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The Role of Geomorphology in Locating Underground Sandy Dams (Case Study: Gilan-e-Gharb)

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Abstract

The use of temporary runoff and underground dried-up water courses has been implemented by managers in recent years to compensate for water shortages in arid and semi-arid regions. One way to use this water is to set up an underground sandy dam in front of such water courses; selecting a suitable water course is the most important issue of such a purpose. In the present research, this matter was investigated using both library and field work methods during three stages in a part of the Gilan-e-Gharb basin. The following 11 variables were considered: lithology, structure, fault direction, length of water course, slope of water course, grade of water course, valley shape, granular of sediment, thickness of sediment, lithology of valley bed, and distance from habitation. First, 15 valleys were selected from aerial stereoscopic photos of 1:55000 over the hillsides dominating the plains of Gilan-e-Gharb; the variables considered were lithology, structure, fault direction, length of valley, slope of valley, and distance from habitation. Then, these 15 valleys were investigated through field study and paired comparison matrices considering the 5 factors of valley shape, granularity of sediment, thickness of sediment, lithology of valley bed, and grade of water course. As a result, 3 valleys over the hillsides of Mount Bar-e-Aftab were selected as suitable sites for the current study. The total reservoir volume for these 3 valleys was estimated by measuring the water volume of 1 cubic meter of sediment in a practicable and scientific method. Upon completion of an underground sandy dam project, between 2475 to 2563 cubic meters of water could be stored in each valley.

Key words: Geomorphology; Underground Sandy Dam; Locating;Gilan-e-Gharb

1. Introduction

Water storage procedures have always been considered major inconveniences by the inhabitants of arid and semi-arid regions, because life in these areas depends strongly on regional precipitation. What is more, a considerable portion of the each rainfall is rendered useless in different ways (Taleghani, 2010). For example, in the occurrence of a rain shower - which is the typical type of precipitation over these regions - water waste and the occurrence of flood are unavoidable. If topographical and geological conditions are suitable, part of the water infiltrates the ground through fissures in the stone bed and joins underground water resources. Water that has penetrated the earth's surface is primarily considered wasted water by the residents of the mountainous regions and hillside districts in this area, because the underground aquifers are mostly located in the plains bed, and funds and techniques are required to access this water for human use. The underground sandy dam is a modern procedure which would allow this water

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to be accessed for use (Telmer and Best, 2004; Nilsson, 2003). The first issue in setting up an underground dam is to identify a valley whose bed is composed of alluvial silt. Moreover, the bedrock should be impermeable to prevent the water from escaping. Other important factors to consider when determining where to build an underground sandy dam are the reservoir volume which depends on the valley size, the existence of enough water in the valley which depends on the area of the drainage basin and the volume of precipitation, the efficiency rate of the dam over a long period of time, ease of access, and the quality of water (Hansen and Nilsson, 1986). Thus, all overlying variables must be considered in order for the project to run successfully. In this research, therefore, the above factors were considered and geomorphologic studies were used in an attempt to select a suitable place(s) to build an underground sandy dam in the Gilan-e-Gharb basin in order to compensate in part for the shortage of drinkable water the residents of villages in this region face.

Even though the history of underground sandy dams goes back to the distant past, this subject has just recently caught the attention of Iranian researchers, because accurate locating has only recently been achieved through the use of GIS. Much has been published in the past decade about underground dams and the efficient techniques and variables involved in identifying a suitable dam location. Some articles include: Maghrebi (2005); Mokhtari (2008); Baghdadi (2008); Salami & Naseri (2006); Saleh Pour (2010); Omrani (2007); and Kheirkhah *et al.* (2008). It should be pointed out that, in addition to Esfahan's Meimeh Dam, Iran's first underground dam, underground dams are also in operation in Kahnooj and Shahdad in the province of Kerman as well as Kharanegh in Ardakan. Research on underground sandy dams does not have a rich background on the global stage. In fact, scientific research into sandy dams just began in the second half of the twentieth century, though much progress has been made over the past three decades. Attention can be drawn to the geological research work of Skibitzke *et al*. (1961), Matsuo's (1975) report on operating a dam at a depth of 10 to 25 meters on the Japanese island of Kabashiam, and Baghdadi's (2008) report on the research of Larsen *et al.* (1980) regarding the volume capacity of reservoirs of underground dams. The central office of India's successful progress in locating and setting up several underground dams in the region of Kerala brought the subject of underground dams to the attention of other regions. As a result, sandy dams have been applied in Namibia, Tanzania, Arizona, China, and United Arab Emirates (Baghdadi, 2008).

