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Model for Determination the Optimum Location of Subsurface Dam Using Analytical Hierarchy Process AHP

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ABSTRACT

Limited amount of available water in one hand and population growth and industrial and agricultural development on the other hand, resulted to increasing demand of water. This is while subsurface water is one of the water resources in any country. In many cases with favorable geological conditions, implementing dams have been very simple and economical, and even with local financing and help is possible. However the biggest issue is finding a suitable location to construct these dams. In this study, in order to provide a model for optimal location of subsurface dam, AHP method was used. In this research the research area of Khomein city in Markazi Province was studied. After obtaining the necessary data and results for this area, 9 regions were considered for the construction of dams and were examined by AHP. These 9 regions were ranked in order to find the optimal location of subsurface dam. Eventually it became clear that the calculated adjustment rate for the above scenario is (0.01148), which shows the accuracy of the weights assigned to the criteria.

Key words: Optimum location, construction sites, subsurface dam, Analytical Hierarchy Process AHP

Introduction

Limited amount of available water in one hand and population growth and industrial and agricultural development on the other hand has increasingly made the ground water as a valuable source of water supply. This especially important in arid and semi arid areas or areas with limited surface water flows due to variety of reasons including high evaporation and high permeability of the soil surface. In such areas underground water control and management and strategies to increase the potential utilization of these resources by storage is of high and sensitive importance. Construction of subsurface dams and water storage in the alluvial and grain materials is one of these methods [1]. A quick look at the international research, papers and projects regarding the containment and use of groundwater, certificates that growth and development of subsurface dams, and scientific approaches to them in the last three decades has increased [14,15,8,6]. Subsurface dam is generally defined as an obstacle placed in the path of groundwater flow in a natural or synthetic hydrated layer that almost stops the connection of downstream and low stream flow (Figure 1). The main body of n subsurface dam is formed by a curtain or its impermeable wall. Most of the existing dams of this type have been built in arid and semiarid regions [1].

Although the need of subsurface dams is more felt in arid areas, the most important problem in development and structure of subsurface dams, is determining suitable construction areas. This is a problem because technical standards, environmental and economic - social decisions are involved in selecting a suitable location [2]. In this regard Hashemi *et al*. [4] have examined the subsurface dam location in the Haj Ali Quli catchment located in Semnan Province. In this study parameters of this watershed area, watershed erodibility, runoff rate, basin's slope, river cross width, alluvial thickness and deposits texture are determined by examining the topography and geology maps, visual survey of satellite images and field studies and finally, according to the above criteria the proposed locations are prioritized. Also Tabatabaei Yazdi [3] located the subsurface dam in some parts of Tehran and Semnan provinces using field visits, field and laboratory tests, based on technical criteria. Naseri *et al*. [9] conducted a study on northern slopes of Karkas Mountains to determine optimum areas for subsurface dam construction using decision support systems. For this purpose by analytical hierarchical process they conducted the three steps of identifying potential areas, determining the most appropriate axis and assessment and Prioritization of axis. The result showed that the use of decision support systems along with field surveys is effective in reducing costs and determining suitable time for locations of subsurface dam construction, therefore hierarchical analysis process is a powerful tool capable of sorting

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criteria in the decision tree structure. Salman Poor [12], simulated the idea of modifying and controlling aqueduct using subsurface dams, by evaluating the effect of this idea on aqueduct performance by a numerical model. In this research, to model the aqueduct, MODFLOW software was used. By comparing the effects of modified aqueduct with subsurface dam and traditional aqueduct, the idea of modifying aqueduct was evaluated. The results showed at least 30 per cent increase in the flow of modified subsurface aqueduct compared with the traditional aqueduct, and also indicated the improved hydraulic balance in the studied fields. Forzieri *et al*. [7] in a research investigated the method for selection the appropriate sites to construct small subsurface dams in arid regions by a case study in the region of Kidal, Mali. Optimum areas were selected in three stages, including identifying areas by interpretation of satellite images and large-scale maps, quality selection of identified areas based on functional and geomorphological features, and the third stage was to prioritizing areas with multi-criteria decision making method. Results showed that this method is a general method to determine appropriate locations for construction of subsurface dams, and interpretation of satellite images and large scale maps are valuable tools for preliminary land analysis and tectonic features.

