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Investigating Remediation Reagents Injection and Rainfall Effect by using Self-Potential Method in a Soil and Groundwater Contamination Site located in Yung Kang, Taiwan.

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⊙ Abstract

This poster presents the use of time-lapse SP (Self-Potential) monitoring system to investigate remediation reagent injections and rainfall effect in the soil and groundwater contamination site.

From the daily SPTs (Self-Potential Tomography), we get the following results,

(1) Determine the regional groundwater flow direction.
(2) Infer the near-surface artificial structure and the forefront of contamination.
(3) Monitor the reagent injections from 13th to 18th Oct., 2015 and from 23rd to 25th Nov., 2015.
(4) Evaluate the Apparent Hydraulic Conductivity from reagent injections.
(5) Show the SPTs response to the rainfall effect.
(6) Evaluate the Streaming Potential Coupling Coefficient from rainfall effect.

Keywords: Soil and Groundwater Contamination, Self-Potential Method, Apparent Hydraulic Conductivity, Streaming Potential Coupling Coefficient

⊙ Introduction

Chlorinated organic solvents represent a significant contamination problem. Geophysical techniques can not only cover spatially extensive areas, but also deploy at higher temporal sampling to compensate for the limitations of geochemical studies at contaminated sites. Among such techniques, Self-Potential method is directly related to the hydrogeophysics mechanism[1].

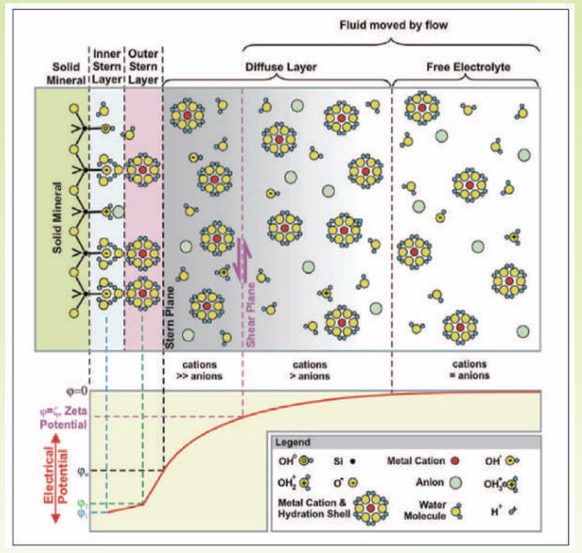

Fig.1 Sketch of the electrical double layer[2].

1.1 Electrical Double Layer

When a mineral like silica is in contact with water, its surface becomes charged due to chemical reactions (see Fig.1). The negative surface sites (>SiO⁻) attract the cations (e.g., Na^+), and form the electrical layer called Stern Layer. On the other site of this layer, so-called Diffuse Layer, its Coulomb forces are weaker than inner parts. Therefore, the ions in the Diffuse Layer can be moved by groundwater flow, and accumulate cations downstream, make the positive and negative potential distribution at both sides. It is also called streaming potential.

⊙ Field Site & Research Method

In this study, the research area is located in Yung Kang, Taiwan. The contamination is detected in 2003, including 1,2-DCA and VC. The regional hydrogeological characterization consists of paleo-river alluvium of Holocene, which is interbedded sandstone and shale. Based on the rock cores, there is backfill soil above 3m, and followed by 4m silty clay layer, 7m fine sand layer and 6m silty clay layer.

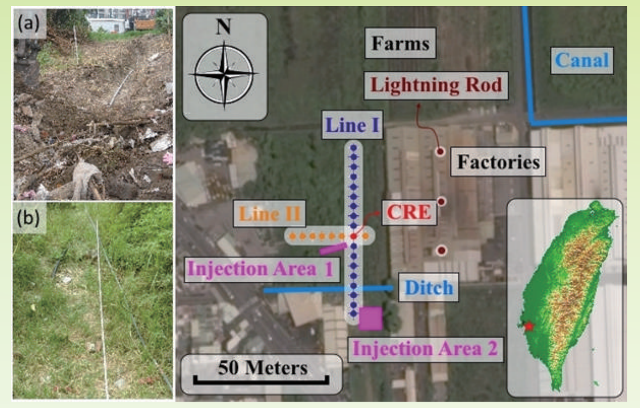

Fig.2 Map of the field site with SP survey lines. (a)There are lots of buried waste in this study area. (b) There is a ditch across Line I.

