Combination of Remote Sensing and Ground Penetrating Radar methods to estimate suitable areas for locating subsurface dams in Abouzeidabad Plain

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Abstract

The subsurface dam is considered a way to store and utilize subsurface flow in dry and warm areas. In this study, the appropriate locations for constructing a subsurface dam in an Abouzeidabad plain were pinpointed using remote sensing and geophysical methods. To this end, topography, slope, lithology, land use, stream density, fault density, and qanat density information layers were provided. In providing these layers, Digital Elevation Model (DEM) and Landsat 8 satellite images were used. Due to the importance of alluvial formations in the reservoir volume of the subsurface dam, the lithology layer in the form of a geology map subject was made to separate the formations suitable for the dam storage. Analytical Hierarchy Process (AHP) method was used to compare and evaluate the layers and substrates. A final map of location priorities for the construction of a subsurface dam was then developed using the results from the AHP method. After identifying three locations of high priority (4 to 5), the geophysical data were collected from these locations using Ground Penetrating Radar (GPR) method to determine the bedrock position and alluvium thickness in each cross-section. Using the obtained data and hydrological information of the area, discharge capacity was calculated for each of the identified locations. At the most appropriate location, a subsurface dam with 311 meters length and 17 meters depth was proposed to reach the discharge capacity of over 4.35 million cubic meters, which is considerable for supplying the water demands of downstream regions including Badroud and Abouzeidabad.

1. INTRODUCTION

The lack of equal distribution of rainfall in terms of time and space, as well as the climate in arid and semi-arid areas on the planet, have made inhabitants exploit subsurface water resources. However, these resources are not inexhaustible and the effects of overexploiting them will be noticed in geological and environmental formations over time. Generally, the strategies for coping with water shortage are divided into two types of strategies for proper management of water resources and strategies for the extraction of new water resources. Ross (2018) has explored the ways to accelerate the integrated management of surface and subsurface waters in Australia. This research is the first comprehensive assessment of progress in the management of continental water communications, which offers an innovative approach to overcome barriers across all Australian states. He believes that the systematic and integrated management of surface and subsurface waters should cover the allocation of subsidies to the surface water storage and drinking water recovery, which requires the support of managers at the macro-political level [1].

Subsurface dams can be used either as water resource management tools or as new water resource providers. Stevanović (2016) presents the successful construction of subsurface dams in northern parts of Iraq, Algeria, Ethiopia, and Somalia. In his view, the right places for establishing and locating subsurface dams are North and East African and Middle East countries in which dams, if constructed, will directly or indirectly feed Karstic aquifers [2]. The subsurface dams are not always used to store water, such as the subsurface dams in the northern parts of Okinawa in Japan that have been built to prevent seawater flow into fresh-water aquifers [3]. Abdoulhalik and Ahmed (2017) have also examined the effect of heterogeneous geological layers on the performance of subsurface dams in protecting coastal aquifers against sea-water penetration. They have employed two laboratory and numerical models to simulate similar conditions in their study. Four layers of soil, one homogeneous layer, and three layers with low permeability above, between, and below the aquifer were utilized for simulation. Based on their studies, subsurface dams reduce the longitudinal penetration of salt water from the sea to the aquifers by 78%. However, the existence of heterogeneous aquifer layers reduces the efficiency of subsurface dams in preventing salt water penetration into the aquifer [4]. Sometimes, subsurface dams are utilized to improve or modify qanat discharge systems. Salmanpor et al. (2009) used the MODFLOW software program to simulate the improvement in the performance of qanat discharge in the presence of underground dams. An increase of at least 30% in the modified qanat discharge relative to traditional qanat was suggested [5]. Therefore, qanat areas should not be completely neglected from the study of locating subsurface dams. Rather, dams can be used to increase the qanat discharge and qanat life [6].

In comparison with conventional surface dams, the subsurface dams do not leave damaging environmental impacts upstream or downstream of the dam. Additionally, subsurface dams do not require extensive consolidation of their structures due to being underground where the risks of dam failure are not forthcoming. The subsurface dams have advantages such as simple construction, increase in the discharge capacity of existing wells, low operational costs, replicability, ease of use by local people, and low pollution risks [7]. Since the conditions for the construction of a subsurface dam vary according to the geomorphological and hydrological features of each region, the local study of these features focusing on varied information layers for finding suitable locations seems necessary.

Laa et al. (2005) studied the semi-arid water basin of Khorat located in the northwestern part of Thailand to develop groundwater resources through the construction of a subsurface dam. Hydrogeology conditions (effective porosity, impermeable bedrock, and aquifer), environmental conditions (lack of water and soil salinity and lack of pollution sources), and geological and topographic features were reported to be necessary for locating a subsurface dam in suitable sites such as alluvial fans between two mountains, river alluvium, watercourse sediments, volcanic terraces, and weathering intrusive igneous rock [8]. RAIN (Rainwater Harvesting Implementation Network) (2008) in executive guide report for locating and constructing sand storage dams, found that slope, topography, geology, hydrology, vegetation coverage, material resources, and water demand should be considered for the choice of waterways [9]. Foster et al. (2002) showed that the reservoir volume, bedrock depth from the surface, permeability, and chemical quality of reservoir soil are defining factors in the successful construction of subsurface dams in Brazil [10]. Jamali et al. (2014) delved into the study of locating suitable regions for building subsurface dams in the northern parts of Pakistan using the spatial multi-criteria analysis. They used geological data, slope, land use, soil, and a topographic wetness index to locate subsurface dams. To prioritize the regions, two decision-making models, the AHP and factor interaction method were used. The results showed that the hierarchical analysis process prioritized 3 percent of the regions in the first place and 4 percent of the regions in the second place, while the factor interaction method prioritized 2.7 percent of the regions in the first place and 4 percent of the regions in the second place. In general, the hierarchical analysis process modeled a better prioritization of the regions. According to the sensitivity analyses, the most important criterion for land use was achieved [11].

