

A New Approach to the Landslide Early Warning using the Chemical Composition Fluctuation in the Leakage from Susceptible Slopes

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ABSTRACT Landslides are natural disasters that annually inflict great damages to public and private properties which may associate with loss of life. In recent decades, research on developing methods for predicting the time of landslide has been one of the significant attempts made by scientists. Since in some type of material, landslides are preceded by undetectable movements that cannot be recorded and revealed by conventional instruments, recording the chemical changes of the water flowing out from the toe of the slopes susceptible to sliding can provide important and reliable indicators of landslide activities and early warning. In this study, changes in the chemical composition of water seeping out from the toe of an active landslide were investigated. This process was studied in a laboratory physical model, in which a sliding surface was simulated and the changes in the ion concentration of potassium (K), sodium (Na), magnesium (Mg), calcium (Ca), sulfate (SO₄), chlorine (Cl), and bicarbonate as well as EC and pH in both stable state and in the conditions of slight rupture along the sliding surface were investigated. The results indicated that the appreciable chemical changes in the outflowing water, particularly changes in the concentration of some ions, could be used as suitable indicators for early warning of the landslide occurrence.

Key words: *Early Warning, Landslide, Leakage Chemical Composition, Mass Movement Monitoring*

1 INTRODUCTION

Study of natural disasters has been in the focus of research by scientists and scientific societies in recent decades. The main objective in most of these studies has been to understand the phenomena and the factors affecting their occurrence in order to develop some methods for their prediction and control. Considering the available technologies and the high costs of monitoring, the majority of these studies and the prediction methods for such events as earthquake, flood, and landslide are based on statistical analyses and present some reasonable

success. Along with the progress in developing suitable technologies for monitoring instrumentation and information transfer in recent years, research has begun on prediction of the time of natural phenomena occurrence and post-event behavior. However, the complexity of the sub-surface structures from the geological and geotechnical standpoint together with the uncertainties associated with precipitations forecasts, the diversity in groundwater behavior, the unpredictability of the time of earthquakes and its severity, and many other unknown factors complicates

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understanding of the processes leading to landslides. Thus, it may be said that one of the most effective and reliable methods in prediction of time and behavior of landslides occurrence is the monitoring of the movement at some slopes in a region together with the changes in triggering factors.

To monitor the behavior of slope activities, various type of equipment have been designed for surface and in-depth displacement determination. Usually, most landslides have early signs that could be used to predict the occurrence of the main failure (Shoaiei *et al.*, 2001, 2002). Therefore, the most important issue in such prediction at the potentially unstable slopes is the presence or absence of observable early warning signs. In some research, it has been shown that usually in fine grain soils, the sliding behavior is of creeping type in which prediction will be possible if the phases of the creep consisting of the primary, secondary, and tertiary creep are carefully monitored and recognized (Fedaa, 1992, Shoaiei and Karamoltani, 2011). Shoaiei (2005) showed that in some types of soils such as loess, landslide occurrence is sudden and there is almost no indicative movement before the main failure that can be recorded by the conventional instruments.

Considering the mechanism of formation of a sliding surface in a soil mass, it is acceptable that, in most cases, before any movement can be observed on the surface or in the observation wells, a very slow movement starts that gradually continues to form the sliding surface. When the surface is formed, observable movements can be recorded by the conventional instruments. In many landslides, the short time interval between the formation of the sliding surface and occurrence of the landslide does not allow provision of the risk management and necessary mitigation measures. Thus, if the small and slow movements along the sliding surface can be sensed and revealed, it will be

possible to issue early warning notices in a proper time interval. In the present study, the possibility of initial and undetected movements monitoring at the sliding surface is investigated based on effects of these movements on water seeping out from the slope chemical composition.

Presence of water is one of the main factors provoking slope failures and usually 90% of landslides occur in saturated or semi-saturated soils (Yan, 1994). In fine grained soils with high plasticity, 90% of soil shearing strength may be lost upon absorption of water. This loss is probably due to soil expansion and disruption of the bonds between soil particles (Leroueil and Vaughan, 1990). Following this phenomenon, the soil mass may experience small shears and disruption in its natural drainage, which could in turn result in changes in the chemical composition of the water percolating through the soil mass. The relationship between changes in the opening of the surface cracks in a landslide and changes in the ionic composition of water seeping out of the sliding mass has been reported in some research (Sakai, 2001 and 2009). He showed that the increase in ionic concentration had a direct relationship with the opening of cracks and the fissures newly formed as a result of slope movement.

It has been well established that cation exchange is one of the important properties of clay soils. Due to its lattice structure resulting from octahedral and tetrahedral arrangements, a clay unit has a negative charge on its surface which attracts and adsorbs the free cations from its surrounding. These cations surround the clay particles. The surface and outer part of this "layer" of ions is under weaker force and can be leached and drained out by the flowing water. However, the interlayer ions have no high exchange capacity. Ion exchange capacity in silty sandy soils is low or non-existent.

The concept used in this work can be summarized as follows;

1. Water that has infiltrated a sliding mass of soil moves through the pores preferentially toward lower positions down the slope.
2. The draining water will dissolve different compounds along its way depending on their composition and pH and will transfer them out of the soil mass.
3. If the soil structure remains intact, the chemical composition of the water will also remain constant.
4. In case the structure is disrupted by displacement along the sliding surface, the drainage condition and path of the water percolation will also change, resulting in changes in dissolution of the ions and ion exchanges of the water with the surrounding soil masses, thereby, affecting the concentration of the ions in the water leak from the soil mass.
5. In case of those changes are recorded continuously, their monitoring could be used as a sign of the onset of a landslide. It can be used for landslide behavior monitoring and, possibly, prediction of the time of main failure.

Considering the diversity of the chemical composition of the natural soils, chemical analysis of soils for recognition of the compounds and elements susceptible to leaching in each region should precede the establishment of the chemical monitoring plan.

