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Qualifying the geotechnical and hydrological characteristic of the Bandawaya stream valley – Northern Iraq

Key words: geotechnical characteristics, hydrology, Bandawaya, dam, stream valley, Northern Iraq

Introduction

Hydrological systems are critically important for maintaining vital water supplies, which alarmingly deplete every day. Suitable structures are necessary to maintain permanent or seasonal vapor surface runoff or basic flow. This water is used for improving soil moisture availability, recharge the groundwater, circumvent extreme runoff, and assistance in flood control in the inferior catchment. Such structures are responsive, depending on these parameters, to variations in geotechnical and hydrological parameters through the intact rock properties, discontinuities features, location, slopes of land, type of soil, rainfall and land cover.

Bandawaya village is about 40 km northwest city of Mosul, beside the village a permanently flowing stream, the stream formed from Duhok mountain in the north passing the village and later pouring in Mosul dam reservoir, as shown in Figure 1. The good amount of water flowing in the stream is from runoff in the rainy season and/or from springs in even dry season (summer), as shown in Figure 2A. At the middle length of this stream the cross-section of the valley is contracted at the plunges of Alquosh and Dahkan anticlines. This contraction is the study area, and looks a good place for dam construction from the first view.

Geomorphologically, the region of the meandering stream valley generally extends from north to south. The high of the west bank is approximately 120 m, and the east bank is approximately 80 m (Fig. 2B).

The topographical, hydrological, and geological parameters should be well given in the advancement of site selection for the performance of the dam safety guarantee. The seven sections of the

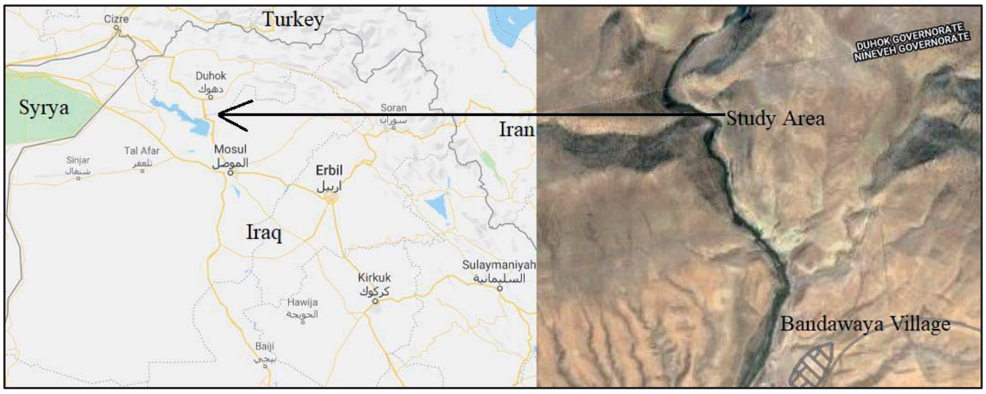

FIGURE 1. The location of the study area with the stream spilling in Mosul dam reservoir

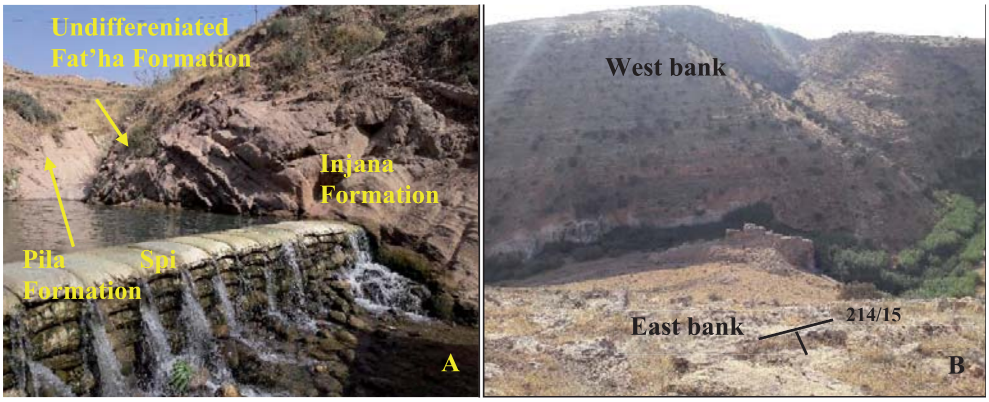

FIGURE 2. Bandawaya stream valley: A – water quantity in the summer season (photo by Azealdeen Al-Jawadi, 03.08.2018); B – view of proposed site dam

