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DAM SITE SUITABILITY MAPPING USING GIS-BASED DAM SUITABILITY STREAM MODEL 'DSSM': A CASE STUDY ON THE ARGHISTAN WATERSHED IN HELMAND MAJOR BASIN, AFGHANISTAN

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Abstract: Suitable dam site selection is an essential or very important task in water resource management. The southern zone of Afghanistan is one of those areas that faces many Dam-related problems, such as hydroelectric power, agricultural products, low water table or less recreational activity. At the same time, the economy of this area is largely based on agriculture. Therefore, to solve these problems we should construct more dams at different areas, because dams can serve and solve these problems. This study used six influencing factors (Stream Order "Distance to Stream", Slope, Geology, Land use/cover, Soil and Digital Elevation Model DEM) in conjunction with Dam Suitability Stream Model DSSM as Multi-Criteria Decision Analysis (MCDA), to generate dam site suitability map of the Arghistan watershed, which is located in the Helmand major basin along Paktika, Ghazni, Zabul, and Kandahar provinces of Afghanistan. Each influencing factor in DSSM is weighted using Analytical Hierarchy Process AHP, before being subjected to two-time overlay analysis in Geographical Information System (ArcGIS 10.7.1) platform. 1st where Stream Order is considered as the main parameter to create suitability on the stream map. 2nd as a counterpart of Stream Order, the Distance to Streams layer is utilized to create an overall suitability map. Four kinds of suitability's are visualized in each of the resulting maps, such as "Not, less, moderate, or high suitable". By storing water for various local or regional applications the planned dam sites will lower the risk of flooding and provide hydroelectric power. Additionally, using the reservoir's stored water for farming.

Keywords: DSSM; GIS; AHP; MCDA; Dam Site Suitability; Arghistan Watershed

1 INTRODUCTION

Air, water, food, heat and light are the five elements that are most necessary for human life to survive. Of those next to air, water is the most crucial requirement for human life to exist. Water is a basic human requirement [5], that is essential to geophysical cycles [19], microclimate regulation, runoff cycle regulation [26], and the continuation of life as we know it for all living things on earth [15]. Water is a limited yet renewable resource that is necessary for human life and activities since water promotes economic growth, agriculture, sanitation, and other things [24]. Water is essential to life and livelihoods because it maintains ecosystem health and is a key component of sustainable development, water scarcity has been notably rising in tandem with urbanization, population growth, and demand [4]. One of the main socioeconomic concerns of the twenty-first century is the availability of fresh water, as highlighted by The United Nations Millennium Development Goals water mandate and other new global goals and commitments [3]. Large volumes of water are stored and safely retained by dams, after which they are released for a range of uses such as hydropower, inland navigation, irrigation, recreation, flood prevention and so on [25]. Due to its unequal distribution in the terms of time and space, the world's water resources have been causing floods and droughts in various regions [24]. For example, in 1997 there were Southeast Spain [6], while in Papua New Guinea there was a drought event in 1997 [13], in 2003 there were floods in South France [10], in 2003 a drought event occurred at South Africa [14], and other years, there were floods in the Northwest Iberian Peninsula in 2000 [9], and in 2005 a drought event occurred at the Amazon River basin [2]. Investing in agriculture is crucial in Afghanistan, where it contributes 25% of the country's GDP and supports the livelihoods of roughly 76% of the population, nearly 90% of whom are impoverished and live in rural areas, and 50% of all households earn at least some of their income from the sector [21]. The southern zone of Afghanistan is one of those areas that is facing problems such as water scarcity, low water table (especially in Kandahar province), less electricity (for residential and commercial purposes), less agricultural products, flood events, less recreational activity, etc. To solve those problems, we should construct more dams at different areas because dams can serve and solve the above problems. Therefore, I choose Arghistan watershed as the selected watershed for the case study. The aim of the study is to create dam site suitability map of Arghistan watershed and proposed suitable dam sites to assist decision - makers in selecting the best site for dam(s) construction. The selection of suitable dam sites will be primarily determined by the environmental factors, and the primary functions of these dams will be the production of hydroelectric power and irrigation water supply. Dam siting, the process of choosing an appropriate location for a dam, is a prerequisite for building dams. The study of dam site selection, or "dam siting" is a subset of decision-making and coordination, and other disciplines. As the field develops, siting choices are revised frequently, and there will undoubtedly be more obstacles in the way of dam siting process [23]. The selection of dam sites is typically done using conventional procedures, such as traditional decision-making techniques, or in accordance with political objectives [8]. Based on the basic analysis process of dam siting, the siting methods can be divided into three categories: GIS/RS method, MCDA-GIS method, and machine learning approaches. There are fever complicated factor weights to calculate and simpler types in the GIS/RS-based approach. Robust decision-making analysis systems that systematically handle weight interactions among various criteria underpin MCDA-GIS-based techniques. Large volumes of data are used as training datasets in machine learning techniques. The two categories of algorithmic model-based and suitability-based evaluation can be used to summarize these three sorts of techniques Table 1 [23]. In this study, dam site suitability maps were created using the DSSM in conjunction with MCDA.

Table 1 Dam siting methods

Classification	Particular techniques
Evaluation based on suitability	Methods based on GIS/RS Methods based on MCDA and MCDA - GIS
Based on algorithms	Machine learning - based methods

2 MATERIALS AND METHODS

2.1 The Study Area

The case study was carried out in the Arghistan Watershed. Which is situated along Paktika, Ghazni, Zabul, and Kandahar provinces of Afghanistan. The study area latitudinal extent is from $30^{\circ}\ 46'48''\ N$ to $32^{\circ}\ 30'21''\ N$, and the longitudinal extent is from $65^{\circ}\ 32'6''\ E$ to. The watershed is about 939 to 2909 meters above sea level (masl). The watershed covers an area of. And has a perimeter of $1009441.2\ m$, as depicted in Figure 1.