In this research, this process was investigated in a laboratory model simulating sliding surface. The concentration of potassium (K), sodium (Na), magnesium (Mg), calcium (Ca), sulfate (SO_4), chlorine (Cl), and bicarbonate (HCO_3) ions as well as EC and pH were compared in the stable state and after of slight displacement along the sliding surface.

2 MATERIALS AND METHODS

2.1 Saturated sliding surface model

The sliding model has basal dimensions of 130x170 cm and a height of 70 cm that was placed in a container box of transparent Plexiglas (Figure 1).

To control and direct the seepage water along the sliding surface, the lower part of the model is made of an impermeable block in which all joints of the box are waterproofed with silicon glue, preventing any leakage downward. The upper surface of this block with a slope of 30 degrees constitutes the lower part of the sliding surface (Figure 2). On the lower surface, the soil layer is laid as the model of sliding surface. To prevent the soil mass from sliding during shearing displacement, a number of nails have been driven into the surface with an effective height of about 2 cm into the soil.

On the upper part of the soil layer, a moveable plate is placed which has a number of nails, similar to those in the lower surface to ensure its complete contact with the upper part of the soil and prevent soil sliding over the upper plate (see Figure 2). Two guiding beams were installed on the wall of container in order to control the vertical displacement of upper plate and keep the soil compaction unchanged at the time of leaching and shearing displacement (is not visible in the section).

Considering the necessity of using the constant chemical composition of the inflowing water throughout the study, the entire amount of water was stored in a 180-liter tank at a proper hydraulic head (Figure 1).



Figure 1 A complete view of the physical model made in the laboratory

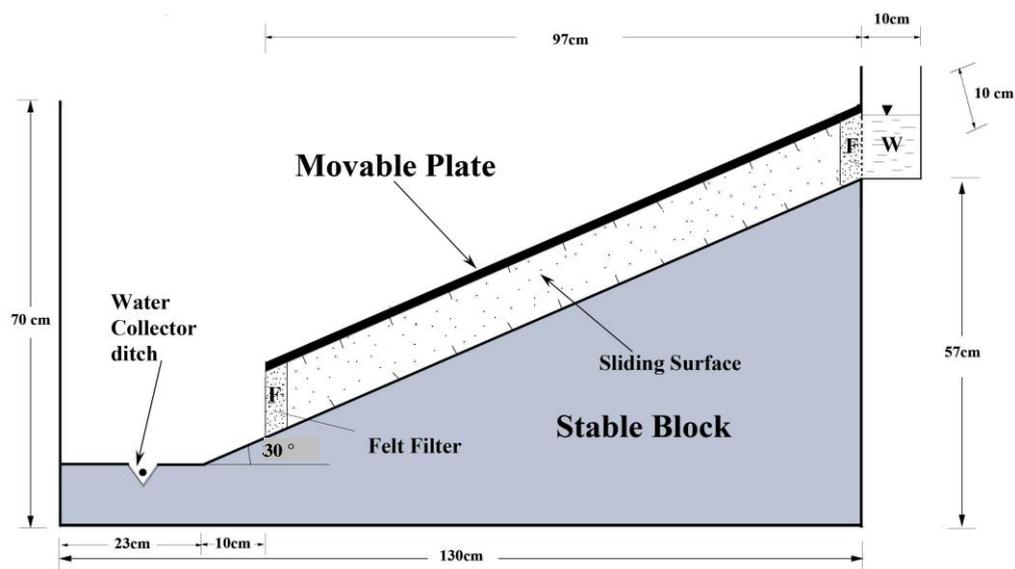


Figure 2 Longitudinal cross section of a physical model made for a saturated sliding surface

To control the hydraulic head of the water flowing over the sliding surface, a secondary tank was attached to the model to provide the inflow water needed for the model ("w" in Figure 2). The height of water in this tank is controlled by an automatic valve.

Since the sudden change in the hydraulic gradient at the inflow and outflow sections of the model could cause turbulent flow and disturbance of soil structure, two felt filters with a thickness of 2 cm (F in Figure 2) were placed at the up and downstream sections of the soil mass.

At the downstream section of the slope, a narrow ditch was made across the model width to collect the outflowing water (Figures 1, 2). The water in the ditch was guided out of the model and was collected in a graduated cylinder to be taken to the laboratory for chemical analysis.

2.2 Model Preparation

The soil for this model should have the proper compaction for simulating the sliding surface and adequate permeability to allow water movement through it. Besides, the soil should contain suitable clay minerals to participate in the ion exchange processes. A silty-clayey soil of Quaternary sediment in southwest of Tehran (Iran) that was resulted from the weathering and erosion of Eocene limestone, andesite and tuff of Alborz mountain in north of Tehran

was selected. X-ray diffraction analysis (XRD) of the sample showed the presence of chlorite, illite, and montmorillonite. To determine the general physical and mechanical characteristics of the soil, grain analysis, Atterberg limits, direct shear test under saturated condition, and permeability with a bulk density similar to that in the model ($\gamma_w=1.70 \text{ g cm}^{-3}$) were performed. The results of these tests are shown in Table 1. Considering the presence of 27% clay, 43% silt, and 30 % sand, this soil is in class CH based on the Unified Classification (ASTM, 2010).

To provide steady flow of water in the soil the sample should be relatively homogeneous with isotropic compaction. Extra care must be taken while pouring the soil into the model box and its compaction. To achieve the proper compaction, after selecting adequate amount of soil, it was moisturized and then, compacted uniformly.

The soil sample was poured into the model in several layers and each was compacted separately until the thickness of the soil in the model reached 10cm. Then, the upper-layer plate, which had been equipped with 2 cm nails similar to the lower plate, was placed on the soil surface.