2. Material and methods

2.1. Study area

The region under study in the current research extended between 34^{o}N to 34^{o} 15$^{'}$N and 45^{o} 45$^{'}$E to 46^{o}E. The runoff is drainage of the Cheleh River and flows towards the Alvand River. Structurally, the basin of Gilan-e-Gharb is composed of a synclinal plain surrounded on both sides by two long ranges of fold mountains and is spread out in a southeastern–northwestern direction (Fig. 1). The thrust of Gilan-e-Gharb is considered the most significant structure in controlling the region's morphology because of the form of the folds, like Mount Sarkesh with its hogback structure, and the fact that it lies in the same direction as the active faults (Yamani et al., 2010). Therefore, the folding system in Gilan-e-Gharb is taken into account from those types of the flexure fault similar to most folded regions of Zagros (Kolmansad, 1978). The surface of anticlines and hogbacks are covered with Asmari limestone, such as Mount Sirvan and Mount Bar-e-Aftab. Shahbazan dolomite, Gorpi formations (marl and shale), and Pabdeh formations are other stones in the folds' structure.

The Gachsaran formation deposits and the emergence of sandstone and marl in the Aghajari formation have constructed the foothills in the space separating the adjacent mounts of the Gilan-e-Gharb plain. The Gilan-e-Gharb plain is covered with quaternary deposits 90 meters thick in the center of the plain. Naturally, the thickness of deposits decreases towards the edge of the plain to a depth of 6 meters in the sub-mount districts (Advisor engineers of force water, 1991). Despite receiving 372mm of precipitation annually, the runoff in the Gilan-e-Gharb basin is considered the dominant dynamic over the region now as in the past. The erosion over the surface of the folds resulted in the formation of some dependent landforms, including water gaps (clus), anticlinal-valleys (ruz), alluvial fans, hogbacks, and combs (Fig. 2).

