Locating Suitable Sites for Construction of Underground Dams through Analytic Hierarchy Process

Farid Dorfeshan [1], Mohammad Heidarnejad [2], Amin Bordbar[3], Hasan Daneshian[4]

***Abstract*—**Iran has been stated in dry and semidry area. Therefore development and storage of ground water by underground dams can be suitable. Andika region has been placed in Khuzestan province-200 Km North east of Ahvaz city , and according to DO Marthon classification is considered as semidry climate. In this study, Decision making tree is consisted of : Reservoir and economic criteria for reservoir , four minor criteria were considered : Decline , hydraulic conductivity , effective porosity and foundation permeability and for economical factors to location of dam and distance of dam from usage place were considered . To determine the exact location of dam axis in a point of route 27 primary locations were districted. Them regarding to location of the selected locations in map , site priorities of 15 locations were recognized . Finally storage rate of each of the suggested priorities were calculated.

***Keywords*—** Andika region – Underground dams – Multi-criteria decision making.

I. Introduction

UNDERGROUND dams are subsurface structures blocking the fluid flow in the Earth's layers, thus leading to water storage in the upper alluvial through developing an obstacle against groundwater flow. In other words, underground dam can be broadly defined as an obstacle built against the groundwater flow in a natural or artificial aquifer, altering the flow status in order to attain the construction goals [4]. Being located in a semi-arid region, Iran constantly suffers from water shortages and drought. The country's average annual precipitation is lower than the world annual average mostly concentrated on certain spring and winter [3]. Not being an exception, Andika in Khuzestan is facing surface and subsurface water shortage due to its specific geological and structural conditions. There is extensive research done on this subject in Iran and around the world. Furthermore, a great deal of research has been done regarding location and construction of subsurface dams with numerous projects completed the operation phase. For instance, several subsurface dams have been constructed in Kandar Kohnuj (Kerman), Kuhzard (Damghan) and Tuyehdavar (Yazd). Moreover, there are a number of foreign examples including those constructed in coastal area at Horn of Africa, the Japanese islands and the coastal areas, Miyako Island in southwestern Japan, Nakajima Island, central Tanzania, arid and semi-arid regions of North and North West of Tibet in China and Phuket in Southern Thailand, etc Furthermore, Vanrompay concluded in an assessment report on 5 underground dams that such structures bring about the following advantages; increased capacity of existing wells, operational low cost and simplicity, repeatability, low risk of infection and ease of operation by local residents [6]. Aminizadeh et al (2000) examined the methods of surveying underground dams as a case study on Raver, an underground dam in Kerman. They concluded that good operation of the dam left a positive impact on sub-basin flows. Heidari and Shahriyari (2011) examined the locating of underground dams in the basin of Garmab River located in Golestan. Having taken into account the sediment accumulation throughout the main river, they specified three sites in priority for construction of underground dams.

Farid Dorfeshan [1] , Department of Irrigation , College of Agriculture, Ahvaz Branch , Islamic Azad University, Ahvaz, Iran

Mohammad Heidarnejad[2], Department of Irrigation , College of Agriculture, Ahvaz Branch , Islamic Azad University, Ahvaz, Iran (corresponding author's phone: +989113919533 ; e-mail: mo_he3197@yahoo.com).

Amin Bordbar[3], Department of Irrigation , College of Agriculture, Ahvaz Branch , Islamic Azad University, Ahvaz, Iran

Hasan Daneshian[4], Water and Power, Khouzestan, Iran

II. Location And Geographical Features Of The Area Under Study

Andika is an area located in Khuzestan, Iran, about 50 kilometers from Masjed Soleyman and about 200 kilometers from Ahvaz, situated between 2.49°6.49 'E and 32°3.32 'N. Andika is an area of 3200 kilometers square and an average altitude of 780 meters. Geologically, this region is located in Zagros fold and thrust belt and part of the Karun River catchments stretched across Khuzestan. The catchment area is located in west of Shahid Abbaspour Dam and vicinity of Karun River(Fig 1).

Fig 1: Geographical location of the area under study

III. METHODOLOGY

Prior to initiation of every surveying project, a set of preliminary data is required. Having been collected, such information can lead to achievement of the project goal: locating the best site for construction. The data consist of geological maps prepared by NIOPDC, satellite images, Digital Elevation Map of the area, weather information and maps at scale of 1:25000 prepared by the Iranians National Cartographic Center (NCC). In order to configure the information layers of the required data in proper format, a database was created through AC GIS. The data was imported in the software and then sorted and stored in separate layers so as to be employed according to needs of various units. The mentioned layers have ideal characteristics to ensure a certain site is whether or not suitable for construction of underground dams.

