EJGE

Integration of Multi-Criteria Decision Matrix and Geographical Information System to Site Selection for an Underground Dam

Kourosh Shirani*

Assistant professor, Soil Conservation and Watershed Management Research Department, Isfahan Agricultural and Natural Resources, Research and Education centre, AREEO, Isfahan, Iran.
**e-mail: k_sh424@yahoo.com*

Abdolrasoul Shafiey Dastjerdi

Master of Science in Engineering Geology, Soil Conservation and Watershed Management Research Department, Isfahan Agricultural and Natural Resources, Research and Education centre, AREEO, Isfahan, Iran.
e-mail: a.shafiey@areeo.ir

Jafar Rahnamarad

Associate professor, Department of Geology, Zahedan Branch, Islamic Azad University, Zahedan, Iran.
e-mail: rahnamarad@iauzah.ac.ir

ABSTRACT

Underground dam is an efficient construction for optimizing water utilization and proper management of groundwater. Delineation of suitable locations for construction of underground dams is an important issue but due to inaccurate preliminary studies, they are constructed with inefficient performance. This study deals with delineating proper locations for underground dam construction in Ardestan region, north of Isfahan by using spatial multi criterion evaluation method and GIS techniques. Effective factors were determined using engineering geology criteria then the process was segmented to several minor steps according to the main effective parameters and based on analytical hierarchical process (AHP). Selected parameters were weighted based on engineering judgement. In order to facilitate analysis with higher accuracy and lower time, determined weights for each index of vector layers were used in ArcGIS and parameters with higher index were selected. Results refer to alluvial fans located in west, north and north-west of Ardestan as the best places for underground dam construction.

KEYWORDS: AHP, GIS, locating, underground dam.

INTRODUCTION

Ground water is a suitable solution for overcoming seasonal water scarcity. Today, the exploitation of such resources has been developed for several consumptions including agricultural, industrial, and specially, drinking consumptions so that it is generally the only way of water supply in arid regions as well as regions far from rivers. In recent years, the use of underground dams has been developed due to their many advantages in managing water resource using nature-friendly techniques.

Relying on their low cost, ease of construction, reserving fresh water and many other advantages, compared with ground dams, they can serve as an economic solution for reserving and utilizing ground water. Similar to ground dams, the determination of a suitable site is the first step in the process of constructing underground dams. The body of these dams is located beneath the ground. Therefore, the complexity of determination and selection of a suitable site is one of the most important challenges in the way of developing and constructing such dams. In addition, different criteria and factors including socio-economic, environmental and geological factors affect the location of such dams and so, they make the problem more complex. The traditional techniques of studying and determining these factors are very costly and time-consuming. This is why some advanced techniques such as Geographic Information System (GIS) are used to minimize feasibility study costs, to save time and to raise accuracy. GIS is a suitable solution for accurate location of regions in accordance with available standards and criteria. Analytical hierarchy process (AHP) is one of the most comprehensive systems designed for multi-criteria decision-making. This approach was first suggested by Thomas L Saaty (2008). It makes it possible to formulate a problem in a hierarchical manner and to take different qualitative and quantitative criteria into consideration. AHP introduces different alternatives to decision-making process and can analyze susceptibilities of criteria and sub-criteria. Moreover, it is based on pairwise comparison technique facilitating calculations and judgments. In addition, it shows the consistency and inconsistency of decisions, which is a superior advantage of this technique in multi-criteria decision making (Ghodsipour 2016). There are several case studies on this field. “Identification of potential groundwater recharge zones in Vaigai upper basin, Tamil Nadu, using GIS-based AHP (Kaliraj et al. 2014), “A GIS based DRASTIC model for assessing groundwater vulnerability in shallow aquifer in Aligarh, India (Rahman 2008), “prioritization of flood distribution using AHP, DSS, GIS and satellite images for improving ground water status and locating underground dams (Singh et al. 2017; Lalhmingliana and Goutam 2016; Iftikhar 2016; Cuirong et al. 2016; Barkhordari 2015; Chezgi et al. 2016; Dorfeshan et al. 2014; Oh et al. 2011; Jiang et al. 2001)”,“different aspects of underground dams; how to construct them (Forzieri et al. 2008; Ishida et al. 2011; Raju et al. 2006; Onder and Yilmaz 2005; Ajalloeyan and Safary 2015; Alaibakhsh et al. 2013; Ali 2010; Al-Taiee 2010; Amini Zadeh and Ghasemi 2015; Farokhzadeh et al. 2015; Hasanzadehnofoute et al. 2016; Hatefi Ardakani and Ekhtesasi 2016; Jamali et al. 2013; Nishigaki et al. 2004; Salahaldin et al. 2014; Telmer and Best 2004) are a number of such studies.

THE GEOGRAPHICAL AND GEOLOGICAL STATUS OF THE STUDIED REGION

In present study, the conditions required for locating underground dams in Ardestan, located in the north west of Isfahan Province have been investigated. The area of the studied site is 258265.18 hectares. It lies inside 33° , 00′ to 33°, 30′ north latitude and 52°, 00′ to 52°, 30′ east longitude. Figure 1 shows the geographical location and access roads to the studied region .

Regarding tectonic classifications, the studied site is located in central Iran zone and Urima-Dokhtar alluvial-volcanic sub-zone where the majority of outcrops are related to Eocene volcanic activity with the combination of andesite, dacite and rhyolite that tuff and ignimbrite are seen among them.