2.1 Apparatus Setting

Line I extended in N-S for a length of 85 m with 17 electrodes. Line II extended in E-S for a length of 35 m with 7 electrodes. And the CRE (Common Reference Electrode) is located at the cross point between two survey lines (see Fig.2). These two mutually perpendicular survey lines record SP at a sampling rate of 25 Hz. After averaging 1 day hourly SP median data, we calculated daily SPTs with a published code SP2DINV[3] every day, and analyzing the electric potential distribution.

2.2 Rainfall Effect Elimination

As shown in Fig.3, the rainfall events happened on 22nd Oct., 2015 has a significant influence on SP. In order to monitor the reagents injection from 18th Oct., 2015, this study calculates the revised data with cubic spline interpolation method. Besides, by subtracting the revised data from original data, it provides SP response to the rainfall effect.

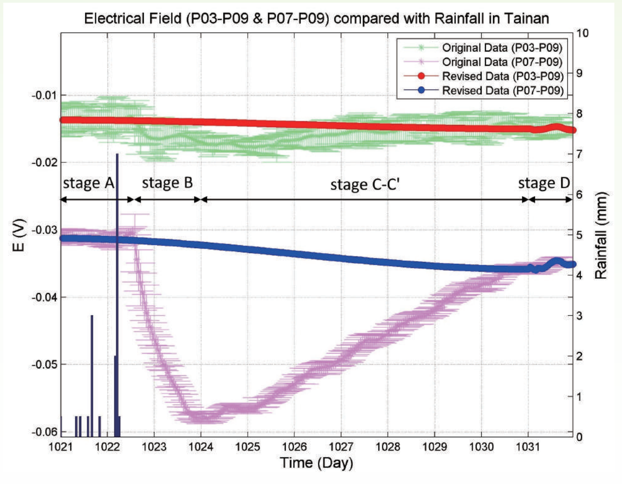

Fig.3 SP response to the rainfall effect. stage A and D means the background SP; stage B means the SP rapid changing periods due to rainfall effect; stage C-C'means the SP recovery periods.

⊙ Interpretation

3.1 Groundwater Flow Direction

Based on the theory of streaming potential, the positive potential points out the downstream direction[4][5][6]. By observing the SPTs in Line I and Line II, we determine the groundwater flow direction is NE (see Fig.4 (a)(b)). It is consistent with measured data (see Fig.9).

3.2 Near-Surface Artificial Structure

There are several strong regional positive and negative potential (>100mV) at a depth of circa 10m in SPTs. Because they exist for a long time and never disappear. According to the self-potential mechanism[7][8][9], we contribute these near-surface potential to some buried artificial structures.

3.3 The Forefront of Contamination

The forefront of contamination is an area where biochemical reaction occurred[10]. We infer the relatively strong electric current located at 20m in Line I has relation with the contamination, because after reagents injection in Oct. and Nov., the electric current decreased and move backward(see Fig.4 (c)(d)).