The Geographic Information System (GIS) is employed as an efficient means to prepare and integrate information layers for locating purposes. Jamali et al. (2013) investigated locations for building subsurface dams in the Boda-Kalvsvik region in Sweden. The variables under investigation in this study were Topographic Wetness Index (TWI) and geological data of the region. The suitable locations were found using groundwater balance modeling. Six locations were identified for constructing a subsurface dam where extra water was extracted [12]. Without preparing extensive information layers in some studies, locating was done with the help of basic morphological features relying on individual experiences. As an example, studying and recognizing subsurface dams have been conducted in the Kaidal district of Mali using the visual interpretation of satellite images and GIS. After the initial study of morphological features such as the valley available in the waterway, length of the waterway, basin area, vegetation index, as well as geological features such as faults, bedrock depths, porosity, precipitation, and the presence of people and beneficiaries in this research, 17 regions out of 66 regions were selected and then restricted to 3 regions based on the estimation of the dam importance and practical aspects. Finally, the best region for the construction of the dam was suggested [13].

The application of geophysics in locating subsurface dams is based on the recognition of subsurface conditions including alluvium depth, bedrock depth, and lithology of layers. Gomes et al. (2018) applied Electrical Resistivity Tomography (ERT) method to determine suitable locations for subsurface dam construction in semi-arid southeastern parts of Brazil. In his view, geoelectric measurements can locate suitable sites for subsurface dams, which have sufficient penetration conditions suitable to the rainy seasons. The results show the presence of a layer with high electrical resistance under a low resistance sub-layer at locations which are appropriate for underground dam construction. The upper layer is made of sandstone, and the lower layer contains the metamorphic rock mass. Therefore, surface water penetration conditions are well-provided and metamorphic rock acts as the basement rocks of the reservoir, which results in an adequate storage of water [14].

Ground Penetrating Radar (GPR) is a geophysical method which offers a new way of investigating shallow soil and rock conditions with high resolution. This technique has been advancing over the years as the need to better understand overburden conditions for activities has increased. Activities such as geochemical sampling, geotechnical investigations, and placer exploration, as well as the factors controlling groundwater flow, have resulted in an increasing demand for techniques that can be used to image the subsurface with increasing resolution than previously possible [15].

GPR is an electromagnetic pulse reflection technique based on physical principles similar to those of reflection seismic surveys. In comparing the two methods of seismic reflection and GPR, both methods are based on wave propagation and provide detailed and continuous images of the subsurface. The two methods are complementary. The deep subsurface is the domain of seismic reflection and is beyond the reach of GPR, but in the shallow zones, radar offers an alternative that is both attractive and cost-efficient [16]. GPR has been used successfully in geotechnical investigations for over a decade, generally to depths of a few meters [17, 18 & 19]. A recent development in digital instrumentation and low-frequency antennae have extended the GPR domain in radar-favorable areas (low soil conductivities) to depths of several tens of meters, making the method suitable for geological applications; hence the name ‘georadar’ [15].

Generally, a GPR system consists of two parts; the main transmitter and receiver antennae, and screen display. The waves are produced from the transmitter antenna to the earth. After facing discontinuities and subsurface heterogeneity, the reflection was finally recorded by the receiver antenna. This discontinuity is detected by a conductivity or dielectric constant [20]. Lima et al. (2017) used a three-dimensional GPR survey for detecting subsurface structures in the Rio Grande Norte state of Brazil with the assumption that the establishment of a surface dam with the lowest wall length and cost results in a water reservoir with the highest storage volume [21].

2. Materials and methods

Finding suitable sites for locating a subsurface dam is the most important stage in the construction of a dam. Locating and identifying geomorphology and natural features of a dam result in successful construction. The first step in locating a subsurface dam is to prepare a database. All information includes maps, aerial and satellite images, hydro-climatic statistics, soil texture information, geophysical data of the region, piezometric and observational wells, socio-economic information, and field survey data. This information can be useful in determining the best location for a subsurface dam and can be developed and valued depending on the studied region.

In this study, the data collected from the digital elevation model (DEM) and Landsat 8 satellite, as well as a 1:100000 geological map of the region were prepared using the remote sensing software. The layers used in this study included topography, slope, lithology, land use, stream density, fault density, and qanat density. Considering different values as well as the positive and negative effects of different layers on the selection of suitable sites for the construction of a subsurface dam, weighting layers should be relative to their effect on the project success. For this purpose, the analytical hierarchy process (AHP) method was used to select the appropriate weight for the information layers and sublayers. The weights were assigned to layers and sub-layers according to Saaty's Weighting Table [22].

After the calculation of the relative weight of the existing layers and sub-layers, the weight overlay tool in ArcMap software was used to integrate layers for the final weighting map. One of the features of the weighted overlay method is the possibility of making a comparison between the available layers. In other words, in the map resulting from the integration of the layers, a score between 1 (the most inappropriate) and 10 (the most appropriate) is given to each location, where the inappropriate locations are those regions with the negative effect of the layers. After field observations of the appropriate regions, high priority locations were identified in the final map.

