Fell, R., Macgregor, P., & Stapledon, D., 1992, "Geotechnical engineering of embankment dams", *Balkema, Rotterdam, 675p.*

Holmgren, G. G. S., & Flanagan, C. P., 1977, "Factors affecting spontaneous dispersion of soil materials as evidenced by the crumb test, in: Dispersive clays, related piping, & erosion in geotechnical projects", *ASTM Special Technical Publication, American Society for Testing and Materials, No. 623: 218-239.*

Khamehchiyan, M., Rahimi, H., & Soloki, H. R., 1999, "Study of dispersive soil in relation with geological condition in Khuzestan Province, Iran", *Proceeding of 2nd Asian Symposium on Engineering Geology and the Environment, Bangi, Malaysia, 63-70.*

Krinsley, D. B., 1970, "A geomorphological and paleoclimatological study of the playas of Iran", *Part 1 and 2, U.S Geological Survey, 486 p.*

Lashkaripour, G. R., 2002, "Drought in Sistan and Baluchestan Province of Iran and the dead of Hamun Lake", *Proceeding International Conference Environmental Problems of the Mediterranean Region, p.: 445*

Lashkaripour, G. R. & Soloki, M. R., 2002, "Study of dispersive soils in Sistan Plain", *A Report to University of Sistan and Baluchestan of Iran for Project No. 11.7657 (in Persian).*

Ludwig, H., 1979, "A study of some aspects of dispersive clay particle interaction", *Master thesis, McGill University, 201 p.*

Mojtahed-Zadeh, P., 1993, "Evaluation of eastern Iranian boundaries", *PhD thesis, University of London.*

Ouhadi, V. R. & Goodarzi, R. V., 2006, "Assessment of the stability of a dispersive soil treated by alum", *Engineering Geology Vol. 85: 91-101.*

Rahimi, H. & Delfi, M., 1993, "New chemical method for evaluation of soil dispersive", *Proceeding of the Second International Seminar on Soil Mechanics and Foundation Engineering of Iran, :199-218.*

Sherard, J. I., Dunnigan, L. P. & Decher, R. S., 1976, "Identification and nature of dispersive soil", *Journal of Geotechnical Engineering Division, Vol. 102: 287-301.*

Sherard, J. I., Dunnigan, L. P. & Decher, R. S., 1977, "Some engineering problems with dispersive soils", *ASTM STP, No. 623: 3-12.*

including crumb test; soil pore water chemistry correlation (chemistry test), double hydrometer (SCS), and the pinhole erosion test were conducted on the collected samples.

The results of the pinhole test, chemistry test, crumb test, and double hydrometer test are usually disagreeing. The difference in the results of the laboratory tests for the

Table 4. The results of pinhole tests.

Sample Number	Pinhole test Results	Sample Number	Pinhole test Results
1	-	11	-
2	ND3	12	-
3	ND1	13	ND3
4	ND2	14	-
5	ND2	15	ND3
6	ND1	16	ND1
7	-	17	ND3
8	ND1	18	ND2
9	ND1	19	ND2
10	-	20	ND3

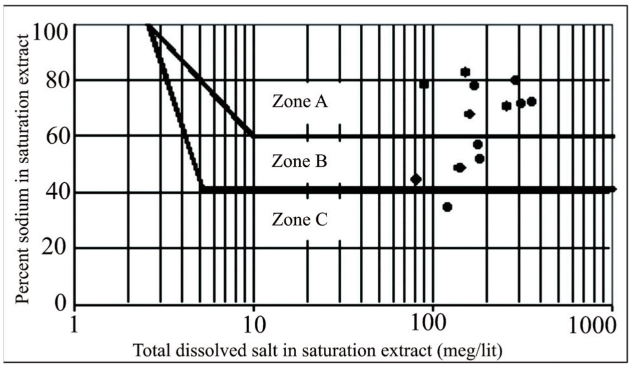

Fig. 3. chemical test results.

identification of dispersive clay indicates the soil dispersivity can not be recognized only by one method. Therefore, different methods combining with field evidence must be considered to decide about the soil dispersivity. However, the results of finding in this study do not strongly support dispersivity for the soils of this region, but field observation such as the type of erosion support the dispersivity. Therefore, it is recommended to collect more samples from different locations and carrying out more tests in this regard. Moreover, it may be that insufficient treatment of the embankment is the reason for erosion and severe damages in this area.