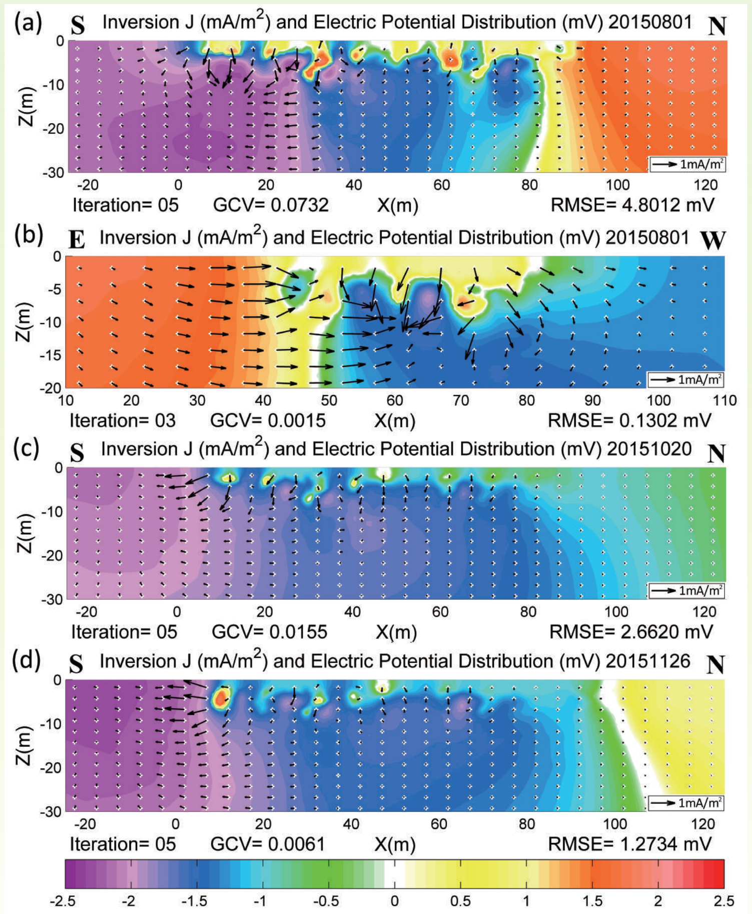

Fig.4 SPTs in Line I & Line II. The arrow means the current density, and the colorbar is SP in log-scale.

⊙ Results

4.1 Monitor Reagents Injection in Oct.

After remediation reagents injection in Area 1 from 13th to 18th Oct., 2015, daily SPTs show a point-shaped increased electric potential located in 40m at a depth of 5m in Line I (see Fig.5). Its potential increased to 30mV until 5th Nov., then decreased gradually. It may be caused from the chemical potential of reagents.

Apart from Line I, because injection area 1 is parallel to Line II, we also observe regional increased potential from 53m to 68m in Line II (see Fig.6). Its highest increased potential is also 30mV.

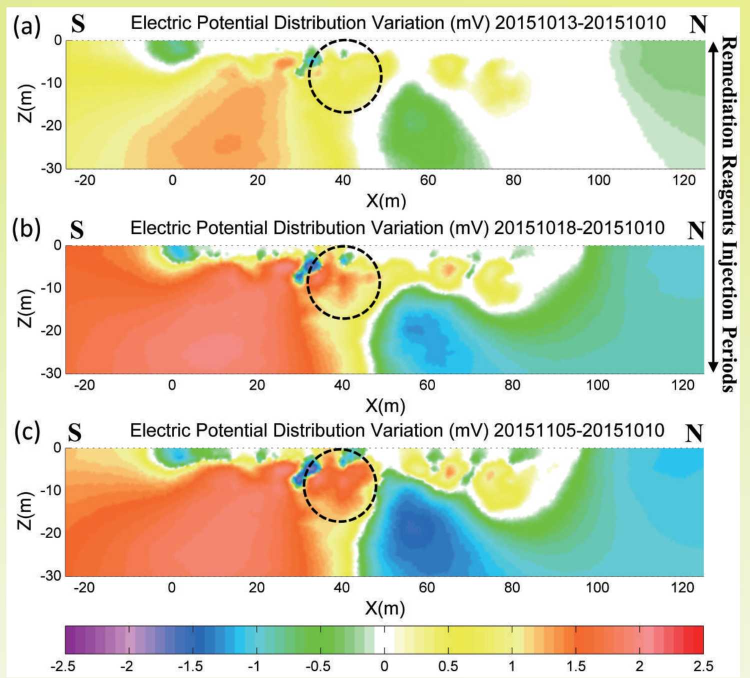

Fig.5 Daily SPTs variation in Line I after reagents injection from 13th to 18th Oct., 2015. The dashed black circle points out the regional increased electric potential.