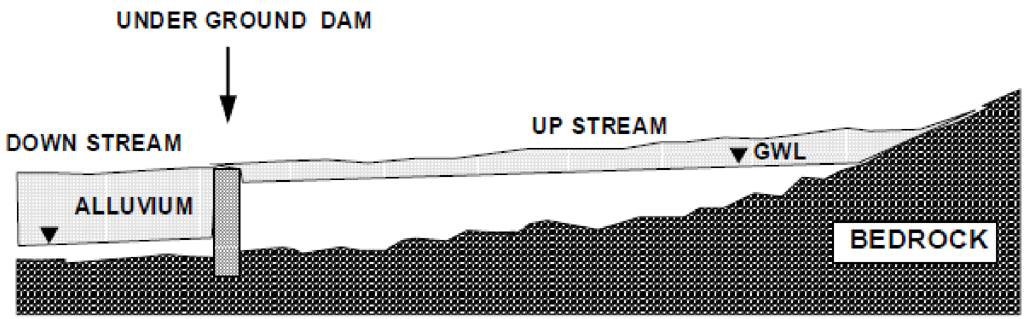

Fig. 1: Overview of how the subsurface dam is constructed and its performance.

2 – Studies of subsurface dams construction:

To identify, select a location and design and implementation of subsurface dam according to the scale size and importance of the project, necessary studies are needed which in this paper they are referred as preliminary and complementary studies.

2-1- Preliminary studies:

According to the following instructions, the prone locations are chosen for detailed study:

● Aerial photos, topographic maps, geological maps and any kind of a map that is useful for study of basins and sub basins are collected, then the location of residential areas, rivers, floodways, Alluvial fans, old channel, aqueducts and other complications with regard to necessary requirements such as slope and basin area are identified on maps and required documents are prepared. At this stage the most elementary requirement in choosing the primary axes is narrow alluvial valley and significant extension of alluvium in the upstream areas.

●All the information is provided on a map if possible (e.g. topography).

●The information about ground water levels (depth of water in the wells) in different years and seasons, especially during low water times is collected by any way possible, even in some cases by asking from locals. Seasonal fluctuations in the aquifer level show the sensitivity of aquifer to the drought.

●The annual surface or groundwater water, the state of possible flooding and average precipitation and evaporation of the area shall be anticipated to be used in future decisions.

● At this stage of the study it is possible to evaluate the reservoir dam and the subsurface dam to some extent by surface geology studies, and then by geophysics experiments that costs less compared with exploratory drilling, gather more information from the ground surface, and then plan for future exploratory drilling in the next phase. Geophysical studies, can include geo-electric and seismic refraction methods. Geo-electric method provides good information on the approximate determination of the position of bedrock, ground water conditions and status of tissue and combination of granulation in reservoir sediments. Seismic refraction method also provides bedrock morphology and qualitatively shows ideas about the density of alluvial sediments. Applying geophysical methods as a suitable tool, with low cost and high accuracy has provided valuable information about of subsurface conditions in axis and repository areas and these data can be used to decide whether to continue the studies or not.

●To monitor and qualitative study of subsurface water, the average amount of salts and minerals and likely microbial contamination in water shall be determined.

2-2- Further Study:

At this stage in order to select the location of dams, in the preliminary study stage more advanced and accurate studies are conducted on the selected areas and eventually the suitable axis are selected. Generally, the following activities should be performed:

●More accurate assessment of level of the wells water in region to determine seasonal fluctuations in underground water levels.

● Drilling test wells in selected areas according to the preliminary information and in particular, the geophysics engineering results to determine the depth and characteristics of the floor stone, the thickness of the alluvium and eventually draw a longitudinal and latitudinal profile of the water flow.

