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Site Selection for Underground Dam Construction by Fuzzy Algorithm in GIS Platform

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ABSTRACT

Aim The global need for water-conserving increasing in arid and semi-arid areas and water preserving by improving vegetative cover in rangelands by reducing the erosion effects is a rational justification for the performance of underground dams. This research aimed to locate underground dams using GIS integrated with the fuzzy algorithm.
Materials & Methods The data layers included geology, LU/LC, streams, villages, water resources, and slopes of the Sarakhs region, Iran, were prepared and standardized by the sigmoidal membership function.
Findings Almost 98% of the final maps were in the fuzzy range of 0 to 0.5. This means that suitable locations for constructing underground dams with the fuzzy range of 0.5 to 1 found in less than 2% of the Sarakhs basin.
Conclusion The superiority of fuzzy method for more scalability from other overlaying methods comes from this fact that in the second step of site selection and in the different management scenarios, we can take advantage from multiple fuzzy ranges.

Keywords Geology Layer; Groundwater; GIS; Qanat; Site Selection; Sarakhs

CITATION LINKS

[1] Conflict and cooperation along international ... [2] Decision making in fuzzy discrete event ... [3] Identifying of Suitable Location for Underground ... [4] Assessing potential land suitable for surface ... [5] Sustainable use of groundwater with underground ... [6] A methodology for the pre-selection of suitable ... [7] Appropriate technology for artificial ... [8] Ground water dams for rural water supplies ... [9] Modeling of underground dams Application ... [10] Fuzzy Sets ... [11] Round water dams for small scale ... [12] Irrigation technology, society and environment ... [13] Integrating GIS based fuzzy set theory in multicriteria ... [14] Suitable site selection for groundwater dams ... [15] Site selection for groundwater artificial recharge ... [16] Locating suitable sites for construction of ... [17] Locating suitable sites for the construction of ... [18] A multi-criteria evaluation approach to ... [19] Fuzzy logic-a modern perspective ... [20] Municipal solid waste landfill sitting using ... [21] Study on the trend of range cover changes ... [22] Progress, opportunities and key fields ... [23] An optimized solution of multi-criteria evaluation ... [24] Application of fuzzy measures in multi-criteria ... [25] GIS-based multicriteria decision analysis ... [26] Fuzzy comprehensive evaluation-based disaster ... [27] Multi-criteria supplier selection using fuzzy ... [28] Soil moisture estimation in rangelands using ... [29] Underground dams: A tool of sustainable ... [30] Comparison the AHP and fuzzy-AHP decision ... [31] Site suitability analysis for subsurface dams using ... [32] Combination of boolean logic and analytical hierarchy ... [33] Sustainable conjunctive use of surface and ...

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Introduction

There is much evidence that the likelihood of a global conflict over water in the near future is very high [1]. Groundwater qualities and quantities worldwide are increasingly being hampered negatively by anthropogenic sources and activities [2]. The main part of Iran is in the arid and semi-arid regions, and water is a limiting factor of human activities in this area [3]. So the careful management of water resources is necessary, especially in arid lands. Water resource availability in arid lands is mostly connected with the characteristics of shortage and periodicity of precipitations which determine run-off during only short periods of the year. With large evaporation from vegetation that generally characterizes the arid zones, these problems impede the formation of perennial streams capable of satisfying the environment and population's requirements. Groundwater is more suitable for irrigation than surface water since it has a slow response to climate variability and requires less treatment [4]. Considering the limited water resources, the attitude of existing resource management should be a move towards finding new management ways.

The selection of suitable sites for artificial recharge is very important and needs to be carried out accurately. Underground dams are a new technology for improving and protecting water resources and are compatible with arid and semi-arid areas. These dams are the structures built under the ground's surface and block the flow of groundwaters from water reservoirs under the ground. These dams are mostly built near the dry rivers and seasonal streams to store the water below the ground's surface. This water is very unlikely to get polluted easily by animals or humans, and it can be obtained by a pump or well.

One of these methods that cause the least environmental damages and reduces the water loss to the minimum is the construction of underground dams. To store groundwater, a dam is constructed underground. However, in a dam to store very shallow groundwater like underflow in the current river sediment, part of the dam is sometimes exposed above the ground surface. An underground dam allows the development of water resources in regions where the construction of surface dams is difficult due to geological conditions, and groundwater cannot be used in its current state [5].