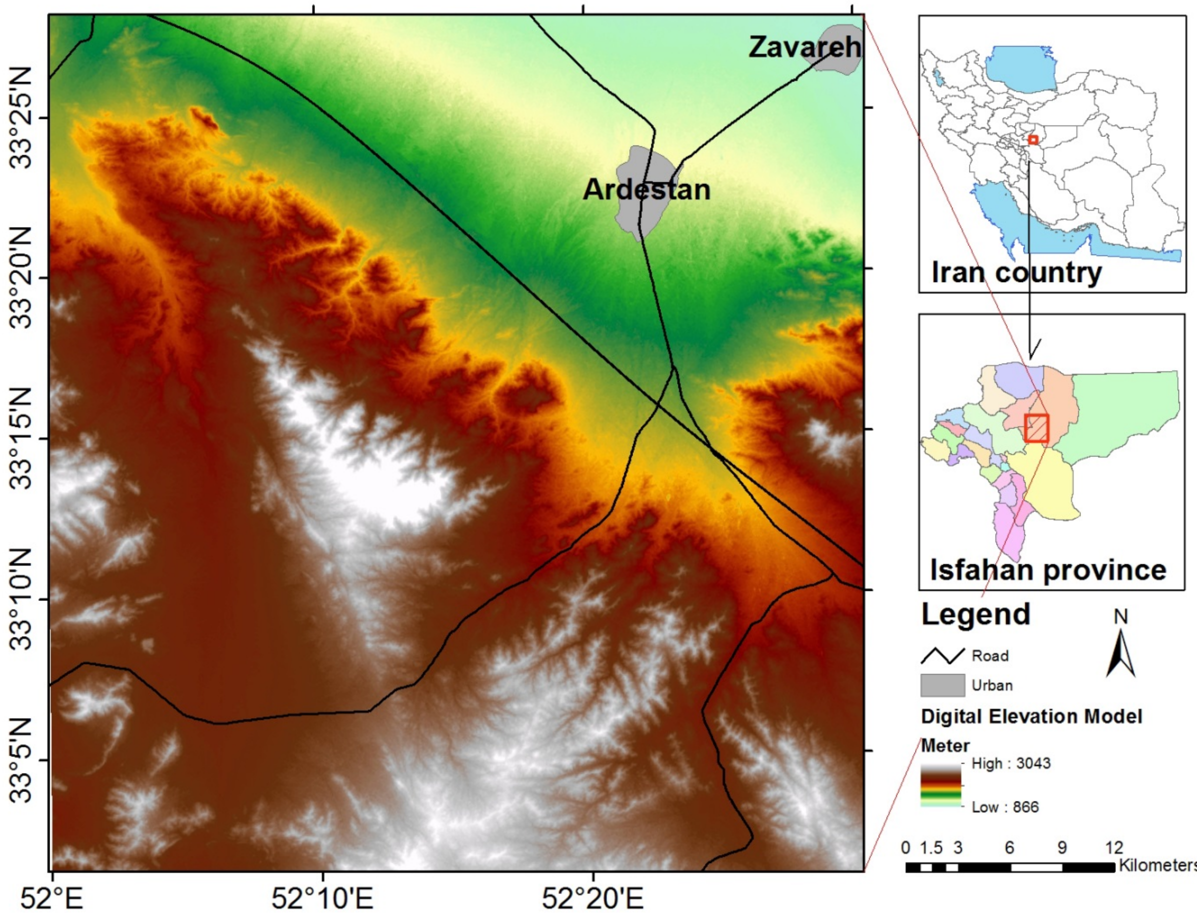

Figure 1: The geographical location and access roads of the studied region

MATERIALS AND METHODS

PREPARING THE MAP OF INFLUENTIAL FACTORS

Following geo-referencing of satellite images as well as topographical, geographical and land use maps, the required layers were prepared using Arc GIS 9.3 and ER Mapper 7.0.

The information layers of slope and distance from canal were prepared in ArcGIS using digital elevation model as well as the topographical map of the basin. It should be noted that the maps of Iran National Cartographic Center (Scale 1:25000) were used as the base of the employed topographical maps. In addition, the information layers of lithology and bedrock permeability were prepared based on Iran National Cartographic Maps (Scale: 1: 100.000). In order to prepare the layers of the thickness of alluvium and the depth of ground water, the data of pumping well, boreholes and the geophysical reports of Isfahan Regional Water Authority were used. Furthermore, the TM digital data of Landsat satellite 5 was analyzed in ER Mapper to identify available faults in the studied basin. Following processing was performed on the images:

A) Adopting band combination of RGB=741

B) Adopting high pass and sun angle filters and

C) Image equalization (of the type of histogram equalize)

Available faults within a region with a radius of 100 km were identified. According to investigations, the number of active and important faults is higher than that of indicated in the available maps for the studied area.

Figure 2 shows the processed image of the studied area along with identified faults. It consists of 53 faults with a length exceeding 15 km. Finally, the obtained results were transferred as a linear Shapefile to GIS and the zones located in the studied location area (Ardestan 1:100000 geographical sheet) were cut using Clip command and separated from other zones.

It should be mentioned that in order to obtain homogeneous units and to quantify some studied factors including distance from canal and fault, buffer was defined for these areas using distance function. Moreover, geological maps, bedrock permeability maps and land use maps were categorized considering the contents of each layer. Data associated with alluvium thickness and the depth of ground water were introduced as point data to the software, were interpolated using Kriging technique and were saved with a pixel size of 30 m. Again, the layers were categorized considering their contents.

AHP TECHNIQUE

Analytical Hierarchy Process (AHP) is founded on pairwise comparison of criteria. In this system, firstly, the considered factors are weighed and then all the classes of each criterion are scored and finally some coefficients are estimated that the final model is developed based on them. AHP is generally used in making decisions on problems where the aim is to select the best alternative or to rank available alternatives. The final weights are presented as numerical values. The AHP technique used in this study is HTA (hierarchical task analysis) with partial structure and based on expert's knowledge. In HTA, components interact with each other in the form of credit or task and form a system. The importance of such components and factors varies in different conditions and they may be added or deleted depending on the problem. In partial HTA, however, factors are divided into additional sub-factors but sub-criteria are not compared with all the criteria of the next higher level. In this technique, each effective factor is compared with other classes of the factor only within the factor in terms of effectiveness.

In AHP, factors are weighted by three methods: expert's knowledge, data and a combination of expert's knowledge and data. As it was mentioned before, in this study, expert's knowledge was used for this purpose. With this method, each factor was weighed according to the experts' experience and knowledge and available data. Creating a graphic representation of the studied problem is the first step of AHP analysis. This graph shows objectives, criteria and alternatives [Ghodsipour, 2009]. In this structure, hierarchical objectives, influential factors of underground dam locating, the ranks of the influential factors and alternatives constitute the first, second, third and fourth levels, respectively (Figure 3).

