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Evaluation of the ability of rock (soft) dispersion at the basement of the Darbandikhan Dam's reservoir, NE Iraq, with a new investigation and Crumb test

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Abstract:

The Darbandikhan Dam reservoir in NE Iraq is located on soft sedimentary rocks which sporadically were affected by erosion. The basement rocks include sandstone, siltstone, and claystone, and mineralogically comprise quartz, and feldspar with some lithic fragments that are distributed in a soft matrix. The scanning electron microscope (SEM) images show sheet layers with clay structures for the matrix which is confirm by Semi-quantitative analyses of the EDAX data. The results demonstrate that samples categorize as dispersive soil based on the crumb test (ASTM D 6572–21). The Crumb tests were done in six hours, and the short duration can be considered as a defect. In this research the test time was extended and the behavior of the samples was investigated up to 7 days in intervals of two minutes, one hour, 6, 24, 72 hours, and 7 days. The results indicated that some samples which didn't show any sign of dispersion in standard duration underwent some kind of egg-shaped erosion after 72 hours, which completely were separated in 7 days, so it would perhaps be better to make modifications to the crumb test. Correspondingly, the Sodium Absorption Ratio (SAR) and Exchangeable Sodium Percentage (ESP) results of soft grain units demonstrated that these units are mainly dispersive.

Keywords: Erosion; Crumb test; Dispersion; Soft sediments

1. Introduction

Appropriate geological conditions are favorable everywhere, especially where associated with water flow; however, access to optimal conditions is not always possible. Where geological formation is poor and erodible, unstable, dense valleys and rough morphology may be formed, which is known as badland, a common landscape in soft, clay-rich sedimentary rocks in arid to semi-arid areas. Besides geological characteristics, these areas are sensitive to environmental changes arising from dense drainage systems and sharp slopes in barren areas (Yang et al., 2019). In an erodible geological unit, erosion may occur in both physical and chemical forms; in the physical type, the adhesive matrix is leached away between the grains, and the grains are separated. In chemical erosion, which takes place in dispersive soils, the chemical composition is the main cause of erosion; when it is in contact with water, the phenomenon is activated, and the particles are chemically dissolved or dispersed (Rahimi and Abbasi, 2019). Dispersive soils are always considered as causing various problems. Dispersion is a physico-chemical phenomenon that is primarily influenced by the sort of soil minerals and chemical properties of the soil pore liquid (Yong and Warkentin, 1996), and dispersive soils can be found in different types of climate in various areas in Australia, Brazil, Iran, New Zealand, United States (Sherard et al., 1976), Iraq, and numerous other nations. This issue has long been of interest to researchers, as the adverse effects of these soils on engineering projects were first raised by Folk in 1937. Dispersion (chemical type) occurs due to the high percentage of sodium in the soil, and studies demonstrate that the presence of different anions affects the rate of dispersion besides the presence of sodium (Abbasi, 2011). These types of soil have been considered by researchers, so the dispersive mechanism has been detailed by different analysts such as Sherard et al. (1976) and Heinzen and Arulanandan (1977), and Holmgren and Flanagan (1977). It is important to identify these soils in order to be aware of their behavior with respect to structures, so numerous slopes and instances of soil dam breakage and foundation and pavement fracture have been observed in these sorts of soil (Indraratna et al., 1991). Water moving through the cracks picks up dispersive clay particles, with the rate of removal rising as leakage speed increases (Mitchell and Soga, 1993).

Some researchers have studied the properties of problematic soils, methods for their identification, and solutions for their treatment (Wan and Fell, 2004; Ouhadi and Goodarzi, 2006; Umesha et al., 2009; Umesh et al., 2011; Abbasi and Nazifi, 2013; Sayehvand and Dehghani, 2014; Abbasi et al., 2017; Singh et al., 2018). Some have proposed optimum additive materials such as lime, cement, and natural zeolite for stabilization (Goodarzi and Salimi, 2015; Savaş, 2016). Identification of erodible soils is crucial when they are in contact with hydraulic structures whether as a borrow material, as a foundation, or as reservoir slopes that cause plenty of sediments and can occupy the useful reservoir volume. Fine grain soils have complex behavior and also have variety of application, hence, various studies have been conducted in different fields for them (Dutt et al., 2016; Kumar et al., 2022).