4.2 Monitor Reagents Injection in Nov.

After remediation reagents injection in Area 2 from 23rd to 25th Nov., 2015, daily SPTs show a regional increased electric potential located in 10m at a depth of 5m in Line I (see Fig.7). Its highest increased potential is 80mV. Furthermore, because its flowability is higher than the injected reagents in Oct. we also observe the increased potential diffuse to 20m gradually.

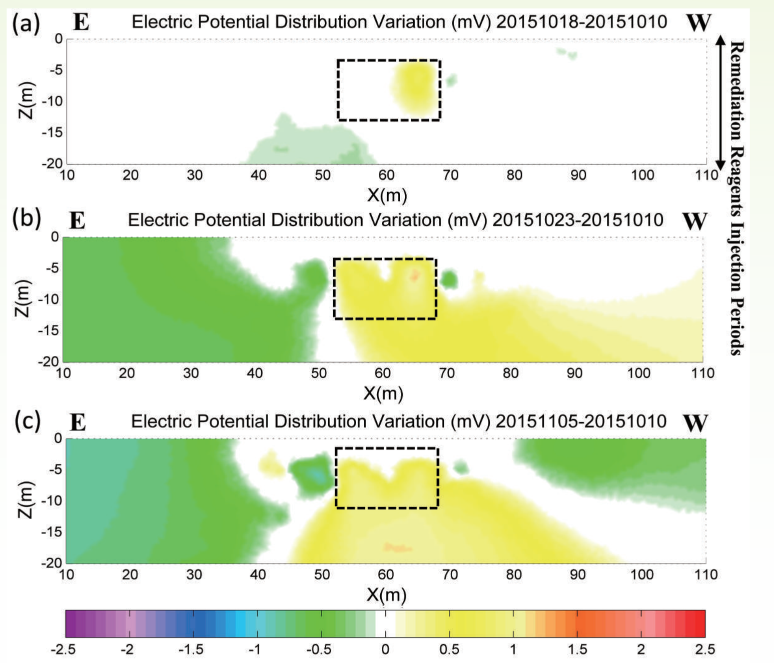

Fig.6 Daily SPTs variation in Line II after reagents injection from 13th to 18th Oct., 2015. The dashed black square points out the regional increased electric potential.

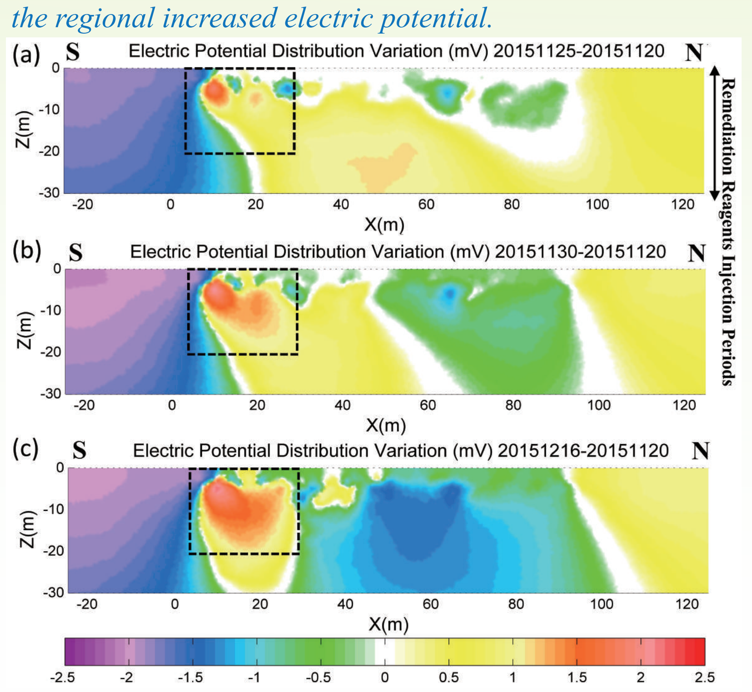

Fig.7 Daily SPTs variation in Line I after reagents injection from 23rd to 25th Nov., 2015. The dashed black square points out the regional increased electric potential.

4.3 Rainfall Effect in SPTs

Inversing SPTs with SP data which is response to rainfall effect, this study show the potential distribution variation during SP rapid changing and recovery periods (see Fig.8). The potential pattern is consistent with the potential distribution from groundwater flow mechanism, so the precipitation could probably lead to the increased groundwater pressure, and therefore enhance streaming potential[11][12].