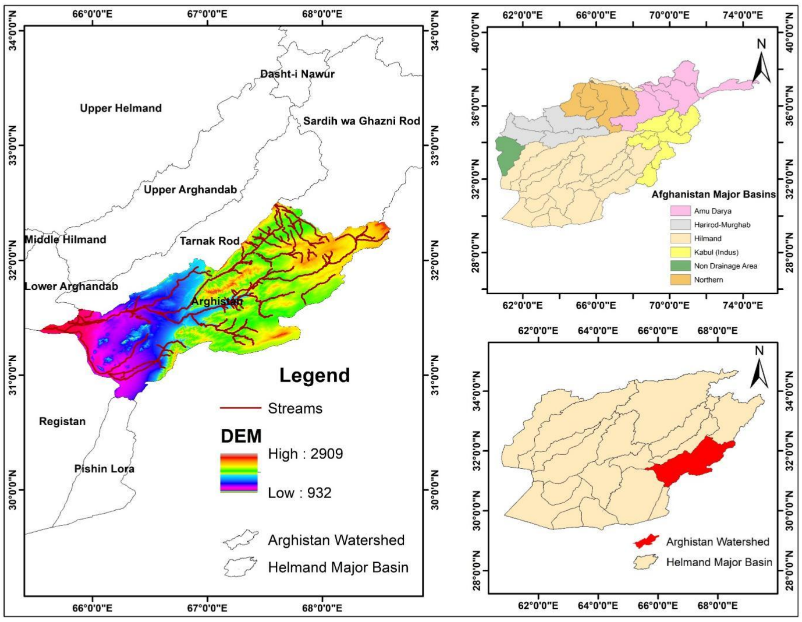

Figure 1 Location of study area

2.2 Data and Sources

The present investigation utilized open-access data (online resources) to acquire remote sensing data, including geology map, soil map, land use/cover, and Digital Elevation Model (DEM). Table 2 provides a discussion the gathered data along with their sources. To prepare the gathered data for study area, some other vector data was also used, which is also discussed in Table 2.

Table 2 Collected data and their sources

S. No	Data Type	Original Format	Data Source
1	DEM	Raster	USGS
2	LU / LC	Raster	https://livingatlas.arcgis.com/landcover/
3	Geology map	Vector	Afghan Geological Survey Department
4	Soil map	Vector	https://www.fao.org/soil-portal/data-hub/soil-maps-anddatabases/faounesco-soil-map-of-the-world/en/

5	Watersheds Boundaries	Vector	https://mapcruzin.com/free-Afghanistan-arcgis-maps-shapefiles.htm

2.3 Methodological Flowchart

The study area dam site suitability map is created through some process; the methodological flowchart of the study is shown in Figure 2.

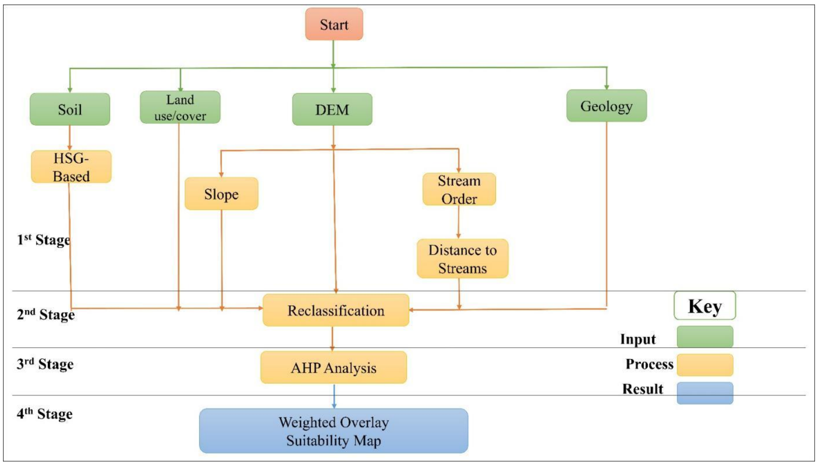

Figure 2 Flow chart of the study

2.4 Generation of Essential Parameters

2.4.1 Digital elevation model (DEM)

DEM is a digital depiction of the topography of the earth that takes into account any reference datum. It can also be used to show the topographical surface of the earth without any trees, buildings and any other surface items. In this study, the Shuttle Radar Topography Mission (SRTM), Digital elevation model (DEM) is used, which is downloaded with a 30m resolution, and then the study area DEM is extracted in ArcGIS 10.7.1 platform. The DEM of the study area is shown in Figure 1(Study Area).

2.4.2 Stream order

the stream order or waterbody order is a positive whole number used to indicate the level of branching in a river system. There are different methods for quantitative stream order. But the most used are Strahler method [20], or Shreve method [18]. These two approaches idealize stream order as a tree with slender branches and a robust root. The study area stream order map is shown in Figure 3.

2.4.3 Distance to streams

Distance to streams map in this study used for generating overall suitability map instead of stream order. The stream order map was used to create the study area distance to stream map, by using the Euclidean Distance tool under Distance in spatial analyst tools of ARCGIS 10.7.1 platform. Distance to stream map shown in Figure 4.

