Transportation Infrastructure Geotechnology (2020) 7:46–54
https://doi.org/10.1007/s40515-019-00089-4

TECHNICAL PAPER

The Influence of Natural Pozzolans Structure on Marl Soil Stabilization

Hadi Bahadori[1] · Araz Hasheminezhad[1] · Sakineh Alizadeh[2]

Accepted: 31 July 2019 / Published online: 7 August 2019

Abstract
Marl as a calcareous soil has heterogeneous nature in terms of structure and properties. Any change in the water content of marl can cause significant strength loss; therefore, prior stabilization while constructing civil infrastructures is necessary. A fundamental element in soil stabilization is the relationship between soil structure and stabilizers, but this important factor has been ignored in the available literature, especially in the case of marl soil. Lately, alternative environmentally friendly additives (natural pozzolans) as well as traditional chemical stabilizers (cement and lime) have been successfully used for stabilization of marl soil. This paper presents the results of an experimental study which investigates the influence of natural pozzolans structure on marl soil stabilization. Transmission electron microscopy (TEM), X-ray fluorescence (XRF), and Fourier transform infrared spectroscopy (FTIR) tests were used for size and structure analysis of marl soil and two types of natural pozzolans called Qizkorpi and Mamaloo of Iran which have been successfully used for marl soil stabilization by the authors, recently. Based on the obtained results by TEM, FTIR, and XRF tests, due to the similarity of the structure and size of Gizkorpi volcanic ash and marl soil when compared to that of Mamaloo volcanic ash, it can be concluded that the electrostatic and magnetic interactions in marl and Gizkorpi volcanic ash lead to a better stabilization and strengthen of the marl, while these interactions are less in Mamaloo volcanic ash when mixed with the marl soil.

Keywords Marl · Natural pozzolans · Structure analysis · Stabilization · Soil improvement

✉ Hadi Bahadori
h.bahadori@urmia.ac.ir

Araz Hasheminezhad
a.hasheminezhad@urmia.ac.ir

Sakineh Alizadeh
solmaz.alizade@gmail.com

Extended author information available on the last page of the article

1 Introduction

Due to the crucial role of construction in the establishment of public places such as hospitals, airports, underground tunnels, highways, and dams, the need for building materials has greatly increased (Wijesundara and Dayawansa 2011).

Marlies whether in the form of rock or soil, are sedimentary deposits. Mostly, various proportions of clay and calcium carbonate are available in Marlies; this range may vary from 35 to 65% (Potter and Pettijohn 2012). According to the mineralogical attitude, physical properties, dough properties, inflation ability, durability, and fluctuation are due to the alterations in carbonate, percentage of clay minerals and carbonate to clay minerals, and also clay minerals (Soltani et al. 2006). Marl due to its diverse characteristics can be considered as an independent group of soil. It seems to be the result of the physical and chemical weathering of carbonate rocks (limestone, dolomite, carbonate sandstone, etc.). Marl soil can be found in different parts of the world such as Mediterranean, dry, and desert areas. Diverse types of marl are also available in the Near East and in Pakistan, Iran, Iraq, Jordan, Lebanon, central Sudan, Egypt, Saudi Arabia, and other Gulf states.

Marl as a problematic soil is sensitive to water content changes and often requires prior stabilization. Otherwise, a significant strength loss will occur after the construction of civil infrastructures. Therefore, soil enhancement techniques are recommended before conducting any construction. Common and affordable method in engineering to improve soil characteristics is soil stabilization. This method can provide cheap materials for the construction of low-cost roads; therefore, it can be used in building material. In order to improve the performance of soil stabilization, conventional additives such as sand, silt, lime, fly ash, and volcanic ash are commonly added to the soil. Using natural materials as stabilizers in soil stabilization has various advantages; therefore, recently, much attention has been paid on this method by researchers (Kukko 2000; Moon et al. 2009; Al-Amoudi et al. 2010; Jiang et al. 2010; Maaitah 2012; Latifi et al. 2018; Silveira et al. 2018; Bahadori et al. 2018; Bahadori et al. 2019).