The main goal of this paper is investigation of the reason of erodibility of the geological units in the Darbandikhan Dam reservoir regarding to physical and geochemical properties of units.

Study area

Darbandikhan Dam, in the southeast of Iraqi Kurdistan, is located in the High Folded Zone of the outer platform of Arabian Plate. The soft geological units have led to erodible behavior in the reservoir (Sissakian and Fouad, 2014). The northern parts of the region are covered by badlands, which are comprised of various steep-sided valleys and canyons. Cyclic deposits of weak sandstone, siltstone, red claystone and gypsum of Fatha formations are observed in the area (Mio2) (Fig. 1).

Weak layers have generated tight, steep valleys, and erosion can be observed in fine and coarse grain layers. As can be seen, coarse grains are more resistant to erosion, so different erosion has given a jagged appearance to the walls of the valleys (Fig. 2).

Although the units within the range are basically not resistant to erosion, the formation of badland with a high degree of density indicates unusual conditions, so the explanation should be sought in the geochemical characteristics of the units. Moreover, the morphological evidence shows that erosion is greater in some areas, an issue that is focused on in this research (Fig. 3).

2. Method

Site visits and field studies showed that the geological units in the area had been replicated periodically so sampling was performed from different points to identify the geological and geochemical characteristics. Fig. 4 shows the geological

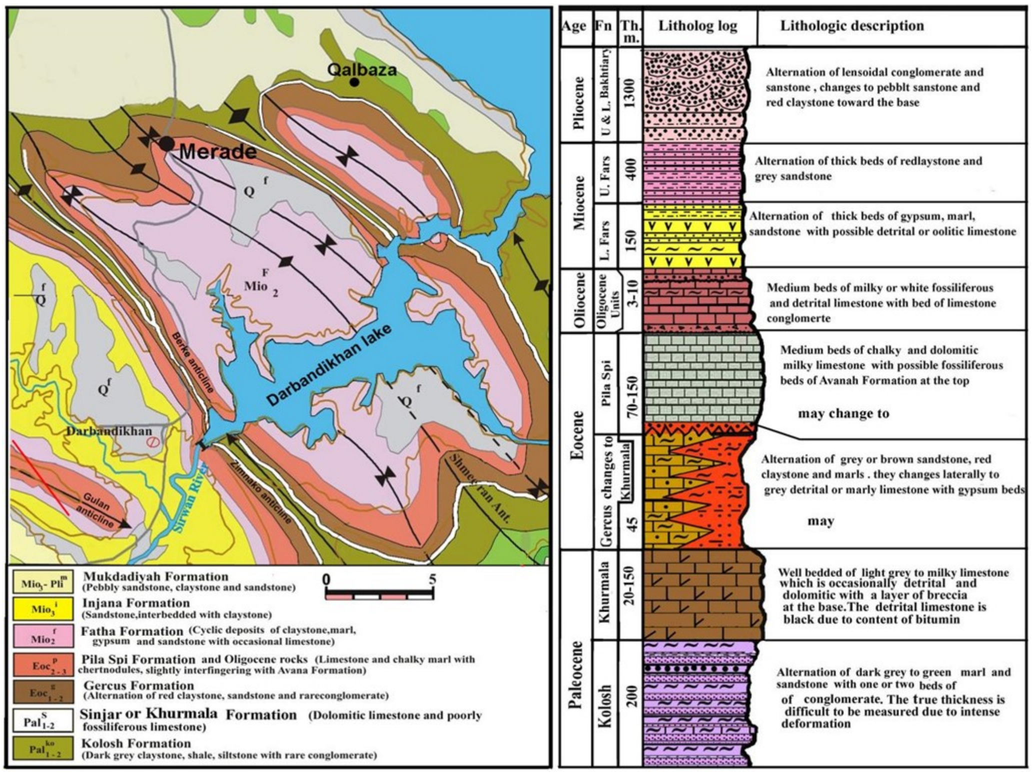

Figure 1. Geological map and stratigraphic column of the study area (Sissakian and Fouad, 2014).

Figure 2. (a) a view of steep an narrow valley in area which include of cyclic fine and coarse deposits, (b) a close view of the layers.

maps and the location of the sampling.