Table 5. Type of tested soil based on USCS.

Sample Number	Soil type	Sample Number	Soil Type
1	ML	11	SP-SM
2	CL*	12	ML
3	CL*	13	ML**
4	CL*	14	ML
5	CL*	15	ML**
6	CL*	16	CL**
7	SP-SM	17	ML*
8	MH**	18	CL*
9	CH*	19	CL*
10	CH*	20	ML**

***Nonndispersive** ****Dispersive**

6. Acknowledgements

The research presented in this paper has been supported by a grant from University of Sistan and Baluchestan, for which we express our sincere thanks.

7. References

Bell, F. G., & Maud, R. R., 1995, "Dispersive soils and earth dams with some experiences from South Africa", *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts, Vol. 32: 342A- 343A.*

Bell, F. G., & Walker, D. J. H., 2000, "A future examination of nature of dispersive soils in Natal, South Africa", *Quaternary Journal of Engineering Geology and Hydrogeology, Vol. 33: 187-199.*

Benito, G., Gutierrez, M., & Sancho, C., 1993, "The influence of physico-chemical properties on erosion processes in badland areas, Ebro basin, N.E. Spain." *Zeitschrift für Geomorphologie, Vol. 37: 199-214.*

Decker, R. S., & Dunnigan, L. P., 1977, "Development and use of the soil conservation service dispersion test", *ASTM STP, No. 623: 94-109.*

Farhoudi, G., Rahnama-Rad, J., & Derakhshani, R., 2005, "Morphotechonic analysis of Chahnimeh depressions in Sistan, Iran", *Journal of Applied Geology, Vol. 1(1): 30-37*

Faulknera, H., Alexander, R., & Wilson, B. R., 2003, "Changes to the dispersive characteristics of soils along an evolutionary slope sequence in the Vera badlands, southeast Spain: implications for site stabilization", *CATENA, Vol. 50: 343-254.*

Faulkner, H., Ruiz, J., Zukowskyj, P., & Downward, S., 2003, "Erosion risk associated with rapid and extensive agricultural clearances on dispersive materials in southeast Spain", *Environmental Science & Policy Vol. 6: 115-127.*

and the hole does not enlarge. The applicability of this testing may be great in the evaluation of piping potential of earth embankment.

Two limitations of the pinhole erosion test for identifying dispersive soils have been observed. Undisturbed soil samples of high sensitivity may be classified as dispersive from the pinhole erosion test. Apparently, the natural structure of the soil is destroyed by punching the pinhole in undisturbed soil specimen and a reaction analogous to dispersion is obtained in the pinhole erosion test. Soils with high sodium (>80%) and low total dissolved solids (<0.4 meg/l) in the soil pore water may show nondispersive in the pinhole erosion test, while the soil may exhibit dispersive performance in the field. This may occur because a decrease in the concentration gradient between the soil pore water and eroding fluid results in a decrease in the erosion rate for soils.

A total of 14 pinhole tests were carried out on the selected specimens. Method A of standard ASTM4647-87D was conducted on samples with optimum water content. In this method D1 and D2 are dispersive soil, ND3 and ND4 are intermediate, and ND1 and ND2 are nondispersive soil. The results of the pinhole test are shown in Table 4.

4. Discussion

The results of the dispersive soil investigation are

summarized in tables 1, 2, 3, and 4 which described earlier in this paper. The results of the chemical analyses are

summarized in Table 1 and are given in detail in Figure 3. Referring to the results plotted in this figure, it is evident that there are many points which fall in Zone A which correspond to highly erodible clays. A number of samples fall in Zone C. Zone C is intermediate area, and the soils in this area may be dispersive or nondispersive. One sample falls in the zone of erosion-resistant soil (Zone B).

Table 2. The SCS test results.