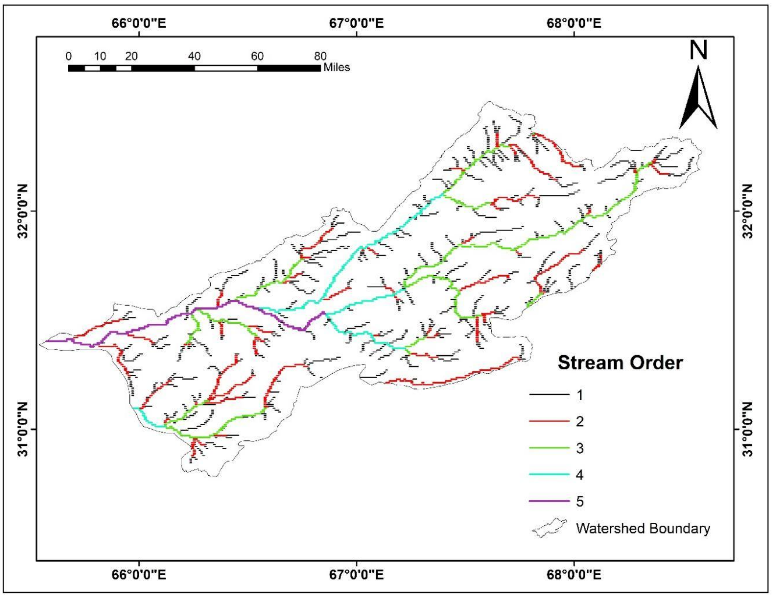

Figure 3 Stream Order (Strahler Classification)

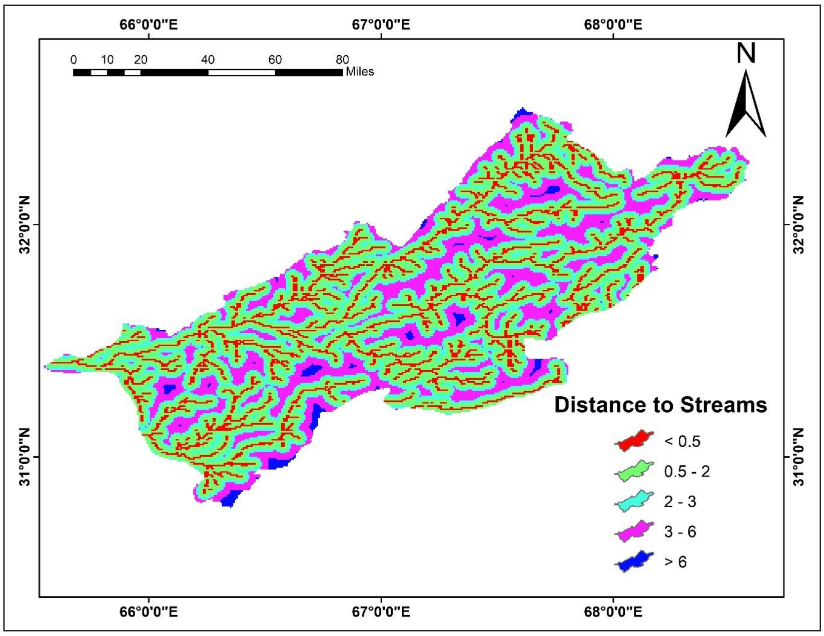

Figure 4 Distance to streams map of the study area

2.4.4 Slope

Slope is a surface's steepness or degree of inclination. It can be stated as a percentage or in degrees. Using the surface tools of ARCGIS, the slope map has been created using the prepared DEM. A DEM's slope can be expressed as a function of the gradients in both X and Y direction at any given position.

Given that slope effects surface water flow, recharge runoff, and sedimentation, it is important to consider slope when choosing a dam site [1]. Figure 5 displays the slope map of study region that was created with the 30m SRTM DEM using the Slope Tool under Surface Tools in ARCGIS 10.7.1 platform.

The primary factors that indicate topographic features are elevation and slope. It is often acknowledged that, while higher and lower elevations are not suitable, sites of moderate elevation are more suited for the construction of dams. On the suitability of steep vs moderate slopes for dam construction, academics have differing opinions.

2.4.5 Land use/cover

The key component in the creation of surface runoff is land use [7]. In actuality, runoff velocity, the infiltration rate, and the evapotranspiration of an area all greatly impact by land use/cover [7]. Land use map of the study area is shown below in Figure 6. And the land cover type and area in percentage are discussed below in Table 3.