Although the planning for water resources management and exploitation is done at a regional scale, we need to consider that often with limited financial resources [6]. Barrages are divided into two different types: underground barrages and surface barrages. Both types are constituted by the main structure that will be eventually located below the ground surface to stop the groundwater flows [7]. An underground barrage rests on bedrock a few meters deep, allowing increased infiltration into the subsoil and, consequently, larger availability of water resources into the aquifer. Underground dams have some privileges over surface dams that are as following: Evaporation is an essential problem in surface dams that are eliminated in underground dams. These are structurally more stable, so less likely to lead to life or financial losses. The water stored in them is less probable to get polluted [8].

Furthermore, the reservoir of the surface dams are filled to a great degree by the sediments, a problem that cannot be found in underground dams. Moreover finally, these dams can be executed with lesser costs. In general, a subsurface dam is more stable than a surface dam from the viewpoint of dynamics because it is buried underground and thus does not need maintenance. Even if it breaks, there is no damage to the downstream area because the breakage occurs underground. The site selection of sub-surface dam is difficult compared to the surface dam [9, 10]. These dams are constructed below the river beds, preferably dry rivers, and usually are extended to impermeable bedrock. Using this method, the river streamlines are stopped under the ground, forming a limited aquifer in the alluvial reservoir of the river bed [11]. A combination of underground dams' technology with Qantas can provide a novel solution for this problem. Using these dams, the loss of small underground flows is inhibited and channelized towards the qanat [12].

A great deal of research has been done already about underground site selection. In research in Yazd province of Iran, the spatial and non-spatial Analytic Hierarchical Process (AHP) was used by Azizi *et al.*. Concerning assessment criteria, five convenient locations for constructing an underground dam in the area of Pishkuh catchment in Taft's township of Yazd province were prioritized [13].

Mehrabi *et al.* studied site selection for artificial groundwater recharge in Silakhor rangelands in

Iran and concluded that integrated assessment of thematic maps using AHP and GIS techniques is a suitable method for identifying preferred artificial recharge sites [14].

The parameters affecting the suitability of a reservoir are the volume of the reservoir, the permeability of the soil, the depth of the bedrock, and the chemical quality of the soil. Since GIS and RS techniques are very powerful tools in processing spatial data pertinent to this large-scale project, they are called to help in dealing with this huge amount of information to make it more constructive and functional for spatial planning, particularly in finding an opposite site for small underground dams, GIS must be linked to the other advanced mathematical modeling capabilities such as fuzzy algorithms for dealing with spatial complexities. GIS-based MCDA provides a collection of powerful techniques and procedures for dealing with decision-making problems and designing, evaluating, and prioritizing possible alternative courses of action [15, 16].

This chapter aims and novelty to present a general framework for the preliminary phase locating of underground dams in areas with no detailed numerical data, and instead, linguistic information from expert experiences exists. Therefore, an extended. The fuzzy method in the context of GIS was applied to reach this target.

Using the underground dams, in addition to charging the Qantas, we can control their discharge. This way, by storing the Qantas water, in the alluvium behind the dam, the loss of underground flows during the cold seasons can be prevented, resulting in a qualitative improvement of the aquifer charging the qanat. The second step is site selection, finding the optimal location for the dam. GIS and RS techniques are very powerful tools in processing spatial data pertinent to this large-scale project.

Materials and Methods

Study area

The study area is located on the eastern of Kopet Dagh mountains in the range of 35° 53′ 20″ to 36° 32′ 4″ North latitude and 60° 17′ 42″ 0 to 61° 9′ 47″ East and with an area of about 4500 km^2. The city of Sarakhs is located in Khorasan Razavi province, and its neighbor from the north is the Republic of Turkmenistan, from the south, is the city of Torbatejam, and from the west is Mashhad plain. The natural boundary of the area in the south is the Kashf river, and the eastern boundary is the Tajan river, and the natural boundaries of the west and southwest are the vast stretches of the Kopet Dagh mountains. The height of this area is 235 meters, and its center is Sarakhs city (Figure 1).