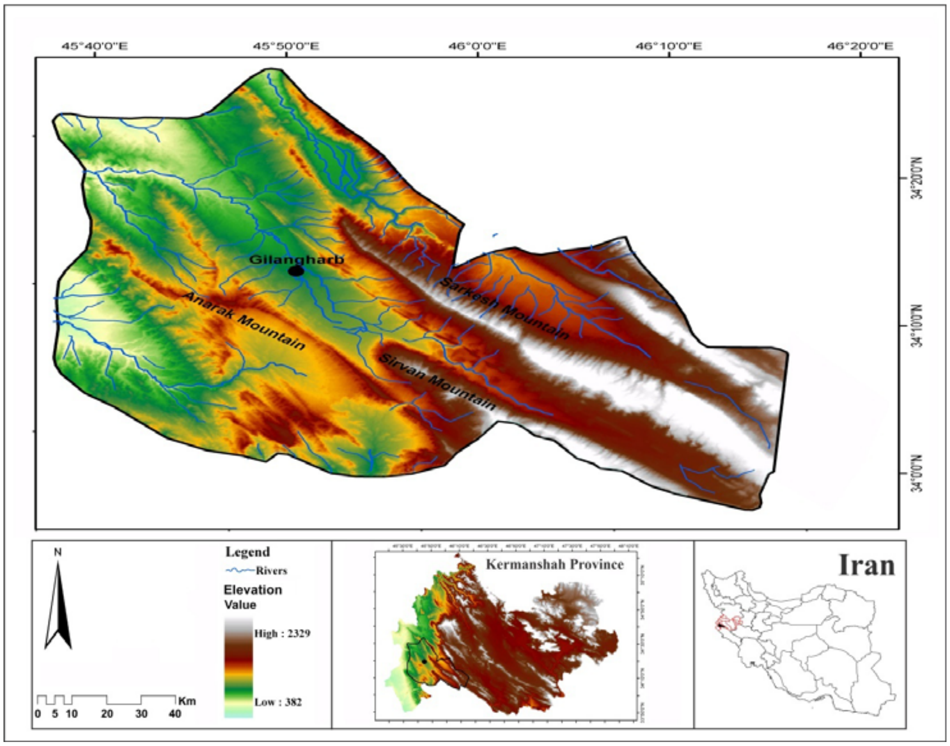

Fig. 1. The topographic map for the region of Gilan-e-Gharb

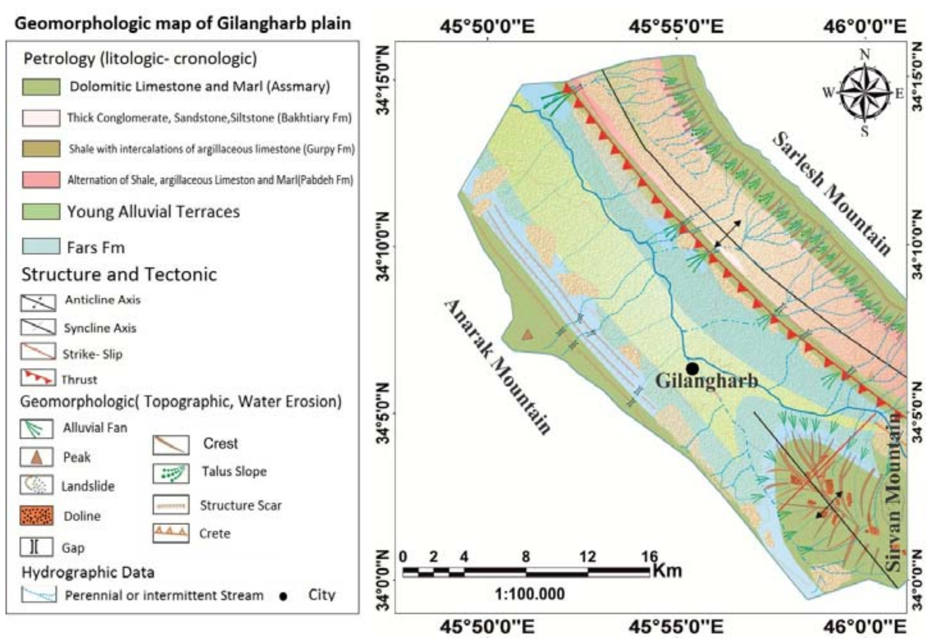

Fig. 2. The geomorphologic map for the region of Gilan-e-Gharb

3. Methodology

This research was carried out using both library and field work methods. It was done in three stages in order to achieve the best results. In the first stage, 15 valleys on the mountainous hillsides of Gilan-e-Gharb plain were identified by aerial stereoscopic photos of 1:55000 while considering 6 variables: lithology, structure, length of valley, fault direction, distance from habitation, and degree of the valley bed slope. In the second stage, the 15 selected valleys were investigated based on field work and the characteristics of 5 variables: grade of valley, form of valley, texture of sediment, thickness of sediment, and lithology of bedrock. The data obtained through this method were used to create a matrix with which a paired comparison of the 15 first stage valleys was performed. Based on the results, 3 valleys were selected as the best sites in the study area to construct underground sandy dams. Finally, an attempt was made to empirically measure the water volume of 1 cubic meter of deposit (one sample per valley) in order to estimate the reservoir volume of these 3 places. The results will be discussed subsequently. The wooden index in 1 meter square size and through a random method (2 samples per valley) was used to measure the texture of alluvium. To measure its thickness, it has been used of a excavation hollow in the valley and/or a lever index to pierce within the alluvium. The sizes of the valleys were evaluated by simple meter in order to estimate the volume of the reserved reservoir. The form and lithology of the valley beds were determined through field observation. Other data were also acquired from a topographic map of 1:50000, a geologic map of 1:250000, aerial photos of 1:55000 and the 30-year precipitation records from the Gilan-e-Gharb station.