After field investigations and observation of erosion of the geological units, tests of physical properties such as dry and saturated specific gravity, water absorption and porosity, preparation of thin sections of samples for petrography and matrix condition were performed. Also, SEM images and EDAX analysis were used to check the mineralogy of the matrix. In addition, double hydrometric and crumb test was performed to check the tendency of fine grains to dispersion, and the SAR and ESP tests were performed to check the chemical status of the soft grain units.

3. Result and discussion

Sandstones are usually well resistant to erosion, and do not erode easily against weak currents unless there is a problem with lithology and the matrix. In this area, sandstone layers form an important part of the units, and exhibit significant erodibility, which is partially separated from the beds and eroded in part and, in some cases, in blocks. In order to specify how and to what extent the grains are connected and also what kind of matrix is composed, a number of thin sections were prepared (Fig. 5).

Thin section studies indicate the presence of empty spaces and lack of matrix development and the matrix is generally made of clay (Fig. 7) according to the results obtained by SEM images (Fig. 6) and Energy-Dispersive X-ray spectroscopy (EDAX) analysis.

The sheet domain that can be observed in Fig. 6 suggests that the clay mineral and other particles in the matrix may be carbonate. According to the analytical diagram of matrix composition (Fig. 7), Si and Ca exhibit the highest amounts, and the presence of other elements such as Al, Mg, and Fe indicates the availability of clay minerals in the composition.

The results of the physical properties tests demonstrated that fine particles exhibit a great tendency to absorb water compared to coarse particles, which causes them to loosen and eventually spread in water. The test results are shown

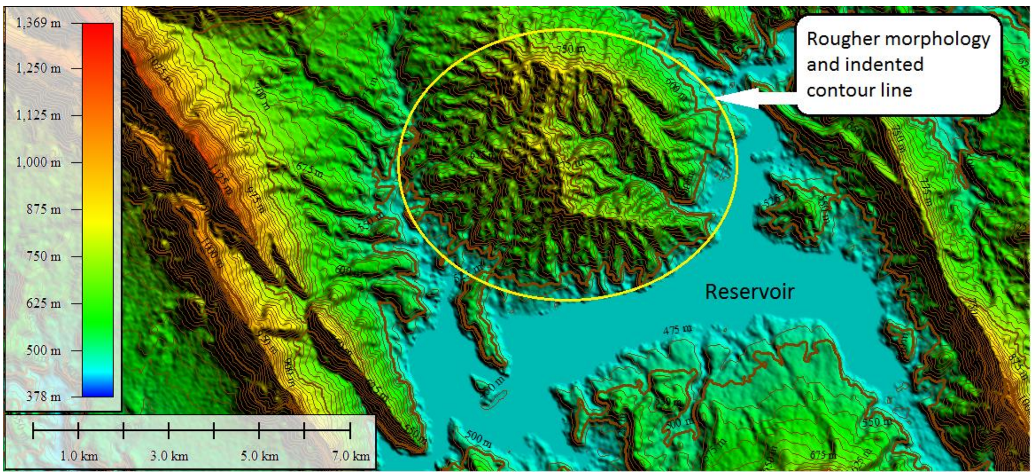

Figure 3. Satellite image shows closer, indented contour that indicates valleys with steep slopes in the northern part of the reservoir.

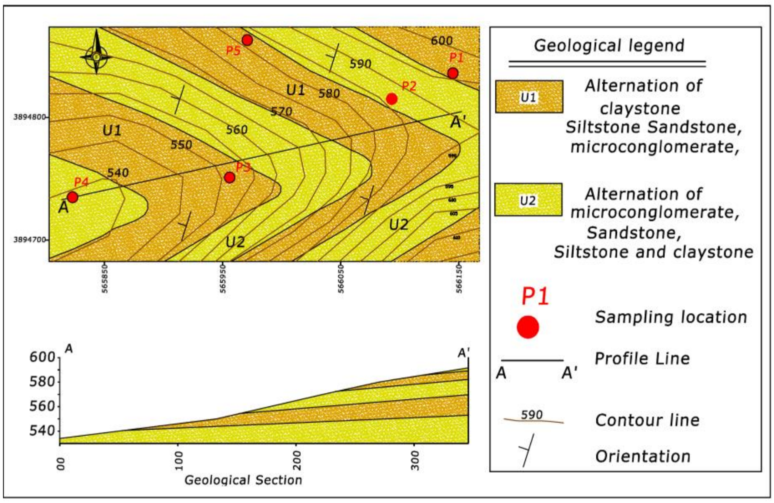

Figure 4. Geological map of the study area along one profile; U1 and U2 are layers of same cyclic deposits, so that each layer is separated from the other by repeating the cycle.

in Fig. 8.