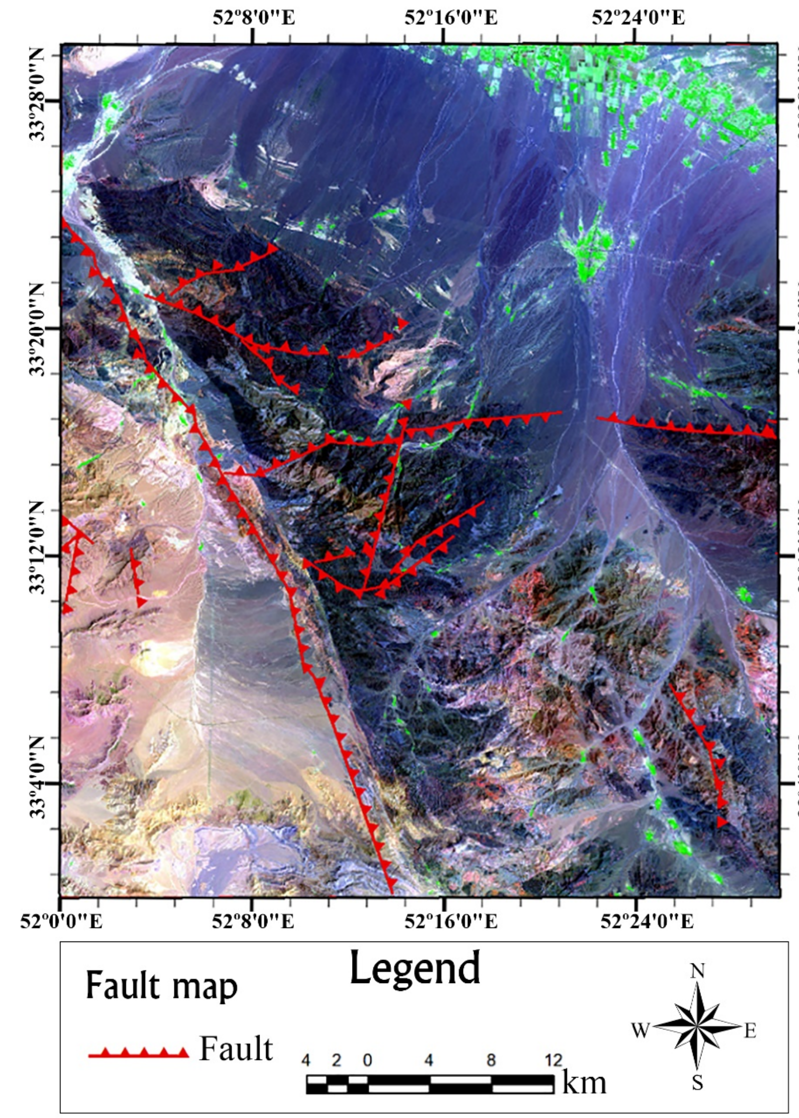

Figure 2: Processed image of TM data of the studied region in combination with RGB=741 along with identified faults

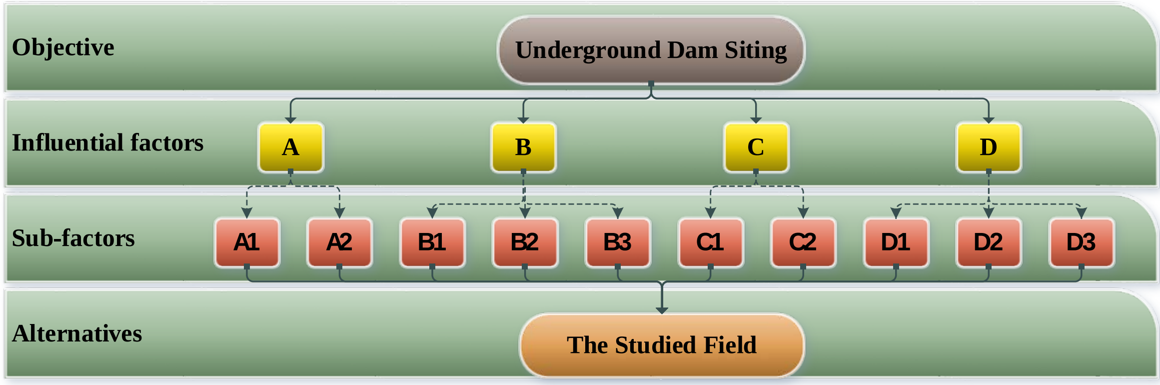

Figure 3: An example of partial HTA for zoning

Pairwise comparison matrix and calculating the weight of items (factors and classes)

Following the identification of the influential factors of underground dam siting in Ardestan, a number of questionnaires were developed in order to determine the preference of factors to each other considering the dam site. To quantify judgments and to apply them to pairwise comparison matrix, the preference of each factor to other factors will be as one of the following cases (table 1). According to table 1, all factors and criteria are ranked numerically from 1 to 9 where 9 shows the complete preference of an item to other items. Then, the obtained results are consolidated and pairwise comparison matrices are formed based on experts' judgments about factors and sub-factors. Table 2 shows the pairwise comparison matrix of the factors contributing to the employed AHP and table 3 shows the pairwise comparison matrix of slope classes.

Table 1: Assigning weights to factors based on their priority using pairwise comparisons (Ghodsipour 2016)

Priorities (verbal judgments)	Numerical value
Absolutely more important or preferred	9
Strongly more important or preferred	7
More important or preferred	5
Slightly more important or preferred	3
Equally important or preferred	1
Absolutely more important or preferred	2,4,6,8

Table 2: The pairwise comparison matrix of influential factors formed using expert's knowledge

Criteria	Slope	Depth of water table	Alluvium thickness	Distance to drainage	Bedrock permeability	Distance to fault	Land use
Slope	1	3	3	7	9	9	9
Depth of water table	0.333	1	3	5	7	8	9
Alluvium thickness	0.333	0.333	1	3	7	8	9
Distance to drainage	0.143	0.2	0.333	1	5	7	7
Bedrock permeability	0.111	0.143	0.143	0.2	1	3	5
Distance to fault	0.111	0.143	0.125	0.143	0.333	1	3
Land use	0.111	0.111	0.111	0.143	0.2	0.333	1
Sum	2.142	4.93	7.712	16.486	29.533	36.333	43

Table 3: Pairwise comparison matrix of slope classes

Slope (%)	0-10	10-20	>20
0-10	1	7	9
10-20	0.143	1	5
>20	0.111	0.2	1
Sum	1.254	8.2	15

Data normalization and calculation of the weight of factors and classes

Following prioritization step, arithmetic mean was used to make the data dimensionless and to calculate the weight of parameters. To this end, the total sum of each column was firstly calculated and then the ratio of the value of each parameter to the sum of all columns associated with that parameter was calculated. Then, the mean value of each row was calculated in order to obtain the weight of the parameter located in that row. Table 4 shows normalized data of the pairwise comparison matrices of influential factors and table 5 shows sub-factors or slope classes as example. In this normalized matrix, the column of mean value i.e. the mean value of each row, indicates the normalized relative weight of each element. Following the calculation of the relative weights of factors, the relative weight of each factor is multiplied by corresponding sub-factors in order to calculate the final weight of classes or sub-factors (table 6).