2.1. GPR

To know the subsurface conditions, bedrock position, and alluvium depth in each selected location, geophysical methods were used. The most appropriate method in terms of resolution is Ground Penetrating Radar (GPR), which does not require excavation or direct access to subsurface. In this study, in cooperation with the ZAP (ZAMIN AB PEY) company, geophysical Georadar complex "Loza-M" was made available for data collection. This device is designed with 3, 6, and 15 meters transmitters by the company (Figure 1), and the frequency range can be between 50-300 MHz.

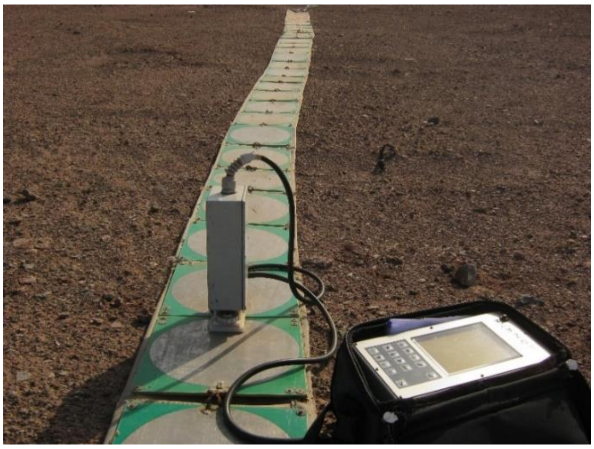


Figure 1. Georadar complex Loza-M with 15 meters transmitters

After collection of the raw data on the specified axes, the data was examined in the company by ReflexW software, and the results were presented in the form of images that show the thickness of the alluvium, the depth of the bedrock, and the distance and travel-time waves. Based on these data, the height of the dam wall and the volume of the reservoir can be calculated.

2.2. The Study Area

The target area is a part of central Iranian plains, located in the north of Isfahan province, between the cities of Kashan, Aran and Bidgol, Natanz, and leads to Abouzeidabad. This area is 2530 square kilometers, between the geographic longitudes 51° 21' and 51° 58', and geographical latitudes 33° 32' and 33° 56' (Figure 2). The area under this study is located in regions with warm and arid to semiarid climate, with some evidence of cold and humid climate in the near past. The mean temperature, annual precipitation, and evaporation of the area are 19.1°C, 138.4 mm, and 2120.89 mm, respectively. High evaporation leads to the ineffectiveness of surface dams and surface water storage in this area. However, the amount of evaporation can be greatly reduced by the construction of subsurface dams rather than surface dams.

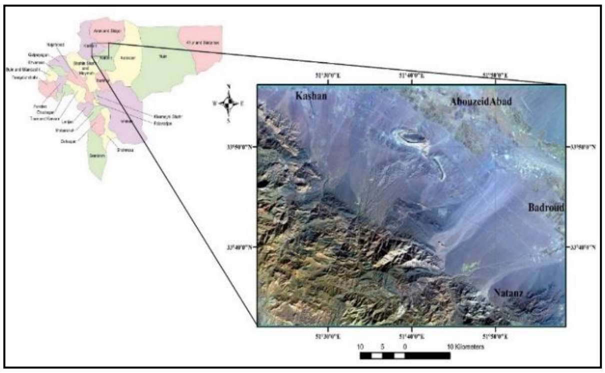


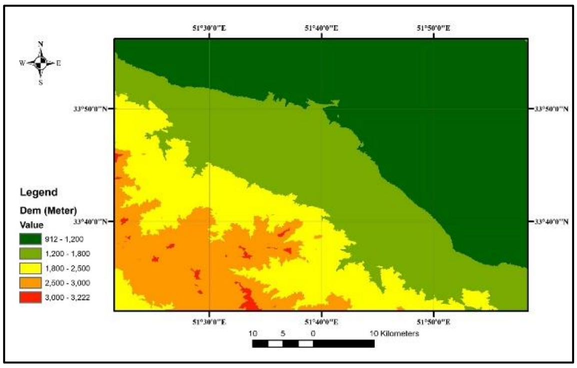
Figure 2. The study area upstream plains of Abouzeidabad (Landsat 8 image, the color combination of 7.4.1 RGB)

2.3. Information layers

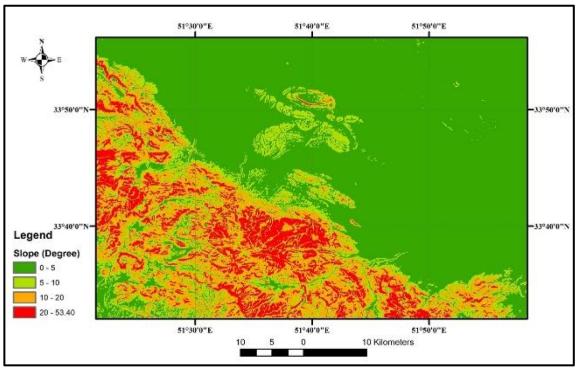
The first step after determining the study area is the preparation and extraction of effective information layers for underground dam location. In this study, seven layers were identified and digitized by using Geographic Information System (GIS) as shown in Figure 3 (A to G).