IV. ABSOLUTE FACTORS

The presence or absence of absolute factors contributes to locating underground damn. There are several such factors as follow:

Topography: One of the major parameters for construction of underground dams with appropriate reservoir is topographic conditions. Having specified the boundaries and altitude variations in order to acquire precise data about the topographical conditions and determining the region's slope layer, the Digital Elevation Model layer of the region was employed. Based on the investigations done, the maximum slope for construction of underground dams is less than 10%. Therefore, an elevation plan map was imported to ArcGIS, preparing a raw slope map through the estimated values. According to the map, the minimum slope in Ankida varies from lower than 2 to at most 70 degrees. The areas with slopes of less than 10% have been indicated as blue in the image. Moreover, the waterway slope should also be less than 5% so as to expect formation of underground water reservoir in a favorable volume [Figure 5].

Waterway: In locating underground dams, the level of runoff is a key parameter having a direct correlation with waterway category. The mentioned layer was imported to ArcGis through the files prepared by DGN maps at scales designated by the Iranian NCC [Figure 4].

Fault boundary: faults are also one of the factors contributing to selection of suitable sites for dam construction. In case there is a fault boundary, structural instability appears in foundation and abutment of the dam, thus leading to escape of water from reservoir. The faults map was prepared using the digital geological map at 1:100000 and based on monitoring satellite images [Figure 3].

Road boundary: In order to preserve the dam reservoir as well as to prevent possible flooded reservoir caused by heavy rainfall. It is recommended that the minimum distance be taken into account between the construction site of such structures and the roads in the boundary under study. Furthermore, there is a contamination possibility caused by roads endangering the dam reservoirs, such as disposal of chemical substances, petroleum and car engine oil, which are in turn transported into the reservoir [Figure 2].

Rural boundary: In order to prevent reservoir contamination due to village activities, rural wastewater and also prevent potential physical damages to reservoir, it is vital to take into account the minimum distance from villages for locating the sites of underground dam construction [Figure 9].

V. RELATIVE FACTORS

Permeability: As one of the basic requirements for construction of underground dams, there should be a dense and impenetrable bedrock [1] (Figure 8).

Hydraulic conductivity, specific yield: In Andika waterways from Sarab down to lower lands, the topographic slope and in turn the hydraulic power decreases. Moreover, the geological formations through which rivers pass generally transform into smaller grains along the water flow and finer material is led into the waterway. Taking these into account, the layers of hydraulic conductivity and specific yield were measured through ArcGIS10 using the combination of slope layer and geological layer [Figures 6,7].

Distance from consumption site: It is essential to determine the distance between the dam and the consumption site prior to underground construction. Depending on the purpose of underground dam construction, the water preserved in reservoir might be used for drinking, livestock, irrigation of farm lands and gardens. For that reason, it is highly crucial in terms of water efficiency and economical measures to place the preserved water near to the consumption site [Figure 11].

Access to the dam site: Convenient access to the dam construction site can extremely contribute to the project cost. This parameter, therefore, should be taken into account as one of the economical factors contributing to any construction project of underground dam, even though it is relatively less significant than distance from consumption site [Figure 10].

The following figures illustrate the entire layers exported to ARC GIS.