Table 4: Normalized matrix and the relative weight of influential criteria derived using expert's knowledge

Criteria	Slope	Depth of water table	Alluvium thickness	Distance to drainage	Bedrock permeability	Distance to fault	Land use	Mean
Slope	0.467	0.61	0.39	0.425	0.3	0.25	0.21	0.38
Depth of water table	0.21	0.22	0.24	0.3	0.39	0.203	0.155	0.245
Alluvium thickness	0.21	0.22	0.24	0.182	0.13	0.067	0.155	0.172
Distance to drainage	0.163	0.193	0.17	0.061	0.043	0.041	0.067	0.12
Bedrock permeability	0.12	0.083	0.034	0.012	0.018	0.029	0.052	0.05
Distance to fault	0.07	0.028	0.011	0.009	0.017	0.029	0.052	0.031
Land use	0.023	0.009	0.007	0.009	0.014	0.023	0.052	0.019
Sum	1	1	1	1	1	1	1	1

According to the normalized matrix and the relative weight of each item (table 4), slope and land use are the most and the least effective factors with the priority values of 0.38 and 0.019, respectively. Considering the normalized matrix as well as the final weight of each item, the slope class 0-10 and rocky and arid lands of land use factor are the most and the least effective factors with the priority value of 0.285 and 0.001, respectively.

Table 5: Normalized matrix of slope classes

Slope (%)	0-10	10-20	>20	Mean
0-10	0.797	0.854	0.6	0.75
10-20	0.114	0.122	0.333	0.189
>20	0.088	0.024	0.066	0.106
Sum	1	1	1	1

Calculating inconsistency rate

The possibility of controlling decision consistency is an advantage of AHP technique. In other words, it is always possible to calculate decision consistency and to judge that whether it is accepted or rejected. Inconsistency rate is an index measuring the significance and accuracy of data introduced to matrices. In AHP, its acceptable range is <0.1. To calculate matrix inconsistency, after forming the pairwise comparison matrix (A) and deriving weight vector (W), the former (A) is multiplied by the later (W) in order to have an acceptable estimation of λmax W. In other words, $A \times W = \lambda max\ W$. By dividing λmax W by the corresponding W, the value of λmax is calculated. Following the calculation of mean λmax, the value of inconsistency index can be calculated using equation (1) (Ghodsipour 2016):

Equation (1) $$I.I. = (\lambda max - n)/ (n-1)$$

where I.I and n are inconsistency index and matrix dimension, respectively.

Table 6: The final weight of the influential sub-factors of siting

Factor	Relative weight	Class	Relative weight	Final weight	Factor	Relative weight	Class	Relative weight	Final weight
Alluvium thickness	0.172	6-30	0.632	0.11	Depth of water table (m)	0.245	5-25	0.632	0.155
		0-6	0.316	0.054			0-5	0.316	0.08
		>30	0.052	0.009			>25	0.052	0.013
Slope class (%)	0.38	0-10	0.75	0.285	Distance to fault (m)	0.031	>250	0.9	0.028
		10-20	0.189	0.072			0-250	0.995	0.003
		>20	0.106	0.04					
Land use	0.019	Agricultural and civil regions	0.702	0.013	Distance to drainage (m)	0.12	0-500	0.657	0.08
		Forest	0.243	0.005			500-1500	0.263	0.032
		Rocky and arid lands	0.0556	0.001			<1500	0.08	0.01
Bedrock permeability	0.05	Low	0.7	0.035					
		Moderate	0.243	0.012					
		High	0.056	0.003					

To calculate the inconsistency rate of data, arithmetic mean is used. The value of inconsistency was derived 0.01 for the influential factors matrix which is an acceptable value.

RESULTS OF LAYER PREPARATION IN ARCGIS

ArcGIS was used to perform the aforementioned calculations, to correctly assign the obtained weights to parameters and to derive the final zoning map for constructing underground dam. Inconsistency rate is estimated by equation (2):

Equation (2) I.R. = (I.I.)/ (I.I.R.)

where I.I.R and I.R. are inconsistency index of random matrices and inconsistency rate, respectively.Following the determination of the weight of layers, using above techniques, and the calculation of the inconsistency rate of matrices, and the confirmation of the acceptability of data, the final weights of sub-factors were applied in order to derive the zoning map of the studied region. To this end, the so-called weight field was added to the data bank of all layers (attribute table), and the weights of each class of information layers were recorded in the field and the weight maps of the considered factors were derived (Table 7). Figures 4 to 11 show the weight maps derived from the influential factors of underground dam locating using AHP.