Table 1 Physical and mechanical characteristics of the employed soil

Soil Class (Unified)	Density ($\gamma_w, \text{g cm}^{-3}$)	Liquid limit (LL, %)	Plastic Limit (PL, %)	Permeability (cm s^{-1})	Soil Strength Parameter (Saturated)	
					C (kg cm^{-2})	ϕ ($^\circ$)
CH	1.70	59.2	16.69	3.8×10^{-7}	0.8	16

2.3 Operation of the model

After soil was placed in the model, the water tank was connected to the system and the operation started. Once the secondary tank ("w" in Figure 2) was filled, water started flowing slowly through the upstream felt filter (F) into the soil mass and passed along the slope downward to the lower parts of the sliding surface being driven by the hydraulic gradient. At this point, water permeating through the lower felt filter (F), was collected in the water collector ditch at the bottom of the model and underwent chemical analysis. Generally, the model operation was conducted in two phases:

2.3.1 Phase I

The soil was collected from the mine as a disturbed sample and was poured in the model unsaturated. It was expected that in the first run of the study, the concentration of different elements in the outflowing water would be high. Thus, the first run of the model operation was continued until the inflowing water saturated the soil mass, leached elements, and free the exchangeable ions, while their concentration remained constant. To monitor the changes in the concentration of the elements and changes in the chemical parameters, water sampling started at the toe of the soil mass immediately after water leaked from the model outlet. This was followed by chemical analysis of the water samples. The first run was continued until the changes in ionic concentrations reached a minimum value.

Water samples were collected in 1000 ml containers and sent to the chemical laboratory. In the first run, a total of 24 samples were collected from the start of the run to the time when the ionic concentrations remained constant. This phase of the study lasted for 637 hrs (~ 27 days), during which almost all of the ionic concentrations reached a reasonably constant level. Once this constant level was reached, the second phase of the study started.

2.3.2 Phase II

This phase started immediately after ionic concentration in the outflowing water became constant. A 5 cm shearing was made along the sliding surface. This was done after the inflow was stopped temporarily to avoid disruption in the saturated soil. During shearing through the sliding surface of the model, an adequate amount of weight was placed on the upper surface to prevent separation of the upper plate from the soil and its uncontrolled disturbance. Afterwards, the water was turned on again and sampling of water from the toe of the sliding surface continued. Sampling and analytical procedures were similar to those at phase I. Water sampling continued until the concentrations of the ions under consideration remained constant. A total of 27 samples of 1000 ml were taken during 355 hrs (~15 days).

3 DISCUSSION

The total time for the first phase was 637 hours and, for the second phase, 355 hr, thus, the total time spent for both phases was 992 hrs (~42 days). A complete chemical analysis was carried out to determine the concentration of cations and anions as well as the EC and pH of the inflowing water (column 1 of Table 2).

The amounts of chemical elements in the inflow water were subtracted from the corresponding values in the outflowing water, since they were considered as external elements added to the system. Thus, the changes in ionic concentrations of the outflowing water showed the net values resulting from the water passing through the soil.

Results of changes in the cation and anion concentration of the outflow water in the two phases of the study are shown in the diagrams of Figures 3 to 9. Also, a summary of the results is shown in Table 2.

The first cation studied was the monovalent sodium cation (Na^+) (Figure 3). In the beginning of the first phase of the study, Na^+

concentration was measured at 7.15 meq l^{-1} , while the Na^+ concentration in the inflow water was 2.28 meq l^{-1} (Table 2).

Subtracting the latter value from the former gives the total sodium cation leached from the soil body as 4.87 meq l^{-1} , which is the result of water passing through the soil pores of the sliding surface in the model. With continued drainage in some 490 hrs, the change in concentration of sodium cation was almost

negligible and, after 637 hrs, reached a relatively constant value of 1.75 meq l^{-1} . In the phase II, when a shearing of about 5% of the slope length was made in the sliding surface, the concentration of Na^+ showed a clear increase to 3.2 meq l^{-1} in 20 hours after displacement, which reflected the excellent sensitivity of this cation to displacement in this soil.

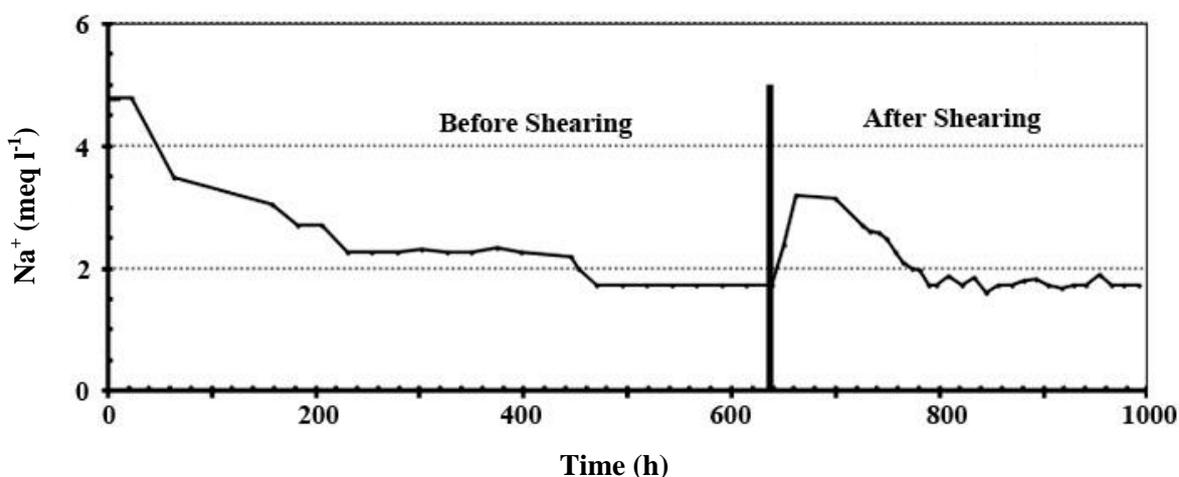


Figure 3 The changes in monovalent Na^+ cation

Table 2 Summary of the results of the chemical analysis

		Inflow Water B	Initial state A	Net amount A-B	Steady state before shearing	Peak state after shearing	Steady state after shearing
EC	$\mu\text{s cm}^{-1}$	610	2800	2190	-	-	-
pH	-	8.03	-	-	-	-	-
Na^+		2.28	7.15	4.87	1.75	3.2	1.74
K^+		0.05	0.26	0.21	0.14	0.26	0.13
Ca^{2+}		4.2	31.2	27.0	4.1	4.1	4.1
Mg^{2+}	meq l^{-1}	0.5	8.0	7.5	0.8	2.75	0.8
Cl^-		4	11	7.0	4.1	4.2	4.15
SO_4^{2-}		1.33	31.36	30.03	1.6	1.5	1.65
HCO_3^-		1.7	4.3	2.6	2.2	2.8	1.8

Forty hours after the Na^+ concentration increased up to the maximum level, it started to decline and reached 1.74 meq l^{-1} , which was close to the value before the soil was sheared. Afterwards, it remained almost constant toward the end of the experiment (992 h).