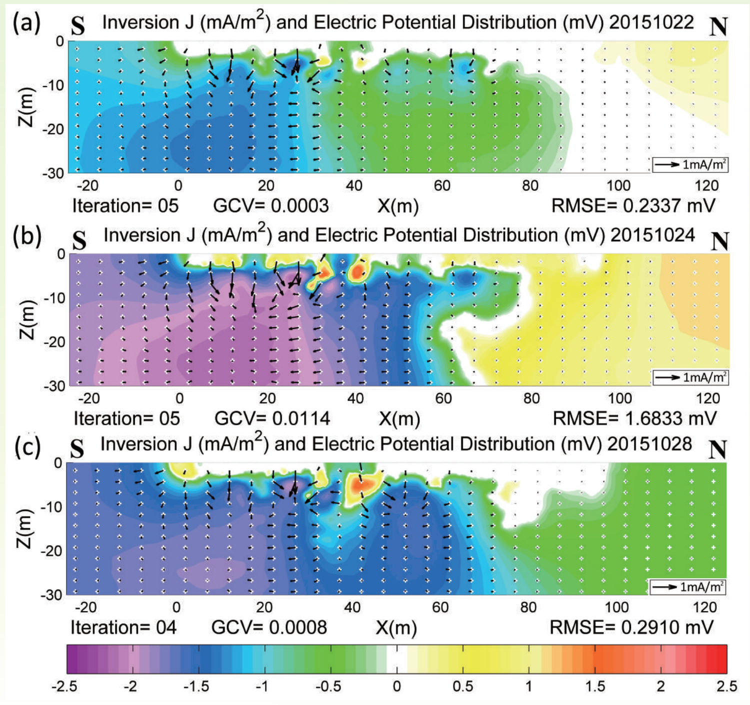

Fig.8 SPTs response to the rainfall effect. (a) In stage B, the upstream direction shows the negative SP. (b) In stage C, the positive SP in downstream and negative SP in upstream are enhanced. (c) In stage C', all the potential decrease gradually.

⊙ Discussion

5.1 Evaluated Apparent Hydraulic Conductivity

Based on other researches[6][13], we set two fixed points A and B to get electric potential time series in the injection area. Then, calculate the necessary time for equal electric potential line to pass through these two points. And evaluate the apparent hydraulic conductivity from these two injection areas.

From injection area 1, the evaluated apparent hydraulic conductivity is 0.57±0.08 m/day. However, the evaluated apparent hydraulic conductivity is 2.40±0.12 m/day from injection area 2 (see Fig.10). Compared with the well measurements, all these evaluated vales are in the range of measured data (see Fig.11). But the value 0.57±0.08 m/day is closer to most of well data. We think the different evaluated apparent hydraulic conductivities are on account of different flowability of remediation reagents.

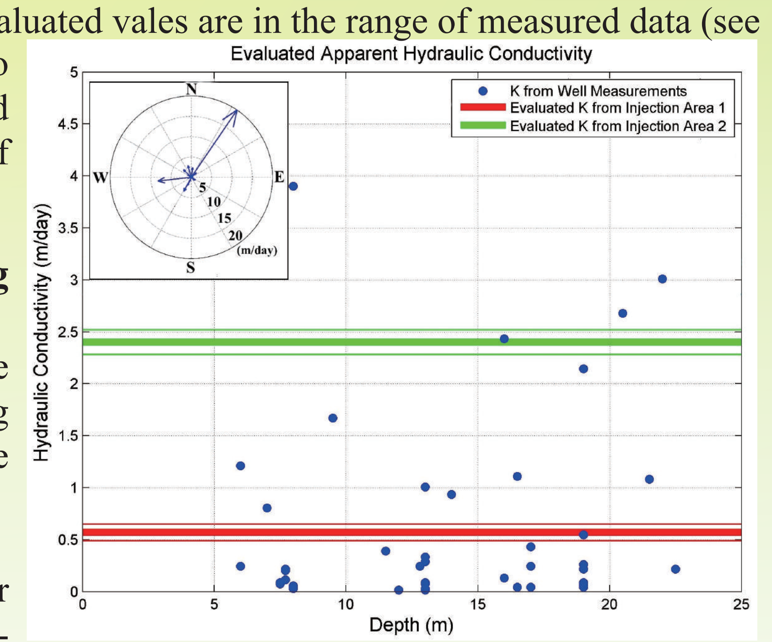

Fig.9 Comparison between the measured hydraulic conductivity and the evaluated apparent hydraulci conductivity.