Due to its low altitude, the city has less rainfall than other northern and eastern parts of the province. It is also characterized by a dry and desert climate due to its proximity to the vast desert of Turkmenistan. In this city, there are different tribes, including Baloch, Sistani, Arab Turks, and Kurd nomads. Sarakhs watershed is the smallest basin of the sixth basin of Iran. The average run-off in this area is 58.88m^3/s. The average rainfall and annual temperature at Sarakhs Meteorological station are 180 mm and 19°C. Another feature of this region is the Doosty dam located on the Heriroud border with annual water storage of 820 million m3 and a lake with 37km2 constructed by Iran and Turkmenistan jointly [14, 15].

The main digital layers of the study are used to evaluate the suitability of sites for the installation of barrages are described below.

Land use/land cover map

This layer includes land uses and land covers; orchard, forests, irrigated farms, undeveloped and bare lands, rangelands, dry farms. The land use/land cover data was generated from Landsat 8 satellite imagery with a 30 m spatial resolution acquired in 2015 through image processing techniques. Some suitable sites include woodlands and riverbanks using land-use maps, while residential areas and water bodies are unsuitable spots. In LC/LU map, some of the classes have priority over other ones. In this study, each class was given a number from 1 to 9 according to their degree of suitability based on expert opinions.

Villages

In order to reduce the cost of transporting material for underground dams, the minimum distance from the village seems essential. At the same time, villagers should benefit from the construction of a dam. Therefore, the Euclidean distance function was used to create a raster layer of distance from the villages.

Lithology

This map has been produced by the Iranian national geology organization at a scale of 1:100000. Contrary to a surface dam whose site conditions can be examined by visual inspection, surveys for site selection and calculating the water storage capacity of a subsurface dam rely on estimates of underground geological structures. In the case of a subsurface dam, water is stored in the pores of geological strata. Therefore, the volume of reserved water is determined by the volume of those pores (effective porosity) and reaches only 10 to 30% of the volume of the reservoir layer. The higher the volume of pores (effective porosity) of the geological strata from the reservoir layer, the more effective the water storage. This is because water is stored in the geological strata. High effective porosity is also necessary for high water fluidity.

Water resources

This layer contains wells, springs, qanats, and surface dams. All information on this layer was obtained from the last available database in 2014 from Khorasan Razavi regional water authority experts. The main purpose of constructing underground dams is to prevent water loss through seepage in the watershed and increase the discharge of water sources such as wells, springs, and qanats. The wells are one of the water resources in any region, and any damage to them may provoke intense local challenges. The main purpose of constructing an underground dam is to improve the available water resources and optimum exploitation of subsurface flows, assuming that a new water resource does not hurt the old ones. 4.3.

Elevation and slope

Using the topographical map of scale 1:50000, the DEM (Digital elevation model) was produced, then the 2D surface of the slope was derived. Some Sections of the river bed, which are too steep, are not suitable sites for making underground dams (Nilsson 1988). The slope is an effective factor for recognizing the suitable locations for underground dams. In the regions where the slope is mild, the water flows more slowly, so it has more time to infiltrate into the ground so more water can be stored in the underground dam. On the other hand, where the slope is mild, the reservoir would have a greater volume.

Stream layer

Rivers of higher orders usually are more suitable locations for constructing underground dams, and rivers of lower order are better for surface dams. Groundwater should exist at a shallow depth because, if the groundwater aquifer exists at a deeper depth, determining the hydrogeological characteristics of the dam site would be more difficult, and the cost and technical difficulties of the construction of the subsurface dam would be much greater. One of the instrumental things in the processes of site selection is the stream layer. The stream network of the study area is derived from the topographic map (Scale 1/50000) and Digital Elevation Model in the GIS program. Usually, the places with great volumes of alluvial deposits are entirely fit for trapping water. On the bed of rivers, these sediments are found in abundance. The fuzzy GIS-based system was developed during a multi-step process, as shown in (Figure 2).