It should be noted that the relationship between soil structure and stabilizers is key element in soil stabilization which can affect the effectiveness of the additivities that are available in soil stabilization. Miller and Azad (2000) evaluated the effectiveness of cement kiln dust (CKD) as a soil stabilizer in a laboratory study. Their research investigated the influence of soil type on stabilization with CKD. Their measurements indicated that the change in pH of soil as a function of CKD content was related to the PI of the untreated soil, and there was a good correlation between pH response and performance of CKD-treated soil. Sharma et al. (2018) examined the independent roles of lime and cement on the stabilization of a mountain soil using X-ray diffraction (XRD), scanning electron microscopy (SEM), and FTIR analysis. Based on their results, cement has a relatively higher influence on the mechanical behavior of soil when compared to that of lime.

A review of the available literature indicated a limited number of reports focusing on soil and stabilizer structures and their influences on stabilization process. Recently, Bahadori et al. (2018) have made a comparative study on the effects of three types of natural pozzolans including Qizkorpi, Mamaloo, and Chichest volcanic ashes of Iran on marl soil stabilization. Based on their obtained results, the sustainable development of the construction infrastructures can be promoted by the proposed stabilization of marl soils with volcanic ashes. In their research, Gizkorpi volcanic ash has been given much better results in comparison to Mamaloo and Chichest volcanic ashes.

This paper presents the results of an experimental investigation focused on the influence of size and structure of Qizkorpi and Mamaloo volcanic ashes on marl soil stabilization. For this purpose, TEM, FTIR, and XRF tests were conducted to characterize the size and structure analysis of the studied marl soil and two natural pozzolans used for marl soil stabilization by the authors, recently.

2 Materials

This research has been organized as an experimental research. Therefore, an appropriate volume of marl soil and two types of natural pozzolans called Qizkorpi and Mamaloo collected from Urmia, Iran were used. Illustrations of marl soil, Gizkorpi, and Mamaloo volcanic ashes have been given in Fig. 1.

2.1 Marl

Marlins are a mixture of clay, carbonate, and other minerals that are of marine origin and lakes and freshwater. Marl stones and freshwater marls are intermediate sediments between clay and limestone. The available grading in marls due to its adjustable nature cannot indicate the rock’s age; therefore, marlin stones are preferred over marl. Marlins appear in the form of sediments that quickly settles in shallow lakes. Marlades are sometimes created in lakes, especially when water is saturated with carbonate; the extraction of carbon dioxide by carbonate algae results in the creation of sediments

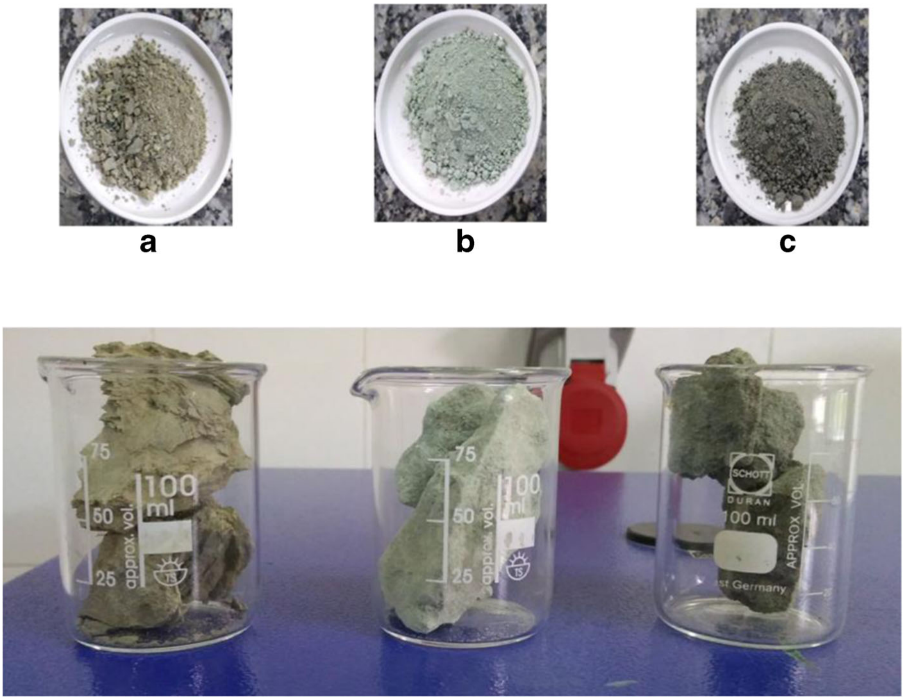

Fig. 1 Illustrations of **a** Marl soil, **b** Gizkorpi, and **c** Mamaloo volcanic ashes

may be deposited in carbonate flowers. In this study, marl soil was collected from Golshahr area in Urmia, Iran.

