there are regions with high stream density in the south and southeast of the study area. Regions with low stream density (with 1 point) showed a homogeneous distribution throughout the study area (Table 6, Fig. 3i).

Pairwise comparison matrix and criteria weights

In order to determine the suitable areas for dam site selection, a pairwise comparison matrix was created with the help of the AHP method. The pairwise comparison matrix was made by taking into account the literature studies on dam site selection (specified in the data supply and software section) and the opinions of experts and academicians (5 hydrogeologists, 5 topographical engineer, 5 environmental engineers and 5 climate scientists). According to the AHP method used in the study, 9 criteria taken into account in the suitability mapping for dam site selection were evaluated in line with the values in Table 5. According to the AHP rating scale (Table 4) suggested by Saaty (1980), all experts were asked to make an evaluation by comparing 9 criteria with each other. The corresponding comparison of one criteria to the other was entered into the matrix by using the geometric mean values of pairwise comparisons made by experts among all criteria and obtained from the literature research (Table 7).

As a result of the evaluation based on the AHP analysis, the CR value calculated for 9 criteria is 0.054. Since the CR value is less than 0.1, it is seen that the results obtained are consistent and acceptable. According to the analysis, SD and *R* criteria were determined as the criteria with the highest weight value in dam site suitability mapping, while DS and DR criteria were determined as the criteria with the lowest weight value (Table 7).

Suitability map

The dam site suitability map (Fig. 4) was obtained with the help of ArcGIS 10.8 software by using the classified raster maps (Fig. 3), which were created according to the effect levels of the criteria on the selection of the dam site, and the criteria weights (Table 7) obtained by the AHP method. The suitability categories revealed by the dam site suitability map created for the study area based on the GIS-AHP-based method were "very high (12.70%)," "high (20.63%)," "medium (25.43%)," "low (25.11%)" and "very low (16.12%)." The "medium" and "low" suitability categories (50.54%) covered the most space in the study area. Areas in the "very high" category (12.70%) are mostly concentrated in Sivas city center, Hafik, Gemerek and Zara districts. The settlements where the areas in the "very low" class (16.12%) are more common were determined as Gürün, Altınyayla and Ulaş districts. When a general analysis was made according to the districts, the areas in the "middle" class (25.43%) showed a homogeneous distribution in all districts (Fig. 4).

Accuracy assessment

The ROC curve (Nandi and Shakoor, 2009) was prepared, and the accuracy of the dam site suitability map was analyzed in the study. In the ROC method, the area under the curve (AUC) values (ranging from 0.5 to 1.0) form the basis of the accuracy assessment. In order to apply the ROC method, a data set containing the number of pixels corresponding to each suitability category revealed by the dam site suitability map and the existing dams was prepared.

Accordingly, data from 22 dams in the study area were used to calculate the AUC (Fig. 5). The AUC of the ROC curve was calculated as 0.69. This result indicated that the performance of the model was "good (0.6–0.8)," and there was also a strong correlation between the suitability map and the available data of dam (Fig. 6).

Analysis of existing and planned dams

The positioning accuracy of the existing dams was analyzed by superimposing 22 dams in the study area on the dam site suitability map (Fig. 7). Considering the distribution of 22 dams in the study area, the districts are listed as: Sivas center (2), Yıldızeli (5), Sarkisla (4), Ulas (2), Susehri (2), Gurun (1), Divriği (1), Kangal (1), Hafik (1), Gölova (1), Imranli (1) and Zara (1). In terms of the planned dams, the districts are listed as: Ulaş (2), Gemerek (2), Kangal (1), Yıldızeli (1) and Divrigi (1). As shown in Fig. 7, Yıldızeli and Şarkışla districts have the highest number of dams (9). When existing dams and dam site suitability categories are evaluated together: 13.4% of the existing dams were in the "very high," 27.7% "high," 36.36% "medium," 18.18% "low" and 4.55% in the "very low" categories. When the planned dams

Table 7 Weights and pairwise comparison of main criterias that influence dam site selection