The second monovalent cation investigated was K^+ , (Figure 4). In spite of its relatively lower concentration in employed sample, K^+ showed a behavior similar to Na^+ . In the beginning of the test, K^+ concentration was 0.26 meq l^{-1} . Thus, considering potassium concentration of 0.05 meq l^{-1} in the inflow water (Table 2), the increase in K^+ due to the dissolution of this cation from the surrounding soil was 0.21 meq l^{-1} . The K^+ concentration in the first phase of the study reduced to 0.14 meq l^{-1} after 566 hrs and remained at this level till the soil was sheared (637 h). After the second phase and the displacement of the sliding surface, the concentration of this ion in the outflow water at the toe of the sliding surface showed a relatively significant increase (118 hours after the soil was sheared) when the concentration reached 0.26 meq l^{-1} . With continued leach of this ion until 147 hours after sliding, its concentration declined to approximately 0.13 meq l^{-1} and

remained close to this level till the end of the test (992 h).

The next cation investigated was the divalent ion of calcium (Ca^{2+}) (Figure 5). In the soils of Iran that are mostly calcareous, this ion is most prevalent. The concentration of this ion in the beginning of the first phase reached 31.2 meq l^{-1} (Figure 5).

Subtracting the concentration of Ca^{2+} from this value in the inflowing water, which was 4.2 meq l^{-1} (Table 2), its concentration in the outflow water due to the dissolution of this cation from the surrounding soil was calculated at 27 meq l^{-1} . Although, the concentration of this ion at the beginning of the experiment was relatively high, it showed high sensitivity to leaching and in a period of 320 hrs, it decreased to 4.1 meq l^{-1} and remained at that level until the end of the first phase (637 h). The interesting behavior shown by this cation after the second phase and displacement of the sliding surface was that, in spite of calcium ion high concentration and quick leaching in the first phase, it did not display appreciable sensitivity and detectable changes in its concentration in the second phase.