The distance between saturated and dry unit weight density is different in different groups, where the lowest value is observed in group 1, and the highest can be seen in group 3. The larger distances indicate the ability and tendency of the samples to absorb water. According to this trend, it can be predicted that the samples in group 3 involve the finest grains and exhibits the highest potential for erosion.

There are various ways to specify the tendency of soil materials to disperse in water, one of the fastest of which can be implemented in the field and in the laboratory using the crumb test (ASTM D 6572 – 21 *"Standard Test Methods for Determining Dispersive Characteristics of Clayey Soils by the Crumb Test"*). Thus, the test is performed on a natural or remold sample with a size or diameter of about 15 mm, where the sample is placed under natural moisture or simply dried in air. Dispersivity is evaluated by the manner and intensity of the reaction of the sample to water in 2 minutes, 1 hour, and 6 hours. On that basis, the soil dispersion potential is evaluated in four categories: non-dispersive, moderately dispersive, dispersive, and highly dispersive. For evaluation of dispersivity, natural samples were selected, and the crumb test was performed thereon. Fig. 9 shows the steps of the test for one sample.

The results indicate that the fine-grained samples exhibit dispersivity, and are categorized as moderately dispersive to dispersive.

A number of samples with greater hardness fissured and cracked as their placement in water was prolonged, although no reaction was observed in the water during the time specified in the crumb test standard, and the samples were completely torn apart finally, after 7 days, as a kind of egg-shell

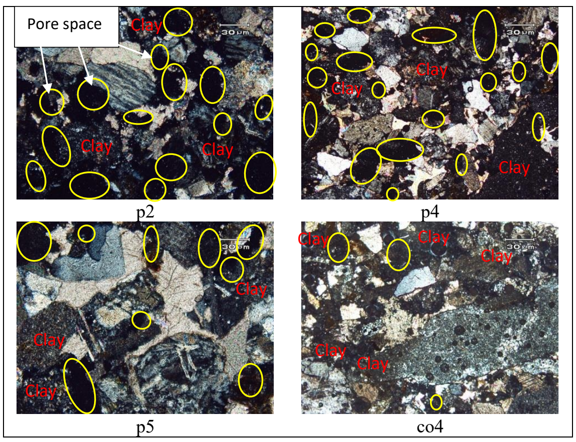

Figure 5. Petrography (quartz, feldspar, lithic) and grain structure in coarse grain units (yellow ovals = pore spaces).

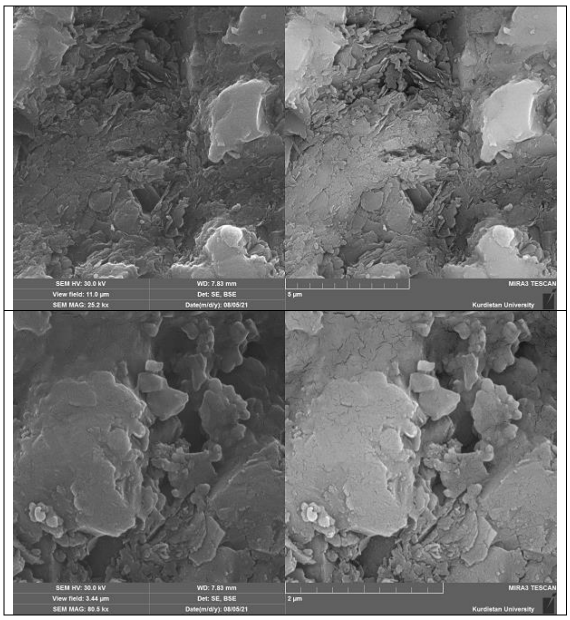

Figure 6. SEM image of the matrix in coarse grain samples, indicating the sheet clay mineral.