Table 7: I.I.R random matrices

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

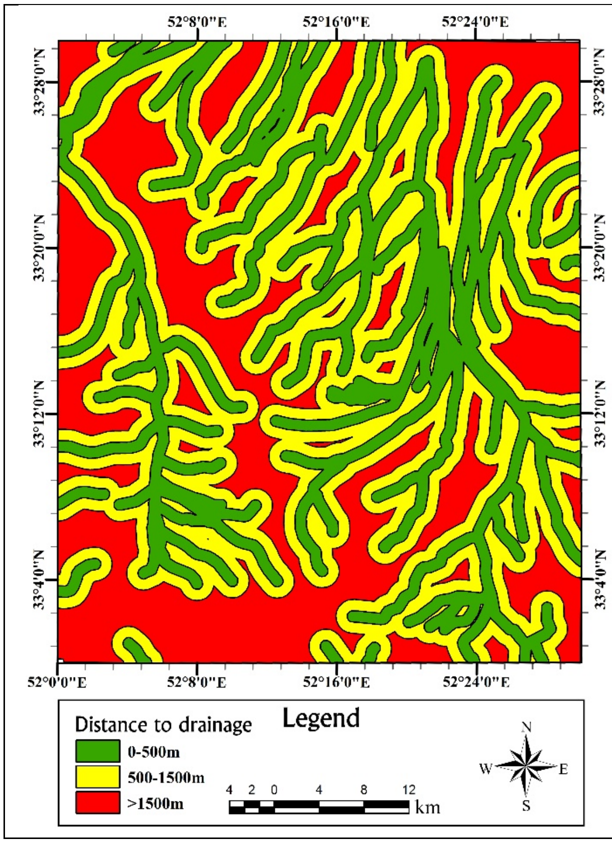

Figure 4: Distance to drainage

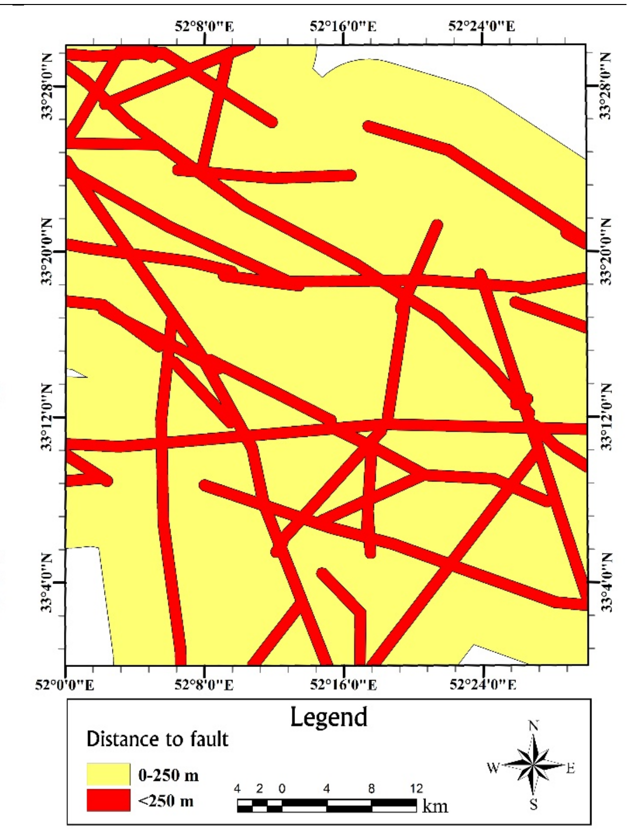

Figure 5: Distance to fault

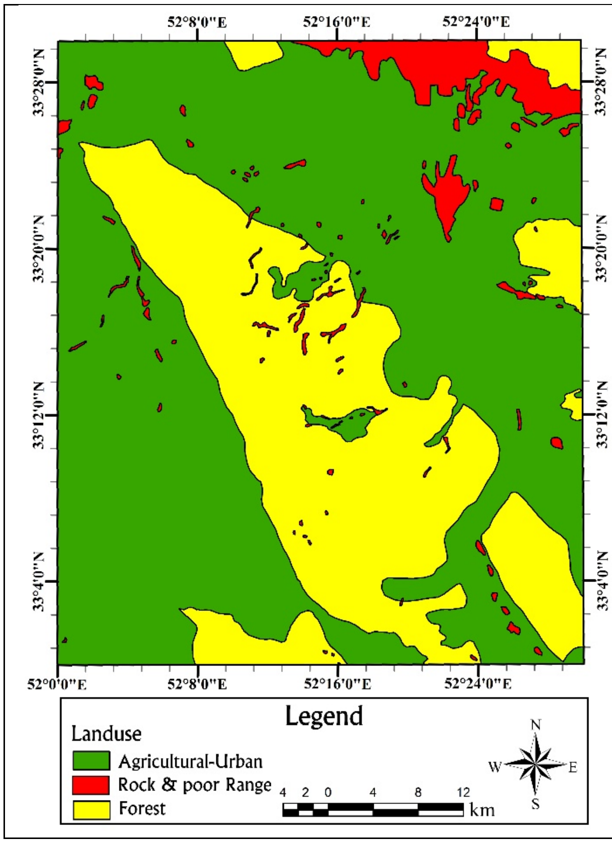

Figure 6: Landuse map

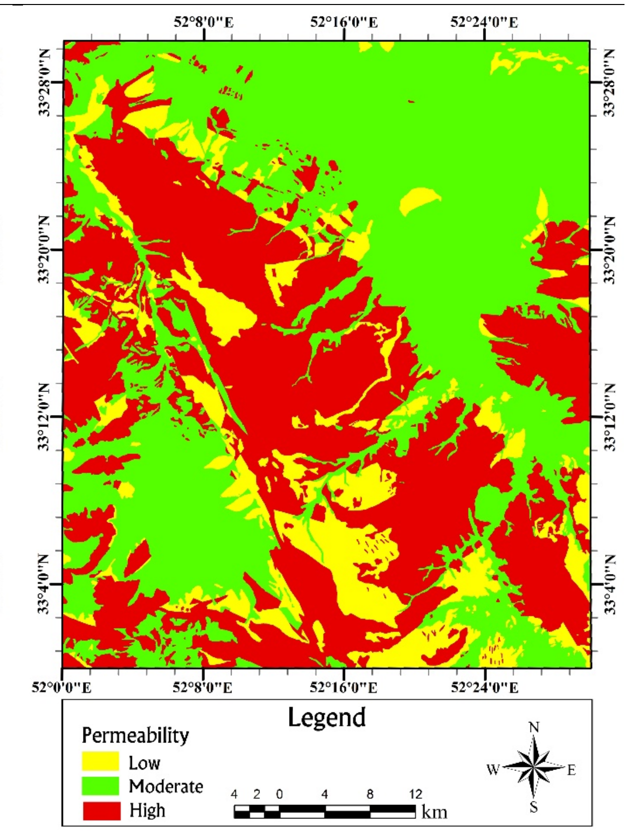

Figure 7: Permeability map

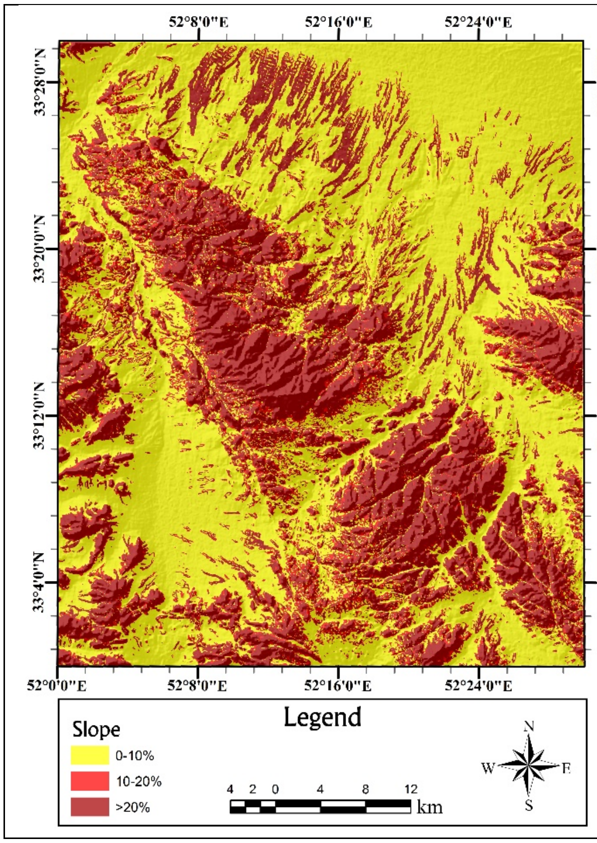

Figure 8: Slope classes map (percentage)