2.2 Natural Pozzolans (Qizkorpi and Mamaloo Volcanic Ashes)

Natural pozzolans (volcanic ashes) are composed of particles such as volcanic material and volcanic rocks that are at the same as powder and sand, blown up by volcanic eruptions. This term is used for materials that are suspended in the air and then spilled on the ground, but after a while, they turn into rocks. Volcanic ash particles are very small in size and have a cavity texture with many cavities. The location where the Qizkorpi volcanic ash was collected as a stabilizer for this study was at 20 Km on the Shahindezh-Takab road. The location where the Mamaloo volcanic ash was collected as a stabilizer for this study was at 12 Km, on the Mamaloo Road.

3 Experimental Program

3.1 TEM Test

Transmission electron microscopy (TEM) is a technique which forms a significantly higher resolution image than light microscopes, due to the smaller de Broglie wavelength. In this technique, a beam of electrons transmits through a specimen which is usually an ultrathin section less than 100 nm thick or a suspension on a grid. The formed image is then magnified and focused onto an imaging device or a sensor such as a charge-coupled device. TEM is a major analytical method in the physical, chemical and biological sciences and virology, and materials science. It also can be used in cancer researches, pollution, nanotechnology, and semiconductor researches.

3.2 XRF Test

As an elemental analysis, technique X-ray fluorescence (XRF) spectrometry has extensive application, and for many years, it has been used to determine the elemental composition of materials including metal alloys, minerals, and petroleum products. In this spectrometry, the individual atoms are excited by an external energy source and therefore emit X-ray photons. The available elements may be identified and quantitated through the number of photons emitted from a certain sample. XRF has the ability to analyze various elements such as sodium and uranium in different concentrations ranging from parts per million to high percent; these elements can be in the form of solid, liquid, or powder. In this study, the results of XRF analysis of the oxides for samples of marl soil and two types of volcanic ash were performed with 92zr-4502 Standard.

3.3 FTIR Test

Fourier transform infrared spectroscopy is an analytical method used to recognize organic, polymeric, and, in some cases, inorganic, unknown materials (e.g., films, solids, powders, or liquids), and contamination on or in a certain material (e.g., particles, fibers, powders, or liquids), additives especially after their extraction from a polymer matrix and oxidation, decomposition, or uncured monomers in failure analysis investigations. Therefore, this method is used to analyze the chemical composition of smaller particles, typically 10–50 μm, as well as larger surfaces (Madrakian et al, 2017). The FTIR analysis method uses infrared light to scan and observe chemical properties of test samples. FTIR spectroscopy as the initial step in the material analysis controls the quality of manufactured material. Therefore, in the case of any problem with the product identified by visual inspection, the initial and original one is usually determined by FTIR microanalysis.

4 Results and Discussion

4.1 TEM Analysis

TEM analysis results for marl soil, Qizkorpi, and Mamaloo volcanic ashes have been presented in Fig. 2. According to this figure, the structure of Gizkorpi