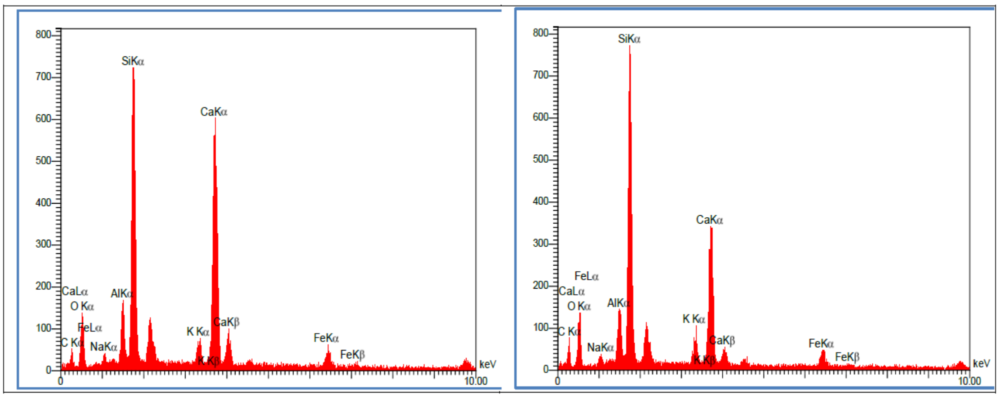

Figure 7. EDAX analytical diagram in the grain specimen matrix.

erosion was created therein (Fig. 10).
Due to the long period of wet days in the region (longer than the time predicted for the crumb test in the (ASTM D 6572 – 21 standard) part of the erosion can occur as egg-shell erosion, which has not been considered in the crumb test; in such cases, the one-week immersion of the samples in water had better be extended to enable verification of their potential for disintegration and erosion. On that basis, a supplementary test can be carried out on the samples. This method is highly appropriate for evaluation of the erodibility of areas with cohesive fine-grained soil and poor fine-grained sedimentary layers. Therefore, it is suggested that an intact sample with dimensions of 5 cm be placed in 500 cm^3 of distilled water at lab temperature, with observations recorded in time intervals of 24 hours, 72 hours, and 7 days, and the potential of erosion can then be expressed as described in Table. 1.
Although the use of the Crumb test is a simple way to evaluate the potential for dispersion, but the studies conducted in this research showed that the short time of the standard method is considered as a shortcoming and therefore a longer test time is required.
There are many other ways to specify dispersion, and the double hydrometer test (ASTM D 7928-21 *"Standard Test Method for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis*) is a common one. In this test, the dispersion potential is analyzed in presence and absence of the dispersant material. If the similarity of the results is greater than a certain value, the soil is said to be dispersive. In this method, the amount of soil dispersion is specified based on the dispersion percentage (PD) (Eq. 1).

$$PD=\frac{\%\text{ of particles} < 5\text{ mic.in the 2nd test (without dispersant)}}{\%\text{ of particles} < 5\text{ mic.in the 1st test (with dispersant)}}\times 100 \quad (1)$$

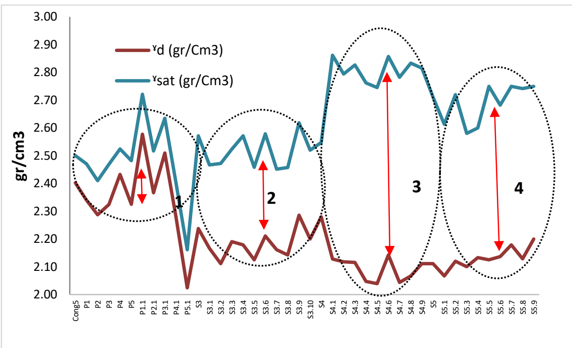

Figure 8. Saturated and dry unit weight density (γ_{sat} and γ_d) of the samples; according to the current trend, four groups 1, 2, 3, and 4 can be distinguished, which exhibit different behaviors in terms of water absorption.

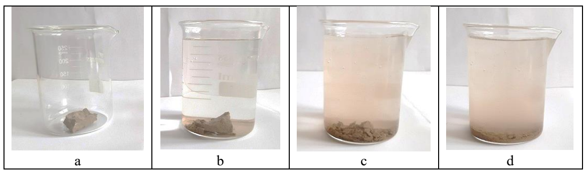

Figure 9. Steps of performing the crumb test; a: Before contact with water, b: 2 minutes after immersion in water, c: 1 hour after immersion in water, d: 6 hours after immersion in water.

Table 1. Evaluation of erosion potential over the time.