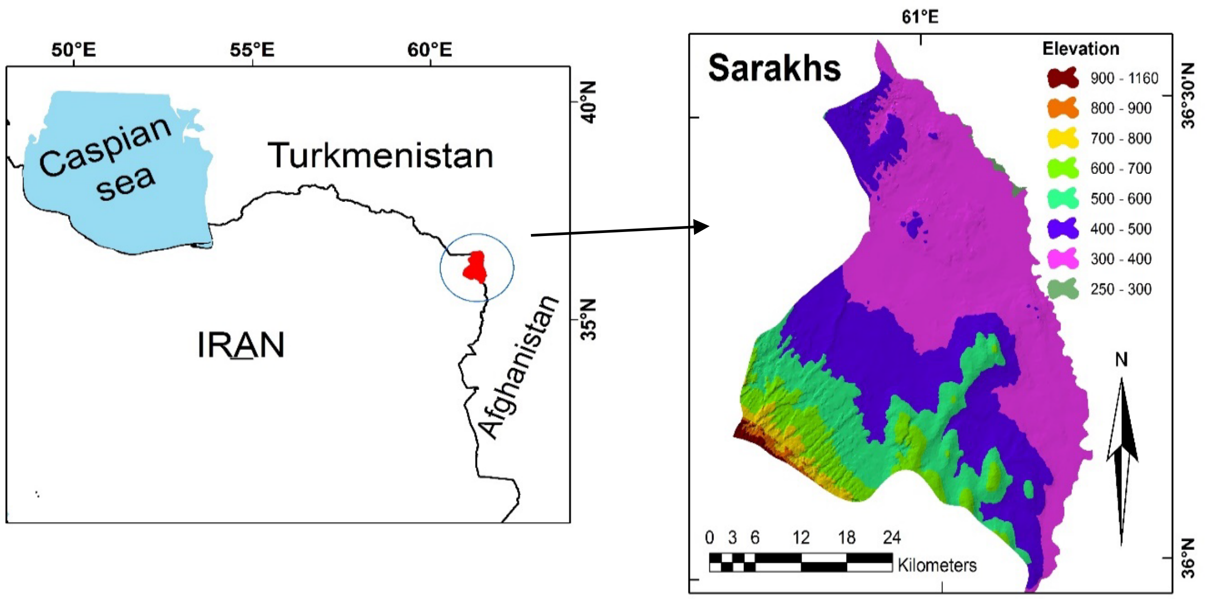

Figure 1) Geographical location and elevation map of Sarakhs

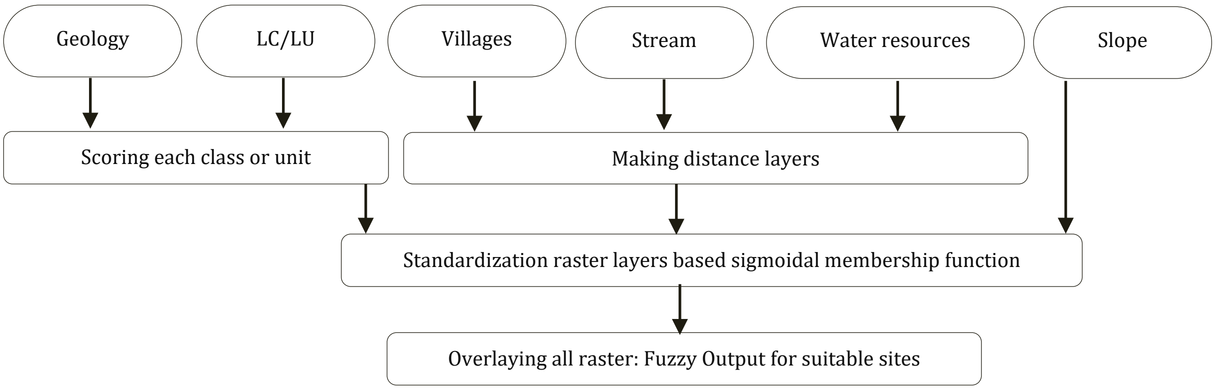

Figure 2) Flowchart of the study process

Fuzzy logic

The concept of a fuzzy set was introduced by Asgar Lotfizadeh in 1965 as a quantitative approach to integrating factors such as human reasoning, knowledge, attribute, spatial variation, and measurement error in environmental data [17]. Fuzzy logic has been a somewhat controversial technology since its birth [18]. In recent years, fuzzy logic has been successfully applied in various disciplines, including computer vision, weather prediction, image processing, nuclear reactor control, control of biomedical processes, and other research fields [19]. The fuzzy set theory is a hypothesis for taking action under uncertain conditions [19]. Uncertainty is a major concept in our daily life. Fuzzy sets and fuzzy logic provide an approach to deal with this concept [20]. Fuzzy sets have been applied in the context of MCDA in order to standardize criterion maps by assigning to each object a degree of membership or un membership of each of the criteria [21, 22].