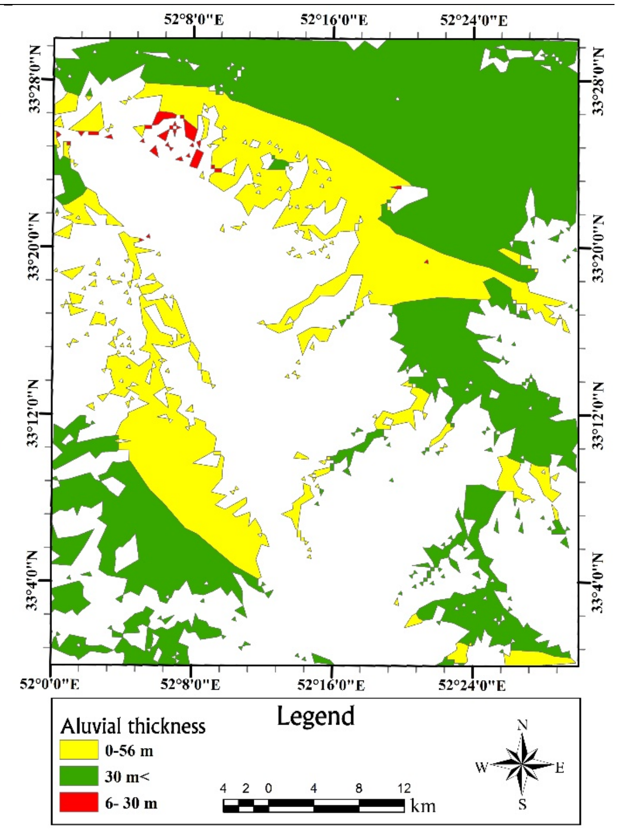

Figure 9: Alluvium thickness

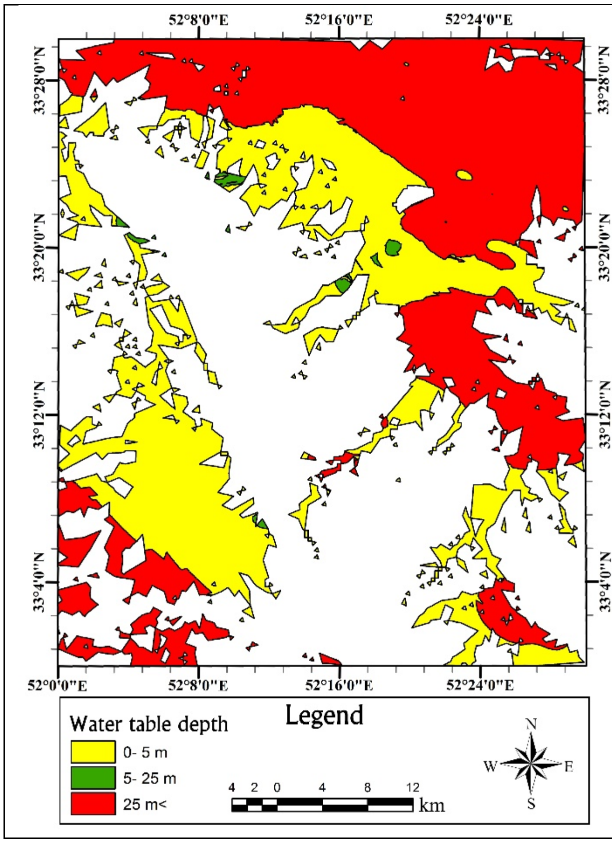

Figure 10: Water table depth

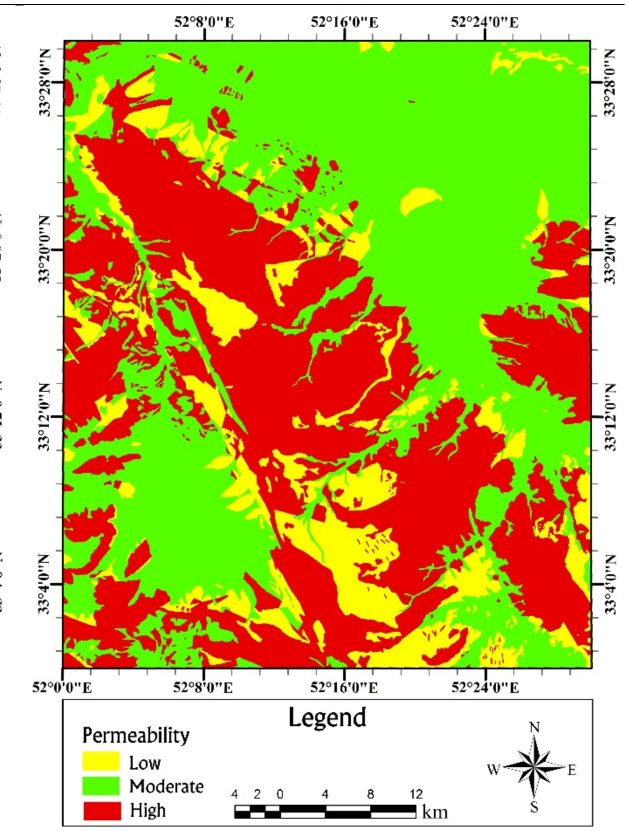

Figure 11: Permeability map

OVERLAYING THE LAYERS AND PREPARATION OF SUITABLE SITES MAP

To derive the final map, the prepared information layers including slope, alluvium thickness (bedrock depth), ground water depth, distance from canal, bedrock permeability, distance from fault and land use, were overlaid using Union function and by applying the calculated final weights.

After overlaying the aforementioned layers, the final map for locating underground dam was derived using Query Builder operator and equation (3):

Equation (3): *perm*0.035 and landuse*0.013 and drainage*0.08 and fault*0.028 and slop*0.0285 and thick.alluv*0.11 and groundwater*0.155*

According to equation 3, the layers were overlaid using “and” index. Therefore, this map represents only the regions meeting all conditions of underground dam locating (Figure 12).