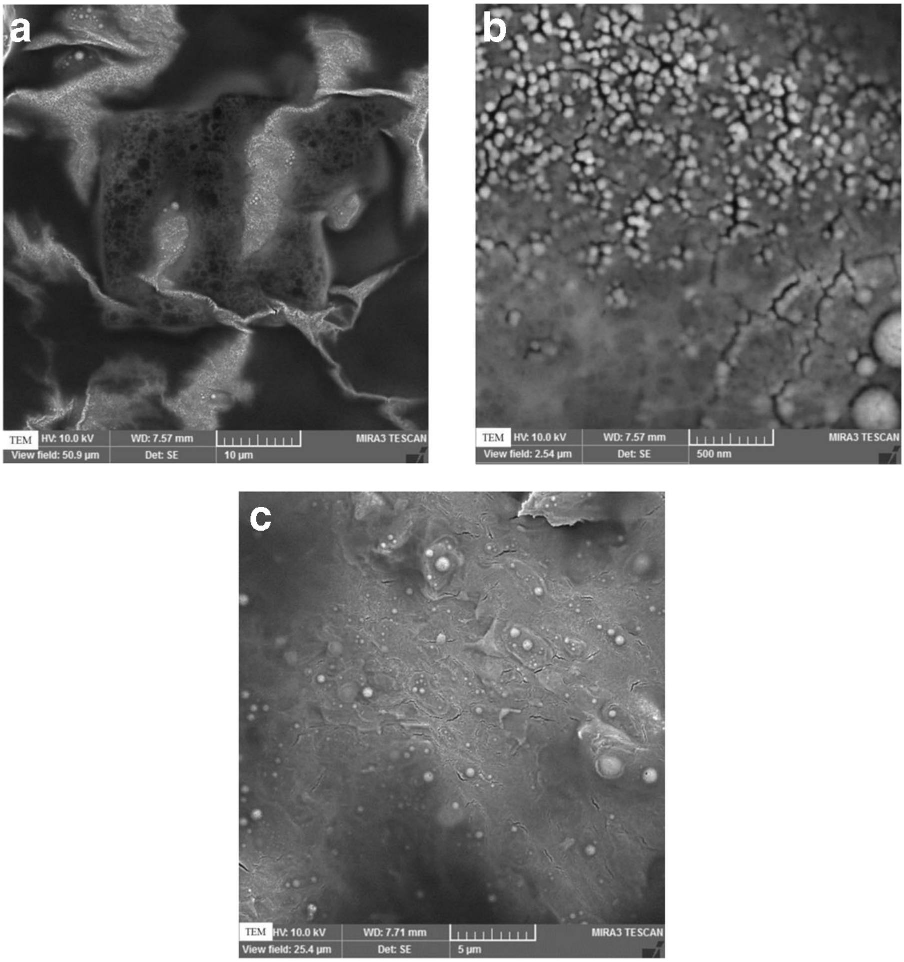

Fig. 2 TEM image of **a** Marl soil, **b** Mamaloo, and **c** Gizkorpi volcanic ashes

Table 1 XRF analysis of Marl soil, Gizkorpi, and Mamaloo volcanic ashes

Compound	Unit	DL	Scheme	Marl soil	Gizkorpi	Mamaloo
SiO_2	%	0.01	WR-01	24.53	61.19	73.26
Al_2O_3	%	0.01	WR-01	4.47	13.86	10.89
BaO	%	0.01	WR-01	0.02	0.07	0.15
CaO	%	0.01	WR-01	35.14	5.06	2.07
Fe_2O_3	%	0.01	WR-01	1.9	5.54	1.38
K_2O	%	0.01	WR-01	0.73	3.43	2.54
MgO	%	0.01	WR-01	1.57	1.67	0.93
MnO	%	0.01	WR-01	0.02	0.09	0.06
Na_2O	%	0.01	WR-01	0.35	1.85	0.99
P_2O_5	%	0.01	WR-01	0.08	0.15	0.06
SO_3	%	0.05	WR-01	0.16	–	0.07
TiO_2	%	0.01	WR-01	0.24	0.67	0.2
Cr_2O_3	%	0.01	WR-01	–	–	–
LOI	%	0.01	WR-01	30.94	6.42	7.48

volcanic ash and marl soil is very similar when compared to Mamaloo volcanic ash. In this regard, the interaction of Gizkorpi volcanic ash with marl soil in stabilization process is much more effective than Mamaloo volcanic ash.