code of practice will be applied to the qualification of the site (BS 5930, 2009). These sections include primary factors, ground studies, field observations, laboratory experiments, soil and rock descriptions, reports, and interpretations (BS 5930, 2009). Khan (1992) explained that small barriers are built over existing rivers for the processing and storage of the rivers from the catchment. In the 1992 environmental restoration of degrade areas, the 13.5-meter high earthen dam installed in the undulating region of the Relmajra village – the Nawashahar District was studied, with a potential for introducing a region of approximately 25 ha of additional irrigation to that dam (Samra, Bansal, Sikka, Mittal & Agnihotri, 1995).

The objective of this study is to qualify and evaluate the geotechnical and hydrological characteristics of the Bandawaya stream valley, since water behind this dam can be restricted and used in agriculture and energy production. Furthermore, aimed to conserve the excellent water quality and good quantity in this valley and not allowed it to spill into Mosul dam reservoir, the access to the goal is constructing a dam in the gorge of Bandawaya.

Geological setting

The study area is the gorge of Bandawaya in a stream valley between the two plunges; western Alquosh anticline and eastern Dahkan anticline (Fig. 3). Single plunge anticlines are both Alquosh and Dahkan. For Pila Spi Formation (Middle--Upper Eocene), the lithology of limestone, dolomitic limestone, or dolomite is dominant for the stream valley and sometimes for the formations Fat'ha (Middle Miocene) and Injana (Upper Miocene), marl, sandstone, and claystone (Jassim & Goff, 2006). Slope deposits are mildly cemented; rock fragments, sand, and silt, surround both anticlines and create deposits in the valley (Fig. 3). Structurally, a horizontal bed plane parallel to the mainstream valley trend represents the bedding strike, and beds dipping from 10 to 15° to the east bank (Fig. 2). Tectonically, the study area is located in the Mosul High of Chemchemal – Butmah sub-zone within the Low Folded Zone that comprises of a wide, low amplitude, gentle folding series (Fouad, 2015). Tectonically, in the Mosul High sub-zone of Chemchemal – Butmah, in the Low Folded Zone, the study area is comprised of a wide, low amplitude, gentle folding range.

Methodology

Geotechnical studies

The field geotechnical study is including define rock type, strength, and weathering, discontinuity attitude, persistence, spacing, openness, filling materials, and ends. For the protection of dams and the stability of the area around the dam and reservoir, geological documentation is important (Szafarczyk, 2019). Rock types vary between limestone, dolomitic limestone, dolomite, and somewhere marly limestone. The uniaxial compressive strength is estimated by using Schmidt hammer type N, which be better than L type to determine the strength based on weathering grade (Basu, Celestino & Bortolucci, 2009). Weathering classifies into five categories, from micro fresh state to completely decomposed state (ISRM, 1980; Williamson & Kuhn, 1988; Hoek & Bray, 2005; Basu et al., 2009; BS 5930, 2009; Cabria, 2015). Numerous weathering and weathering indices have been