4. Theoretical Principle of the Research

An underground dam is described as a barrier and/or any kind of obstacle constructed in order to control the sub-surface currents inside the alluvium of valleys (Nilsson, 2003; Baghdadi, 2008; Mokhtari, 2008). These barriers are usually built inside a ditch and buried throughout the width of the valley to block the underground water course. The ditch is excavated inside the alluvium, and the dam wall is put down on the stone bed. Therefore, the underground dams store the water underground. For semi-buried dams, the wall is constructed a few meters above the valley's bed to block flood waters as well. Semi-buried dams not only control flood waters, but also play a significant role in filtering deposits from the current and in the volume of the sub-surface reservoir by making the surface a suspended reservoir (Ishida *et al.*, 2003; Kankam *et al.*, 2003; Sayadi *et al.*, 2006). Underground dams can be constructed with cement, plastic sheets, gabion, stone, and clay, but sandy dams with clay cores are more prevalent (Maghrebi, 2008). According to the researcher's statement, underground sandy dams are only applicable to valleys located in arid and semi-arid regions. In the gateway of the valley, an alluvial fan should have developed. The slope of the ground must be less than 5% to acquire a greater reservoir. The bedrock of the valley should be impermeable to prevent the water from escaping. The thickness of the alluvium ought to be enough as the reservoir of the underground sandy dams located in the alluvium in order to prevent the evaporation and contamination. The alluvium should be coarse grain (gravel and sand) so that the water simply infiltrates it. The drainage basin above the valley should be enough big to provide enough water. It should be located at the nearest possible distance from habitation. Human activities should not contaminate it. The geologic formations of the relevant basin should not make it saline. The valley should not be situated along fracture lines and faults, and the lithologic formations of the valley's edges should not consist of fissures or cracks which would allow the water to escape from the reservoir. Finally, the form of valley should be such that allows for a suitable reservoir in which to store the water (Salajegheh *et al.*, 2010; Sharafatmandrad *et al.*, 2010). In the current research, an attempt was made to select an appropriate place(s) which comprises the above-listed conditions based on the geomorphologic variables and features for the purpose of building a sandy dam in the Gilan-e-Gharb basin.

5. Research Results Analysis

Based on the results obtained from all 6 variables in the first stage and the 5 variables of the second stage, 3 valleys were selected as sites for underground sandy dams in the Gilan-e-Gharb basin and numbered 13, 14, and 15 (Fig. 3). Although all of the variables considered, other than distance from habitation, were geomorphologic variables, other factors that played important roles in the final selection of relevant valleys in the Gilan-e-Gharb basin were 5 distinguished variables in the geomorphologic studies, i.e. form of valley, lithology of bedrock, grade of valley, texture of sediment, and thickness of sediment. These factors were considered the index components of site location as well. Therefore, the geomorphologic characteristics of these 5 components were analyzed. The statistical information for these 5 components is presented in Table (1). The distribution of the selected valleys is shown in Fig. (3).

5.1. Grade of valley

Each valley has its own catchment. The total surface runoff caused by precipitation is drained into the valley through gullies and discharged from the mountainous basin. Major flooding will undoubtedly occur if more gullies exist. The great floods not only play a positive role in locating underground sandy dams, but are also very important to deposit production. Therefore, if all other criteria are stable, the higher the grade of the valley is, the more extensive its catchment will be. Those valleys that possessed the highest ranking were used in this study. To rank each valley, the river ranking method based on Straler procedures was used, in which a higher ranked gully is obtained by joining two gullies of the same weight (Straler, 1988). In the current research, the grade of the main valley reached 4 in merely 8 of the 15 valleys selected during the first stage, such as valleys 13, 14, and 15.

5.2. Valley Morphology

Those valleys that are uniform in shape lengthwise and have a small entrance are suitable for construction of underground sandy dams (Nilsson, 2003). In valleys with a wide-open entrance, more materials are required to build the dams' walls, and in valleys that vary in their profiles, a suitable reservoir volume cannot be obtained. Indexes show that U-shaped valleys are much more appropriate for such purposes. The results of the field work showed that 6 of the 15 valleys selected in the first stage have U-shaped landscapes, such as valleys number 13, 14, and 15.

Table 1. Characteristics of the selected valleys for underground dam's construction