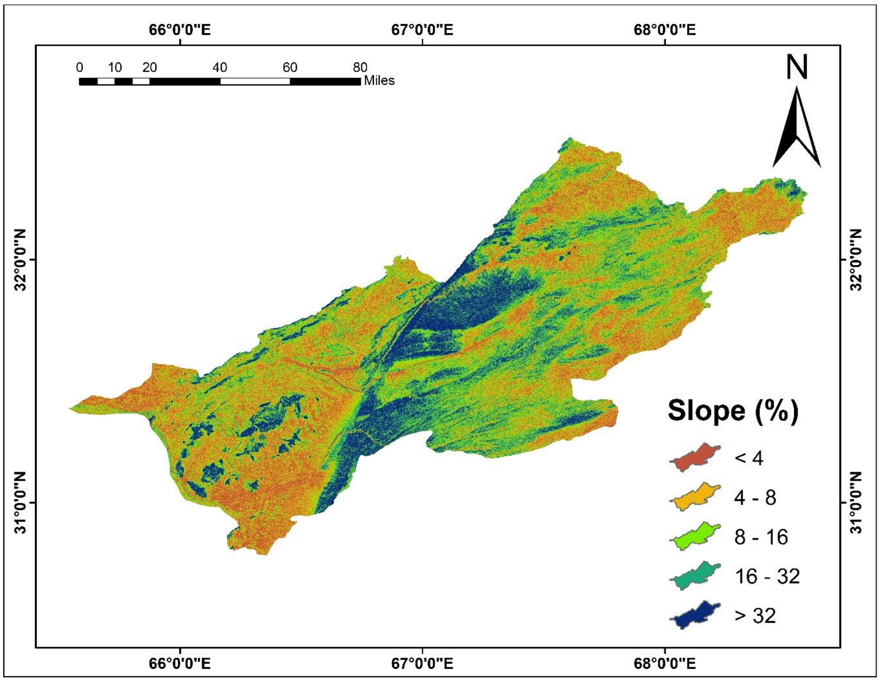

Figure 5 Slope map of the study area

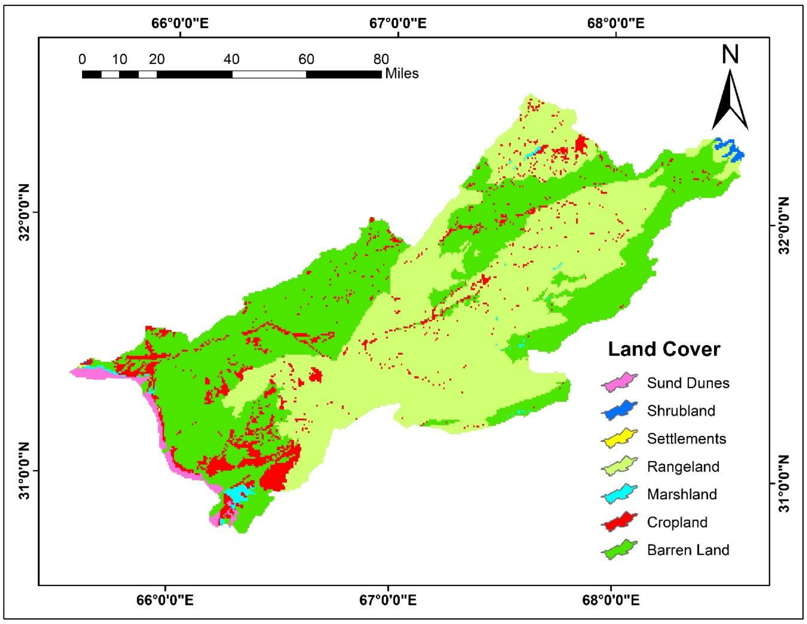

Figure 6 Study area land cover map

Table 3 Types of land cover and area (%)

Land Cover Type	Area (Percentage)
Barren Land	42.6332
Cropland	7.05924
Marshland	0.58289
Rangeland	48.13722
Settlements	0.00248
Shrubland	0.26788
Sand Dunes	1.31709

2.4.6 Lithology

Lithology map of Afghanistan is obtained from "Afghan Geological Survey Department", then clipped the study area lithology map by ArcGIS platform. The study area lithology map is shown below in Figure 7.

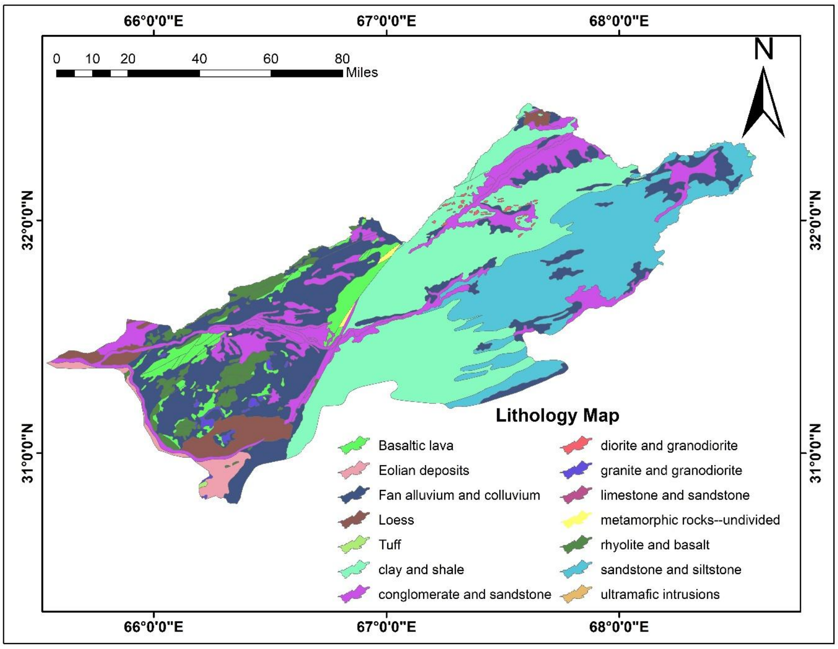

Figure 7 Lithology map of the study area

Subsequently, the lithology map is reclassified into five categories according to its resistance to deformation and seepage, which is discussed in Table 4. And the reclassified lithology map is shown in Figure 8.