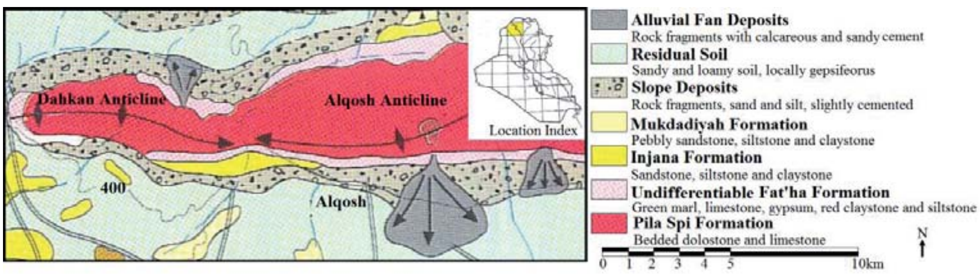

FIGURE 3. Geological map of the study area (Sissakian & Fouad, 2015)

developed for quantifying the consequence of weathering for engineering properties of rocks. The geotechnical investigation for discontinuities is comprising discontinuity attitude that scaled by Silva compass for bedding planes, major two systematic sets of joints, and a random set of joints. Persistence, spacing, and openness are measured by scale tape for each set of discontinuities. Due to the importance of filling materials, they are classified into stronger and weaker than host rock; their types are clay, soil, rock fragments, and calcite. Finally, the ends of discontinuities are not visible unless at the boundaries of outcrop that covered by soil. Consequently, geotechnical parameters have been selected in detail for the proposed site of the dam. These previous parameters help the engineers to evaluate the rock mass according to the most of classification systems such as Q-System, rock mass rating (RMR), geological strength index (GSI), and rock mass index (RMi).

Hydrological studies

The methodology proposed is based on site selection criteria. The favorate site for any dam is a position where a wide valley with high walls lead to a small canyon, with stubborn walls, which leads to a reduction of earthwork and cost. The location is prepared through visual interpretation of satellite images (LANDSAT 8, 2013) data. Digital elevation model (DEM) has been prepared based on the Shuttle Radar Topography Mission (SRTM) with 30-meter resolution data from the United States Geological Survey (USGS). The DEM data is used for extracting the watershed boundary. The delineation of the watershed boundary, catchment area, generating slope drainage pattern and stream ordering based on Strahler method, etc. all were carried out using Arc Gis Ver. 10 software. The morphological and areal data prepared from the Watershed Modeling System (WMS) Ver. 7.1 software. Depending on the data available length and height of the proposed dam were determined. Also area of the reservoir, the volume of storage verse fixed interval elevation at specific dam height was determined. The shape of the reservoir formed upstream the proposed dam carried out by Global Mapper Ver. 13 software.

Results and discussion

Geotechnical results

Since the rocks in the study area carbonate, so the strength is forecasting high. The uniaxial compressive strength of these rocks is ranged between 49 and 103 MPa that classified strong in general (Hoek, Marinos & Benissi, 1998; Marinos & Hoek, 2000). The higher compressive strength rocks; more than 65 MPa are cited in grade fresh and slightly weathered, while the others classified as moderately to highly weathered (Table 1). There are good relations between the strength and degree of weathering (Basu et al., 2009). For any engineering project, discontinuity characteristics are an important geotechnical investigation. Spacing and orientation are reflecting the block size and shape. In the study area, the block size ranges 0.5–5.25 and the shape is regular, i.e. cubic and orthogonal. These characteristics are reflecting a good rock quality designation (RQD) that is very good for dam sites; it is forecast permeability and shear strength (Rastegarnia et al., 2019). Values of RQD are calculated from the volumetric joints count (J_v) values (Palmstrom, 1982). Using of modified blockiness evaluation method shows that rock mass is classified as slight-blockiness (Chen, Yin & Niu, 2018). The mainly worldwide classification systems used are Q-System, RMR, GSI, and RMi, which are published by Barton, Lien and Lunde (1974), Bieniawski (1989), Palmstrom (1995), and Marinos and Hoek (2000). All these systems estimate the rock mass quality quantitatively and estimate the sufficient support of rock mass (Palmstrom, 2009). For various engineering projects, rock mass classification systems have been used to understand the conditions and determine the rock mass quality (Singh & Thakur, 2019). The general classification of the site is good: Q = 35.8, RMR = 69.3, GSI = 71.4, and RMi = 7.3 (Table 1), which means a high value of rock mass compressive strength (σ_{cm}). There are some zones with low thickness classify as fair, these zones can be treat before construction. According to representative elementary volume (REV), the consequence of these small zones to the rock mass characteristics is neglected as the scale of the dam site (Xia, Zheng & Yu, 2016; Wang, 2017). However, the presence of this weak zone and its thickness, which does not exceed 10 cm, may affect the upper rock beds and reduce their strength, as illustrated in Figure 4. Therefore, it is recommended to treat such beds with real treatment before starting any construction work because their impact extends to several meters as shown in zone B in Figure 4. For the Daniel-Johnson dam in Canada, the structural faults, particularly joints, of the rock mass, needed severe attention during the construction of the dam. These surveys used to determine the classification of rock masses to allow the evaluation of the quality of rock mass and the measurement of joint openings. When an RMR