Figure 3-A shows the topography layer of the area. Since the study area is composed of the heights and lowland areas leading to the flat plains, where the priority of the construction of subsurface dam is to be at the inlet of the waterway to the hillside, the topography layer of this region was used to increase the intensity of the weighted points of the hillside. In this area, an elevation of 1200 to 1800 meters above sea level

covering the hillside of a mountain chain was considered an appropriate height for the construction of a subsurface dam. Figure 3-B illustrates the slope of the study area. The suitable slopes of lands for constructing dams are typically about 0.11 to 5 degrees, but in some cases, there are dams with slopes of 6 to 10 degrees [23]. Therefore, considering the narrow valleys and rivers, the suitable slope for the subsurface dam construction is considered less than 10 degrees. Figure 3-C is stream density. Waterways and streams are noticed because they are the main area for the flow of seasonal rivers and subsurface flows resulting from floods. Figure 3-D shows the faults density. For the preparation of this layer, first, the faults of the area were identified using the 1:100000 geological map of Natanz and introduced as a digital layer in Arcmap software. The main faults of the region are generally northwest-southeast oriented parallel to the Zagros orogenic phase. Areas with a high density of fault are not suitable sites for underground dam construction and are used in weighting with a negative effect on location.



A



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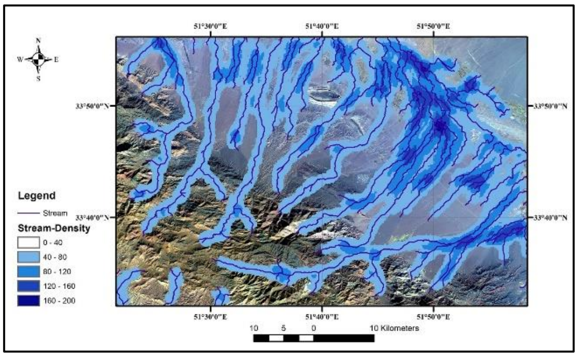

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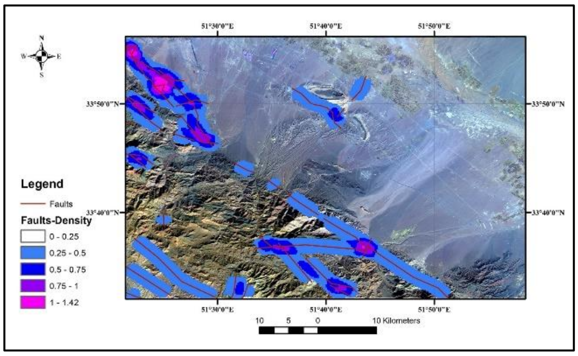

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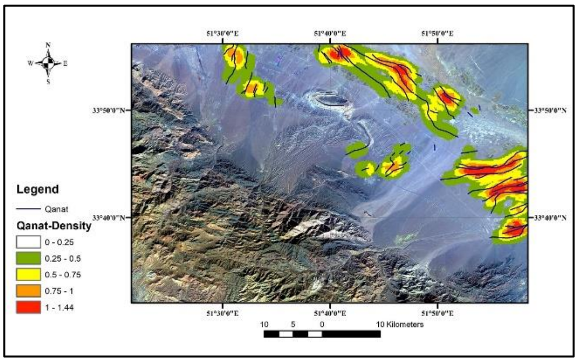

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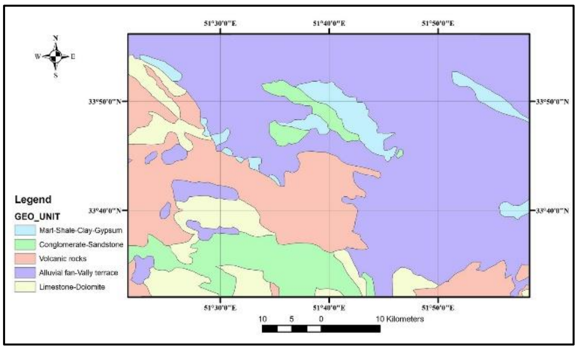

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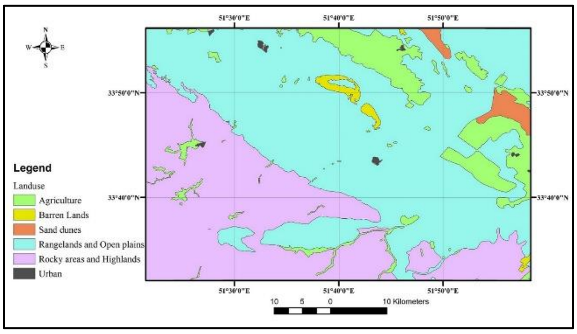

G

Figure 3. Information layers prepared from the study area, including A-Topographic map, B-Slope map, C-Stream density, D-Fault density, E-Qanat density, F-Lithology, G-Land use

Figure 3-E also shows the density of qanats in the study area. Qanats of the area are important from two viewpoints. First, establishing a subsurface dam does not have a detrimental effect on the structure of a qanat. Second, it facilitates the qanat discharge. To identify the qanats in the area, a 1:100000 geological map of Natanz as well as a digital layer of qanats were developed.

In figure 3-F, a lithological map of the study area was prepared. In locating subsurface dams in terms of lithology, the locations of alluviums as the main source of subsurface water storage are more important than outcrops, geological age, and lithological origin. Hence, it is necessary to prepare a geological map subject to locate the subsurface dam. In this study, five lithology groups that have a different effect on locating a subsurface dam were organized into digital layers using Landsat 8 satellite data and the 1:100000 geological map of Natanz. Geological layers of marl, shale, clay and gypsum are considered to be evaporative formations which are not suitable sites for subsurface dam construction due to their negative effect on groundwater quality. Igneous and volcanic rock layers are not capable of subsurface water storage due to their impermeability, but they are suitable supports for subsurface dam walls. Alluvial fan, valley terraces, conglomerates, and sandstone layers are the most suitable sites for subsurface water storage because of their high permeability. The limestone and dolomitic layers also form the karstic aquifers and the construction of subsurface dams in these layers will recharge these aquifers. The resulting information layer is a geological map subject which is provided to locate a subsurface dam based on the permeability index and suitable subsurface water storage.