No.	Clay%<.005mm No Dispersant & No Mixing	Clay% <.005mm Standard	Percent Dispersion	Description
2	2.82	41.88	6.73	interermediate
3	4.78	35.72	13.38	Nondispersive
4	2.79	44.98	6.20	Nondispersive
5	9.17	53.92	17.01	Nondispersive
6	9.42	29.24	32.22	Intermediate
8	10.73	20.26	52.96	Dispersive
9	17.6	47.88	36.76	Intermediate
13	6.75	20.33	33.20	Intermediate
15	8.75	23.15	37.80	Intermediate
16	4.17	43.00	9.70	Nondispersive
17	11.88	24.40	48.69	Dispersive
18	5.19	30.44	17.05	Nondispersive
19	3.24	47.81	6.78	Nondispersive
20	4.55	12.16	37.42	Intermediate

SCS dispersion test is a good indicator of soil dispersiveness. SCS activity in the field of design and construction of earth dams was greatly expanded and accelerated in the 1940's and early 1950's. Percent dispersion values used for identifying critical soils were: > 25 for inorganic silt or low plasticity (ML) and silty clay (SC), > 35 for inorganic clay of low to medium plasticity (CL), and > 40 for inorganic clay of high plasticity (CH) (Decker & Dunnigan 1977). Type of tested soils according to the Unified Soil Classification System is shown in Table 5.

Table 3. The results of the crumb tests.

Samples: 2-4-6-7-8-9-10-11-12-13-14-15-17-18-19-20	No reaction
Samples: 1-3-5-16	Slightly reaction

Based on type of specimen and the percent dispersion values

used for identifying critical soils by Decker and Dunnigan, 5 samples of 14 tested samples (35.7%) are subject to dispersive erosion.

The results of the crumb test indicated that only 4 samples numbers 1,3,5, and 16 or 25% of tested samples react to the crumb test and they are probably dispersive. It is important to mention that many dispersive soils do not react to the crumb test. Therefore, the result of the crumb test can be use in conjunction with other tests which using for identifying dispersivity.

The pinhole test, which model erosional performance of soil, is currently the most reliable test for identifying soils that are subject to dispersive erosion. However, some of the results of the pinhole test in this research are disagreeing with the results of chemistry test, crumb test, and double hydrometer. One reason seems to be that the pinhole test carried out on samples at water content less than natural moisture content. Consequently, it should be required to run pinhole tests on specimens from samples at natural water content.

Bell & Walker (2000) offered a rating system for identification of dispersive soils. They used the results of the crumb test, the pinhole test, the SAR value and the assessments provided by the CEC vs. ESP and TDS vs. Na+ percent charts in the rating system.

5. Conclusions

Sistan plain or Sistan depression, a lowland region of the eastern part of Iran is covered by fine-grained soils including silt and clay. During the last twenty years there were many reports about erosion in the embankment that constructed to protect Zabol city and villages from flooding.

In this paper four commonly test methods were carried out to study the dispersivity of soil in the study area. The goal of this study was that might be finding a relation between the embankment erosion and dispersivity. Dispersive clay is encountered which has absolutely no resistance to erosion of water. The four commonly test

Fig. 2. Deep erosion ullies in the study area

Table 1. Results of the chemistry tests.

Sam-ple No.	Na+ (m-eq/l)	Ca2+ (m-eq/l)	Mg2+(m eg/1	K+(m-fq/I	T.D.S (m-eq/l)	S.A. R	P.S	Des-cription (Sherard Graph)
2	95.45	30	54	3.87	183.32	14.73	52.067	Intermediate
3	262.00	28	52	20.83	362.83	41.43	72.21	Dis-persive
4	102.27	16	50	11.11	179.38	17.80	57.013	Inter-mediate
5	69.23	20	46	7.84	143.07	12.05	48.389	Inter-mediate
6	111.36	18	28	7.17	164.53	23.22	67.684	Dis-persive
8	127.00	4	16	6.75	153.75	40.16	82.602	Dis-persive
9	70.19	8	6	5.83	90.02	26.53	77.972	Dis-persive
13	236.36	16	24	19.5	295.86	52.85	79.889	Dis-persive
15	68.27	28	38	5.95	140.22	11.88	48.688	Inter-mediate
16	183.82	40	26	10.87	260.69	32.00	70.513	Dis-persive
17	36.06	22	18	5.37	81.43	8.063	44.283	Inter-mediate
18	222.73	42	24	21.53	310.26	38.77	71.788	Dis-persive
19	136.00	18	12	7.29	173.29	35.12	78.481	Dis-persive
20	42.04	48	10	21.75	121.79	7.807	34.518	Nondis-persive

3.1. Chemistry test

The chemistry test or soil pore water chemistry method is a standard test of the agricultural soil scientists. This test carried on the collected samples and the amount of the most important cations such as Mg++, Ca++, K+ and Na+ in the saturated samples has been determined. The percent of sodium (PS) for each sample was determined by using the following equation.