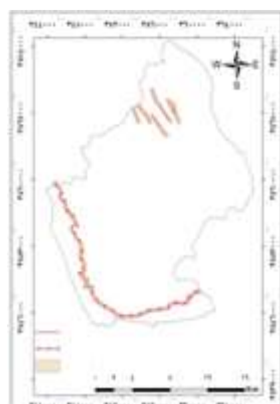

Fig2 : Road boundary

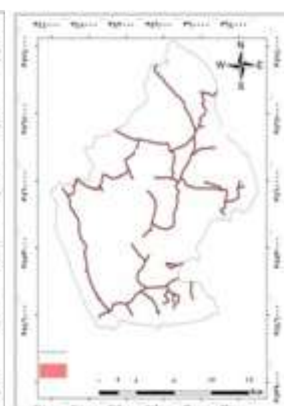

Fig3: Fault boundary

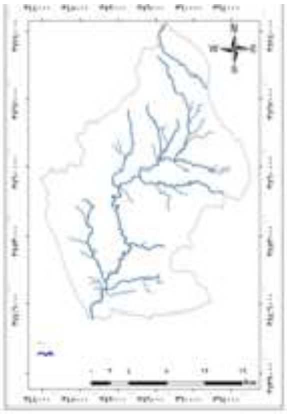

Fig 4: Waterway

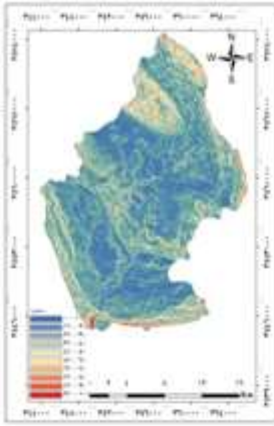

Fig 5: Topography

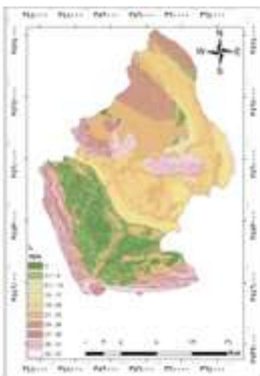

Fig 6: Specific yield

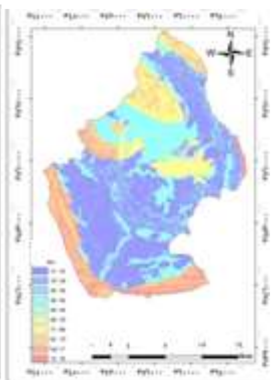

Fig 7: Hydraulic Conductivity

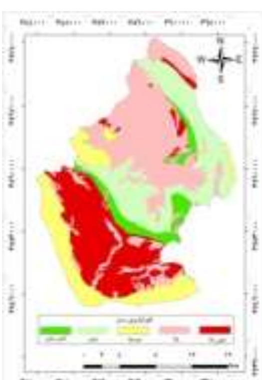

Fig 8: Permeability

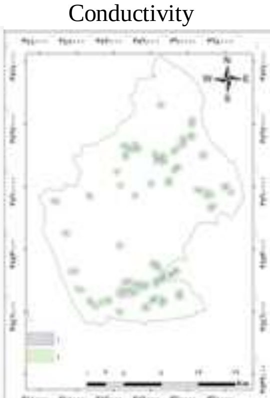

Fig 9: Rural boundary

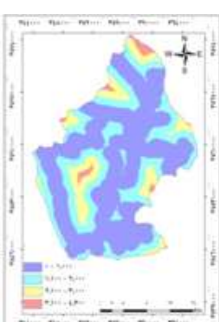

Fig10: Acess to dam site

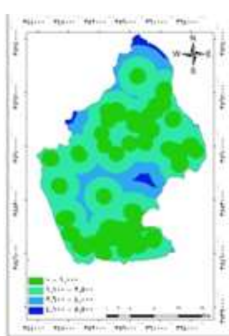

Fig11: Distance from consumption site

VI. Integration Of The Information Layers

In this section, the AHP was employed for combining the layers. The term AHP stands for Analytic Hierarchy Process, which is a method based on three principles of analysis, binary comparison, summarizing, prioritizing and selection among alternatives [7]. The first step to be taken in such process is developing a decision-making tree. That is a main branch is drawn regarding the nature of the task to be done. The main subject is then divided into main criteria, which are in turn divided into various sub-criteria. Figure 18 illustrates the AHP decision-making tree used for the region under study.

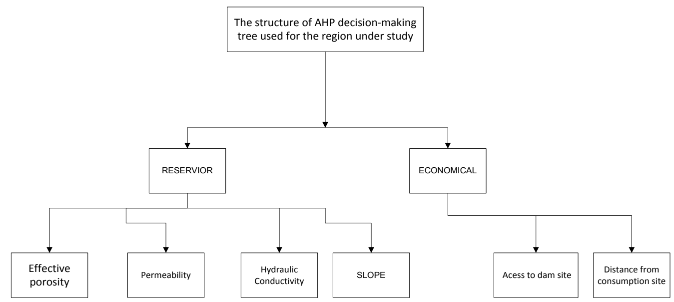

Diagram 1: The structure of AHP decision-making tree used for the region under study

At the next stage, the layers prepared based on expert knowledge, decision-makers comments were ranked and the weight of each index was determined. The rankings were individually assessed through a binary matrix. Finally, each pair of main criteria involved in the main branches of decision-making tree was also compared in binary. These analogies were descriptive at the first stage and numerical at scale from 1 to 9 at the second stage. Table 1 shows the relative value of each criterion based on expert opinion.