Figure 3-G also shows the land use map of the study area. In terms of land use, the existence of free zones away from polluting sources upstream of the subsurface dam is considered. As indicated in the land use map, the study area includes agricultural lands, rangelands and open plains, sand dunes, barren lands, as well as rocky, highland, and urban areas. Rangelands and open plains have a higher priority for the implementation of the subsurface dam.

3. Results and discussion

The information layers and substrates were weighted using AHP method and Saaty's table. The mentioned necessities, such as priority of the stream density and alluvium layers due to the nature of the water supply and subsurface dam storage, as well as the negative effects of the fault density and qanat density layers on the structure of subsurface dam wall, were taken into consideration when comparing the main layers. In comparing the main layers, some layers have positive and some have negative effects on locating the subsurface dams. For example, layers of stream density, and alluvium layers due to their nature of providing water for storage, have a positive effect, and layers with fault density and qanat density due to the nature of permeable bed rocks have a negative effect on the location of subsurface dams. These comparative weights were assigned to each layer using the scoring and prioritization of previous references [6, 10, 23] (Table 1).

Table 1. Weighting the main layers

Main layers	Stream-Density	Lithology	Slope	Land use	Topography	Faults-Density	Qanat-Density	Final Weight
Stream-Density	1	3	3	3	5	7	7	33.96
Lithology		1	3	3	5	7	7	24.81
Slope			1	3	5	7	7	18.13
Land use				1	3	5	5	11.18
Topography					1	5	5	6.56
Faults-Density						1	3	3.10
Qanat-Density							1	2.27

Weighting the existing substrates was also done through the same methods as the main layers. All the necessities for the success of a subsurface dam are the density of stream, lithological permeability of the reservoir, distance from the fault and qanat density, slopes less than 10 degrees, and range of elevations (for focusing on the plain entrance alluvial fans), all of which are given greater weights in locating the subsurface .dams

In the weighted overlay method, weights must be entered in the integer format and the main layer weights were normalized in the range of 0 to 100 and the sublayer weights were normalized in the range of 0 to 10. Therefore, the final weights obtained by the AHP method for the main layers and substrates (Table 2) are rounded to the nearest integer number when entering to the software.

Table 2. Weighting the information layers and sublayers for integration

Layers	*Percentage of the impact of each layer*	*Layer classification*	*Each class score*
Stream-Den	33.96	0-40 40-80 80-120 120-160 160-200	3.11 7.24 18.08 28.05 43.53
Lithology	24.81	Marl-Shale-Clay-Gypsum Conglomerate-Sandstone Volcanic rocks Alluvial fan-Valley terrace Limestone-Dolomite	6.62 25.64 3.85 50.42 13.47
Slope	18.13	0-5 5-10 10-20 20-53.40	53.61 30.95 11.20 4.23
Land use	11.18	Agriculture Bayer Lands Sand Dunes Rangelands-Open plains Rocky areas-Highlands Urban	25.84 10.79 17.92 37.27 5.32 2.86
Topography	6.56	912-1200 1200-1800 1800-2500 2500-3000 3000-3222	28.69 44.53 15.61 7.40 3.76
Faults-Den	3.10	0-0.25 0.25-0.5 0.5-0.75 0.75-1 1-1.42	46.10 25.08 16.16 8.49 4.17
Qanat-Den	2.27	0-0.25 0.25-0.5 0.5-0.75 0.75-1 1-1.44	44.30 25.78 16.61 8.73 4.58

The final image is obtained after integrating the layers and taking into account the weight of each layer and sublayer, which defines the priorities for locating the subsurface dam in the area (Figure 4).

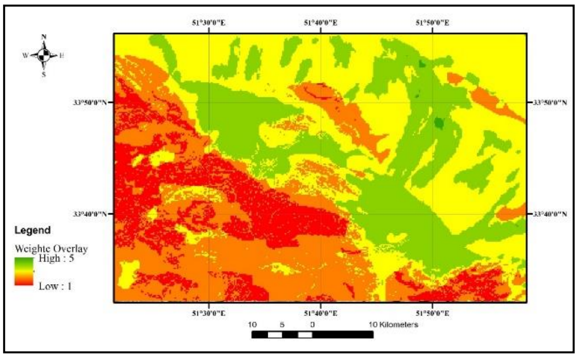

Figure 4. The map derived from the integration of effective layers in locating the subsurface dam

As shown in Figure 4, locations were scored in the range of 1 (most inappropriate) to 5 (most appropriate). The criteria such as fault and qanat cause elimination of the inappropriate regions in the field survey. Regarding the results from the integration of the information layers, appropriate regions were visited, and 3 suitable sites scored between 4 and 5 in the final weighted overlay integration map were identified for establishing the subsurface dam (Figure 5).