● If the project is important or includes a large scale, to determine the hydrogeology characteristics of the alluvium such as storage coefficient or specific discharge, permeability coefficient and transference capability coefficient and to obtain its exact figures (especially when the it is composed of several layers) pumping test in different areas shall be conducted.

●A correct estimation of bedrock permeability and thickness of its weathered and loose layer to calculate the hydraulic conductivity from borders should be performed in order to determine the condition and penetration depth of dam's curtain or wall to the bedrock. This is determined by hydraulic conductivity tests and using excavation samples. This is one of the important data concerning the technical and economical aspects of the work.

● According to the previous stages and available materials and desired impermeability status and in general all relevant technical issues, the type of dam system (dam body) is characterized and the mode of its connection to bedrock and anchors is investigated. In the final stage of axis choice, like normal dams a surface with appropriate area and reservoirs capacity in upstream and a narrow valley at the location of subsurface dam is necessary to reduce the construction costs.

● For optimal operation and reservoir management, water utilization systems have been predicted so that necessary operations such as intubation, wells construction and drains and valves implementation can be done timely along with the progress of other tasks.

It worth noting that the amount of studies and investigations in both phase of preliminary and complimentary studies much depend on the size and importance of the project and geological conditions of the site and should be assessed and decided based on engineering judgment to optimize the cost of studies, implementation and operation of subsurface dams.

3 - Analytical Hierarchy Process AHP:

There are different criteria for prioritization of subsurface dams and each of these criteria have a different weight and value [7,5]. In analysis based on Multi Attribute Decision Making besides choosing the best or prior options, the goal is to rank options in a descending order. Analytical Hierarchy Process is one of the analysis methods based on multi attribute decision making that was presented in 1980 [11] and has been used in this study. AHP method has a simple theory and basis and is based on three principles: decomposition paired comparing and consecutive combining of values, and prioritizing options [10]. Figure 2 shows a simple form of a problem analysis with regard to criteria involved in decision making.

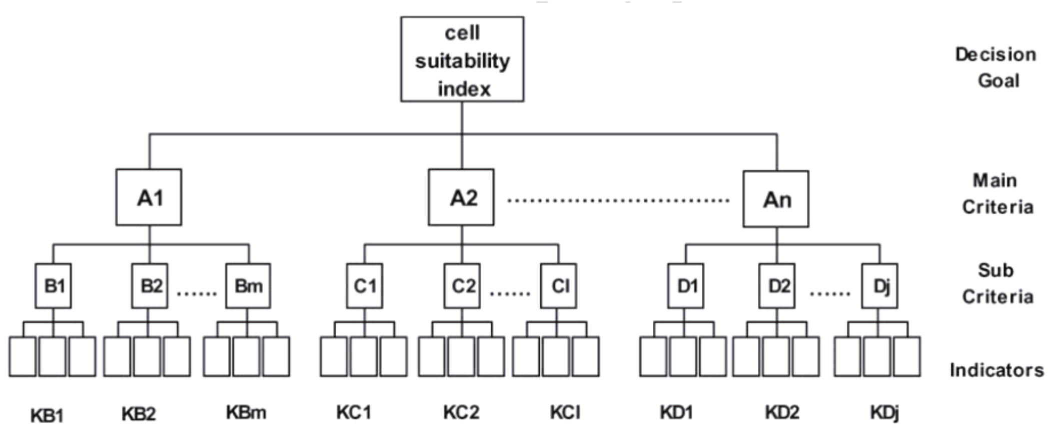

Fig. 2: Structure of decision criteria in the hierarchical approach.

4 - The study area:

In this study the research area is located in Markazi province and in Khomein city. Markazi Province is located at the center and North West of Iran between the geographic East latitudes 57 48° to 04 51° and North longitudes 23 33° to 35 35°. The area of this province is 29406 square kilometers and its capital is Arak with a height of 1708 meters above sea level. According to Figure 3 the region marked with dot lines is studied and 9 proposed axes for subsurface dam construction are considered.