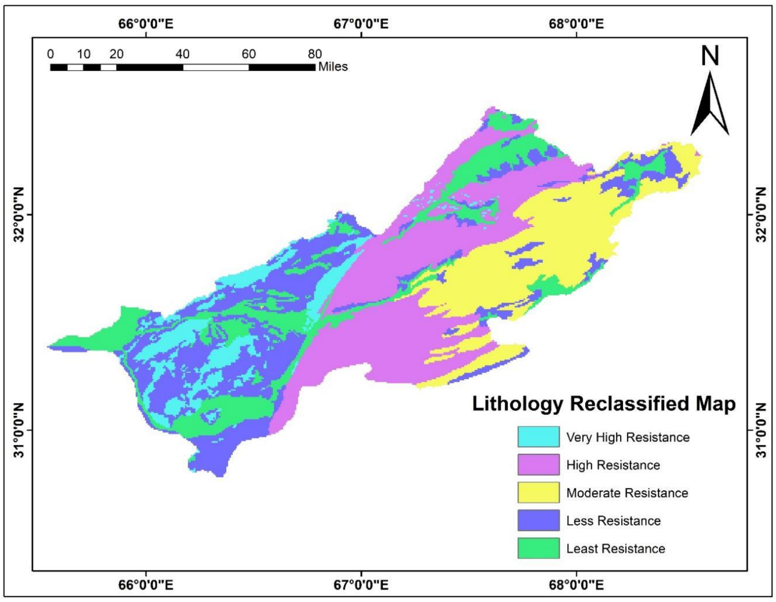

Figure 8 Reclassified lithology map

Table 4 Lithology map reclassifications

Lithology reclassification	
Lithology layers	Resistances
Loess, Tuff, Conglomerates, Sandstones	Least Resistance
Eolian Deposits, Fan Alluvium and Colluvium	Less Resistance
Limestone, Siltstone	Moderate Resistance
Metamorphic Rocks “undivided”, Clay, Shale	High Resistance
Granite, Granodiorite, Rhyolite, Basalt, Diorite, Ultramafic Intrusions	Very High Resistance

2.4.7 Soil

In the soil classification system ,4, hydrological soil groups (HSGs) have been developed by the USDA-Soil Conservation Service based on infiltration rates; these are A, B, C, and D [22]. Table 5 provides a detailed description of the four hydrological soil groups (HSGs) based on texture infiltration rate, and runoff potential. The study area soil map based on food and agriculture organization (FAO) is shown below in Figure 9. And the FAO-based soil types of the study area discussed in Table 6. There are two types of HSGs in the study area “HSG-C and HSG-D”, and covered areas “2.2% and 97.8%” respectively, discussed below in Table 6.

Table 5 USDA-Soil conservative service (SCS) classification system, (1974); ERA (2013)

HSGs	Textures	Properties	
		Infiltration rates	*Runoff potential*
A	Sand, loamy sand, or sandy loam	High	Low
B	Silt loam or loam	Moderate	Moderately low
C	Sandy clay loam	Low	Moderately high
D	Clay loam, silty clay loam, sandy clay, silty clay, or clay	Very low	High

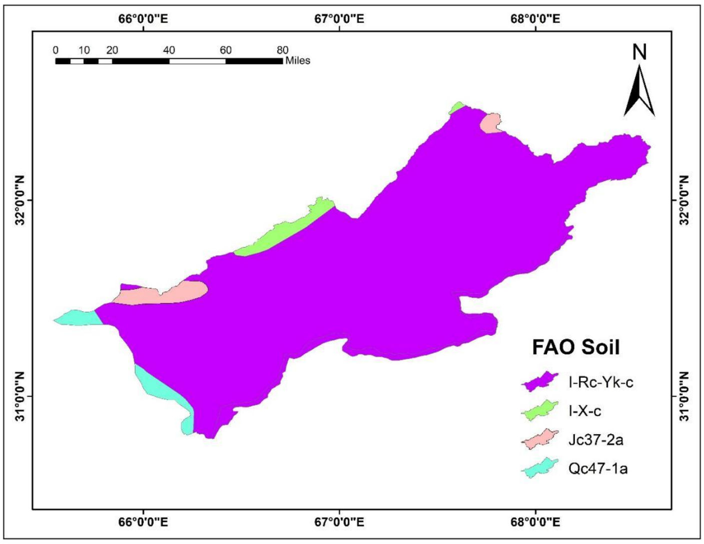

Figure 9. Soil map of the study area

Table 6 Descriptions of study area soil types

Soil Legend Key				
SNUM	FAO - Soil	DOM - Soil	Texture	HSG - Soil
3508	I - Rc - Yk - c	Lithosols	Loam	D
3512	I - X - C	Lithosols	Loam	D
3525	Jc37 - 2a	Calcaric Fluvisols	Loam	D
3542	Qc47 - 1a	Combic Arenosols	Sandy clay loam	C

2.4.8 Rainfall

Generally, each year, even in normal conditions, rainwater has been lost through the Arghistan River, which may cause water shortage during dry years in the area. Therefore, dams are needed to store water. Based on the availability of data, Average monthly rainfall data of 10 years from 2011 to 2020 is obtained, and based on this data, a rainfall map is created. The study area Rainfall map is shown below in Figure 10.

2.5 Dam Suitability Stream Model (DSSM)

This study creates a dam site suitability map using the dam suitability stream model (DSSM), which is based on stream order. Stream and their order are regarded as the primary component in the model, which has other parameters including "slope, geology, land use/cover, soil, and DEM". Creating a dam site suitability map using DSSM has been done in four stages. 1st stage: generation of the considered parameters in raster layers, 2nd stage: reclassification of parameters, 3rd stage: determining the weight of each parameter by using AHP analysis, 4th stage: overlay analysis, to create dam site suitability map, all four stages shown in Figure 2.