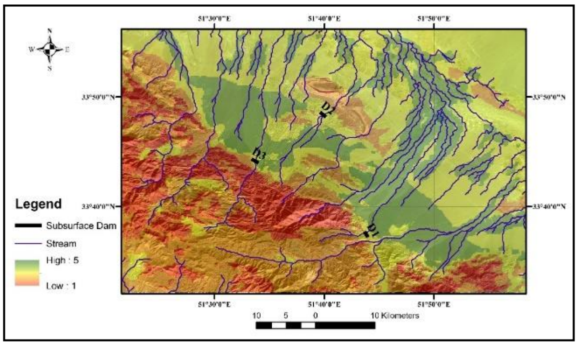

Figure 5. Finding 3 locations suitable for the construction of subsurface dams

The next step in dam locating is to conduct geophysical surveys at identified locations for finding the thickness of the alluvium, and bedrock depth. For this purpose, GPR data profiles were transversely shaped (perpendicular to the waterway axis). Locations D1 to D2 that were identified for the storage of groundwater had good geological conditions for the wall construction of the dam during field visits. Location D1 was determined as the most suitable one for establishing the subsurface dam with regards to dam reservoir volume, discharge efficiency, lack of upstream pollution sources, and proper geological structure. In Figures 6 and 7, the first offered cross-section and the diagram of georadar waves taken from valley D1 with 311 m in width are presented. As it can be seen in the figure 7, the bedrock depth is approximately 17 meters. The approximate 17 m thickness of the alluvium at this location indicates the existence of a large reservoir.

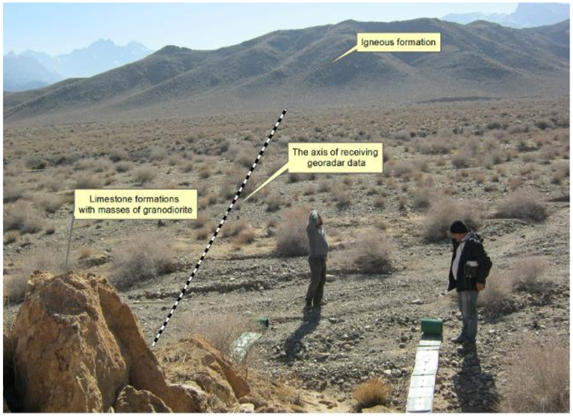

Figure 6. Given axis at location D1 to obtain the georadar data

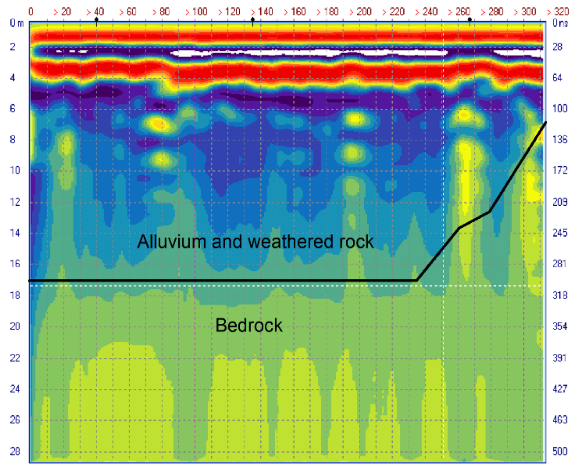

Figure 7. Georadar profile recorded and analyzed by Reflexw at location D1

The river bed in terms of geological materials included coarse alluvium and weathered rocks. Due to porosity, weathered rocks have alluvial conditions and can act as the reservoir, so they were considered as alluvium in all locations. Geological conditions at locations D2 and D3 were similar to location D1.

At location D2, there was a seasonal river flowing from an igneous valley (Figure 8). According to the georadar results obtained at this location, the bedrock depth was about 6 m, and the alluvium was composed of sandstone, gravel, and weathered igneous rocks (Figure 9).

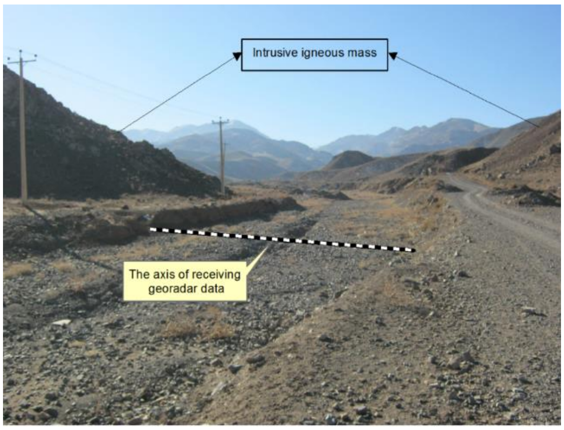

Figure 8. Given axis at location D2 to obtain georadar data

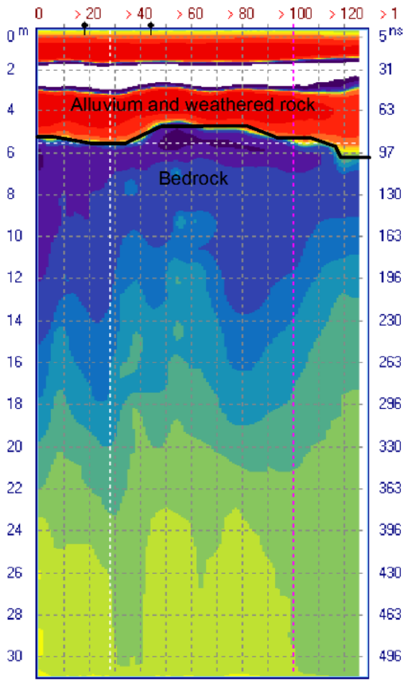

Figure 9. Georadar profile recorded and analyzed by Reflexw at location D2

D3 is located downstream of the alluvium. The bedrock depth was high, and the alluvium consisted of sandstone, conglomerate, and marl. One of the disadvantages of subsurface dam construction in this location is that there is no suitable place for locating the subsurface dam wall. However, one justification for finding this location is the presence of layers with evaporated rocks, gypsy, and marl formations downstream to attenuate the extent to which groundwater will be low quality. Figure 10 shows the conditions of location D3. According to the recorded georadar profile (Figure 11), the bedrock depth reaches up to 16 m and the alluvium is made of alternating layers of sandstone, weathered rock, and marl.