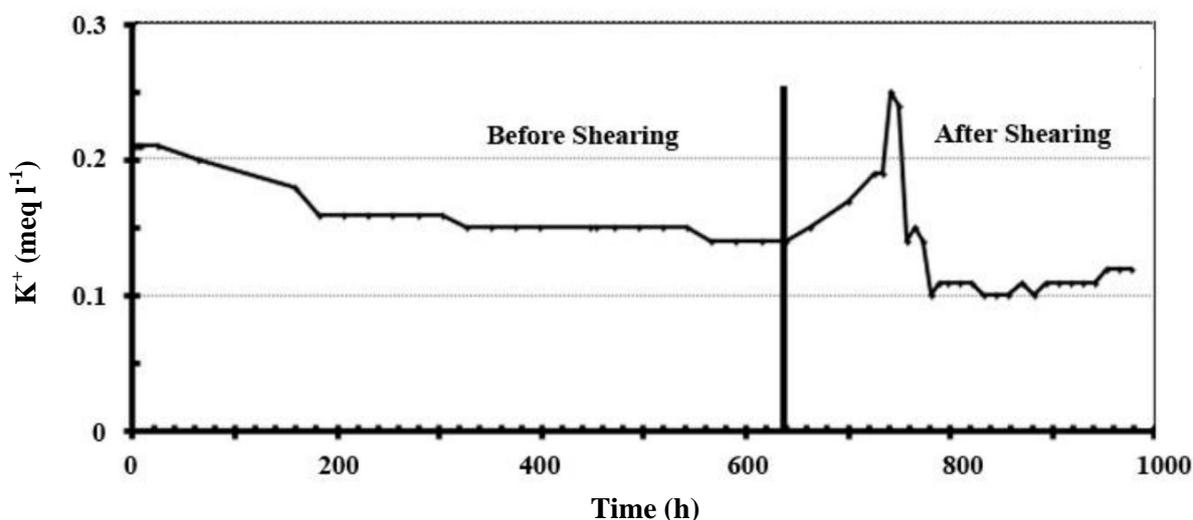


Figure 4 The changes in monovalent K^+ cation

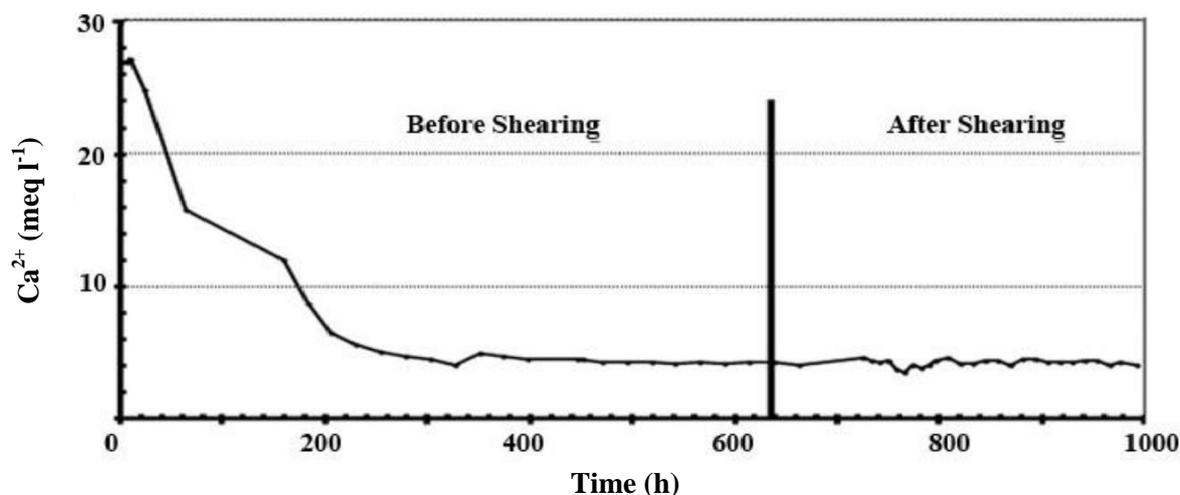


Figure 5 The changes in divalent Ca^{2+} cation

Figure 6 presents the results of the divalent Magnesium cation (Mg^{2+}) studied in this research. The concentration of this cation in the outflowing water at the toe of the slope was 8.0 meq l^{-1} . Subtracting from this value the concentration of Mg^{2+} in the inflowing water, which was 0.5 meq l^{-1} (Table 2), the increase in its concentration in the outflow water due to the dissolution of this cation from the surrounding soil was calculated at 7.5 meq l^{-1} . With continued leaching of this ion until 520 hrs after sliding, its concentration declined to approximately 0.8 meq l^{-1} and remained close to this level until the end of the first phase (637-h). In the second phase, when a shearing was made in the sliding surface, this cation showed a reasonable sensitivity to the displacement and its concentration increased from 0.8 to 2.75 meq l^{-1} in 20 hours after displacement. With continuation of water seepage and outflow and 207 hours after the start of the second phase, Mg^{2+} concentration decreased again and was almost fixed at the original level of 0.8 meq l^{-1} .

The first monovalent anion studied in this model was chlorine (Cl^-), of which the results are shown in Figure 7. The concentration of this

anion in the outflow water at the foot of the slope was 11 meq l^{-1} . Considering Cl^- concentration in the inflowing water, which was 4 meq l^{-1} , the increase in its concentration in the outflow water due to dissolution from the soil of the sliding surface was 7.0 meq l^{-1} . With further leaching, the concentration of this anion decreased relatively quickly and, after 205 hours, was fixed at 4.1 meq l^{-1} and did not show detectable change to the end of the first phase (637-h).

As depicted in Figure 7, there was no appreciable change in the concentration of this anion after the displacement of the sliding surface. Indeed, the observed gradual, but insignificant, rise in the concentration was slight and reflected the insensitivity of this ion to displacement.

The second anion investigated was divalent SO_4^{2-} , which behaved similar to calcium and chlorine ions (Figure 8). In the beginning of the experiment, its concentration was 31.36 meq l^{-1} , which after subtraction of its concentration of 1.33 meq l^{-1} in the inflow water, showed that some 30.03 meq l^{-1} had been drained from the bulk soil of the sliding surface.