Time	24 hours	72 hours	7 days	Description
Crack formation	No	No	No	No Erodible
	No	No	Yes	Low Erodible
	No	Yes	Yes	Erodible
	Yes	Yes	Yes	High Erodible

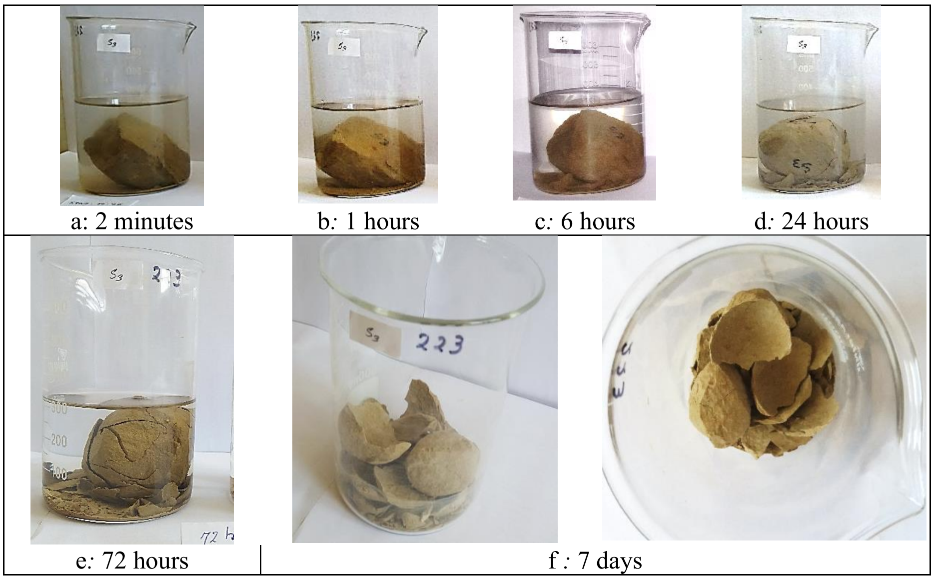

Figure 10. The steps of formation of egg-shell erosion during 7 days; a: 2 minutes after immersion in water, b: 1 hour thereafter, c: 6 hours thereafter, d: 24 hours thereafter, e: 72 hours thereafter, f: 7 days thereafter.

If the dispersion percentage is less than 15, the soil is non-dispersed, and if it is between 15 and 30, 30 and 50, or 50 and 75 or greater than 75, the soil is referred to as slightly dispersive, dispersive, very dispersive, and completely dispersive (IRCOLD, 1996). The tests performed on the samples indicated that the fine-grained ones exhibited dispersion behavior (Fig. 11).

The dispersion may have geochemical reasons, where ions with large ionic radiuses such as sodium are attracted to the surfaces of clay minerals, increasing the distance between the plates and consequently decreasing the attraction of minerals, which enables water molecules to enter easily and the minerals to float in the water.

For examination of the statuses of ions absorbed by clay minerals, a number of criteria were used to verify the dispersion potential, including SAR (Sodium Absorption Ratio)

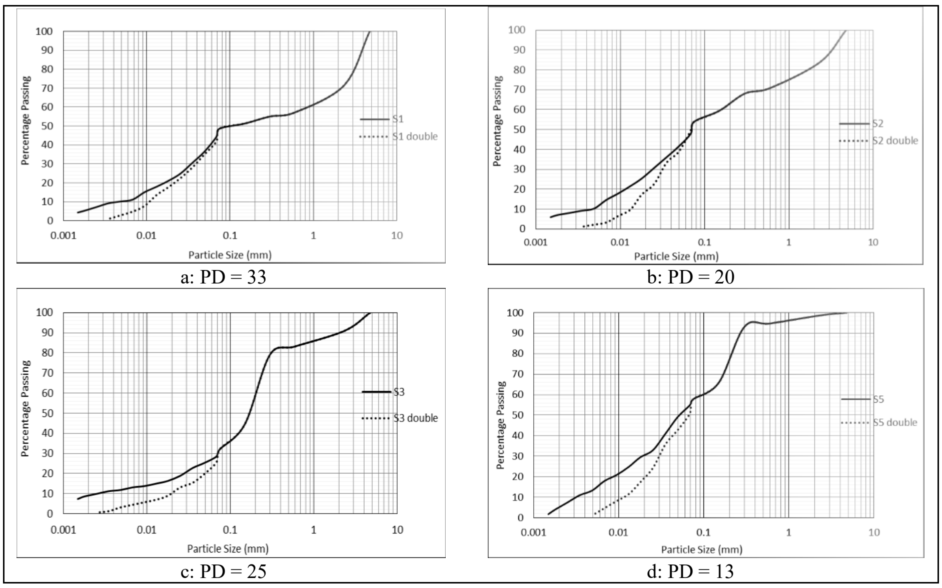

Figure 11. Double hydrometer test results for a number of samples; a: Dispersive, b & c: Slightly dispersive, d: Non-dispersive.