TABLE I
THE RELATIVE VALUE OF EACH CRITERION BASED ON EXPERT OPINION (SAATY, 1980)

Theoretical value based on comparison of two criteria	*Numerical value equal to the theoretical value*
Equal value	1
Value of one is lower than the other	3
Value of one is higher than the other	5
The value of one is certainly more than the other	7
The value of one is absolutely more than the other	9
Intermediate values	2،4،6،8

In Andika area, two major criteria were considered as in Diagram 1 for construction of underground dam. These criteria were named reservoir and economical factor, which were both divided into two sub criteria covering slope, hydraulic conductivity, permeability and effective porosity for reservoir and covering access to dam site and distance from consumption site for economical factor. According to AHP, these sub criteria were compared to another through a binary matrix. Tables 2 and 3 indicate the binary comparison between two parameters of reservoir and economical factor.

TABLE II
THE MATRIX OF RESERVOIR AS A CRITERION IN LOCATING UNDERGROUND DAM IN ANDIKA

Sub criteria	*Slope*	*Permeability*	*Effective porosity*	*Hydraulic conductivity*	*Relative significance*
Slope	1	2	3	9	0.48
Permeability	$\frac{1}{2}$	1	3	7	0.32
Effective porosity	$\frac{1}{3}$	$\frac{1}{3}$	1	5	0.16
Hydraulic conductivity	$\frac{1}{9}$	$\frac{1}{7}$	$\frac{1}{5}$	1	0.04

TABLE III
THE MATRIX OF ECONOMICAL FACTOR IN LOCATING UNDERGROUND DAM IN ANDIKA

Sub criteria	*Distance from the consumption site*	*Access to the dam site*	*Relative significance*
Distance from the consumption site	1	5	0.83
Access to the dam site	$\frac{1}{5}$	1	0.17

In comparing the relative significance of each sub criterion, the values were obtained through either manual calculation or through Expert Choice, the results of which can be seen in Tables 2 and 3 under "relative significance". After measuring the values of relative significance, the relative value of two major criteria, i.e. reservoir and economical factor, were compared. In fact, there are different alternatives to be selected for prioritizing each criterion due to extreme weight and relative significance of the major criteria. Taking into account the equivalent value and weight for the major criteria is among the alternatives selected by decision-makers in prioritizing the potential sites. Concerning the critical need for water in Andika and fairly low costs of underground dam, however, higher weight was considered for reservoir as compared to economical factor in this study. Table 4 illustrates this comparison.

TABLE IV
THE MATRIX OF MAJOR CRITERIA IN LOCATING UNDERGROUND DAM IN ANDIKA

Major criteria	*Reservoir*	*Economical factor*	*Relative significance*
Reservoir	1	3	0.75
Economical factor	$\frac{1}{3}$	1	0.25

By applying the obtained weights on ARC GIS, the priority map was prepared for locating the underground dam in Andika [Figure 12].

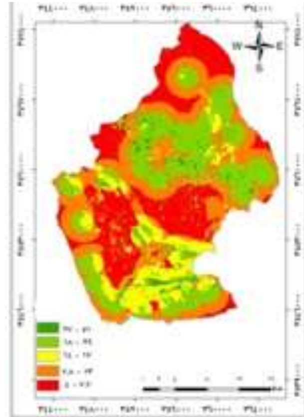

Fig 12 the priority map was prepared for locating the underground dam in Andika

VII. RESULTS

1. The study scope in most areas was fairly flat and low-slope in topographic terms, approximately 25 kilometers long and approximately 15 kilometers wide. The Andika's topographic carried from lower than 2 degrees to maximum 70 degrees. As for a great part of the area, therefore, the slope of waterways is desirable in this study.
2. The geological layers in the region are basically made of chalk, marl, sandstone and carbonates. Although Gachsaran Formation in Andika is not regarded as highly important in terms of groundwater reserves, its harmful effect on surface water resources.
3. There are karst features observed in Andika's limestone and chalk formations including Karrens, dry narrow valleys, caves, sinkholes, dissolved fissures and shafts.
4. A great amount of groundwater reservoir has been formed in the region due to materials with low permeability.
5. In spite of low thickness of the Bakhtiyari Formation, there are numerous springs with highly desirable yield and quality.
6. Sediments at the channel bottom rang from gravel to sand, among which very fine particles can be seen as well. The sediment surface contact with the adjacent bedrock, sediments and formations is destructive. Generally in the region under study, the bedrock sediments of waterways bring about an ideal hydraulic conductivity and reservoir in hydrological terms.
7. Sedimentary deposits along the waterways were observed in areas where the sediments were of more depth and width with lower slope.
8. The region's average annual precipitation was calculated to be 556 millimeters, based on which it can concluded Andika is a semi-arid region in terms of precipitation. The rainfall-elevation was obtained as below:
9. The region's dryness coefficient was calculated to be 11.9, which represents a semi-arid climate based on Domarten Classification.
10. Due to the region's precipitation and permeability of formations, the ranking 3 waterways and higher are capable of supplying the water required to be preserved in the dam.