5.2 Evaluated Streaming Potential Coupling Coefficient

Because the precipitation could enhance the groundwater pressure[14][15][16] and lead to streaming potential based on electrical double layer model, the equation could express as follows[17],

$$\Delta\Psi = C_s \Delta P \quad (1.1)$$

where, **Ψ** is streaming potential; **P** is groundwater pressure; and C_s is streaming potential coupling coefficient. This study show the cross-correlation between daily rainfall and charge density variation above -5m has 1 day time lag (see Fig.11). It is reasonable because the daily rainfall don't be directly associated with soil water content. In order to fit the data in linear regression, we use the Horton's infiltration model[18][19] to evaluate the infiltration water which contribute to the increased pressure. In this study, we use the new name "efficient rainfall" to represent the increased pressure due to infiltration water,

$$H = Ae^{-\beta t} \quad (1.2)$$

where, H is evaluated infiltration water; A is infiltration ratio; β is decaying constant; t is time (day). We calculate the voltage variation from SPTs, and transfer rainfall into evaluated infiltration water in equation (1.2). Then fit the best R2 in linear regression with fminbnd toolbox in Matlab, we evaluate A_1 and β_1 from typhoon event, and A_2 and β_2 from continuously heavy rainfall events (see Fig.12).

The evaluated streaming potential coupling coefficient is 0.1830mV/m, compared with the empirical equation $\log_{10}C_S = -0.921 - 1.091\log_{10}\sigma_f$[20], the conductivity of the pore water is about 0.68 S/m. This value is higher than the measured data (0.22±0.07 S/m) from groundwater sampling, we think it may be caused from the high clay content in research area.