GIS integrated with MCDA methods provides a framework for handling different aspects of the various elements of a complex decision-making problem, organizing the various elements into a hierarchical structure, and studying the relationships between these different components of the problem [22, 23]. Fuzzy Sets are sets (or classes) without sharp boundaries; that is, the transition between membership and nonmembership of a location in the set is gradual [17]. A Fuzzy Set is characterized by a fuzzy membership grade (also called a possibility) that ranges from 0.0 to 1.0, indicating a continuous increase from nonmembership to complete membership. Fuzzy mathematics characterizes the degree of elements belonging to a set by using membership and expanding binary logic of Two-valued logic classic set (0, 1) to continuous-valued logic of Interval [0, 1] to provide an effective means for description and reaction to various fuzzy things and phenomena [24]. A fuzzy set can be described as follows: if Z denotes a space of objects, then the fuzzy set (A) in (Z) is a set of ordered pairs: A {z, MF (z)}, z € Z where the membership function MF (z) is the set A's degree of membership to Z.

Figure 3 shows the triangular fuzzy number (TFN) M contains the basis for the membership function. The TFNs are denoted simply by m_1, m_2, and m_3. The parameters m_1, m_2, and m_3 respectively denote the smallest possible value, the most promising value, and the largest possible value that describes a fuzzy object [25]. Using this approach, each TFNs has a linear representation on its left and right sides, and the membership function can be defined by equation (1).

Equation 1

$$\mu(x \mid M) = \begin{cases} 0; & x < m_1 \\ (x - m_1)/(m_2 - m_1) & m_1 \le x \le m_2 \\ (m_3 - x)/(m_3 - m_2) & m_2 \le x \le m_3 \\ 0; & x < m_3 \end{cases}$$

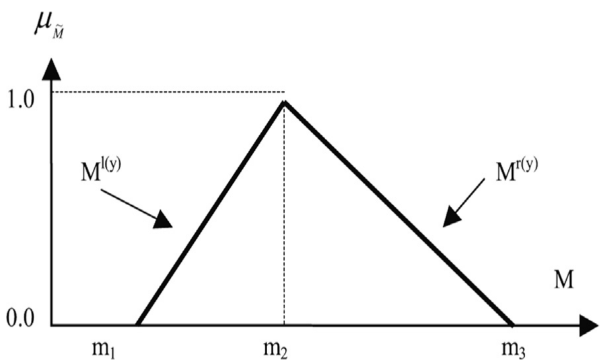

Figure 3) triangular fuzzy number (TFN) [17]

A fuzzy number can always be assigned based on its corresponding left and right representation of each degree of membership [14]. M= (Ml (y), Mr (y)) = (m1 + (m2-m1)y , m3 + (m2 – m3) y). Y € [0, 1] where l (y) and r (y) denote the left and right side representations of a fuzzy number, respectively. The Sigmoidal ("S-shaped") Membership function is perhaps the most commonly used function in Fuzzy set theory. It is produced using a cosine function. Specified by two parameters {a, c} as follows: = where c is the center of the function and α controls the slope.

Findings

Control points and fuzzy functions for standardization of criteria in the fuzzy logic are shown in Table 1. For example, in slope criteria, the value of 0 has been allocated to the slope > 20, and the value of 1 has been allocated to the slope<0.

Table 1) Control points and fuzzy functions (all Sigmoid) for standardization of criteria in fuzzy logic

Criteria	Low	High	Suitability
Slope %	0	20	Decreasing
Distance to water resources (m)	0	5000	Decreasing
Distance to stream (m)	0	1000	Decreasing
Distance to villages (m)	0	5000	Decreasing
Geology	1	9	Increasing
Landuse/Landcover	1	9	Increasing

After investigating rock lithology for permeability of the reservoir bedrock, all units have been classified in the range of 1 to 9 (1: minimum penetrability and 9: maximum penetrability). Permeability fuzzy scoring of lithology units is presented in Table 2.

