沙漠研究 **24**-1, 245-248 (2014)
Journal of Arid Land Studies

Simple Method of Shallow Groundwater Exploration by Groundwater Aeration Sound in Semi-Arid Grassland

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Abstract: The groundwater aeration sound (GAS) has been focused to identify the groundwater path point in the field of slope disaster science. This study aimed to develop a new exploration technique of groundwater level using the GAS, which is suitable for harsh natural environments and to verify the measurement accuracy of the exploration method. In addition this study was aimed to target free groundwater and perched water. The GAS is the kind of elastic wave generated in the vicinity of the saturated / unsaturated boundary. We have developed a device that can collect this small wave from the ground surface. The total weight of the device is 0.9 kg, making it highly portable and workable. On the assumption that there is a relevance of GAS and groundwater levels, we conducted a survey using the existing wells in the dry grasslands of Mongolia. Results indicated that a logarithmic relationship between the GAS and groundwater levels. It was found that the groundwater level could be estimated easily by measuring the GAS value from the surface. Furthermore, the correlation of GAS level and groundwater level showed different trends in each geological condition.

Key Words: Groundwater aeration sound, Groundwater level, Shallow groundwater exploration

1. Introduction

About 40% of the total land area of the earth is arid and semi-arid area (Middleton *et al*., 1997). Many of the water resources in this arid area are dependent on groundwater (Cesare, 2001). In recent years, the depletion of groundwater resources due to excessive pumping has been a major concern. For sustainable use of groundwater, a detailed determination of local groundwater environment is urgently needed. However, significant time and budget are necessary to measure this factor using existing technologies such as geophysical exploration and observation wells. In addition, the field measurement in a harsh drylands natural environment is extremely difficult because the measuring methods are difficult (*e.g*., transport of heavy equipment and exploration drilling operations.)

We focused our attention on the groundwater aeration sound which has been attracting attention for utility in slope disaster science. The purpose of this study is to develop a new exploration technique of groundwater assessment using the groundwater aeration sound which is suitable for drylands and to verify the measurement accuracy of the exploration method. In addition, this study targets free groundwater and perched water.

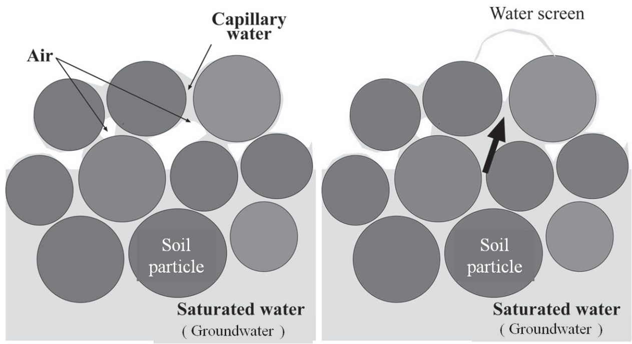

Fig. 1. Pattern diagrams of soil pore and arise of elastic wave.

2. Materials and Methods

2.1. Groundwater aeration sound

The moving speed of groundwater is projected among the mass transfer phenomena under the ground. Therefore, air movement in the soil pore occurs frequently by the wake of groundwater movement in the vicinity of the saturated / unsaturated boundary. This soil air pushes the pore water through the soil gap and the water screen is popped (**Fig. 1**). At that time, the elastic wave is generated. Tada *et al*. (2005) named Groundwater Aeration Sound (GAS) as that complex wave of this elastic wave and various friction sounds.

It was revealed that spring water and pipe flow occurs at

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(Received, September 11th, 2013; Accepted, January 10th, 2014)