Valley NO.	Name of Valley	Form of Valley	Rank of Gully	Bed Lithology	Alluvium Texture	Alluvium Thickness	Water volume of 1 cubic meter deposit
1	Miandar 1	V	4	Marl	Coarse Fragment with Clay mixture	2.40	
2	Miandar 2	V	3	Marl	Coarse Fragment with Clay mixture	2.15	
3	Miandar 3	V	3	Marl	Coarse Fragment with Clay mixture	1.80	
4	Miandar 4	V	3	Marl	Coarse Fragment with Clay mixture	1.50	
5	Najaf	V	4	Marl	Coarse Fragment with Clay mixture	2.10	
6	Tarshkiban	U	3	Marl	Coarse Fragment Sand with Clay mixture	4.5	
7	Ghoba Sia	V	4	Marl	Coarse Fragment Sand with Clay mixture	3.1	
8	Saleh	V	2	Marl	Coarse Fragment Sand with Clay mixture	2.10	
9	Gorsefid	U	3	Marl	Sand and Clay along with gravel and pebble	4.30	
10	Poshteh Gorazan3	U	3	Lime	Coarse Fragment pebble and gravel	4	
11	Poshteh Gorazan2	V	4	Lime	Coarse Fragment pebble and gravel	4.4	
12	Poshteh Gorazan1	V	4	Lime	Coarse Fragment pebble and gravel	4.40	
13	Poshteh Hajian 1	U	4	Dolomite	pebble and gravel along with Cobble	4.30	70
14	Poshteh Hajian 2	U	4	Dolomite	pebble and gravel along with Cobble	5	72
15	Poshteh Hajian 3	U	4	Dolomite	pebble and gravel along with Cobble	4.9	71

5.3. Valley Bedrock

Most of the valleys selected in the first stage of this research possess the required valley bedrock conditions to construct an underground dam, because their beds have been built of either marl or dolomite. Although the anticline surfaces are covered with Asmari limestone, marl and/or dolomite have emerged due to such stones being placed over the Shahbazan and Gorpi formations in 12 bed of the valley. The Shahbazan dolomite in the Gilan-e-Gharb basin is relatively sugar grained and milky coloured. It is very solid with little permeability (adviser engineers of force water, 1991). In addition to the relevant valley beds, the valley walls are also Shahbazan dolomite approximately 4 meters thick. Thus, the lithologic and morphologic features of the three selected valleys possess the capacity to support semi-buried dam walls.

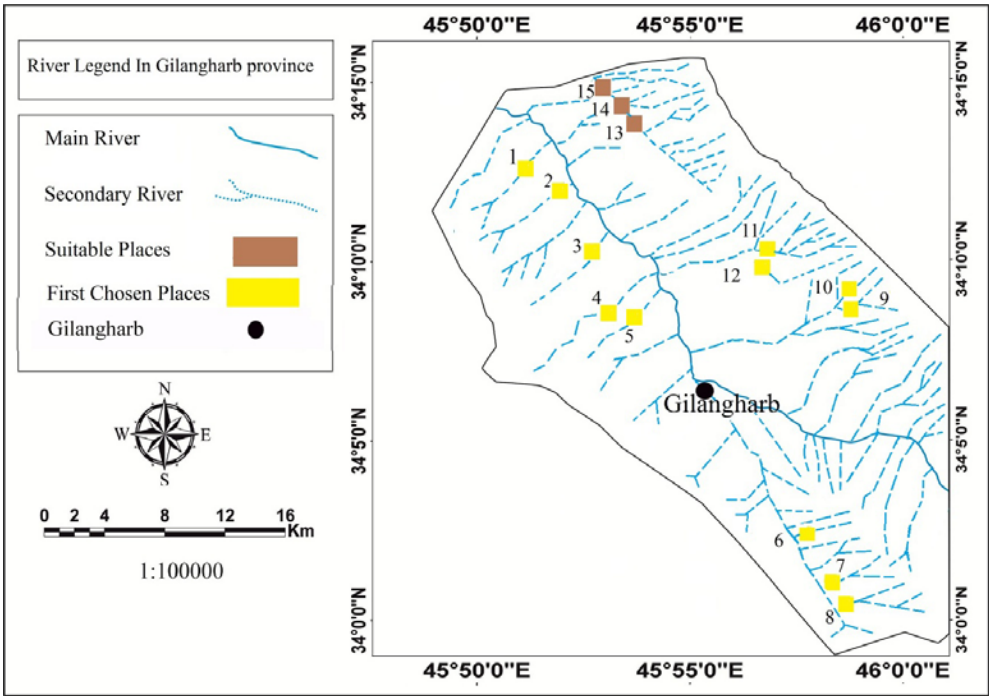

Fig. 3. The distribution map of 15 selected places to construct underground dam in the region of Gilan-e-Gharb

5.4. Texture of Sediments

The researchers believe that coarse fragment sediments like gravel and pebble are appropriate locations for sandy dams as the pore of coarser deposits are bigger. Investigations performed by sampling (random method, two samples for each valley) through 1 cubic meter index has confirmed the texture of sediments in 6 valleys (Table 1). These valleys are filled with gravel, limestone, and dolomite sand. These materials are angled because they pass a short distance, and the percentage of grains that are smaller than sand is low among them.