Based on engineering properties, the alluvial of river deposits is high permeability and porosity of over 30% appropriate for underground dam reservoir. The Permeability Index codes have been allocated to each lithology or combination of lithology for each named rock unit mapped. The Maximum Permeability represents the fastest potential vertical migration rate through the unsaturated zone likely to be encountered in a specific rock unit and lithology combination. Infiltration, run-off, and sedimentation in rangeland are not similar to a forest, or other land uses and ecosystem hydrology [26, 27]. So, based on experts' opinions, land use/land cover classes were scored in the range of 1 to 9 (1: not suitable, 9: completely suitable) (Table 3). In accordance with table 1, all raster layers were reclassified based on the sigmoidal function (Figure 4).

In a fuzzy output map, pixels with a value of 1 indicate the best areas for constructing the underground dam. By shrinking pixel values, suitability is decreased as well (Figure 5 and Figure 6).

Table 2) Penetrability scoring of geology formation

Lithology	Geology Code	Grade
Limestone, Chalky, White-Grey	Ad	1
Marl_shale, Blue-Grey, Sandy	Ab	1
Sandstone, Shale, Glauconitic	At	2
Olive Green Shale and Blue -Granite	Sn	2
Shale. Dark Grey to Black	Sn	3
Shale, Red-Brown.Gypsum.Sandston e	Sj	3
Light Buff-Grey Limestone, Dolomite	Sr	4
Sandstone, Shale, Light Green_Granite	Nz	4
Limestone. Light Brown-Grey	Tr	6
Limestone, Buff, Sandy	Kl	7
Light Buff-Grey Limestone	Mz_2	9

Table 3) Scoring of Landuse/Landcover classes

LC/LU classes	Grade
Water bodies	1
Population centers	1
Dense forest	2
Undeveloped and rocky lands	3
Sparse forest	3
Dense ranges	3
Semi-dense forest	4
Irrigated farm and garden	4
Semi dense ranges	4
Clay plains	5
Low density ranges	5
Silviculture	6
Dry farm	6
Woodlands	7
River bed	9