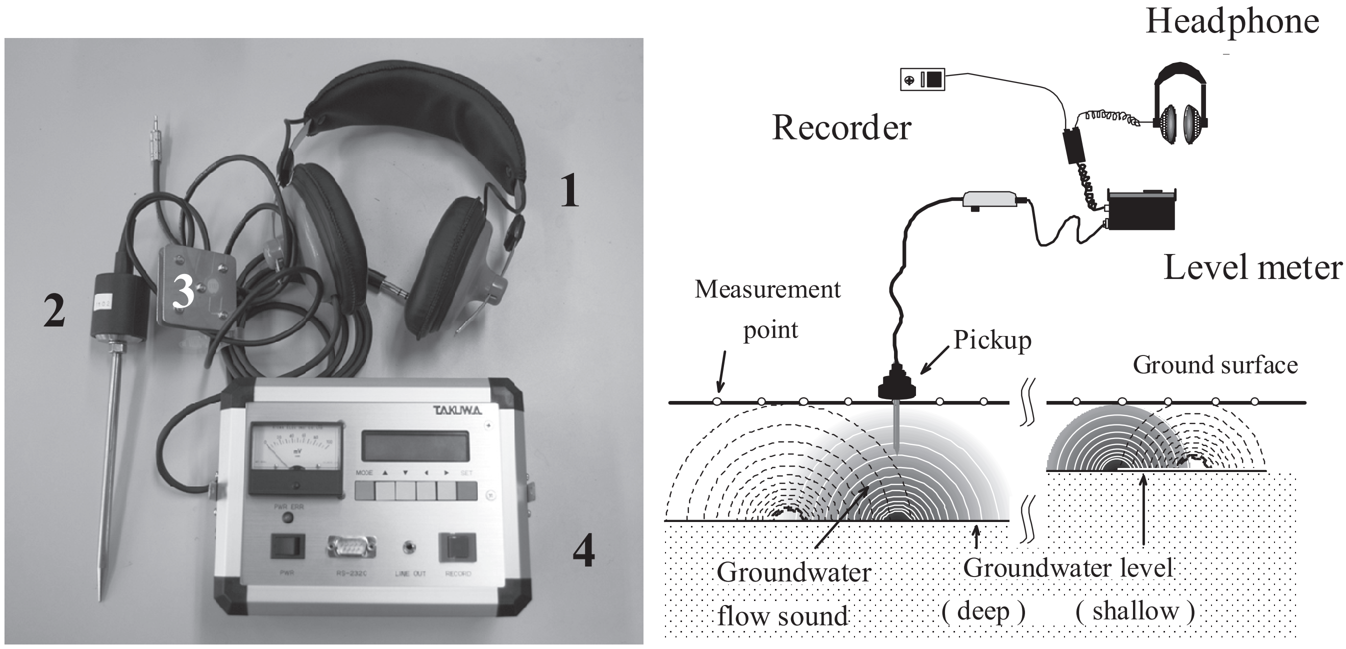

Fig. 2. Measuring device and measurement of Groundwater aeration sound. 1. Headphone, 2. Acceleration pickup sensor, 3. Vibration isolation plate, 4. Level meter.

the high GAS point in natural slopes by Tada *et al*. (2006). This observation may suggest that GAS can be applied to field groundwater exploration.

2.2. Measuring device of groundwater aeration sound

The GAS measuring device consists of headphone, acceleration pickup sensor with needle, vibration isolation plate, and level meter with an amplifying system and filtering functions (**Fig. 2**). The functions of each part are as follows:

1) Headphone: The measurer can hear and confirm an actual groundwater aeration sound in the field.
2) Acceleration pickup sensor: A sensor to capture weak vibration with a stainless needle of φ0.8×18 cm in the pickup sensor to prevent external noise such as winds.
3) Vibration isolation plate: This plate prevents various vibrations above ground surface.
4) Level meter: This part consist of amplification circuit, filter circuit and level meter. The weak sound captured by the pickup sensor is magnified by the amplification circuit. Wind noises are removed by the filter circuit. The filter function can flexibly correspond to various noises in the field. The level meter directs the sound level of the groundwater aeration sound.

The total weight of the device is 0.9 kg with high portability and workability. The measurement method simply requires inserting a needle into the ground surface and to obtain a single sample takes about 5 - 10 minutes. Figure 2 gives an overview of the measurement using the GAS device. The exploration is performed by one person to avoid noise, probing at regular intervals along the survey line. The GAS is recorded by the external device as needed.

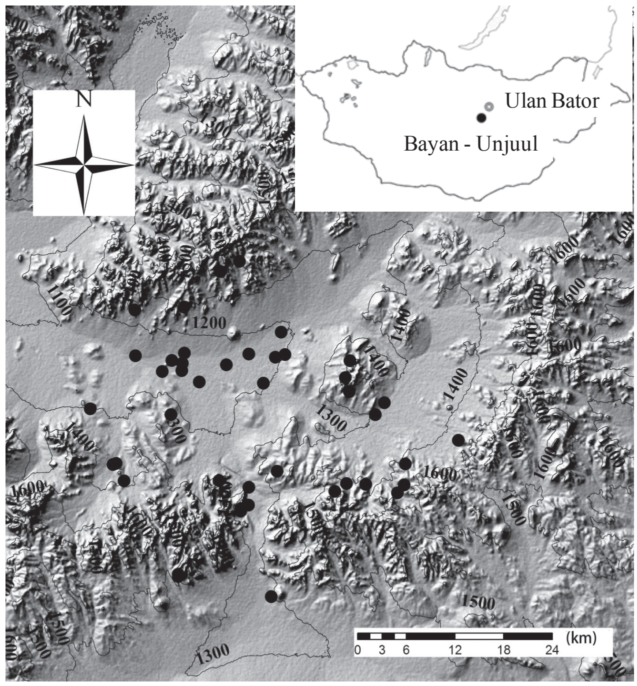

Fig. 3. Shallow well points in Bayan - Unjuul.