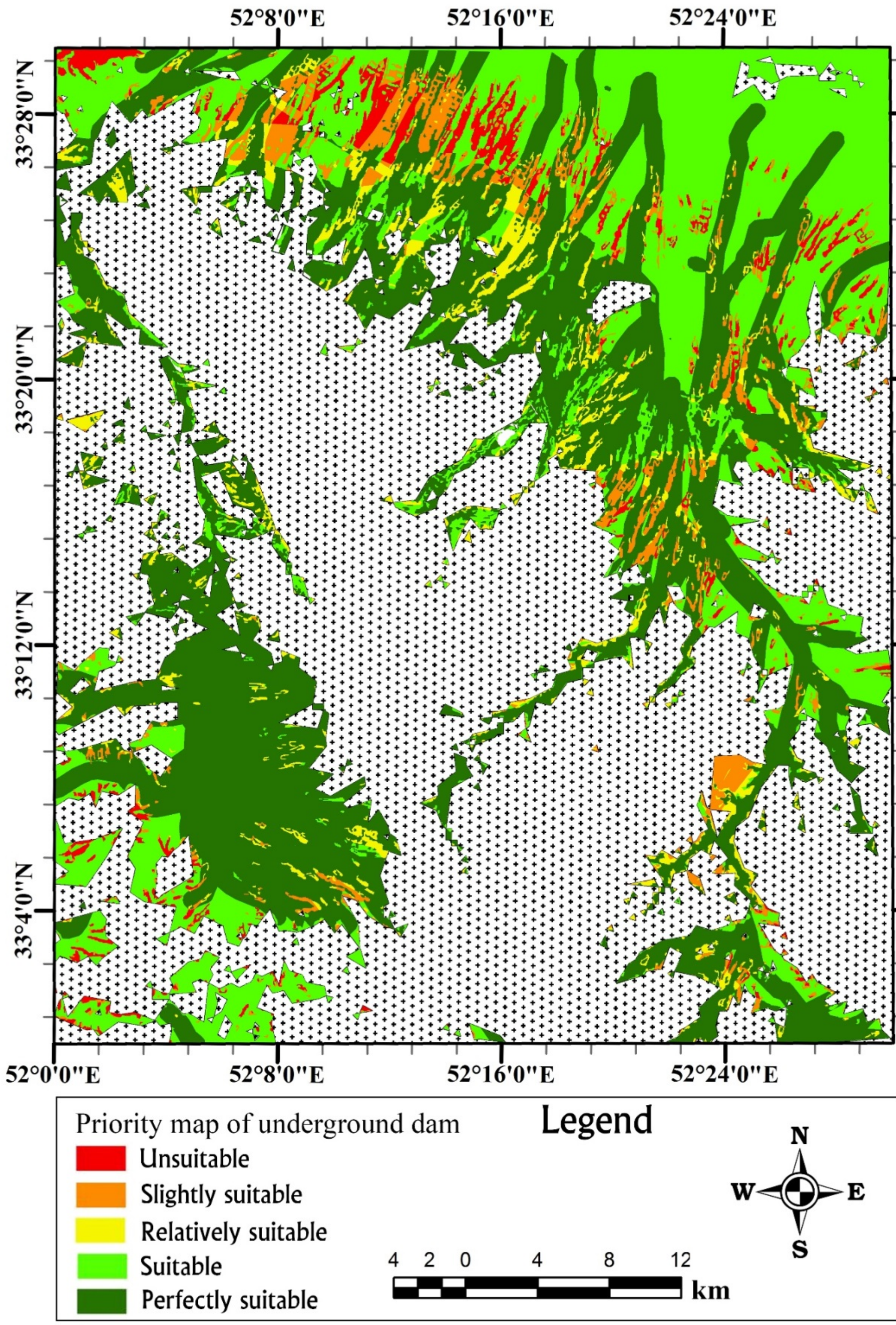

Figure 12: The final map representing fit sites for constructing underground dam

The final map illustrates unsuitable to fully suitable sites for constructing underground dams (figure 12). The sites with a weight >0.5 are suggested as suitable alternatives. These suitable alternatives are alluvial fans extended along north-west and northwest-southeast directions. Performing field visits can significantly affect the priority of the sites.

CONCLUSIONS

(1) GIS systems with a great potential in applying functions and overlaying different information layers on the one hand and applying satellite images and interpreting their results on the other hand can serve as a unique tool for locating. Without GIS, conducting quick and accurate large scale locating studies is a difficult and time-consuming task.

(2) Relying on its wide classification potential, AHP promotes the decision-making ability of experts. The capabilities of AHP facilitate judgments and calculations. The evaluation of this approach showed that by applying different information layers in accordance with their importance order, it is possible to locate the site of the considered objective. In this study, slope, the depth of ground water, alluvium thickness, distance from canal, bedrock permeability, distance from fault, and land use were the influential factors in locating underground dam. In addition, considering the final weight of classes, 0-10% slope class and rocky and arid lands were the most and the least influential classes.

(3) The investigation of all factors affecting zoning and final locating map showed that the alluvium fans located in the west, north and central regions of Ardestan geographical sheet 1:100000 can be suggested as suitable sites for constructing underground dams. In the final map shown in Figure 6, the regions with the following specifications were separated from other regions considering young alluvial areas and permeable bedrocks placed near to residential and agricultural lands:

(4) Slope <10%, the depth of ground water: 5-25m, the alluvium thickness: 6-30m, the distance from faults: above 250m and the distance form canal: less than 500m.

(5) The separated regions meet all aforementioned geometric and geographical conditions for constructing underground dams and are suggested for future studies. By field visits and field study and considering other factors such as water requirement of the region and social and environmental effects, the regions proposed in the final map can be prioritized.

(6) The identification of suitable regions for constructing underground dams, the determination of important and effective factors of the process of locating such sites and determination of effective criteria for identification and determination of GIS and AHP capabilities are the most important achievements of this study.

ACKNOWLEDGEMENTS

This study is a part of the research project titled “identifying and locating suitable regions for constructing underground dams in Isfahan” belonging to Isfahan Agricultural Research and Natural Resources Center. We are very thankful for the supports of this center.

REFERENCES

1. Ajalloeyan, R, Safary, A, 2015. Geotechnical properties assessment of subsurface dams (case study). Journal of engineering geology, 8(4), 2413-2434.