Main criteria	SD	R	LD	S	ST	LULC	E	DS	DR	Weight (%)
SD	**1**	5	7	5	4	4	4	6	7	36.63
R	1/5	**1**	3	2	3	3	3	5	4	16.48
LD	1/7	1/3	**1**	2	2	2	2	3	3	10.51
S	1/5	1/2	1/2	**1**	3	2	2	3	5	10.14
ST	1/4	1/3	1/2	1/3	**1**	2	2	4	5	8.53
LULC	1/4	1/3	1/2	1/2	1/2	**1**	1	1	6	6.25
E	1/4	1/3	1/2	1/2	1/2	1	**1**	2	2	5.37
DS	1/7	1/5	1/3	1/3	1/4	1	1/2	**1**	1/2	3.23
DR	1/6	1/4	1/3	1/5	1/5	1/6	1/2	2	**1**	2.99
Consistency Rate (CR): 0.054										

SD Stream density, *R* Rainfall, *LD* Lineament density, *S* Slope, *ST* Soil type, *E* Elevation, *LULC* Land use/land cover, *DR* Distance to roads, *DS* Distance to settlements

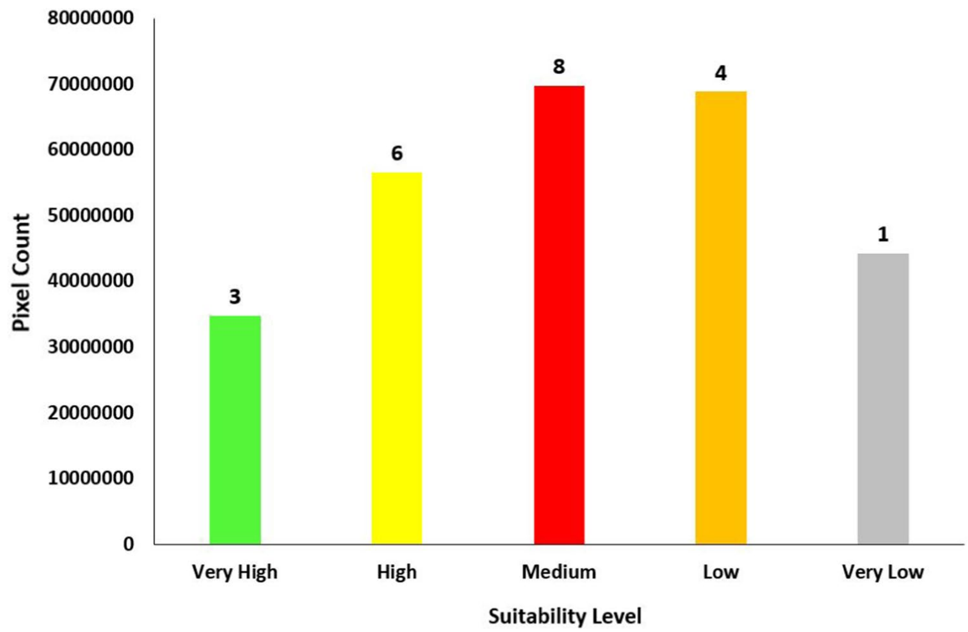

Fig. 5 Validation of dam site suitability map using known current dams in the study area (The numbers above the columns show the current dam numbers)