TABLE 1. Geotechnical characteristics of the dam site

Bed	Lithology	Thickness [cm]	Degree of weathering*	Unit weight [kN·m^{-3}]	Estimated UCS** [MPa]	Rock mass classification			
						Q	RMR	GSI	RMi
1	Dol. Lst.	120	III	22.87	56.8	38	73	68	7
2	Dol. Lst.	60	III	23.03	61.7	38	75	69	6
3	Dol. Lst.	40	III	23.41	67.5	39	75	71	7
4	Dol. Lst.	60	II	23.24	77.9	40	75	71	7
5	Dol. Lst.	60	IV	22.53	52.4	34	68	65	8
6	Dol. Lst.	40	IV	22.33	58.0	34	67	62	7
7	Dol. Lst.	40	IV	22.34	58.2	34	68	60	6
8	Dol. Lst.	80	II	22.27	65.3	38	66	62	7
9	Dol. Lst.	70	II	22.26	67.5	38	63	68	8
10	Mar. Lst.	10	III	22.12	50.3	34	62	67	0.8
11	Dol. Lst.	100	IV	23.01	63.5	36	65	70	8
12	Dol. Lst.	100	III	22.89	65.1	35	63	73	9

TABLE 1 cont.

Bed	Lithology	Thickness [cm]	Degree of weath-ering*	Unit weight [kN·m^{-3}]	Estima-ted UCS** [MPa]	Rock mass classification			
						Q	RMR	GSI	RMi
13	Dol. Lst.	60	III	22.76	60.2	38	62	78	8
14	Dol. Lst.	100	I	23.74	71.7	41	70	79	8
15	Dol. Lst.	100	I	23.43	76.1	41	71	82	10
16	Dol. Lst.	60	I	23.91	70.2	40	68	79	7
17	Bre. Lst.	70	IV	21.32	48.7	22	55	54	0.8
18	Dol. Lst.	1 000	II	22.01	68.6	38	66	72	7
19	Dol. Lst.	70	III	22.74	62.8	34	65	73	8
20	Dol. Lst.	70	IV	22.32	62.7	36	65	69	6
21	Dol. Lst.	70	III	22.96	62.9	36	65	63	6
22	Dol. Lst.	70	III	22.31	62.7	36	63	60	5
23	Dol.	200	I	23.89	103.1	43	82	87	15
24	Dol. Lst.	170	I	22.95	72.5	40	81	83	11
25	Dol. Lst.	100	I	22.73	69.7	40	80	81	6
26	Dol.	200	I	23.67	98.6	40	85	83	12
27	Dol.	200	I	23.77	74.7	39	79	81	9
28	Mar. Lst.	150	IV	22.81	58.7	36	64	68	6
Total thickness		3 470	mean	22.84	66.7	35.8	69.3	71.4	7.3

*Classification according to ISRM (1980), Williamson and Kuhn (1988), Hoek and Bray (2005), Basu et al. (2009), BS 5930 (2009), Cabria (2015).
**Estimated from the Schmidt hammer type N.

assessment of the rock mass classification is used, it is possible to suggest certain values for the deformation module of the rock mass (Quirion, 2015). Therefore, good rock mass refers to safe dams.