The results of the chemistry test are shown in Table 1. The amount of PS in the samples is high. In comparison these results with Sherard curve (Sherard et al. 1976), all tested samples except sample number 20 showing more or less dispersivity. This dispersivity behavior is due to the high rate of sodium. Further studies in Iran confirmed that there is a limitation in using the Sherard curve for samples with TDS more than 100 meq/l (Rahimi & Delfi 1993).

$$P.S. = \frac{Na}{Ca + Mg + Na + K} \times 100 = \frac{Na}{T.D.S} \times 100$$

The double hydrometer test or Soil Conservation Service (SCS) dispersive test is the first method has been used to identify dispersive soils (Decker & Dunnigan 1977). In this method, the particle size distribution is first measured using the standard hydrometer test, in which the sample is dispersed in the hydrometer bath with strong mechanical agitation and a chemical dispersant agent. A second hydrometer test is made without strong mechanical agitation and without a chemical dispersant agent. The later shows less colloidal particles than the former and the difference is a measure tendency of the clay to disperse naturally.

By definition, percent dispersion is the ratio of clay size particles (0.005mm) in the two tests. Based on the Sherard et al. (1976), for dispersion of less than 20 percent, the soil is nondispersive, and the soil is moderately dispersive for the value between 20 to 40 percent, and values greater than 40 percent are nearly always indicate of soils to serve erosion damage.

The results of the double hydrometer dispersive tests are shown in Table 2. These results indicate two samples with SCS dispersion of more than 40 percent and five samples between 20 to 40 percent.

3.2. Crumb test

The crumb test method, while a good quick indication of dispersive clay, should used in conjunction with a pinhole test, a double hydrometer test, and chemistry test for identifying dispersive soils. This test method provides a qualitative indication of the natural dispersive characterization on clayey soils. This method has some limitation in its usefulness as indicator of dispersive soil. For some reason not yet clear, the crumb test does not classify as dispersive those kaolinite soils that are dispersive by the pinhole test. A speculative possibility is that the edge face particle interaction noted for kaolinite soils results in a more porous, open structure (Holmgren & Flanagan 1977).

Based on the tendency for clay particles to go into colloidal suspension that is observed after 5-10 minutes of immersion, soils are classified into four groups 1, 2, 3 and 4 from nondispersive to dispersive respectively.

The results of the crumb test are shown in Table 3. The results of this test indicated that only samples numbers 1, 3, 5 and 16 react to the crumb test and they are probably dispersive (Crumb reading 3).

3.3. Pinhole test

The pinhole erosion test is the most reliable test for identifying dispersive soils. The pinhole test will provide qualitative information on the dispersive tendencies of soil particles. In conducting the test, distilled water under a low hydraulic head is caused to flow through a small diameter hole in the soil specimen. For dispersive soils, the flow emerging from the soil samples is cloudy and the hole rapidly enlarges. For nondispersive soils, the flow is clear

1. Introduction

The Sistan plain or Sistan depression is a lowland area which constitutes the middle section of the eastern Iranian borderlands. Map showing the geographic location of the investigated area is shown in Figure1. This area of E Iran and SW Afghanistan is 15,197 sq km in land area with a population of more than 400,000, makes Sistan the most populated region in the entire eastern Iranian borderlands. Zabol city is the biggest city in this area with a population about 120,000 (Lashkaripour & Soloki 2002).

This lowland region fed mainly by the spring floods of the Hirmand river and other streams. The Hirmand river rises from the Hindu Kush mountains and runs about 1000 km through Afghanistan to enter into Sistan depression in Iran (Farhoudi et al. 2005). The Sistan depression contains a big lagoon that is called Hamun or Sistan lake and is the lowest part of the area. Krinsley (1970) reported that the Hamun lake is the largest fresh water lake in the Iranian Plateau. The Hamun, apparently a much larger lake in the past that it can ever be in a high water level year of our time (Mojtahed-Zadeh 1993). The surrounding lands have an almost negligible slope toward the lake.