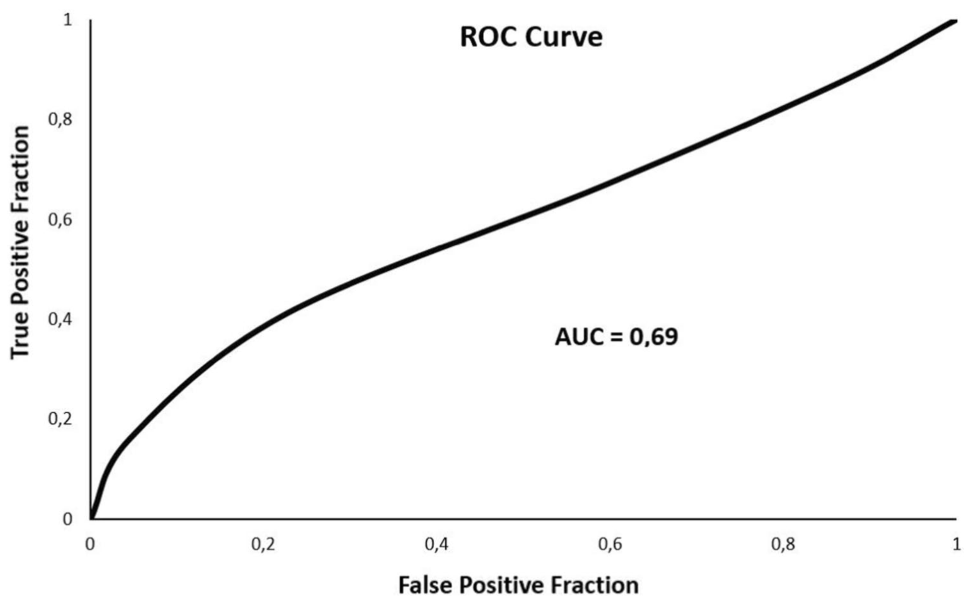

Fig. 6 ROC curve for the obtained dam site suitability map

and dam site suitability categories are evaluated together, 14.29% of the planned dams were in the "high," 14.29% "medium," 57.14% "low" and 14.29% in the "very low" categories. There are no dams in the "very high" category among the planned dams. In terms of the number of dams in the districts, Kangal (1), Sivas center (1) and Zara (1) were in the "very high" category; Şarkışla (2), Suşehri (2), Gölova (1) and İmranlı (1) were in the “high” category; Yıldızeli (3), Şarkışla (2), Ulaş (1), Hafik (1) and Sivas center (1) were in the "medium" category; Yıldızeli (2), Gurun (1) and Divrigi (1) were in the “low” category; Ulaş (1) was in the “very low” category. In terms of the planned number of dams in the districts: Kangal (1) was in the “high” category; Gemerek (1) was in the “medium” category; Ulaş (1), Divriği (1), Gemerek (1) and Yıldızeli (1) were in the “low” category; Ulaş (1) was in the “very low” category (Fig. 7).

The relative size of the stream is known as the order of the stream flow. The smallest tributaries of the stream are represented by first order flow, while the largest tributaries are represented by the highest order (Shashikumar et al., 2018). All of the existing dams in the study area, according to the river flow degree, were built on rivers with a flow degree of less than 5, that is, with a very low flow. Six of the existing dams were built on rivers with flow degree 1, 9