2.3. Field survey

Tada *et al*. (2006) suggested that the waveform intension of GAS is formed by the distance from the aeration source point. The first point to be considered is whether this result is also adapted to natural groundwater that flows under three dimensions. Therefore, we determined the relationship

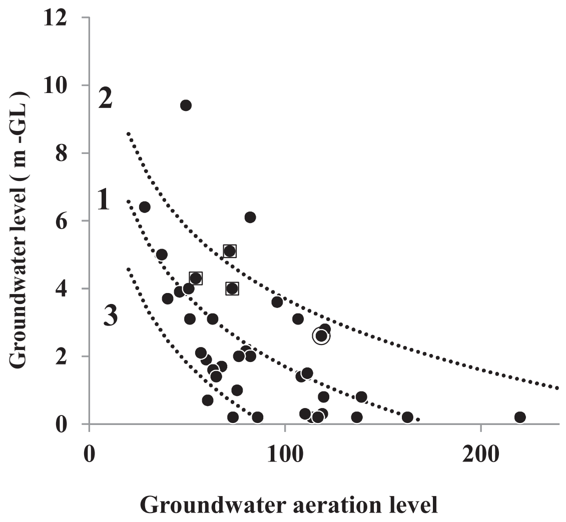

Fig. 4. Relation between groundwater level and GAS level. Gas is dimensionless number. Line 1 is the expression of logarithmic approximation. Lines 2 and 3 are the range of error with a margin of plus or minus 2 m of groundwater level. ○ is a well in sand dune and □ are wells in weathering granite.

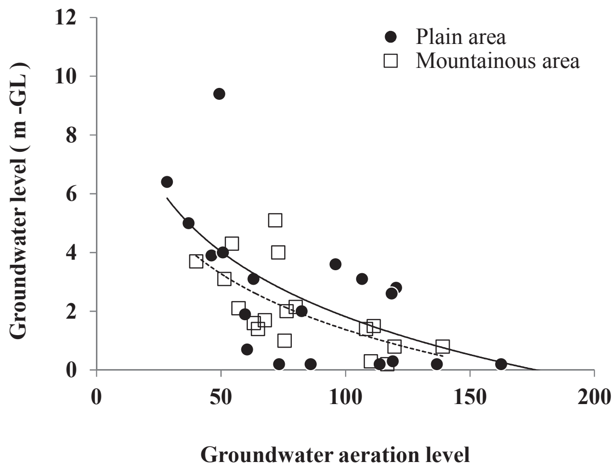

Fig. 5. Relation between groundwater level and GAS level of each physical feature.

between groundwater level and GAS level in the dry grasslands of Mongolia.

The study site was Bayan Unjuul, located about 130 km south of Ulan Bator (**Fig. 3**). There are many shallow wells used by nomadic people around the Bayan Unjuul area. The water level of these wells is about 1 - 10 m. Then, we measured GAS level at the same time as the measurement of groundwater level from the surface.

Based on preliminary data, the measurement frequency is 800 Hz for the upper limit and 200 Hz for lower limit. The measurement period was from August 24th to September 3rd of 2010. There was no precipitation during this period.

Figure 3 showed the measurement points of wells. The total number of wells for the survey was 39, located in both the plains and mountainous area. The water level in each well was measured by a contact type water level measure. The copper wire is contained in this measure and a buzzer sounds when the head reaches to the water surface.

3. Results and Discussion

The actual measured groundwater level from the surface ranged from 0.21 - 11.95 m (- G.L.).

Figure 4 shows the correlation between the groundwater level and GAS level. A trend in the data was observed that GAS level became stronger as the groundwater became more shallow. The relationship between GAS and groundwater level was observed up to 9.4 m. This result suggested that the groundwater aeration sound survey method gave an accurate estimation of groundwater level up to 10 m depth.

We derived an equation to estimate the round groundwater level from GAS level. Incidentally, the data of 87.67 (GAS level) and 11.95 m (groundwater level) were not used for the calculation. The estimation equation was able to approximate the natural logarithm and the coefficient of determination was 0.4384 and average estimation error was 1.30 m. This result was sufficiently accurate to estimate the approximate groundwater level in the field. From these results, it was shown that the GAS data which were collected with the developed device was useful to estimate the groundwater level.

Figure 5 shows two groups of plots by dividing the approximate physical features by the same result as Figure 4. Although divided into mountains and plains, there was no significant difference in the trend of the two groups.

On the other hand, we noticed a large estimation error. For example, such data outside the line of the estimated error lines (Line 2 and 3 in Fig. 4) show that the range of error with a margin of plus or minus 2 m of groundwater level. The point of groundwater level was relatively deep despite large GAS levels, and was due to the geological condition that the groundwater flow was relatively fast, such as with sand dunes and weathering granite. Conversely, the point of groundwater level was relatively shallow despite the GAS level being small and was associated with the geological condition that the groundwater flow seems to be slow, such as near the small lake, or basalt. The estimate equation of groundwater level may change with groundwater flow velocities. From these results, it was shown that the groundwater aeration sound has a tendency to be influenced by different geological conditions.

4. Conclusion

In this research, we proposed a new exploration method to estimate the groundwater level by Groundwater Aeration

Sound. We adapted this method to dry grasslands and obtained the following results.

1. The sound collection device that was developed is lightweight and is suitable for measurements in dry land.
2. A correlation was observed for groundwater level and the GAS level, and it was possible to approximate the natural logarithm.
3. The coefficient of determination for estimate equation was 0.4384 and average estimation error was 1.30 m. The results showed that the GAS was effective in exploration of shallow groundwater in the field.
4. The GAS can estimate the groundwater level to approximately 10 m deep under the conditions of arid land.
5. There was a difference in GAS distribution depending on geological conditions. Accumulated data for each geological condition were desirable.

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