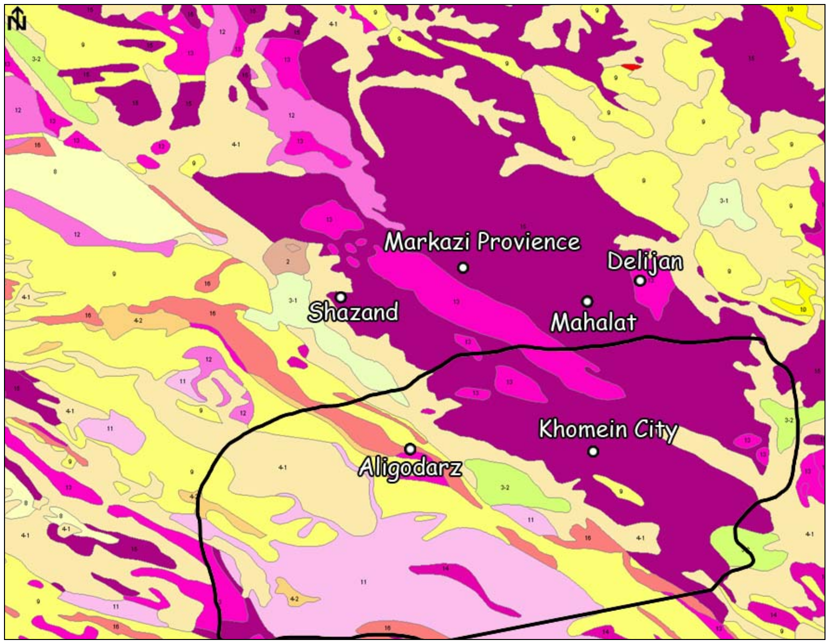

Fig. 3: The research study area

5 - Research Methodology:

As a first step in subsurface location a database is needed. This database includes the figures, aerial and satellite photos, hydroclimatological statistics, soil texture data, regional geophysical data, the Piezometric and test wells, economic – social data and data collected from field surveys. After establishing a comprehensive database, accuracy of existing data is evaluated and they will be matched with each other, which include correction of information and topographic maps and related three-dimensional images, then the desired catchment area is identified. To determine the alluvium area, aerial and satellite photos have been used. Areas outside the scope of the alluvium were deleted as not optimized regions, and in the next step using a height model, narrow and suitable valleys are determined for subsurface dam. In this study, considering the affecting factors and conditions that absolutely involve in the location of subsurface dams, factors such as the presence of impermeable bedding, faults, aqueducts etc., and some regions were selected as suitable areas for subsurface dam construction. In this way, regions which were qualified by all the absolute terms for subsurface dam construction scored the value of 1 and other areas valued 0 and were removed. In the next stage appropriate areas were evaluated according to the relative impact factors [2]. Finally using the AHP matrix, suitable areas for the construction of subsurface dams were prioritized and presented in the form of a map. The research process is presented in Figure 4.

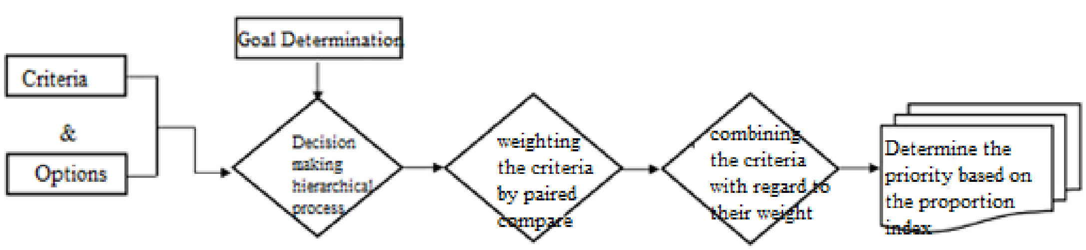

Fig. 4: A model for research process.

As shown in Figure 4, in this study first the main criteria, including environmental, technical and socio-economic criteria is determined. Then sub-criteria and indicators for each criterion were determined by experts and were compared in pairs. Then by weighting the mentioned criteria, the optimum locations of subsurface dams were determined.