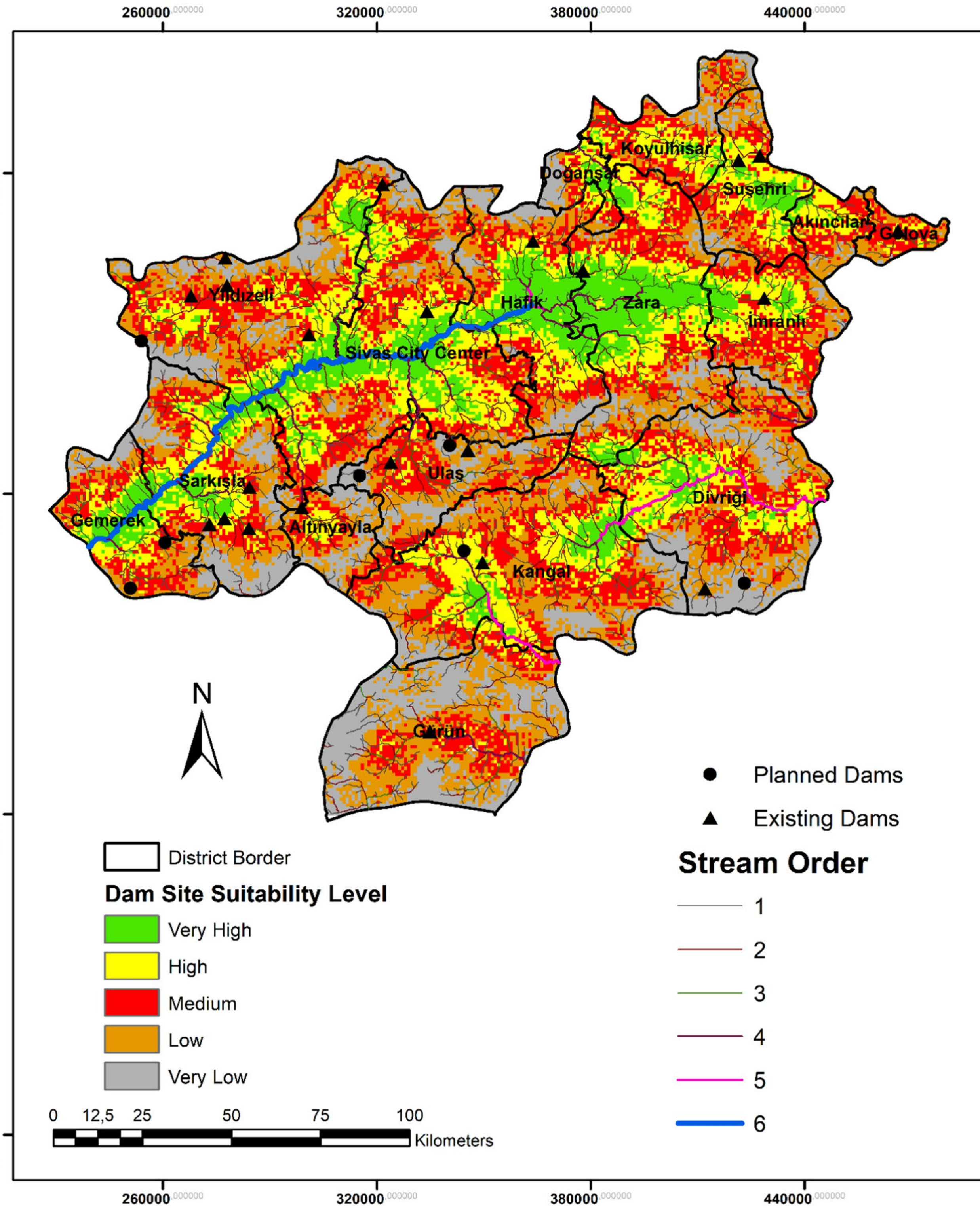

Fig. 7 Overlaid of existing and planned dams with dam site suitability categories

on rivers with flow degree 2, 6 on rivers with flow degree 3 and 1 on rivers with flow degree 4. 4 of the planned dams are planned on rivers with a flow degree of 1, and 3 of them are planned on rivers with a flow degree of 2 (Fig. 7).

Conclusion

This study contributes to a case study for the determination of suitable areas in terms of dam location in Sivas province and the accuracy assessment of existing/planned dams by using the AHP approach, which is one of the GIS-based multi-criteria decision analysis methods. In the study, 9 criteria, including elevation, slope, distance to roads, rainfall, lineament density, distance to residential areas, land use/land cover, soil types and stream density, were taken into consideration for dam site selection. Stream density (36.63%), rainfall (16.48%) and lineament density (10.51%) criteria, respectively, were the primary criteria of this study in the selection of dam site suitability based on local expert knowledge and literature resources. According to the dam site suitability map obtained in the study, 12.70% of the study area was in the "very high," 20.63% "high," 25.43% "medium," 25.11% "low" and 16.12% "very low" suitability categories. The AUC value, which is the indicator of the accuracy of the dam site suitability map, was calculated as 0.69, and this value shows that the performance of the model is "good." According to these results, approximately 58.76% of the study area is quite suitable for dam site selection. This result is an indication of the natural potential characteristics and economic characteristics of the study area in general. It also shows that the study area has an important potential for dam site selection. While 64.63% of the dams currently in operation in Sivas province are in the "high" and "medium" level of suitability categories, 57.14% of the planned dams are represented by the "low" category of suitability. The dam site suitability mapping based on the method applied in this study is very important in terms of providing resource data to decision makers for regional water resources management and sustainable development in determining the most suitable sites to build new dams.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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