Table 2. Descriptive statistics results of the geochemical analysis.

Parameter	Number	Minimum	Maximum	Mean	Std. Deviation
Na (mil eq. /Lit)	21	27	70	54.10	12.361
Ca (mil eq. /Lit)	21	6	23	13.43	4.308
Mg (mil eq. /Lit)	21	1	9	4.23	2.604
SAR	21	8	30	18.90	5.466
ESP	21	18	60	38.65	10.646
Valid N	21				

(Eq. 2) and ESP (Exchangeable Sodium Percent) (Eq. 3), which is the ratio of the total amount of exchangeable sodium ions to the cation exchange capacity of the soil (CEC).

$$\mathrm{SAR} = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}} \qquad (2)$$

where Na is the concentration of sodium, Ca is the concentration of calcium, and Mg is the concentration of magnesium in mEq/L. In general, soil resistance to erosion increases as solute concentration rises and SAR decreases, and erosion resistance decreases as SAR increases.

$$\mathrm{ESP} = \frac{Na}{CEC} \times 100 \qquad (3)$$

In this formula, CEC is the cation exchange capacity of the soil, and Na is the amount of exchangeable sodium in milli equivalents per 100 gram of dry soil. If the ESP of the soil is larger than 10, it is considered dispersive, and it is semi-dispersive if ESP is between 7 and 10 and non-dispersive if ESP is less than 7 (Rahimi and Abbasi, 2019). Moreover, ESP can be obtained from the following relationship (which was used in this research).

$$\mathrm{ESP} = (\mathrm{SAR} \times 1.95) + 1.8 \qquad (4)$$

Dispersion is shown for the samples according to the chemical analysis using ASR and ESP (Table. 2).

4. Conclusion

Erosion of soils and loose rock units is strongly influenced by their geological characteristics, and badlands can be formed if erosion spreads. The geological units in the study area are highly prone to erosion, so narrow, dense, steep valleys can be observed therein. These units are composed of intervals of fine- and coarse-grained sediments.

The thin sections, SEM images, and EDAX analysis demonstrated that the matrix of the coarse-grained units is incomplete, and is mostly of the clay type that has loosened the units and eroded the coarse ones.

The results of the crumb test indicated that the samples mainly exhibit the potential for dispersion; the significant point that has not been taken into account in the existing standards is the duration of the crumb test. In this research, it was found that the samples that remain healthy during the standard time in the Crumb test, exhibit egg-shaped shell erosion as the test time is extended for a week, as introduced in the present study. This type of unknown erosion plays a significant role in the erosion of the region. Since the similar regions such as study area are characterized by wet periods of more than one week during the year, the Standard crumb test which is ended in 6 hour is not an appropriate way to evaluation of dispersion and erodibilty; so it is suggested that the erosion potential be considered for seven or more days. This can be realized through modification of the crumb test and its extension to 7 days.

The results of the implementation of the SAR and ESP chemical methods demonstrated that fine grain samples exhibit the potential of dispersion, and are categorized as dispersive based on the existing classifications.

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Authors Contributions

All authors have contributed equally in preparing the paper.

Availability of Data and Materials

Data is available on request from the authors. The data supporting this study's findings are available from the corresponding author, upon reasonable request.