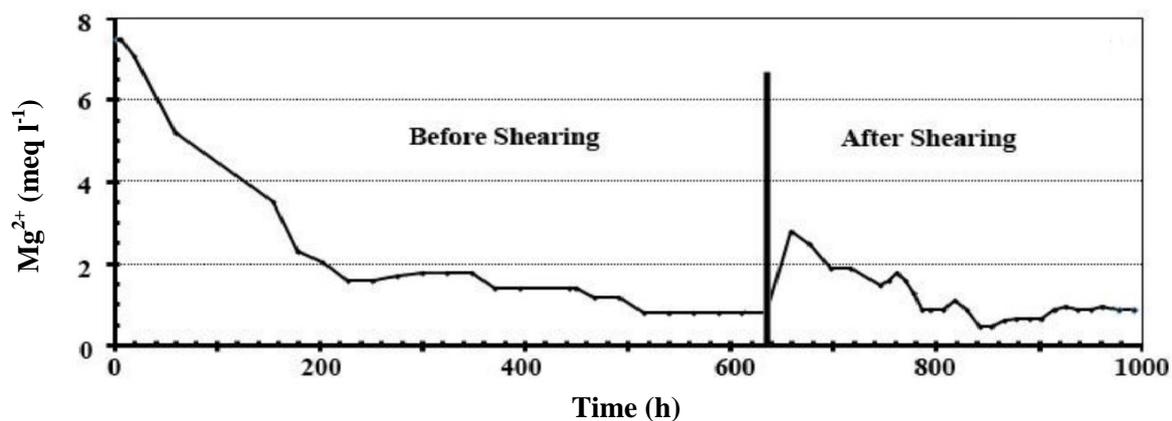


Figure 6 The changes in divalent Mg^{2+} cation

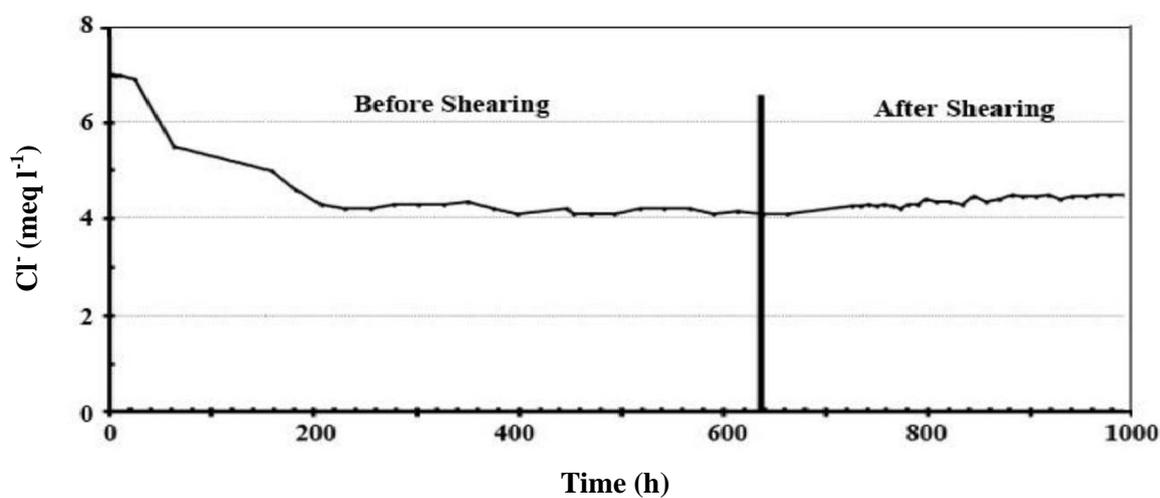


Figure 7 The changes in monovalent Cl^{-} anion

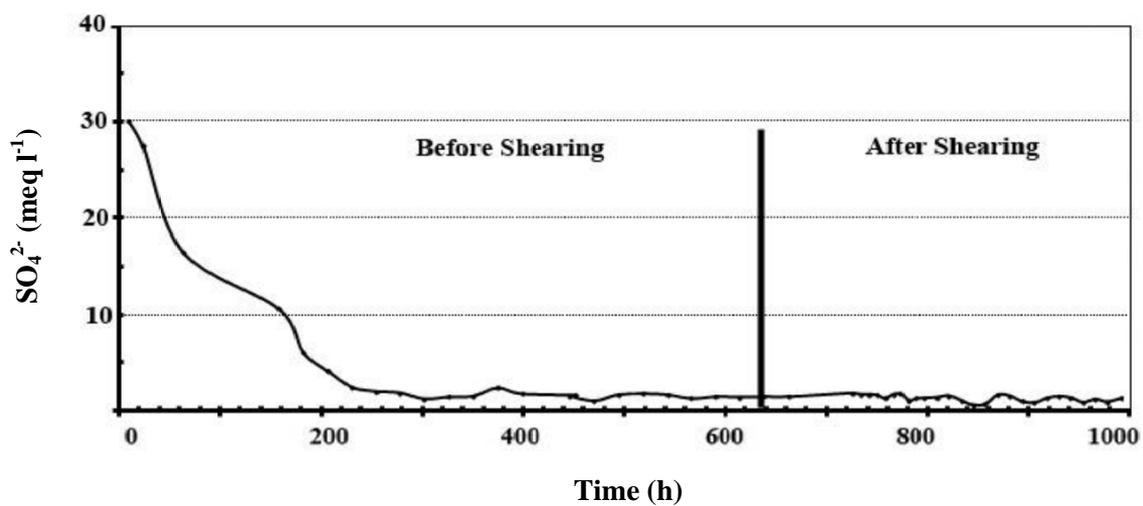


Figure 8 The changes in divalent SO_4^{2-} anion

This anion showed a relatively high susceptibility to leaching in the first phase, however, in about 200-h, its concentration decreased to 1.6 meq l^{-1} and was fixed at this level. As Figure 8 shows, in spite of SO_4^{2-} high sensitivity to leaching, it did not show remarkable response to the displacement in the second phase. Thus, there was no significant change in SO_4^{2-} concentration in the outflow water after shearing took place. Figure 9 shows the results of the third monovalent anion studied (bicarbonate, HCO_3^-). The concentration of this anion in the outflow water in the beginning of the experiment reached 4.3 meq l^{-1} . After subtraction its concentration of 1.7 meq l^{-1} in the inflow water, some amount of 2.6 meq l^{-1} had been drained from the bulk soil of the sliding surface. This concentration decreased at a slight rate and was almost fixed at 2.2 meq l^{-1} . In the phase II and 140 hrs after the shearing, the concentration in the outflowing water reached 2.80 meq l^{-1} . With continued leaching after the shearing, the concentration decreased. It became 1.8 meq l^{-1} and remained relatively constant at this level.

Throughout the study, two important parameters (EC and pH), which are generally affected by the total ions and dissolved salts, were investigated. The results obtained for these factors are depicted in Figures 10 and 11. In the beginning of the experiment, due to a relatively high dissolution potential and as the result of presence of free ions in the original soil, the EC of the outflow water was measured as $2800 \mu\text{s cm}^{-1}$ (Figure 10). However, during the first phase of the study, this value quickly decreased to $700 \mu\text{s cm}^{-1}$, which was almost the same as that of the inflow water. Upon displacement in the second phase, no appreciable changes were observed for EC. Thus, EC did not show detectable sensitivity to the displacement.

In the case of pH, the pattern of change was sporadic and irregular in both phases of the study (Figure 11). The changes of pH followed a zigzag pattern due to rapid variations and did not show an acceptable stable value, although the general trend of pH values were descending in the first phase and ascending in the second phase (after soil cut).