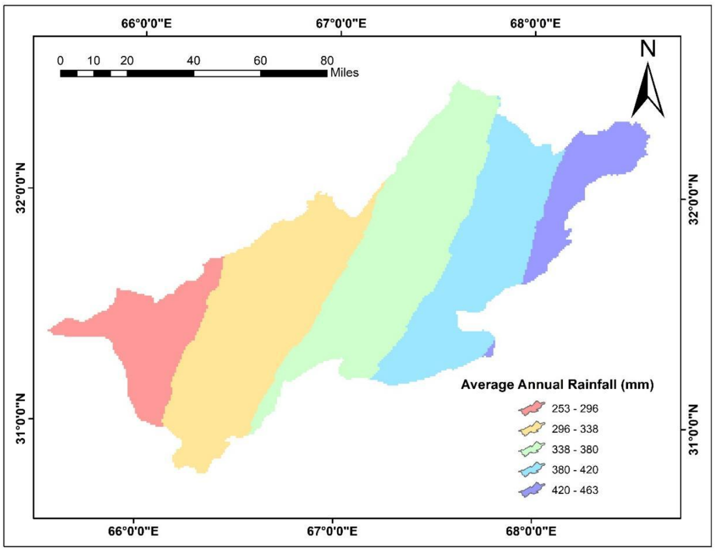

Figure 10 Rainfall map of the study area

2.6 Reclassification

Using ARCGIS's reclassification tool, all of the chosen criteria were reclassified. Raster layers undergo reclassification in order to be divided in to five classes. Of the criteria, only "soil-HSGs", which has two types, gets reclassified into its two classes. Reclassification of the chosen raster layers discussed in Table 7.

Table 7 Reclassification of thematic layers

S. No	Criteria	classes	Preference value	Weight (%)
1	Stream order	1st order	1	37
		2nd order	2	
		3rd order	3	
		4th order	4	
		5th order	5	
2	slope	$S \leq 4$	5	25
		$4 < S \leq 8$	4	
		$8 < S \leq 16$	3	
		$16 < S \leq 32$	2	
		$S > 32$	1	
3	Geology	Least resistance	1	16
		Less resistance	2	
		Moderate resistance	3	
		High resistance	4	
		Very high resistance	5	
4	Land use/cover	Barren land	5	10
		Cropland	4	
		Rangeland	3	
		Shrubland	2	
		Marshland	1	
		Settlement	0	
		Sand dunes	0	
5	Soil	C	3	7
		D	5	
6	DEM	939-1200	5	5
		1201-1500	4	
		1501-1900	3	
		1901-2300	2	
		2301-2909	1	

2.7 Analytical Hierarchy Process (AHP)

Analytical hierarchy process AHP is a widely used decision-making model in MCDA, determining criteria and factors' weight, and has been extensively used with GIS since the early 21st century [11]. AHP's integration with GIS provides a user-friendly solution to difficult problems by combining decision-making assistance methods with sophisticated tools for mass data computation, visualization, and mapping [12]. The weight of each criterion is determined by pairwise comparison using the Saaty's 1-9 fundamental scale [17] Table 8. First, the pairwise comparison decimal matrix Table 9 constructed. Next, the normalized pairwise comparison matrix Table 10 was calculated.

Table 8 Saaty's pairwise comparison scale

Numeric values	Intensity of importance
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 strong to extremely strong importance
9	Extremely strong importance
Reciprocals of above	If activity i has the above non zero number assigned to it. When compare to activity j. The j has the reciprocal value when compare with i

Table 9 Pairwise comparison of six criterion decimal matrix

Criteria	Stream order	Slope	Geology	LU / LC	Soil	DEM
Stream order	1	2	3	4	5	6

Slope	0.5	1	2	3	4	5
Geology	0.333	0.5	1	2	3	4
LU / LC	0.25	0.333	0.5	1	2	3
Soil	0.2	0.25	0.333	0.5	1	2
DEM	0.167	0.2	0.25	0.333	0.5	1
Sum	2.45	4.283	7.038	10.833	15.5	21

To create normalized pairwise comparison matrix, divided each value in the columns of the matrix to the column wise sum in pairwise comparison decimal matrix.

Table 10 Normalized pairwise matrix calculated

criteria	stream order	slope	geology	LU / LC	soil	DEM	Weight	influence %
stream order	0.408	0.467	0.423	0.369	0.323	0.286	0.37	37
slope	0.204	0.233	0.282	0.277	0.260	0.238	0.25	25
geology	0.136	0.117	0.141	0.185	0.193	0.190	0.16	16
LU / LC	0.102	0.078	0.072	0.092	0.129	0.143	0.10	10
soil	0.082	0.058	0.047	0.046	0.064	0.095	0.07	7
DEM	0.068	0.047	0.035	0.031	0.031	0.048	0.05	5
Sum	1	1	1	1	1	1	1	100

In the last step find the consistency ratio (CR), and check the value with CR < 0.1 "consider acceptable". For finding the consistency ratio, use the following equations.

$$CR = \frac{CI}{RI} \tag{1}$$

Where: CI is the consistency index and RI is the random inconsistency index.

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{2}$$

Where: n is the number of criteria for AHP analysis, and λ_{max} is the sum of the products of the column-wise sum in pairwise comparison matrix Table 9, and the average weights from normalized pairwise matrix Table 10, λ_{max} obtained in Table 12.
The Random Inconsistency Indices (RI) for the number of criteria (n) discussed below in Table 11 [16].