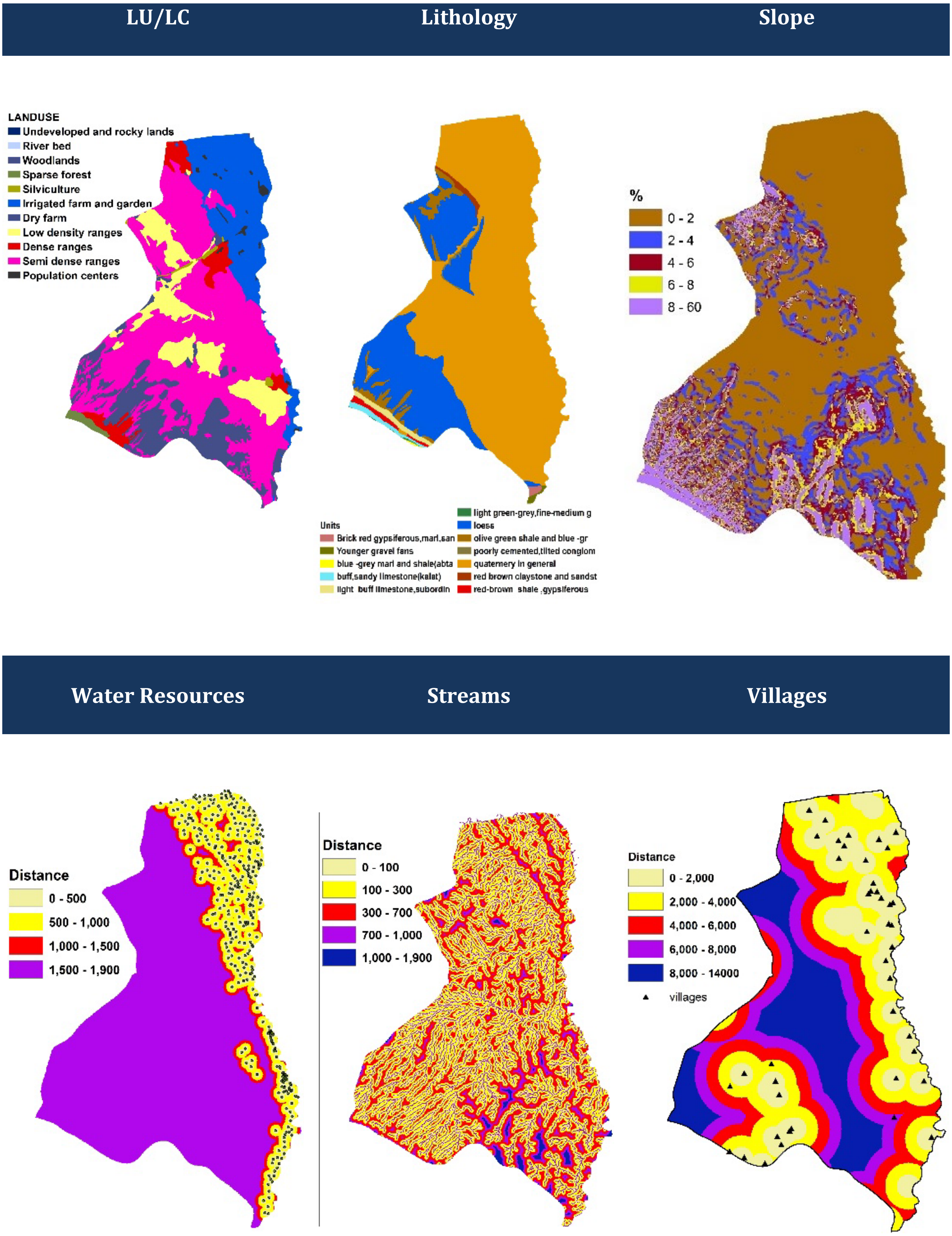

Figure 4) Input maps for fuzzy function

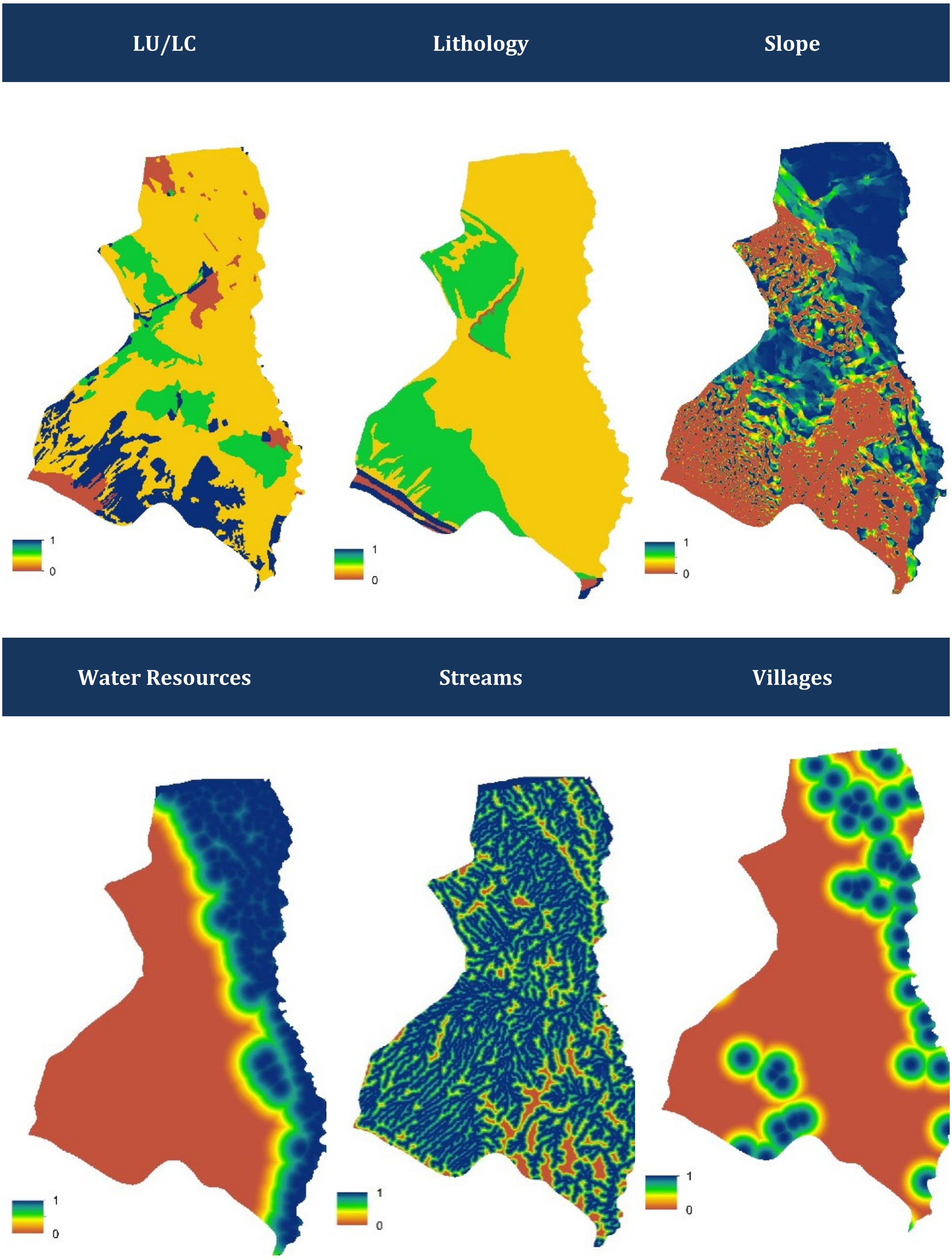

Figure 5) Fuzzified Raster layers Based on Sigmoidal Membership function

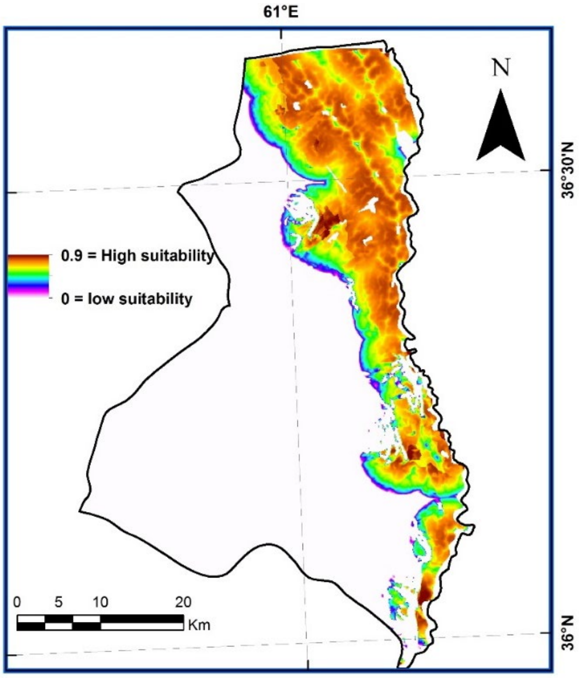

Figure 6) Fuzzy map output

Discussion and Conclusion

To prevent the performing of structures in inaccessible remote areas, it is decisive to keep at a distance from the villages. The proximity to villages can be considered an easiness index to find the necessary skilled human resources to realize the barrage. Sites too distant from villages present additional costs during the realization phase [28, 29].

By increasing the fuzzy grade, the percentage of suitable areas is reduced. This means that less than two percent of the Sarakhs basin has fair suitability for constructing underground dams with a fuzzy extent of 0.5 to 1. The outcome showed that the final map is a good deal of flexibility. Esavi *et al.* (2012) drew similar conclusions in their research. They compared two AHP and fuzzy-AHP decision-making methods in underground dam site selection in the Taleghan basin [30, 31].

Their results showed that the fuzzy-AHP method has more flexibility and greater ability to determine suitable areas for constructing the dam [32, 33].

This methodology describes a general procedure for assessing the suitability of sites for installing small dams by the integrated approach. The selection criteria are specified both in quantitative and qualitative layers. This research is particularly conducted in regions with insufficient data. It is crucial to observe that the method presented here settles suitable construction sites from current engineering and technical perspectives. A final evaluation of the feasibility and advantage of such projects should consider further variables. The final appropriate locations are determined based on the various aspects of economic, social, and environmental variables. Many important socio-economic aspects related to the local area, which can influence the project's understanding and efficient advantage, have been ignored here; e.g., roads network dislocation of nomadic people, tensions between near villages, and other complex dynamics which are difficult to understand and quantify without a multidisciplinary viewpoint. Such endeavors can analyze the potential for artificial recharge in the arid and semi-arid areas to ensure sustainable groundwater utilization.

The results of the current study showed that the GIS-based fuzzy approach, as a promising tool for hydrologists, shows good flexibility with a great ability to determine suitable sites for constructing underground dams.

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Ethical Permissions: -

Conflicts of Interests: This article was extracted from the project related to Reza Dehghani Bidgoli faculty of the University of Kashan. The authors declare that they have no competing interests.

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