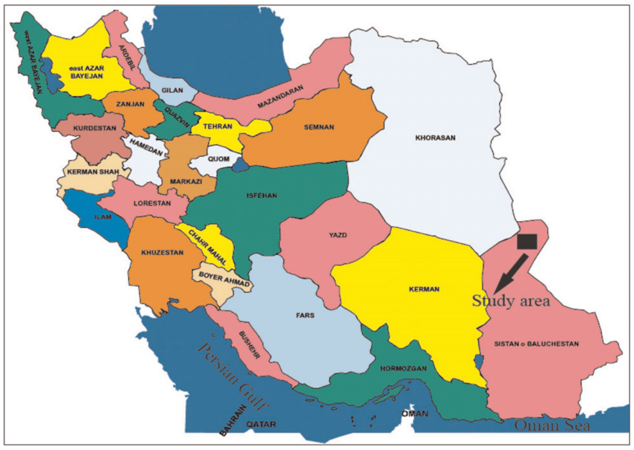

Fig. 1. The location of the investigated area.

The Sistan plain is predominantly a flat land, and is mostly made up of sediments from Hirmand river. Due to this geomorphological condition, a long embankment has been constructed to protect Zabol city and the villages around the city from the spring floods of Hirmand river. During the recent years many damages have been reported in the embankment. Khamehchiyan et al. (2005) reported that mechanical erosion is the main cause of embankment destruction in Sistan. However, signs of dispersive erosion can be seen in the plain. In this paper the Sistan plain soils will be studied in the term of dispersivity that may related to embankment erosion.

Dispersive soils have been found to exist in various types of climates in various locations in Australia, Brazil, Iran, New Zealand, Spain, the United States and many other countries (Sherard et al. 1976, Ludwig 1979, Khamehchiyan et al. 1999, Faulkner et al. 2003). Dispersive soils have been responsible for failures in several geotechnical and geoenvironmental projects associated with dispersive soils. However, in many cases chemical treatments have been used to overcome problems associated with dispersive (Ouhadi & Goodarzi 2006).

2. Geology

The geology of an area such as existence of a source for sodium cation in the region can be a guide to dispersivity. Based on the observed dispersive soil in the world, clays of alluvial origin, some soil derived from mudstone laid down in a marine environment can be dispersive (Sherard et al. 1977, Fell et al. 1992, Khamehchiyan et al. 1999). Soil derived from weathering of igneous and metamorphic rocks and soil with high organic content are usually nondispersive.

Sistan plain is covered by Quaternary sediments with a maximum thickness of about 500 m in the central part of the plain (Lashkaripour & Soloki 2002). The Main source of the Quaternary sediments is geological formation in Hindu-Kush mountains in the eastern part of Afghanistan that erodes by the fluvial processes and deposited in the plain where the topography is smooth with low slop. The major portion of this sediment made of clay and silt such as CL and ML based on the Unified Soil classification System.

3. Identification of dispersive soils

Dispersive soils are a particular type of soil in which the clay fraction erodes in presence of water by a process deflocculation. This occurs when the interparticle forces of repulsion exceed those of attraction so those clay particles are detached and go into suspension. If the water is flowing, as in a crack in an earth dam, the detached clay particles are carried away and piping occurs.

Dispersive soils are found in arid and semi-arid areas. Bell & Maud (1995) reported occurrence of this type of soil in the area of South Africa with less than 850 mm annual precipitation. The Sistan plain is characterized by an arid climate prone to droughts with extremely low rainfall of about 56 mm/year and very high evaporation rate of about 4000 mm/year (Lashkaripour 2002). Sherard et al. (1977) reported that dispersive soil could be formed anywhere in the arid, semiarid. Benito et al. (1993) and Faulknera et al. (2003) found that in dispersive marls in southeast Spain, fresh material is often much more dispersive than surface samples, which suggests leaching or exchange of surface sodium on badland surface through time.

Identification of dispersive soils is required for earth structures. Positive identification of dispersive soils is by observed performance of the soil in the field. Where dispersive soil is prevalent is usually marked by deep erosion gullies. Figure 2 shows deep erosion gullies in the study area. Usually this type of erosion is dominant in the dispersive soils.

Dispersive soils cannot be identified by conventional index tests such as particle size distribution, Atterberg limits and compaction characteristics. Four commonly laboratory tests which used to identify dispersive soils are the crumb test, chemistry test, double hydrometer or Soil Conservation Service (SCS), and the pinhole erosion test. In this study all In this study all these tests were carried out on samples that collected from the study area.