Hydrological results

For satellite images of the study area a catchment area was used of the proposed dam from the SRTM DEM and the area of interest (AOI). DEM, drainage pattern, satellite image maps of the study shown in Figures 5, 6 and 7. Important linear and arial parameters and features such as basin area, perimeter, basin length, shape factor, sinuosity factor, etc. have been calculated. The drainage patterns of the watershed are dendritic with fourth-order streams. The details of various morphometric parameters in this study are shown in Table 2. With fourth-order flow stream, the water drainage patterns are dendritic. Table 2 displays the descriptions of the different morphometric parameters for this study.

The maximum and minimum elevation in the watershed 1,336; 431 m a.s.l., respectively, and the watershed covers 115.64 km^2. Depending on the site topography and dam height, the accessible

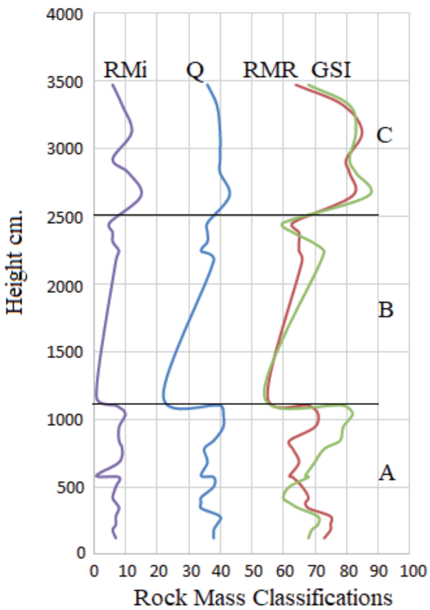

FIGURE 4. Rock mass classification of the proposed dam site

storage capacity of a reservoir depends. At that specific location and the cross--section of the valley, three scenarios were assumed to the dam height 450, 460, 470 m a.s.l., the length of the dam, area of the reservoir upstream the dam, volume of storage at each height are defined as shown in Table 3. These parameters (storage capacity, water spread area at different elevations) are used to generate indexes based on the primary parameters combination. The ratio between the average storage volume (mean *V*) and the mean surface area (mean *A*) at the specific elevation is calculated to determine the index (mean *d*) of the evaporation losses, (0.0104, 0.0107, 0.0089) are the index (mean *d*) at each elevation.

The form of the reservoir, of course, will affect the amount of water lost during the evaporation progression. A narrow and deep reservoir would have slightly less loss of evaporation than a shallow reservoir abroad. The surface area of water and water depth are the major factors associated with the evaporation process. The metrological factors, however, are "e.g. Relative humidity, precipitation density, wind speed and temperature" are mostly the same and have a minor impact. Therefore, in the