5.5. Sediment Thickness

Valleys that possess more sediment prove to be better sites for the construction of such dams, because the reservoirs of the underground dams will be set up inside the alluvial deposits of the bed or at the valley's entrance (in case of being analogous of other criteria). The thickness of sediment at the entrance of some valleys was less than 3 meters. Based on these criteria, only 8 valleys possess the required conditions. In the proposed valleys, the thickness of sediment measured between 4 and 5 meters.

5.6. Water Volume of One Cubic Meter of Sediment

To estimate this criterion, first a column of alluvium was created measuring one meter in height 25*25 in area and covered with plastic on all sides. Then, water was added by cup until the column became saturated. The volume of added water was multiplied by the number 176 and considered the water volume of 1 cubic meter sediment. The water volume of 1 cubic meter of sediment in the above-mentioned valleys measured 70 liters for valley 13, 72 liters for valley 14, and 71 liters for valley 15.

6. Discussion and Conclusion

Many valleys in the Gilan-e-Gharb basin similar to other sections of Zagros have cut up the side of folds. These types of valleys are known in geomorphology as anticlinal valleys or ruz (Mahmoodi, 1995). The most classic type of these valleys is found in anticlines that are covered with layers of Asmari limestone. In such conditions, sometimes water has cut its bed among the limestone layers and has made valleys in the form of canyons (Alaee Taleghani, 2002). These types of valleys are usually U-shaped, and their beds are wide and covered with coarse-grain alluvium. The current research showed that such valleys that have not been settled along a fault and have stone beds that are impermeable or have little permeability- in case of availability of other criteria - are suitable locations in which to construct underground sandy dams. The results of this study - which have been controlled and completed through field work - have identified only 3 valleys for such purposes in the Gilan-e-Gharb basin. These valleys (numbers 13, 14, and 15 in Fig. 3) have cut the internal side of the Mount Bar-e-Aftab, which has a limestone construction, and have reached the dolomite stone bed (Shahbazan formation). Dolomite, an impermeable stone, is exposed up to 4 meters from the edge of the relevant valleys in addition to their beds. The Gilan-e-Gharb basin is tectonically active, and so many valleys have been fissured and/or shifted there by the thrust fault of Gilan-e-Gharb (Yamani, 2010). Nevertheless, the three valleys selected for this research have been saved from such negative effects. The grade of the main gully in these valleys measures 4 at the entrance, which represents progress in its watercourse in order to develop a catchment for the valleys. Meanwhile, the bed, with a U–shaped section, is covered with pebble and gravel. This feature is maintained throughout most of the length of the valley (between 400 and 500 meters). The width of the valley at the entrance point of valley number 13 is around 12 meters, of valley number 14 is approximately 10.5 meters, and of valley number 15 is about 8 meters. The appearance of these valleys is dry, and floods only pass through during torrential rainfall. In other cases, the rainwater easily penetrates the cracks and fissures existing in the limestone, making sub-surface currents in the alluvium bed of the valleys which is recognized as a feature of dried-up rivers in arid and semi-arid regions (Trikar, 1990). During the rainy season, sub-surface currents come out as temporary springs after exiting these valleys (Parvin, 2003). If underground dams are constructed, this water will be stored within the alluvium. Such characteristics, along with their being distant from any source of contamination and easily accessible by the adjacent valleys, have made the studied valleys quite suitable for the construction of such projects. Based on the volume of sediments, the total volume of water that can be stored in these places – if dams (buried type) are constructed – equals 2563 cubic meters for valley 13, 2560 cubic meters for valley 14, and 2475 cubic meters for valley 15. In cases where semi-buried underground sandy dams are built, a reservoir with an almost doubled capacity will be obtained. It would be useful to construct underground dams in such places to supply drinking water to the inhabitants of surrounding villages. The distance of said dams, in case of construction, from the nearest village for valley number 13 will be approximately 130 meters, about 280 meters for valley number 14, and around 320 meters for valley number 15.

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