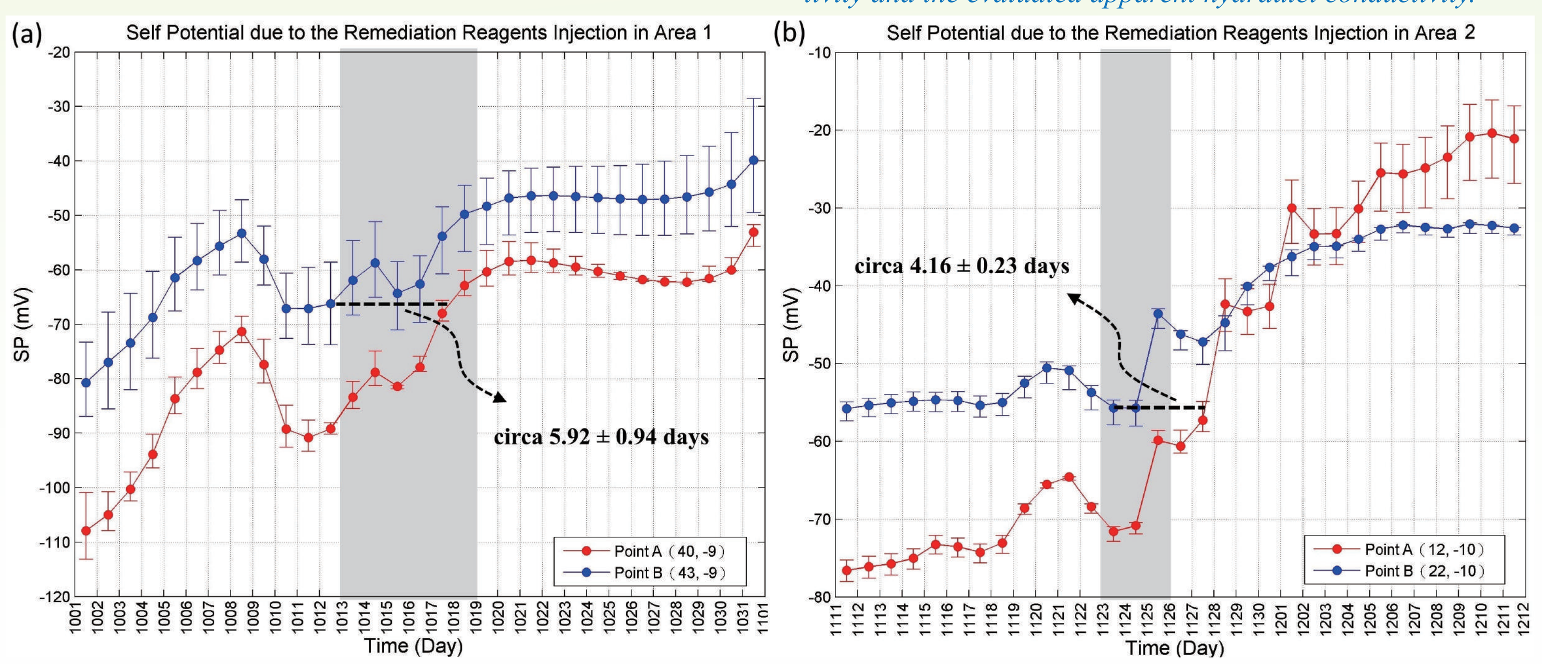

Fig.10 SP due to the remediation reagents injection. (a)The passing time of the equal-potential lines between two fixed points is circa 5.92±0.94 days. The evaluated apparent hydraulic conductivity is 0.57±0.08 m/day.(b)The passing time of the equal-potential lines between two fixed points is circa 4.16±0.23 days. The evaluated apparent hydraulic conductivity is 2.40±0.12 m/day.

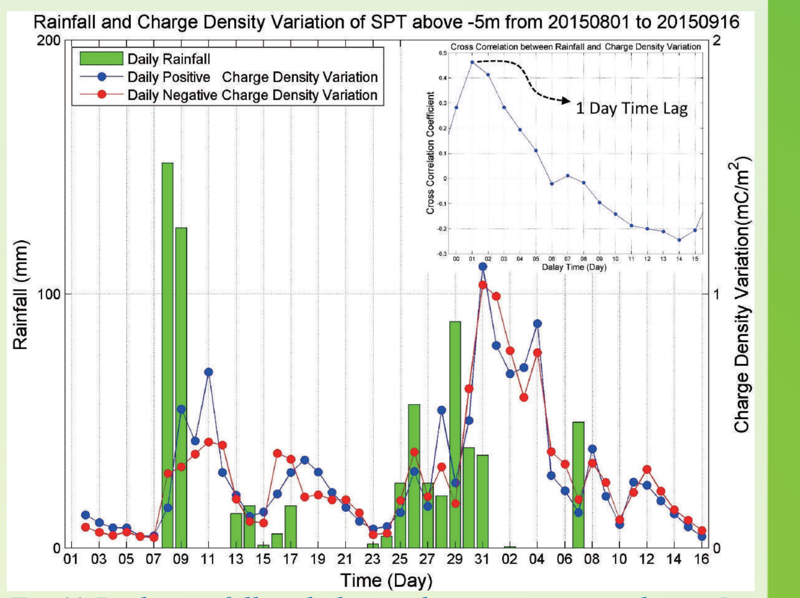

Fig.11 Daily rainfall and charge density variation above -5m. The cross-correlation shows that there is 1 day time lag between two time series.