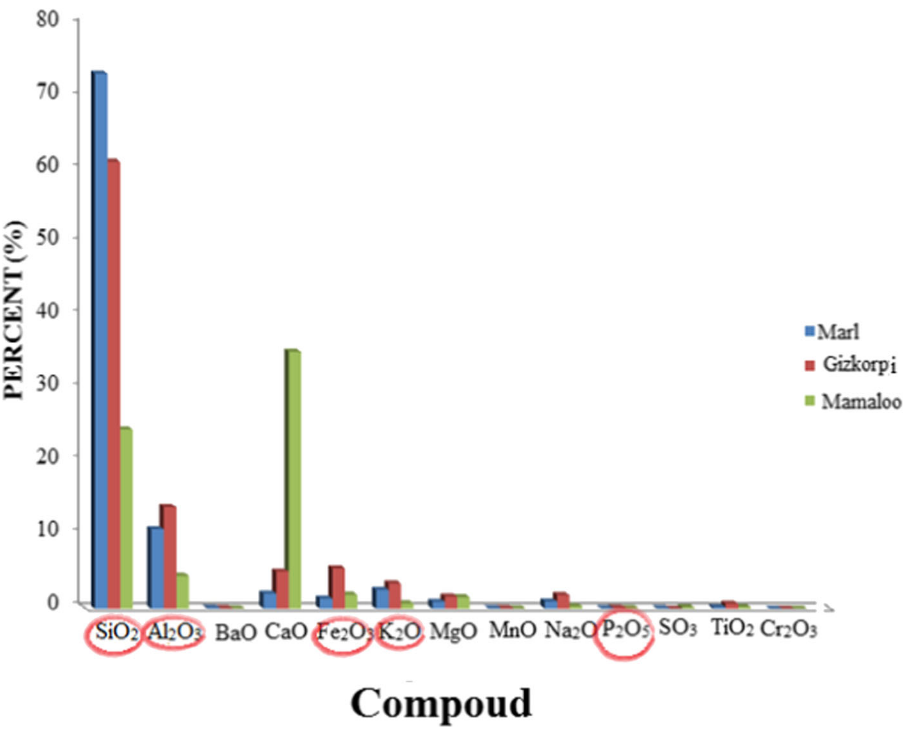

Fig. 3 Column type plot of compound/% from XRF result

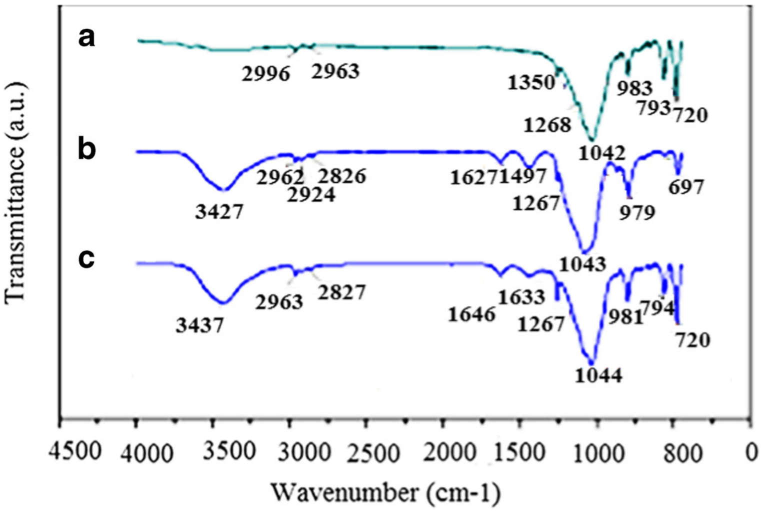

Fig. 4 FTIR spectra of **a** Marl soil, **b** Mamaloo, and **c** Gizkorpi volcanic ashes

4.2 XRF Analysis

XRF analysis of marl soil and volcanic ashes has been given in Table 1. The XRF results in Table 1 and column type plot of compound/% from XRF result as shown in Fig. 3 indicate that calcium oxides present in Gizkorpi volcanic ash are more similar to marl. This similarity was also available in the higher iron oxide levels that included magnetic interactions when compared to Mamaloo volcanic ash. Eventually, the presence of phosphorus oxide as the oxidizing agent and the oxidation and hydrogen band interaction in Gizkorpi volcanic ash will further strengthen its mixture with marl.

4.3 FTIR Analysis

FTIR spectra of marl soil, Mamaloo, and Gizkorpi volcanic ashes have been presented in Fig. 4. According to this figure, the absorption band at about 3420–3440 cm^{-1} in the FT-IR spectrum of Mamaloo and Gizkorpi was assigned to the stretching vibration of hydroxyl groups and interlayer water molecules that is effective in compression behavior of soil, volcanic ashes, and hydrogen bonding. The weak band at 1627–1646 cm^{-1} was due to the bending mode of water molecule. The band with maximum peak at 1267 cm^{-1} was attributed to the stretching vibration of ions intercalated in the soil and volcanic ashes gallery. Finally, the bands at 600–1000 cm^{-1} were assigned to M–O stretching modes and M–O–H bending vibrations.