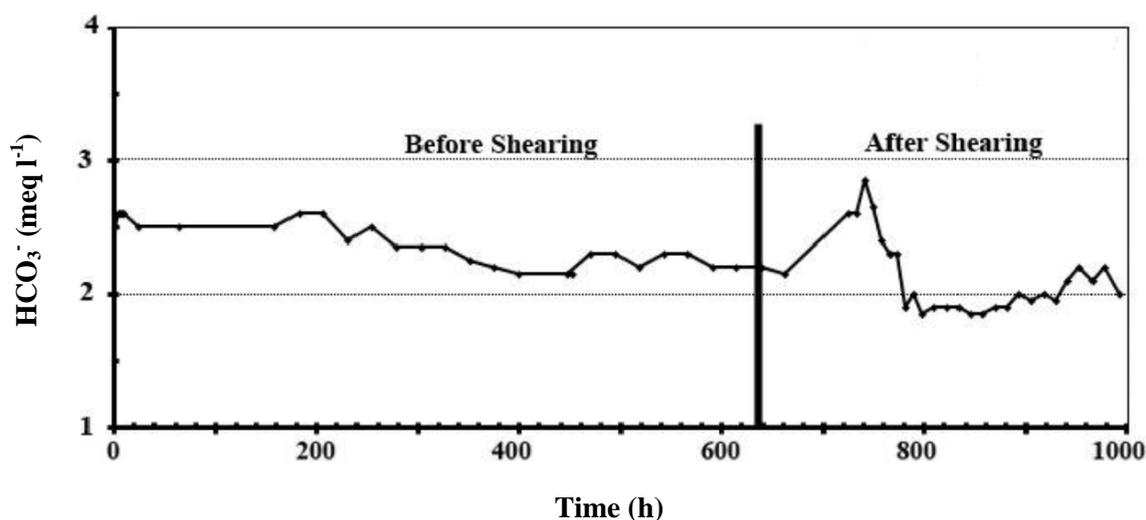


Figure 9 The changes in monovalent HCO_3^-

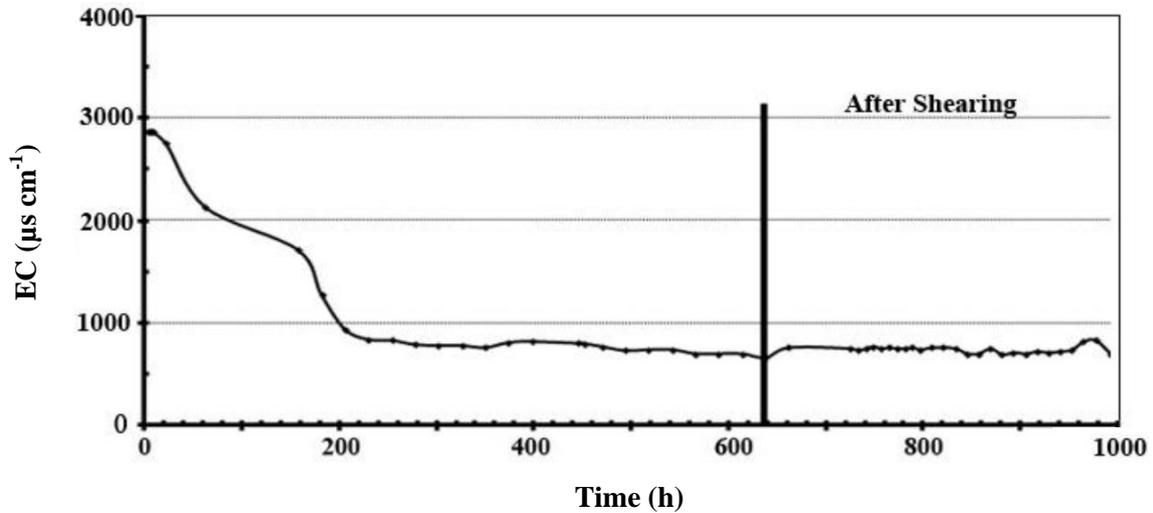


Figure 10 Changes in EC of water flowing out of the model

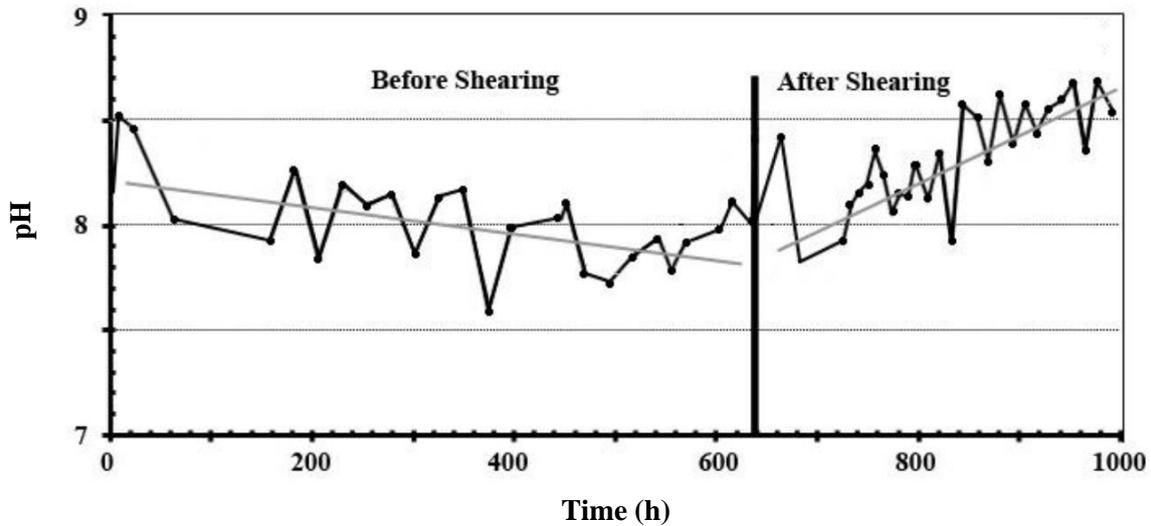


Figure 11 Changes in pH of water flowing out of the model

4 CONCLUSION

The present research was based on the hypothesis that chemical fluctuation of the water leak from the slopes might be applied as an early warning system in landslide events. The results of this study showed that some of the ions in the water flowing out from the toe of the slope (including cations and anions in the

soils through which the outflow water has passed) could act as a good indicator for this purpose. As stated in the discussion of the results, the ions sensitive to slight movement of the sliding surface could be different depending on soil properties; thus, to identify the ions sensitive to sliding event, it is necessary to carry out several studies with soils having

different properties. In our case, use of the physical model for the selected soil sample showed that among the ions studied, *i.e.* Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Cl^- , SO_4^{2-} , and HCO_3^- , ions of sodium (Na^+), potassium (K^+), magnesium (Mg^{2+}) and, to some degree, bicarbonate (HCO_3^-) have acceptable relative sensitivity to the occurrence of landslide in the tested soil. In contrast, ions of calcium, chlorine, and sulfate do not have adequate sensitivity to be used as early warning sign in slight movements of a potentially unstable slope.

Generally, in selecting an ion to be used in monitoring programs for early warnings, the most important characteristics include the increase in concentration upon soil displacement, the time taken to reach equilibrium, the maximum concentration after displacement, and the time taken to return to equilibrium. In the present research, the R_1 index is introduced as the ratio of concentration in the outflow water at the toe of the slope before the soil shearing to that after the shearing as a suitable parameter for monitoring and early

warning in slope areas susceptible to sliding. Figure 12 shows this index for the ions studied in the present study. It is expected that, under normal conditions, R_1 will be equal or greater than unity.