Conflict of Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Abbasi N. (2011) The role of anions in dispersion potential of clayey soil. *Journal of agricultural engineering research* 12 (3): 15–30. https://doi.org/10.22092/aridse.2011.102252

Abbasi N., Farjad A., Sepehri S. (2017) The use of nanoclay particles for stabilization of dispersive clayey soils. *Geotech. Geol. Eng.* 36:327–335. https://doi.org/10.1007/s10706-017-0330-9

Abbasi N., Nazifi M. H. (2013) Assessment and modification of Sherard chemical method for evaluation of dispersion potential of soils. *Geotechnical and Geological Engineering* 31 (1): 337–346. https://doi.org/10.1007/s10706-012-9573-7

Dutt A., Saini M. S., Singh T. N., Verma A. K., Bajpai R. K. (2016) Analysis of thermo-hydrologic-mechanical impact of repository for high-level radioactive waste in clay host formation: an Indian reference disposal system. *Environmental Earth Sciences* 66 (8): 2327–2341. https://doi.org/10.1007/s12665-011-1455-4

Goodarzi A. R., Salimi M. (2015) Stabilization treatment of a dispersive clayey soil using granulated blast furnace slag and basic oxygen furnace slag. *Applied Clay Science* 108:61–69. https://doi.org/10.1016/j.clay.2015.02.024

Heinzen R. T., Arulanandan K. (1977) Factors influencing dispersive clays and methods of identification, Dispersive clays, related piping, and erosion in geotechnical projects. *ASTM Special Technical Publication* 623:202–217.

Holmgren G. G. S., Flanagan C. P. (1977) Factors affecting spontaneous dispersion of soil materials as evidenced by the crumb test. *Dispersive Clays, Related Piping, and Erosion in Geotechnical Projects, ASTM STP* 623:218–239.

Indraratna B., Nutalaya P., Kuganenthira N. (1991) Stabilization of a dispersive soil by blending with fly ash. *Quarterly Journal of Engineering Geology and Hydrogeology* 24 (3): 275–290. https://doi.org/10.1144/GSL.QJEG.1991.024.03.03

IRCOLD (1996) assessment and application of dispersive soils in earth dams. *Iranian national Committee on Large Dams* 8

Kumar B., Verma A. K., Bajpai R. K., Singh T. N. (2022) Numerical analysis of heat dissipation through granite and clay in the multi-barrier system of a geological disposal facility. *CURRENT SCIENCE* 122 (9): 1089. https://doi.org/10.18520/cs/v122/i9/1089-1093

Mitchell J. K., Soga K. (1993) BOOK: Fundamentals of soil behavior. *New York: John Wiley & Sons* 3 (1st Ed.): USA.

Ouhadi V. R., Goodarzi A. R. (2006) Assessment of the stability of a dispersive soil treated by alum. *Engineering geology* 85 (1-2): 91–101. https://doi.org/10.1016/j.enggeo.2005.09.042

Rahimi H., Abbasi N. (2019) Geotechnical engineering of problematic soils. *university of tehran press* 4:848.

Savaş H. (2016) Consolidation and swell characteristics of dispersive soils stabilized with lime and natural zeolite. *Science and Engineering of Composite Materials* 23 (6): 589–598. https://doi.org/10.1515/secm-2014-0202

Sayehvand S., Dehghani M. (2014) Identification and management of dispersive soils. *Electron J Geotech Eng* 19:9023–9032.

Sherard J. L., Dunnigan L. P., Decker R. S. (1976) Identification and nature of dispersive soils. *Journal of the Geotechnical Engineering Division* 102 (4): 287–301.

Singh B., Gahlot P., Purohit D. G. M. (2018) Dispersive soils-characterization, problems and remedies. *Int. Res. J. Eng. Technol.* 5 (6): 2478–2484.

Sissakian V. K., Fouad S. F. (2014) Geological Map of Sulaimaniyah Quadrangle. *Iraq Geological Survey Publications* 1:250.

Umesh T., Dinesh S., Sivapullaiah P. V. (2011) Characterization of dispersive soils. *Materials Sciences and Applications.* 2 (6): 629–633. https://doi.org/10.4236/msa.2011.26085

Umesha T. S., Dinesh S. V., Sivapullaiah P. V. (2009) Control of dispersivity of soil using lime and cement. *International journal of geology* 3 (1): 8–16.

Wan C. F., Fell R. (2004) Investigation of rate of erosion of soils in embankment dams. *Journal of geotechnical and geoenvironmental engineering* 130 (4): 373–380. https://doi.org/10.1061/(ASCE)1090-0241(2004)130:4(373)

Yang C. J., Yeh L. W., Cheng Y. C., Jen C. H., Lin J. C. (2019) Badland erosion and its morphometric features in the tropical monsoon area. *Remote Sensing* 11 (24): 3051. https://doi.org/10.3390/rs11243051

Yong R. N., Warkentin B. P. (1996) Introduction to soil behavior. *MacMillan,* 451.