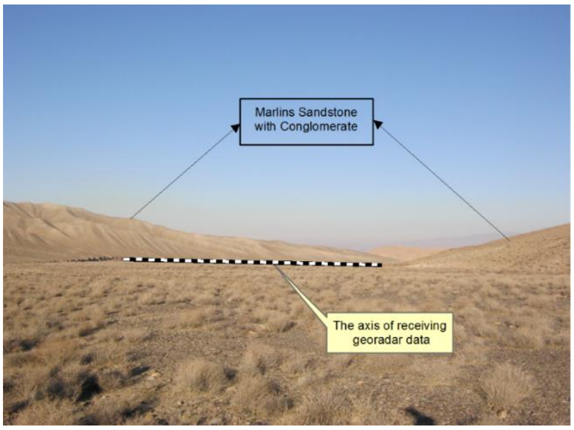

Figure 10. Given axis at location D3 to obtain the georadar data

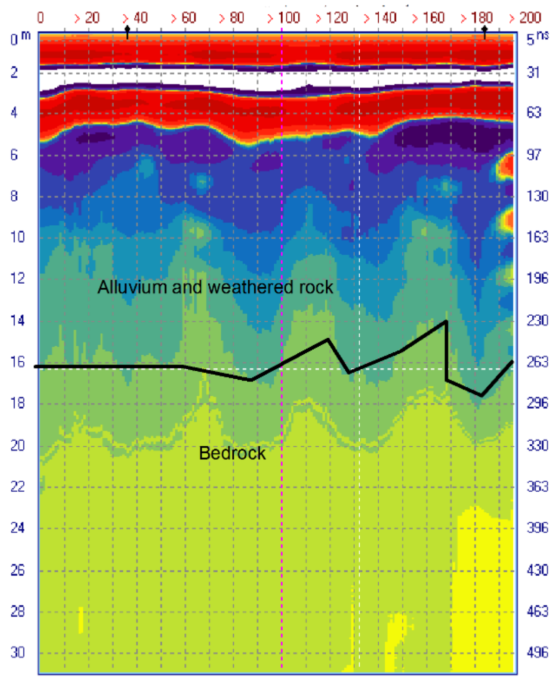

Figure 11. Georadar profile recorded and analyzed by Reflexw at location D3

Considering the hydrological, morphological, and lithological information of the given locations collected by GIS and GPR records, the storage volume and discharge efficiency of the subsurface dam can be estimated. The results of the estimates are summarized in Table 3 [24].

Table 3. Characteristics of identified locations for subsurface dam construction [24]

Identified locations	Design purpose	Alluvium thickness(m)	Cross section length(m)	Upstream area (Km2)	Area with storage capacity (Km2)	Annual Storage (MCM)	Discharge capacity (M.C.M)
D1	Storage	17	311	28.2	6.4	1	4.35
D2	Storage	5	125	72.6	2.02	2.6	0.404
D3	Maintaining water quality	16	196	53.7	18.3	1.93	11.71

4. Conclusion

To identify locations for constructing subsurface dams, information layers from the study area were provided, including topography, slope, lithology, land use, stream density, fault density, and qanat density, which were then digitally introduced into the GIS software. According to the studies, the geological and alluvial fan layers are high on the list of priorities of suitable sites for the construction of a subsurface dam [8, 9] and hence are focused on the current research. Given that the Abouzeidabad plain extends from the Zagros heights (KarKas mountain) to the lowlands leading to the central desert, and due to the presence of the alluvial fans and alluvium, it was found that this region is a suitable place for the construction of subsurface dams by using the topographic layer in addition to the other layers in the study. In other words, the topographic layer is selected as a strategy for increasing the weight of alluvial fans.

In studies based on binary criteria, inappropriate regions are eliminated from the outset. In this study, based on the weighted overlay method, all locations are scored between 1 (inappropriate) and 5 (appropriate), and then during field visits, inappropriate regions are eliminated. This method is more flexible in selecting suitable sites for subsurface dam construction in regions with a combination of appropriate and inappropriate geological formations and qanat.

Among the identified locations, D1 to D2 had suitable geological conditions for building subsurface dams. Location D1 with a bedrock and stone wall suitable for the subsurface dam construction had an approximate upstream alluvium to bedrock depth of 17 m, providing adequate water storage. According to a 1:100000 of Natanz, about 6.4 km^2 of the area upstream of D1 is covered by sandstone and conglomerate and the catchment area upstream of D1 equals 28.2 km^2. Given the average annual rainfall and penetration and alluvium of this area, a subsurface dam constructed in location D1 is capable of about 1 million cubic meters of water storage per year and 4.35 million cubic meters of water discharge, which is considerable for supplying the water demands of downstream regions including Badroud and Abouzeidabad.

Location D3 has been identified for a different purpose. As mentioned in the study, the subsurface dam can be used to prevent the degradation of available water resources [3]. According to the lithology map, the Nawab anticline is located downstream to this location, and is composed of evaporation rock, gypsum, and marl formations. This causes a decrease in the quality and an increase in the hardness of the water penetrated into the downstream aquifers. Therefore, subsurface dams in this area have been located to redirect subsurface waters and to maintain the quality of inlet waters to the aquifer.