VIII. Conclusion

1. The most important alluvial bedrocks in the region included gypsum (chalk), marl, sandstone, limestone conglomerate and lime in order of frequency. The gypsum and marl layers widely covering the area are not highly permeable. These layers, however, are not capable of holding water and forming bedrock and dam cut-off wall due to their cracks, pores and dissolved fissures as well as extreme solubility of gypsum.
2. The high capability of GIS (Geographical Information System) for analyzing spatial data particularly facilitating, in integration of information layers, the selection of the best site for construction of underground dams. In the present study, the suitable sites were specified after reviewing the previously done research and modification of basic information employing GIS techniques.
3. Since there are physical, social and economical factors contributing to locating underground dam, they vary in importance. Assessment of such factors using traditional methods is extravagant and time-consuming, which is not economically affordable. The Geographic Information System and multiple criteria decision making methods such as AHP were, therefore, synchronized in order to determine the role of each factor based on their influence on selecting the construction site of the dam, which examines the decision-making problem from various dimensions. In most of the similar studies, the performance of this software has been approved.
4. In locating the suitable sites for construction of underground dams, the major criteria of the decision-making tree in this study include reservoir and economical factor. There were four sub criteria (i.e. slope, hydraulic conductivity, effective porosity and bedrock permeability) considered for reservoir and two sub criteria (access to dam site and distance from consumption site) for economical factor. Due to the critical need for water in Andika, however, higher weight was considered for reservoir as compared to economical factor in this study.
5. Some of the sites were eliminated either by the absolute factors or were prioritized in the unsuitable category. The unsuitable sites were eliminated by absolute factors consisting of road boundary, rural boundary and slopes sharper than 5%.
6. The study on underground dams, their pros and cons particularly regarding surface reservoirs indicate that construction of underground dams in integrated watershed management can be an alternative to traditionally expensive and time-consuming methods.
7. A total of 27 sites were identified through Google-Earth satellite images in order to determine the precise location at certain point of a waterway. In fact, areas with the highest accumulation of sediments along the region's waterways were considered as early alternatives using satellite and aerial images. The spatial priorities of 15 sites were suggested based on the selected sites on the map.
8. Examination and comparison of the water preserved in the reservoir indicated that maximum volume was 23760 cubic meters and the minimum volume was 672 cubic meters per 100 meters of length.
9. The study on underground dams, their pros and cons particularly regarding surface reservoirs indicate that construction of underground dams in integrated watershed management can be an alternative to traditionally expensive and time-consuming methods.

References

[1] Ardakani & Danayian (2002), "Locating Underground Dams in Kharaneq, Yazd", a technical report, Deputy of Civil Engineering for unexpected natural disasters, Iranian Ministry of Interior Affairs, Yazd Municipality, Page 121.

[2] Aminizadeh M., Lashkaripour Ghafuri (2000), "Methodology of Surveying Underground Dams" Scientific Journal of Water and Irrigation, Year one, Issue 2, Pages 43-57.

[3] Babayee A. (2001), "A Strategic Approach to Water", Mahab Qods Journal, 15th issue, Pages 2-4.

[4] Behrangi A. (2001), "Underground Dams, A Road Leading to development of Groundwater Resources and Fighting Water Crisis" 1st National Conference on Coping Strategies against Water Crisis, University of Zabol.

[5] Haidari H, Shahriari S. (2011). Location of underground dam in Garmab river basin(Golestan research station). Geographical research journal. Volume 26 , Number 1 (100); Page(s) 131 To 148.

[6] Hashemi, Zahra, Ghayomian, Jafar, Tabatabaei, Seyed Javad, Oroumiyeyi, Ali, 2002. Study of Quaternary deposits in the North Basin of Haj Aligholi Desert to determine appropriate locations for the construction of subsurface dams, Sixth Symposium of Geological Society of Iran. Iran: Tehran

[7] Pirmoradi R., Nakhayee M. Asadiyan F. (2010), "Locating Suitable Sites for Construction of Underground Dams Using GIS and AHP" Journal of Natural Geography, 3rd year, issue 8, pages 58-64