Table 11 Random inconsistency indices (Saaty 1980)

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.46	1.49

Table 12 Calculation of λ_{max}

column-wise sum of criteria	Average weight of criteria	Product of both columns
2.45	0.37	0.9065
4.283	0.25	1.07075
7.083	0.16	1.13328
10.833	0.10	1.0833
15.5	0.07	1.085
21	0.05	1.05
	$\lambda_{max} = sum\ of\ the\ above$ →	6.32883

For finding the consistency index, use Equ.2.

$$CI = \frac{\lambda_{max} - n}{n - 1} = \frac{6.32883 - 6}{6 - 1} = 0.066$$

And the consistency ratio is calculated using Equ.1 where the value of RI is 1.24 for $n = 6$, from Table 11.

$$CR = \frac{CI}{RI} = \frac{0.066}{1.24} = 0.053 < 0.1 \quad (Acceptable)$$

2.8 Overlay Analysis

Using the weighted overlay of the ARCGIS 10.7.1 platform, overlay analysis under spatial analyst tools was used to create the dam site suitability map. The "Scale value" and "Influence value" in the tool are assigned with "Preference values" from Table 7 and "Influence value" from Table 10, respectively. After resampling each raster layer to the same spatial resolution, overlay analysis is carried out twice using weighted overlay. 1st Overlay Analysis, including stream order itself. “where streams and their orders are essential parameters”. 2nd the overall suitability map is created by using the “distance to streams layer” as a counterpart of “stream order”.

3 RESULTS AND DISCUSSION

3.1 Dam Site Suitability Maps

The results are displayed in two distinct dam site suitability maps. One titled “Suitability on stream” which is shown in Figure 11, and another titled “overall suitability” which is shown in Figure 12. Each map has four levels of suitability, which stand for “High, Moderate, Less, or Not suitable”, respectively. The area by percentage of suitability on the stream map shown below in Figure 13, where 23.34% of the area is not suitable, 60.38% is less suitable, 15.80% is moderate suitable, and 0.48% highly suitable. And the area by percentage of overall suitability map shown below in Figure 13, where 2.24% of the area is not suitable, 32.21% is less suitable, 60.69% is moderate suitability, and 4.86% is highly suitable. The large discrepancies between the percentage of suitability levels of “Suitability on the streams map” and “Overall suitability map”, are due to the number of cells in both raster’s’. In the first case, all cells include only streams, and in the second case all cells, include the entire study area. According to the “Overall suitability map”, most of the area dropped into the range of “Less suitability to Moderate suitability”, while the high suitable zone is located in the south-west, north-west, or east part of Arghistan watershed, which mostly falls on Arghistan, Spin Boldak, Shamulzayi, and Shinkay districts in the watershed, which is shown in Figure 14. According to the “Suitability on streams map”, most of the streams dropped into the range of “Not suitable to Less suitability”, while a smaller number of streams are suitable for dam construction, which are generally high order streams, and located in the Arghistan, Shinkay, Spin Boldak, and Maruf districts in the watershed.