Although the remote sensing and geophysical methods to locate suitable sites for underground dam construction are applied in the present study, it is possible to improve these methods in future studies. The present study not only confirms the implementation of a subsurface dam in the part of central Iranian plains but also represents a new strategy to meet the water demands of the area using the existing alluvial potential. The proposed strategy is very cost-effective concerning the problems regarding the cost of projects of water conveyance and deep water well drillings.

REFERENCES

[1]. Ross, A. (2018). Speeding the transition towards integrated groundwater and surface water management in Australia. Journal of hydrology, 567: e1-e10.

[2]. Stevanović, Z. (2016). Damming underground flow to enhance recharge of karst aquifers in the arid and semi-arid worlds. International Journal of Engineering Research and Development, 12: 59-69.

[3]. Ru, Y., Jinno, K., Hosokawa, T. and Nakagawa, K. (2001). Study of effect of subsurface dam in

coastal seawater intrusion. First international conference on saltwater intrusion and coastal aquifers monitoring, modeling, and management. Essaouira, Morocco, 23-25 April.

[4]. Abdoulhalik, A. and Ahmed, A.A., (2017). How does layered heterogeneity affect the ability of subsurface dams to clean up coastal aquifers contaminated with seawater intrusion. Journal of hydrology, 553: 708-721.

[5]. Salmanpor, A., Abrishami, j. and Tabatabayi Yazdi, j. (2009). Investigate the idea of modifying the qanat using underground dam. Eighth hydraulic conference of Iran, Faculty of engineering, University of tehran, 15-17 December.

[6]. Eshghizadeh, M. and Noura, N. (2010). Determine the proper location of underground dam on qanat (Case study: Qanat dahan chenar, Kalat Gonabad watershed). Journal of water and soil conservation, 17(3): 45-64.

[7]. Vanrompay, L. (2003). Report on the technical evaluation and impact assessment of subsurface dams (SSDs). TLDP technical report 14.

[8]. Laa, A., Kampanart, M. and Kriengsak, S. (2005). Approachability of subsurface dams in the northeast Thailand. International conference on geology, Geo technology and mineral resources of Indochina (GEOINDO 2005), Khon Kaen, Thailand. 28-30 November, 149-155.

[9]. Rainwater Harvesting Implementation Network (RAIN). (2008). A practical guide to sand dam implementation, water supply through local structures as adaptation to climate change. RAIN Foundation, Amsterdam, 39p.

[10]. Foster, S., Azevedo, G., and Baltar, A. (2002). Subsurface dams to augment groundwater storage in basement terrain for human subsistence: Brazilian experience. Universidad federal, 82: 49-56.

[11]. Jamali, I.A., Mörtberg, U., Olofsson, B. and Shafique, M., (2014). A spatial multi-criteria analysis approach for locating suitable sites for construction of subsurface dams in northern pakistan. Water resource management, 28: 5157–5174.

[12]. Jamali, I.A., Olofsson, B. and Mörtberg, U. (2013). Locating suitable sites for the construction of subsurface dams using GIS. Environmental earth sciences, 70(6): 2511–2525.

[13]. Forzieri, G., Gardenti, M., Caparrini, F. and Castelli, F. (2008). A methodology for the pre-selection of suitable sites for surface and underground small dams in arid areas (case study: in the region of Kidal, Mali). Physics and chemistry of the earth, 33: 74-85.

[14]. Gomes, J.L.D.S., Vieira, F.P. and Hamza, V.M., (2018). Use of electrical resistivity tomography in selection of sites for underground dams in a semiarid region in southeastern Brazil. Groundwater for sustainable development, 7: 232-238.

[15]. Davis, J. L. & Annan, A. P. (1989). Ground-Penetrating Radar for high-resolution mapping of soil and rock stratigraphy. Geophysical prospecting, 37(5). 531-551.

[16]. Van Overmeeren, R. A. (1994). Georadar for hydrogeology. First break, 12(8). 401-408.

[17]. Ulriksen, P. (1982). Application of impulse radar to civil engineering. Ph.D. thesis, Lund university of technology, Sweden, Published by geophysical survey system Inc, Hudson, New Hampshire, USA.

[18]. Hanninen, P. (1992). Application of ground penetrating radar techniques to peatland investigations. Procceding of the fourth international conference on ground penetrating radar, Rovaniemi, Finland, Geological survey of finland, Special paper 16, 217-221.

[19]. Saarenketa, T., Hietala, K. & Salmi, R. (1992). GPR applications in geotechnical investigations of peat for road survey purposes. Proceeding fourth international conference on ground penetrating radar, Rovaniemi, Finland, Geological survey of finland, special paper 16, 293-305.

[20]. Lin, M., C., Kang, Y., M., Lee, K., F. and Hsu, H.C. (2009). A study on the technologies for detecting underground water level and processing image. International journal of applied science and engineering, 7(1): 61-68.

[21]. Lima, A.D.O., Lima-Filho, F.P., Dlas, N.D.S., Junior, J.A.D.R. and Sousa, A.D.M. (2017). GPR 3D profile of the adequateness of underground dams in a sub-watershed of the Brazilian Semiarid. Rev. Caatinga, Mossoró, 31(2): 523-531

[22]. Saaty, T.L. (1994). How to make a decision: The analytical hierarchy process. Interfaces, 24(6): 19-43.

[23]. Nilsson, A. (1988). Groundwater dams for small-scale water supply. Intermediate technology publications, London, 69 p.

[24]. Ilyati, I. (2013). Feasibility of constructing an underground dam using remote sensing and geophysical methods (Case study: Kashan plane). Master's thesis, Faculty of engineering department of civil engineering, Yazd University.