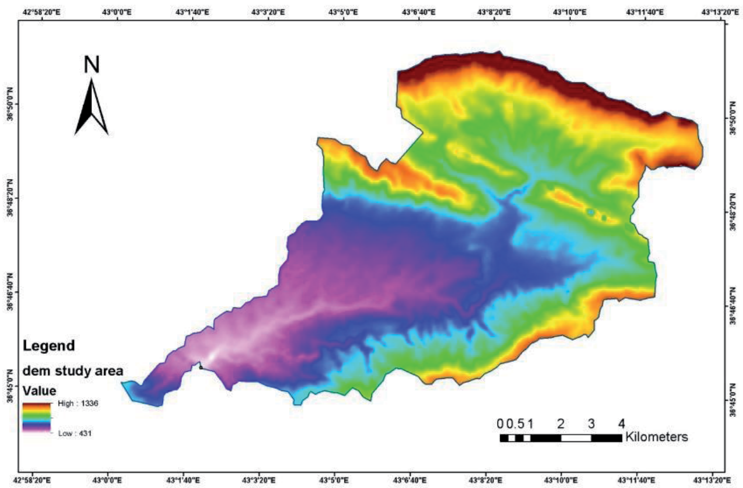

FIGURE 5. The DEM of the study area

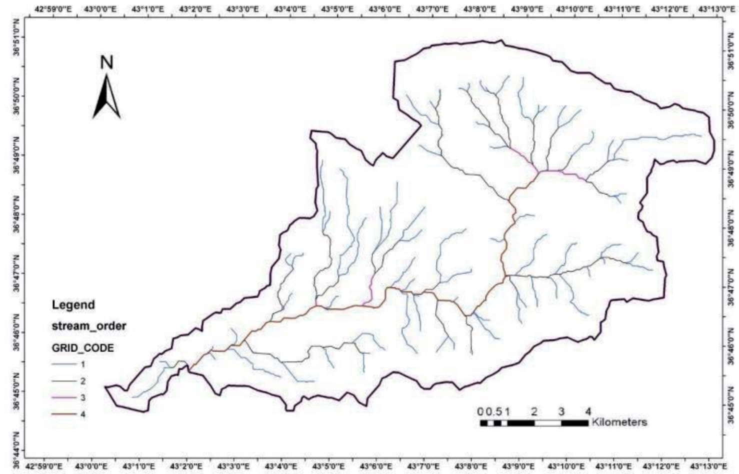

FIGURE 6. The drainage pattern with stream order of study area

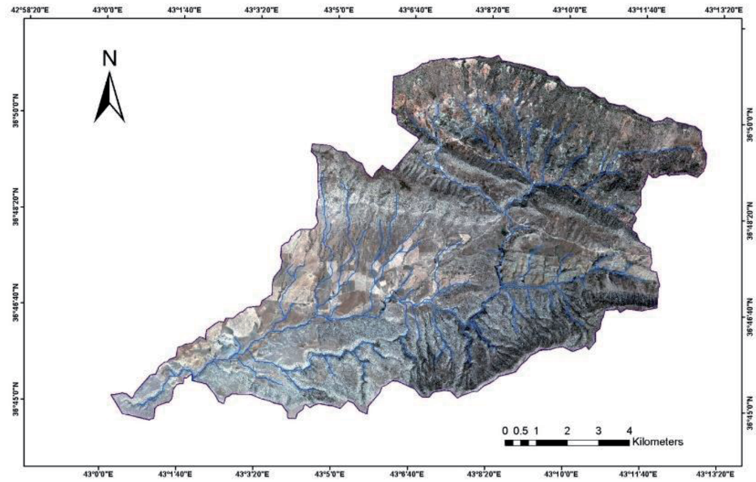

FIGURE 7. The satellite image with the drainage pattern of the study area

TABLE 2. The morphometric and areal characteristics for the proposed dam watershed

Parameter	Value	Parameter	Value
Basin area	113.64 km^2	Mean basin elevation	743.18 m
Basin slope	0.1813	Max flow distance	25 027 m
Basin lengths	18 164 m	Max stream length	23 910 m
Perimeter	78 231 m	Max stream slope	0.021 m·m^{-1}
Shape factor	2.9	Distance from centroid to stream	59.0 m
Sinuosity factor	1.32	Centroid stream distance	12 243 m

TABLE 3. The storage capacity at elevation 450, 460, 470 m a.s.l. for the dam watershed

No	Dam elevation 450 m a.s.l		Dam elevation 460 m a.s.l.		Dam elevation 470 m a.s.l.	
	elevation	storage	elevation	storage	elevation	storage
1	438.50	0	435.50	0	435.50	0
2	439.65	54 121.75	437.95	58 750.58	438.95	100 766.15
3	440.80	86 879.65	440.40	179 456.32	442.40	319 745.59
4	441.95	126 046.7	442.85	357 488.39	44585	638 066.92
5	443.10	179 456.32	445.30	578 248.15	449.30	1 043 980.03
6	444.25	236 782.65	447.75	856 334.23	452.75	1 564 901.85
7	445.40	306 927.28	450.20	1 162 905.45	456.20	2 322 428.28
8	464.55	395 587.25	452.65	1 545 674.39	459.65	3 315 135.07
9	447.70	487 095.73	455.10	2 053 955.94	463.10	4 597 678.06
10	448.85	585 369.43	457.55	2 682 409.13	466.55	6 358 281.65
11	450.00	640 764.41	460.00	3 429 787.74	470.00	8 590 763.41