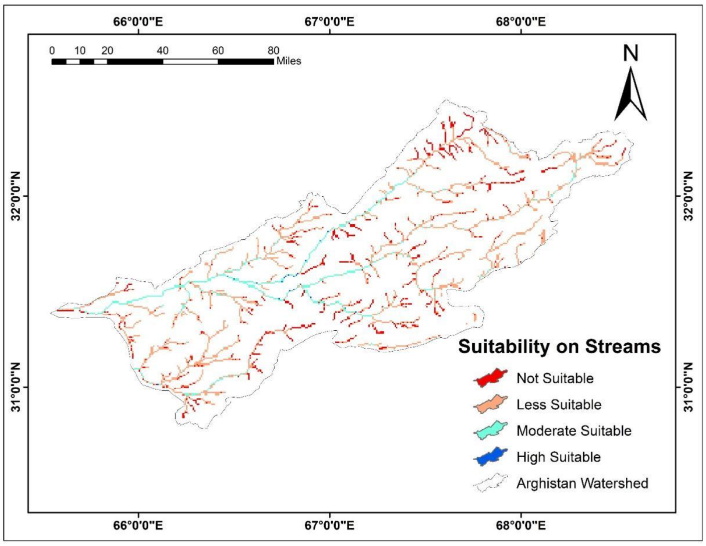

Figure 11 Suitability on the streams map

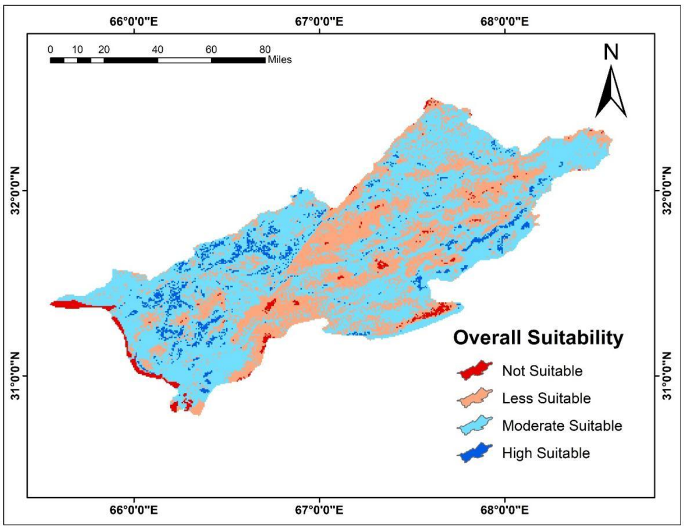

Figure 12 Overall suitability map

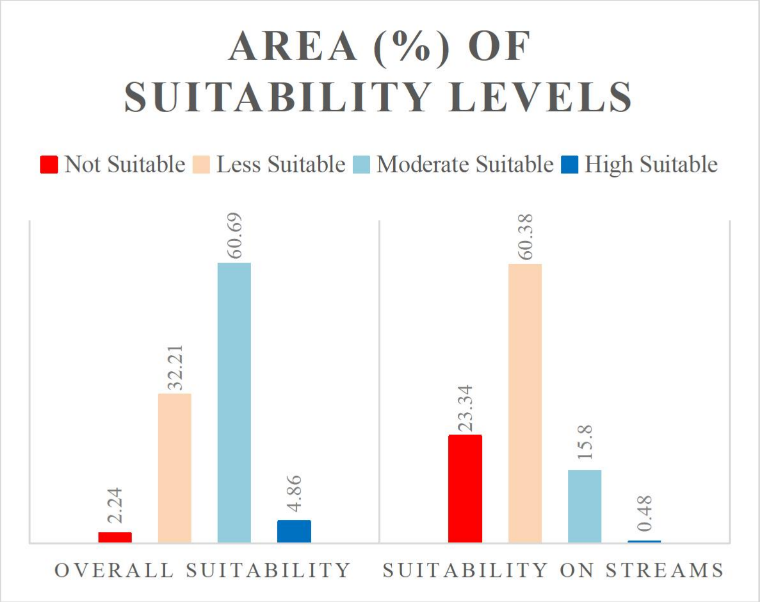

Figure 13 Area (%) of suitability maps

3.2 Proposed Dam Sites

In this study, both of the suitability maps (Suitability on Streams Map and Overall suitability Map) were used to choose the dam sites for this investigation. The optimal dam location is determined by looking for "Moderate" to "High" in "Suitability on streams map", while the suitability level in "Overall suitability map" should be "High". The locations of the proposed dams' sites are shown below in Figure 14, and discussed in Table 13.

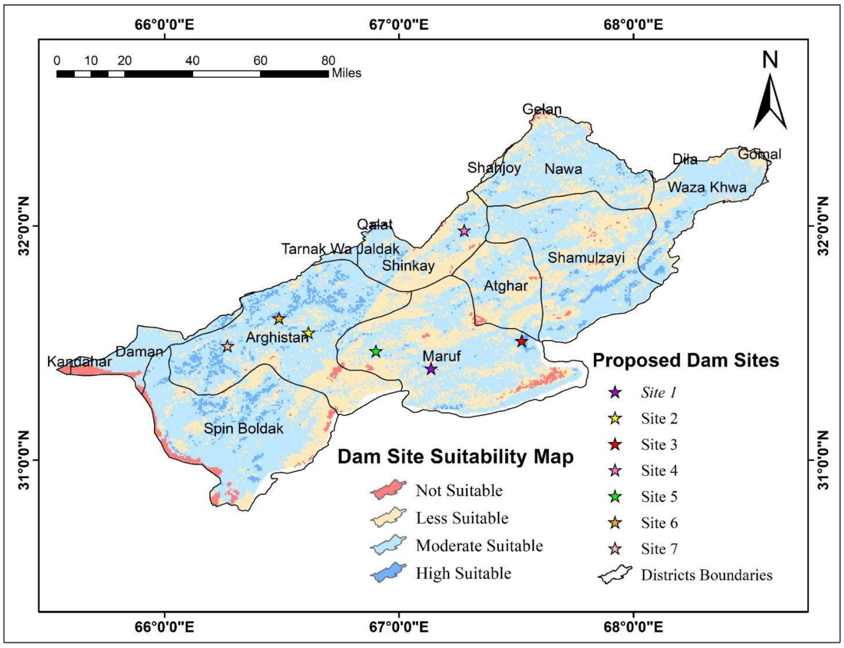

Figure 14 Proposed dam sites

Table 13 Locations of the proposed dam sites

Proposed dam sites	Locations		Elevations (m)	Stream order	Districts	Province
	Latitude (N)	*Longitude (E)*				
Site 1	31.379	67.153	1821	4th	Maruf	Kandahar
Site 2	31.559	66.744	1441	4th	Arghistan	Kandahar
Site 3	31.511	67.548	1983	3rd	Maruf	Kandahar
Site 4	32.015	67.317	1884	4th	Shinkay	Ghazni

Site 5	31.477	66.669	1358	4th	Maruf	Kandahar
Site 6	31.607	66.497	1261	3rd	Arghistan	Kandahar
Site 7	31.529	66.305	1178	3rd	Arghistan	Kandahar

4 CONCLUSION

To fined appropriate locations for dam construction, this study examined the Arghistan watershed's hydrological, environmental, geological, and topographical features. Streams and their orders are regarded as the essential parameters in this study of "Dam Site Suitability Mapping", which also includes to slope, geology, landcover, soil, and Digital Elevation Model (DEM). By using Geographic Information System (GIS), Remote Sensing (RS), or Analytic Hierarchy Process (AHP) to create Dam Suitability Stream Model (DSSM), this study systematized the location analysis procedure as a whole. Stream order, the most significant or crucial parameter in the DSSM model, is assigned the largest weight when DSSM utilizes AHP to allocate weights to each element. As a result, two distinct types of suitability maps, such as "Overall Suitability Map" and "Suitability on Streams Map" based on "Distance to Streams Map" and "Stream Order Map", respectively, are presented. Four appropriate classes, such as "Not, Less, Moderate, or High suitable", are shown in each suitability map. Then, 7 suitable sites for dam construction were proposed based on both suitability maps. The local population will profit greatly from the dam(s), including fisheries, electricity generation, and water for cultivations "instead of ground water".

RECOMMENDATION

In order to improve the accuracy of streams as well as the accuracy of suitability maps, High-resolution sources of all pertinent datasets are recommended for future studies.

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COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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