2. Alaibakhsh, M, Azizi, S, H, Kheirkhah Zarkesh, M, M, 2013. Water resource management with a combination of underground dam/qanat and site selection of suitable sites using GIS. Water science and technology: water supply, 13(3), 606-614. doi:10.2166/ws.2013.039.
3. Ali, I, 2010. Locating suitable sites for constructing subsurface dams using GIS: Architecture and the built environment, Royal Institute of Technology (KTH).
4. Al-Taiee, T, M, 2010. Groundwater dams, a promise option for sustainable development of water resources in arid and semi-arid regions. Paper presented at the 2nd international conference on integrated water resources management and challenges of the sustainable development 2010, Agadir, Morocco.
5. Amini Zadeh, M, Ghasemi, M, 2015. Locating suitable sites for construction of underground dams. Cumhuriyet Science Journal, 36(3), 3205-3217.
6. Ansarifar, M., Rahnamarad, J., Shabanigorji, K., Enayat, M.A., Naroei, A., 2017, Feasibility of Underground Dam Construction in the
7. Zarani River (South-east of Minab), research project for Young Researchers Club Elite, Islamic Azad University of Zahedan.
8. Barkhordari, J, 2015. The pre-selection of suitable sites for small underground dams in arid areas using GIS (a case study in Yazd_Ardakan watershed). International geo-informatics research and development journal, 6(1), 18.27.
9. Chezgi, J, Pourghasemi, H, R, Naghibi, S, A, Moradi, H, R, Kheirkhah Zarkesh, M, 2016. Assessment of a spatial multi-criteria evaluation to site selection underground dams in the Alborz province, Iran. Geocarto international, 31(6), 628-646. doi:10.1080/10106049.2015.1073366.
10. Cuirong, W, Zhaoping, Y, Huaxian, L, Fang, H, Wenjin, X, 2016. Campgrounds suitability evaluation using GIS-based multiple criteria decision analysis: a case study of Kuerdening, China. Open geosciences, 8(1), 289-301.
11. Dorfeshan, F, Heidarnejad, M, Bordbar, A, Daneshian, H, 2014. Locating suitable sites for construction of underground dams through analytic hierarchy process. Paper presented at the international conference on earth, environment and life sciences, (EELS-2014).
12. Farokhzadeh, B, Attaeian, B, Akhzari, D, Razandi, Y, Bazrafshan, O, 2015. Combination of Boolean logic and analytical hierarchy process methods for locating underground dam construction. ECOPERSIA, 3(3), 1065-1075.
13. Forzieri, G, Gardenti, M, Caparrini, F, Castelli, F, 2008. A methodology for the pre-selection of suitable sites for surface and underground small dams in arid areas: a case study in the region of Kidal, Mali. Physics and chemistry of the earth, parts A/B/C, 33(1–2), 74-85. doi:http://dx.doi.org/10.1016/j.pce.2007.04.014.
14. Ghodsipour, H, 2016. Analytical hierarchy process (AHP). Tehran: Amirkabir university publication.
15. Hasanzadehnofoute, M, Jamali, A, Fallah, A, 2016. Site selection underground dams using spatial multi-criteria evaluation (SMCE) (case study: the Adori area in Bam city). Iranian journal of watershed management science & engineering, 10(32), 69-76.

16. Hatefi Ardakani, A, Ekhtesasi, M, 2016. Groundwater potentiality through analytic hierarchy process (AHP) using remote sensing and geographic information system (GIS). Geopersia, 6(1), 75-88. doi:10.22059/jgeope.2016.57823.

17. Iftikhar, S, 2016. Site suitability analysis for small multipurpose dams using geospatial technologies. Journal of remote sensing & GIS, 5(162). doi:10.4172/2469-4134.1000162.

18. Ishida, S, Tsuchihara, T, Yoshimoto, S, Imaizumi, M, 2011. Sustainable use of groundwater with underground dams. Japan agricultural research quarterly: JARQ, 45(1), 51-61. doi:10.6090/jarq.45.51.

19. Jamali, I, A, Olofsson, B, Mortberg, U, 2013. Locating suitable sites for the construction of subsurface dams using GIS. Environmental earth sciences, 70(6), 2511-2525. doi:10.1007/s12665-013-2295-1.

20. Jiang, K, Furukawa, H, Onoyama, Y, Esaki, T, Xinzhu, E, B, L, 2001. Water resource development in the quaternary Ryukyu limestone regions of Japan: application of the GIS to the site selection of underground dams. Acta geologica sinica - English edition, 75(3), 254-259. doi:10.1111/j.1755-6724.2001.tb00528.x.

21. Jianbo Yang, Jianqing Lai, Xiaoshuang Xi, Qunyi Liu, and Hang Lin: “Safety Evaluation of Underground Rock Mass from Microscopic View” Electronic Journal of Geotechnical Engineering, 2015 (20.03) pp 1105-1113. Available at ejge.com.

22. Kaliraj, S, Chandrasekar, N, Magesh, N, S, 2014. Identification of potential groundwater recharge zones in Vaigai upper basin, Tamil Nadu, using GIS-based analytical hierarchical process (AHP) technique. Arabian journal of geosciences, 7(4), 1385-1401. doi:10.1007/s12517-013-0849-x.

23. Lalhmingliana, Goutam, S, 2016. Identification of suitable dam site: a survey. International journal of computer engineering & technology (IJCET), 7(5), 56-64.

24. Ming-Jie Zhao, Xiao Sun, and Suo Wang: “Damage Evolution Analysis and Pressure Prediction of Surrounding Rock of a Tunnel Based on Rock Mass Classification” Electronic Journal of Geotechnical Engineering, 2014 (19.C) pp 603-627. Available at ejge.com.

25. Nishigaki, M, Kankam Yeboah, K, Komatsu, M, 2004. Underground dam technology in some parts of the world. Journal of groundwater hydrology, 46(2), 113-130.

26. Oh, H, J, Kim, Y, S, Choi, J, K, Park, E, Lee, S, 2011. GIS mapping of regional probabilistic groundwater potential in the area of Pohang city, Korea. Journal of hydrology, 399(3–4), 158-172. doi:http://dx.doi.org/10.1016/j.jhydrol.2010.12.027

27. Onder, H, Yilmaz, M, 2005. Underground dams. European water, 11(12), 35-45.

28. Rahman, A, 2008. A GIS based DRASTIC model for assessing groundwater vulnerability in shallow aquifer in Aligarh, India. Applied geography, 28(1), 32-53. doi:http://dx.doi.org/10.1016/j.apgeog.2007.07.008.

29. Raju, N, J, Reddy, T, V, K, Munirathnam, P, 2006. Subsurface dams to harvest rainwater (a case study of the Swarnamukhi River basin, Southern India). Hydrogeology journal, 14(4), 526-531. doi:10.1007/s10040-005-0438-5.

30. Saaty, T, L, 2008. Decision making with the analytic hierarchy process. International journal of services sciences, 1(1), 83-98.

31. Salahaldin, S, A, Foad, A, A, U, Sarkawt, G, S, Nadhir, A, A, Sven, K, 2014. Evaluation of selected site location for subsurface dam construction within Isayi watershed using GIS and RS Garmiyan area, Kurdistan Region. Journal of water resource and protection, 972-987. doi:10.4236/jwarp.2014.611092.

32. Singh, L, K, Jha, M, K, Chowdary, V, M, 2017. Multi-criteria analysis and GIS modeling for identifying prospective water harvesting and artificial recharge sites for sustainable water supply. Journal of cleaner production, 142, Part 4, 1436-1456. doi:http://dx.doi.org/10.1016/j.jclepro.2016.11.163.

33. Telmer, K, Best, M, 2004. Underground dams: a practical solution for the water needs of small communities in semiarid regions. TERRA, 1(1), 63-65.

Editor's note.
This paper may be referred to, in other articles, as:

Kourosh Shirani, Abdolrasoul Shafiey Dastjerdi, and Jafar Rahnamarad: "Integration of Multi-Criteria Decision Matrix and Geographical Information System to Site Selection for an Underground Dam" Electronic Journal of Geotechnical Engineering, 2017 (22.09), pp 3669-3686. Available at ejge.com.