5 Conclusions

A wide variety of additives can be used to stabilize marl soil and improve its geotechnical and engineering properties. Properties of the stabilized marl soil with these additives depend on the characteristics of both soil and stabilization agent. Natural pozzolans as local, cost-effective, and environmentally friendly additive have been successfully used for marl soil stabilization by authors. In this paper, TEM, XRF, and FTIR tests were used to investigate the relationship between marl soil structure and two types of natural pozzolans known as Qizkorpi and Mamaloo. Based on the experimental results, the following conclusions can be drawn:

- According to TEM test, due to the similarity of the structure of Gizkorpi volcanic ash and marl soil, the interaction of these two materials improved marl soil stabilization, while Mamaloo volcanic ash had less interaction with marl soil.
- According to XRF test, the amount of calcium oxides in Gizkorpi was more similar to marl, but higher iron oxide levels were present in the Mamaloo. The presence of phosphorus oxide as the oxidizing agent and the oxidation and hydrogen band interaction with Gizkorpi volcanic ash further strengthen its mix with marl.
- According to FTIR test, the delicate structure was similar in the 600–1000 cm^{-1} area for both marl and Gizkorpi volcanic ash. This structure is important for the existence of specific and similar levels of oxides (M–O band), which was not the case in Mamaloo volcanic ash.
- The outcomes of this study can be used in practical engineering applications and provide new insights into the selection of suitable additives for marl soil stabilization.

Acknowledgments The authors would like to thank the dedicated assistances of technicians at soil laboratory of Urmia University.

References

Al-Amoudi, O.S.B., Khan, K., Al-Kahtani, N.S.: Stabilization of a Saudi calcareous marl soil. Constr. Build. Mater. **24**(10), 1848–1854 (2010)

Bahadori, H., Hasheminezhad, A., Taghizadeh, F.: Experimental study on marl soil stabilization using natural pozzolans. J. Mater. Civ. Eng. **31**(2), 04018363 (2018)

Bahadori, H., Hasheminezhad, A., & Mohamadi asl, S.. Stabilization of Urmia Lake peat Using Natural and Artificial Pozzolans. Proceedings of the Institution of Civil Engineers-Ground Improvement (In press-Ahead of Print), 1–32 (2019) https://doi.org/10.1680/jgrim.19.00024

Jiang, H., Cai, Y., Liu, J.: Engineering properties of soils reinforced by short discrete polypropylene Fiber. J. Mater. Civ. Eng. **22**, 1315–1322 (2010)

Kukko, H.: Stabilization of clay with inorganic by-products. J. Mater. Civ. Eng. **12**(4), 307–309 (2000)

Latifi, N., Vahedifard, F., Ghazanfari, E., Rashid, A., S, A.: Sustainable usage of calcium carbide residue for stabilization of clays. J. Mater. Civ. Eng. **30**(6), 04018099 (2018)

Maaitah, O. N.: Evaluation of Al-Karak ash for stabilization of marl clayey soil. Electron. J. Geotech. Eng., **17**(1), 1041-1046, (2012)

Madrakian, T., Alizadeh, S., Bahram, M., Afkhami, A.: A novel electrochemical sensor based on magneto LDH/Fe3O4 nanoparticles@ glassy carbon electrode for voltammetric determination of tramadol in real samples. Ionics. **23**(4), 1005–1015 (2017)

Miller, G.A., Azad, S.: Influence of soil type on stabilization with cement kiln dust. Constr. Build. Mater. **14**(2), 89–97 (2000)

Moon, D.H., Grubb, D.G., Reilly, T.L.: Stabilization/solidification of selenium-impacted soils using Portland cement and cement kiln dust. J. Hazard. Mater. **168**(2–3), 944–951 (2009)

Potter, P.E., Pettijohn, F.J.: Paleocurrents and basin analysis. Springer Science & Business Media, Berlin (2012)

Sharma, L.K., Sirdesai, N.N., Sharma, K.M., Singh, T.N.: Experimental study to examine the independent roles of lime and cement on the stabilization of a mountain soil: a comparative study. Appl. Clay Sci. **152**, 183–195 (2018)

Silveira, M.V., Calheiros, A.V., Casagrande, M.D.T.: Applicability of the expanded polystyrene as a soil improvement tool. J. Mater. Civ. Eng. **30**(6), 06018006 (2018)

Soltani, A., Gholipoor, M., Zeinali, E.: Seed reserve utilization and seedling growth of wheat as affected by drought and salinity. Environ. Exp. Bot. **55**(1–2), 195–200 (2006)

Wijesundara, C. J., & Dayawansa, N. D. K. Construction of large dams and their impact on cultural landscape: a study in Victoria reservoir and the surrounding area. **22**(1), 211 - 219 (2011)

Affiliations

Hadi Bahadori[1] **· Araz Hasheminezhad**[1] **· Sakineh Alizadeh**[2]

[1] Department of Civil Engineering, Urmia University, Urmia, Iran

[2] Department of Chemistry, Bu-Ali Sina University, Hamedan, Iran