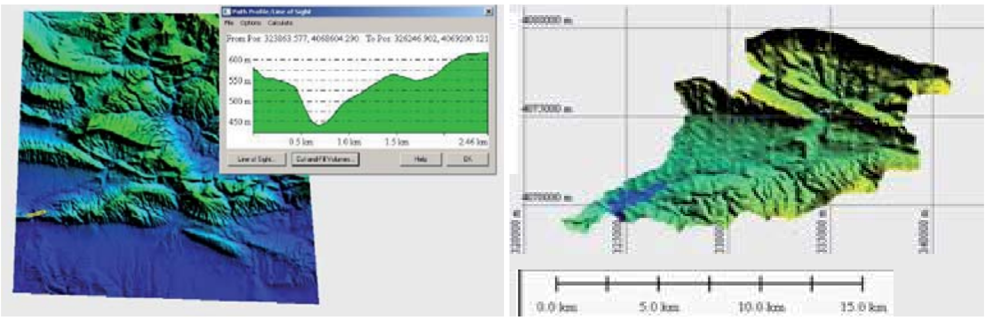

FIGURE 8. The shape of the reservoir formed upstream the proposed dam 470 m with cross section

assessment of the current study, the area of water surface and the depth of water were regarded. The shape of the reservoir formed upstream of the dam at elevation 470 is shown in Figure 8. The important factor affecting the construction of a dam is cost construction, so the earthwork depends on the cross-section and length of the dam, the least length is the best. The length of the proposed dam as measured from contour data is 66, 190, 373 m respectively, the surface area and length of the reservoir also calculated as shown in Table 4.

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An important aspect of any hydrological study is the definition of the curve of storage capacity with levels. The storage capacity at dam elevation 450, 460, 470 m is 640,764.41; 3,429,787.74;

TABLE 4. Length of the dam and reservoir with the storage according to the area of the reservoir at different heights

No	Elevation [m a.s.l.]	Area of reservoir [km^2]	Volume of storage [m^3]	Dam length [m]	Length of reservoir [km]
1	450	123.6	1 286 007	66	9 09.5
2	460	319.8	3 429 788	190	1 150
3	470	962.9	8 590 763	373	2 750
4	480	1 890 573.6	–	469	3 238
5	490	3 293 661.4	–	541	4 856