Prioritizing the locations of subsurface dam construction was performed by non-spatial method through Expert Choice software. In the non-spatial method data obtained from the regional average statistics were used for input data of the Expert choice software [13]. In this study according expert's opinion the decision making tree was formed. This tree consists of four main criteria, water, the axis of dam construction, reservoir and economic - social. Each of the main criteria consists of sub-criteria indications and was orally compared by relevant experts, and weight of each one of them was calculated by particular vector method and with approximation of 0.0001 and was repeated 10 times. The incompatibility index was calculated for each of the matrixes to evaluate the accuracy of the binary comparing matrix. Binary comparison conducted by experts and the relative importance or weight of each of the sub-criteria of the main criteria is presented in Table 1.

Table 1: Weighting the sub-criteria related to the four criteria water, the construction axis, reservoir and economic - social issues.

Water criteria	 Quality Quantity	Quantity 1 0.2	Qualit y 4 2	Weight 0.835 0.167		
Dam construction axis criteria	 Thickness of the alluvial Length Lithology of the fulcrum	Thickness of the alluvial 1 0.2 0.333	Length 5 1 0.2	Lithology of the fulcrum 9 5 1		Weight 0.737 0.207 0.589
Reservoir criteria	 Permeability Slope Surface Thickness of the alluvial	Permeability 1 0.3333 0.111 0.2	Slope 3 2 0.111 0.333	Surface 5 3 1 1	Thickness of the alluvial 5 4 2 1	Weight 0.561 0.250 0.100 0.100
economic - social issues criteria	 Impact on existing water resources Regional water demand Access to subsurface dam	Impact on existing water resources 1 0.2 0.333	Regional water demand 4 1 0.111		Access to subsurface dam 6 3 1	Weight 0.732 0.189 0.081

Results and Discussion

- 11 of 20 optimum ranges specified in field visit step were excluded by absolute terms. These ranges were eliminated by faults and aqueducts.
- Adjustment rate calculated for the above scenario is (0.01148). It represents the accuracy of the weights assigned to the criteria
- AHP method is very effective in prioritizing the suitable specified areas because many criteria are involved in their decision making
- According to the presented scenario suitable sites for construction of subsurface dams, are identified and prioritized in Table 2.

Table 2: Prioritizing the proposed appropriate areas.

	Water		Reservoir				Axis			Water demand			Access		
Proposed axis	Quantity	Quality	Thickness	Slope	Volume	Permeability	Depth	Length	Lithology	Drinking water demand	Agricultural demand	Industrial demand	Access to the roads	Distance from village	priorities
VII.	0.013	0.429	0.068	0.002	0.292	0.135	0.281	0.018	0.021	0.132	0.010	0.017	0.022	0.017	1
VII.	0.033	0.429	0.068	0.002	0.292	0.035	0.017	0.040	0.021	0.259	0.044	0.017	0.022	0.017	2
VII.	0.013	0.429	0.017	0.002	0.659	0.135	0.281	0.080	0.021	0.031	0.005	0.017	0.022	0.004	3
VII.	0.013	0.199	0.017	0.002	0.292	0.135	0.281	0.018	0.021	0.015	0.005	0.017	0.022	0.017	4
VII.	0.066	0.199	0.035	0.003	0.292	0.016	0.017	0.009	0.021	0.661	0.005	0.153	0.022	0.034	5
VII.	0.013	0.429	0.004	0.002	0.017	0.069	0.143	0.040	0.009	0.015	0.005	0.017	0.022	0.034	6
VII.	0.066	0.199	0.004	0.002	0.149	0.035	0.017	0.018	0.009	0.661	0.005	0.153	0.022	0.008	7
VII.	0.033	0.199	0.004	0.002	0.074	0.016	0.017	0.009	0.009	0.015	0.005	0.017	0.022	0.008	8
VII.	0.013	0.199	0.008	0.002	0.017	0.008	0.072	0.040	0.021	0.015	0.005	0.017	0.022	0.004	9

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