Closer is this index to unity; less is the sensitivity of the ion to soil displacement. In this research, the maximum R_1 belonged to magnesium, followed by potassium and sodium cations. The R_1 index of calcium, sulfate, and chlorine was close to unity that reflects their insensitivity to the shearing in the sliding surface. Among the anions studied, bicarbonate's R_1 was greater than unity and could be selected as a cation sensitive to displacement.

Electrical conductivity (EC) of water is an indicator for the total concentration of dissolved ions and components. Since EC did not show appreciable sensitivity to the soil shearing, it seems that the changes in some sensitive ions are not remarkable to affect the EC value measured in the leaked water.

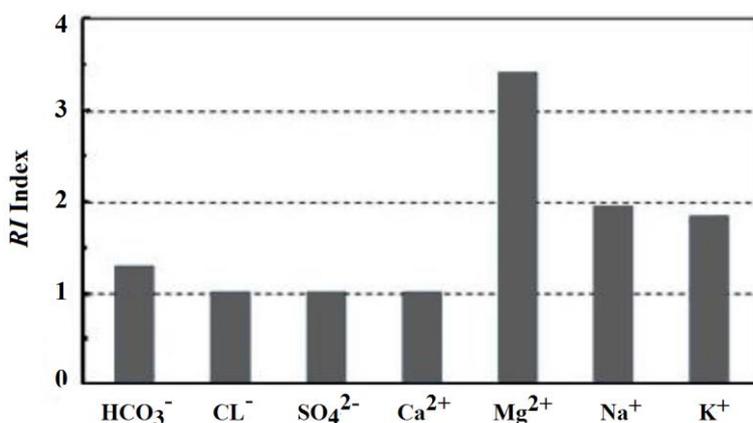


Figure 12 R_1 Index for investigated ions in the model

Thus, changes in EC cannot reflect changes in the activities of the sliding surface. Although, the general trend of pH values were descending in the phase I and ascending in the phase II

(after soil cut), but its zigzag shape shows the susceptibility of pH to the effects of many factors, thus, it cannot be considered a reliable indicator for detection of the activities of the

sliding surface. The summary of the results of this study are as follows:

1. The change in the concentration of some cations and anions in the water flowing out of the sliding surface after each activity seems to be obvious.
2. Considering the limited sensitivity of the monitoring instruments and the relatively long time span between the slight sliding and the appearance of observable signs on the ground surface, the changes in concentration of ions can be used as effective early signs of the activity of a sliding event to control and reduce the risks.
3. Changes in the ions concentration is dependent on the soil properties and clay types present in the soil. Thus, it is necessary to repeat the experiment for each region to identify the ions and factors sensitive to soil movements in that area.
4. The most important characteristics to be considered in selecting an ion for monitoring programs and early warnings include the increase in concentration upon soil displacement, the time taken to reach equilibrium, the maximum concentration after displacement, and the time taken to return to equilibrium. The ions with higher R_1 index are more suitable for monitoring landslide activity and early warning.

5 ACKNOWLEDGMENT

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روشی جدید در اعلام پیش‌هشدارهای فعالیت زمین‌لغزش‌ها با استفاده از تغییرات خصوصیات شیمیایی آبهای نشتی از پایه دامنه‌های مستعد

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چکیده زمین لغزش یکی از بلایای طبیعی است که هر ساله موجب بروز خسارات جبران ناپذیری بر اموال مردم و زیرساخت‌های خدماتی و دولتی شده و در برخی موارد به از دست رفتن جان انسان‌ها نیز منجر می‌گردد. در دهه‌های اخیر توسعه تحقیقات به منظور ارائه مدل‌های پیش‌بینی زمان وقوع زمین لغزش‌ها یکی از زمینه‌های مهم فعالیت محققین بوده است. در برخی از مواد تشکیل دهنده توده‌های مستعد لغزشی حرکات اولیه‌ای که نهایتاً منجر به وقوع زمین لغزش اصلی می‌گردد، توسط ابزارهای معمولی ثبت حرکتی قابل آشکارسازی نمی‌باشد، لذا ثبت تغییرات ترکیب شیمیایی آب‌های خروجی از پاشنه لغزش‌ها به صورت نشتی، می‌تواند به عنوان یک آشکارساز قابل اعتماد در مورد اعلام شروع فعالیت یک لغزش و اعلام وضعیت پیش‌هشدار مورد استفاده قرار گیرد. امکان سنجی این رویکرد در این مقاله مورد بررسی قرار گرفته است. بدین منظور تغییرات ترکیب شیمیایی آب‌های نشتی از یک سطح لغزشی که در یک مدل آزمایشگاهی شبیه‌سازی شده است مورد مطالعه قرار گرفت. غلظت کاتیون‌های سدیم (Na)، پتاسیم (K)، منیزیم (Mg)، کلسیم (Ca)، و آنیون‌های سولفات (SO_4)، کلر (Cl) و بیکربنات (COOH)، و هم‌زمان EC و pH آب‌های خروجی در شرایط پایدار و پس از وقوع لغزش به عنوان عناصر شاهد مورد بررسی قرار گرفت. نتایج به دست آمده از اجرای مدل نشان داد که وقوع حرکت‌های نامحسوس در سطح لغزش یک توده می‌تواند منجر به وقوع تغییراتی در غلظت یون‌های محلول در آب‌های خروجی از پای لغزش گردد. این تغییرات در برخی از این یون‌ها قابل توجه بوده که می‌تواند به عنوان یک آشکارساز مناسب جهت اعلام پیش‌هشدار برای وقوع یک لغزش مورد استفاده قرار گیرد.

کلمات کلیدی: پایش حرکات توده‌ای، پیش‌هشدار، ترکیب شیمیایی آب‌های نشتی، زمین‌لغزش