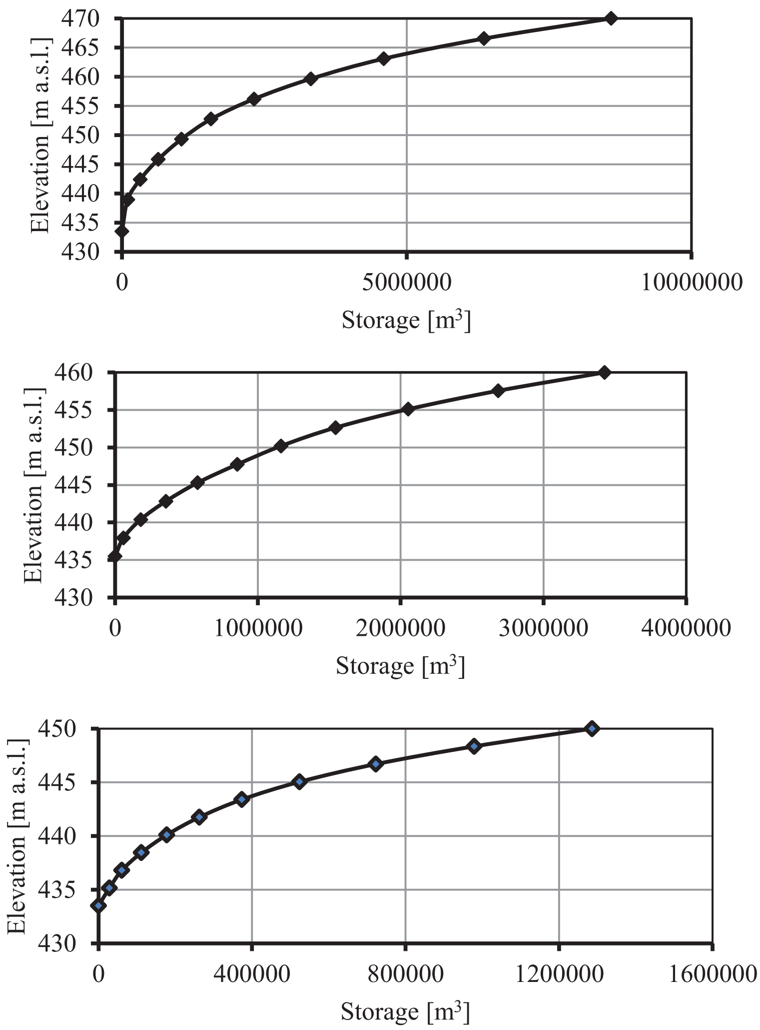

FIGURE 9. Storage at elevations 470, 460, and 450 m a.s.l. respectively

8,590,763.41 m^3 respectively, the plotted curves shown in Figure 9. Table 2 shows the storage at equal intervals for each height.

Conclusions

The proposed dam site is good geotechnically according to the categories of rock mass classification. The stream valley is narrow, meandering with the two significant joints, resulting in high dam stability and low construction costs. The lithology consists of limestone, dolomite, dolomitic limestone, and somewhere marly limestone, with no karstic or caves indication, nevertheless some pores not exceed 5 cm in diameter. For the proposed heights, the basement and the shoulders of the dam are appropriate with a high value of σ_{cm}. Because of its excellent spacing, close openness and presence of marl and calcite as filling materials between adjacent walls, the water is being little filtrated from the reservoir following the discontinuity features. Finally, the suggested dam site is very significant concerning hydrological and geotechnical characteristics.

According to its distinct engineering requirements, the hydraulic study has shown that the proposed position of the dam is very good. The site is distinguished by its narrow valley, its cliffs and rock hardy heights and the abundance of water that flows all seasons. The site has an important characteristic.The availability of suitable geotechnical and hydraulic resources is one of the difficulties that engineers face in selecting the dam sites, but the current situation is characterized by both.

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Summary

Qualifying the geotechnical and hydrological characteristic of the Bandawaya stream valley – Northern Iraq. In northern Iraq, countless non-abuse stream valleys can be used to store water for a variety of purposes; domestic, supplementary irrigation, and recharging groundwater. Bandawaya is one of the stream valleys, which form the first perspective has excellent quality. The location of the suggested dam has been evaluated by hydrological and geotechnical

studies. Geotechnical studies included measurement of all the parameters related to the rock mass classification for evaluation based on four classification systems, which are the Q-System, the rock mass rating (RMR), the geological strength index (GSI), and the rock mass index (RMi). The classification results indicated that the rocks of the valley are good for constructing a dam on them, with some weak zones that may affect the integrity of the dam, which the study recommended treating before starting the construction of the dam. According to preliminary studies on different dam's heights the qualification demonstrates an excellent choice of the site. Four stream orders are recognized, dendritic pattern in the southern part of the watershed, and trellised in the northern part. Three heights assumed to the proposed dam 450, 460, 470 m a.s.l. with 640,764; 3429,787; 8,590,763 m^3 storage capacity respectively. According to the Q-System, the RMR, the GSI, and the RMi, the rock mass of the study area is evaluated. The findings illustrate the excellent selection by geotechnical, hydrological, and engineering features of the dam place.

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