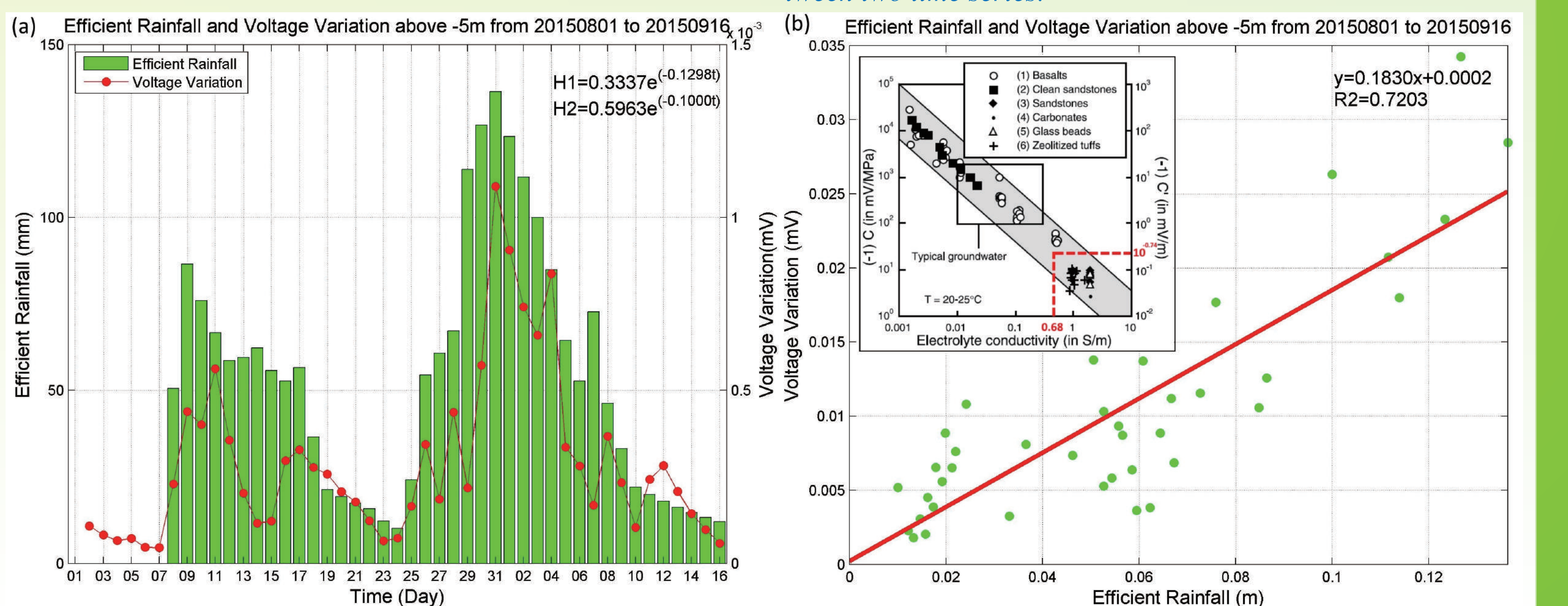

Fig.12 Evaluated streaming potential coupling coefficient from the evaluated infiltration water and voltage variation. (a)Solve the biggest R2 in (b) to get evaluated infiltration water by fminbnd toolbox in Matlab. (b)The linear regression between evaluated infiltration water and valtage variation. The evaluated streaming potential coupling coefficient is about 0.1830 mV/m. Compared with the empirical equation $\log_{10}C_S = -0.921 - 1.091\log_{10}\sigma_f$[20], the conductivity of the pore water is about 0.68 S/m.

⊙ Conclusion & Future Works

In this research project, we use self-potential method to (1) determine groundwater flow direction, (2) near-surface structure and the forefront of contamination. Besides, we sucessfully (3) monitor the remediation reagents injection in two different areas, and use these daily SPTs to (4) evaluate apparent hydraulic conductivity. Moreover, we not only eliminate the rainfall effect in SP data to continuously monitor the reagents injection, but also (5) show the rainfall effect on the enhancement of groundwater pressure. In the end, this study also (6) evaluate streaming potential coupling coefficient from the rainfall effect.

Geophysical techniques such as self-potential method is useful for imaging the underground environment, especially for the hydrogeology application. These burgeoning techniques provide the advantage of fast, cost-effective, fully spatial resolution, and continuously monitoring. In order to get more objective and correct information in detail, combining with different geophysical techniques, such as ERT, IP and so on, will be our future works.

⊙ Acknowledgments

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Reference