Journal of Applied Geology
Vol. 3. No. 1: 73-78
WWW.applied geology.ir

Islamic Azad unversity Zahedan Branch

The characteristics of dispersive soils in Sistan plain, eastern Iran

G.R. Lashkaripour[1], M. Khamehchiyan[2], H.R. Soloki[3] & E. Rahimi[4]
1) Department of Geology, University of Ferdowsi, Mashhad, I.R. Iran.
2) Department of Geology, University of Tarbiat Modaress, Tehran, I.R. Iran.
3) Department of Geology, University of Sistan and Baluchestan, Zahedan, I.R. Iran.
4) SAP Consulting, Tehran, Iran.

Abstract
This paper deals with dispersive erosion of soil in Sistan plain in the eastern part of Iran. This area is a vast flat plain, which lies upon Hirmand (Helmand) River Delta. Zabol city, the biggest city of the Sistan area, is located nearly in the center of the plain. The transportation of huge amounts of sediments in the past periods has decreased the depth of Hamun lake, close to Zabol city. This phenomenon has currently caused a lower elevation for Zabol city than some parts of the Hamun lake. Therefore, a large embankment has been constructed around the city to protect it against Hirmand river floods. One of the problems which the city has confronted during the recent years is the erosion of the embankment. The embankment destruction has caused huge damages to the urban structures.
Sistan plain is covered by fine-grained sediments such as silt and clay, therefore, there is a probability of embankment demolition in some parts due to dispersive erosion. This study was carried out to find any possible relationship between dispersivity of soil and embankment erosion in the region. Thus, 20 samples from different locations of the plain have been tested in various ways with regard to dispersivity.

Key words: **Soil, dispersive, erosion, embankment, sediment, Sistan.**

خصوصیات خاک های واگرا در دشت سیستان، در شرق ایران

غلامرضا لشکری پور۱، ماشا ا.. خامه چیان۲، حمیدرضا سلوکی۳، ابراهیم رحیمی۴
۱) گروه زمین شناسی دانشگاه فردوسی مشهد.
۲) گروه زمین شناسی دانشگاه تربیت مدرّس
۳) گروه زمین شناسی دانشگاه سیستان و بلوچستان
۴) مهندسین مشاور ساپ، تهران

چکیده
این مقاله واگرایی خاک‌های دشت سیستان که بر روی فرسایش‌پذیری آنها تأثیر دارد مورد برّرسی قرار می‌دهد. این منطقه به‌صورت دشت گسترده و مسطّحی در شرق ایران است که در دلتای رودخانه‌ی هیرمند (هلمند) شکل گرفته است. شهر زابل، بزرگترین شهر در منطقه سیستان تقریباً در مرکز این دشت قرار دارد. حمل حجم عظیمی از رسوبات توسّط رودخانه‌ی هیرمند به این دشت در گذشته سبب کاهش عمق دریاچه‌ی هامون در نزدیک شهر زابل شده است. این فرایند سبب شده تا ارتفاع شهر زابل از برخی قسمت‌های دریاچه‌ی هامون کمتر گردد. به همین دلیل خاکریز گسترده‌ای در اطراف شهر جهت حفاظت آن در مقابل سیلاب‌های رودخانه‌ی هیرمند احداث گردیده است. یکی از مسائلی که این شهر در سالهای اخیر با آن مواجه بوده بحث تخریب خاکریز حفاظتی شهر می‌باشد. تخریب قسمت‌هایی از این خاکریز سبب خسارات عمده به تأسیسات شهری شده است.
دشت سیستان از خاک‌های ریزدانه مانند سیلت و رس تشکیل شده است. لذا احتمال تخریب این خاکریز و ارتباط آن با واگرایی خاک‌های منطقه وجود دارد. در این تحقیق احتمال رابطه‌ی بین واگرایی خاک‌ها و تخریب در برخی قسمت‌های خاکریز مورد برّرسی قرار گرفته است. در این راستا ۲۰ نمونه خاک از قسمت‌های مختلف دشت جهت برّرسی واگرایی مورد آزمایش قرار گرفته است. نتایج آزمایش نشان‌دهنده‌ی واگرایی در چند نمونه می‌باشد و این می‌تواند دلیلی بر فرسایش در خاک‌های منطقه‌ی مورد مطالعه باشد.

واژه‌های کلیدی: خاک، واگرایی، فرسایش، خاکریز، رسوب، سیستان.