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Anomalies of mountainous mining paddy in western China

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ABSTRACT

Mining in western China, particularly in the southern regions of the Yangtze River such as Chongqing, has created surface fissures in soils that can cause severe geological disasters, for example, paddies can lose water and become dry land. The objectives of this study are to detect anomalies in paddy fields by using geophysical exploration technologies such as ground penetrating radar (GPR) and electrical resistivity tomography (ERT), and to verify the detection of leaking zones by using saturated hydraulic conductivity (K) with a simplified falling head infiltrometric technique (SFH). We discover that GPR and ERT used in conjunction produce the best results because GPR detects abnormal details in the shallow layers of the soil, and ERT detects water leakage channels in complex terrain and deep underground. However, the soil saturated hydraulic conductivity of our study area could be affected by the depth and soil density above the fissure, which may interfere with anomaly detection.

1. Introduction

Water is increasingly scarce in many parts of the world (Bedjaoui and Weyer, 2011). This fact is particularly evident in agricultural countries, such as China, where a substantial amount of farmland requires irrigation. Official records indicate that China had 0.092 ha of cultivated land area per capita in 2011. Paddies are the most important croplands in the southern region of the Yangtze River. Classic researches in farmland include the physical and chemical characteristics of cultivated soils, soil health, the effects of interaction between cultivated land and biodiversity (Sanderson et al., 2009), and intensive management of cultivated land (Vickery et al., 2009). In areas where paddies are overlapped with coal mining, additional and more complex problems occur (Li et al., 2008). The water leakage caused by mining leads to an unbalance of water supply and demand. When water demand unexpectedly increases, we deduced that external factors affect water loss in paddies. In most cases, the leaking points are hidden, and should be detected by some techniques before the paddy reclamation work is carried out.

Geophysical exploration techniques could be used for measuring the physical properties of the subsurface (Francés and Lubczynski, 2011). For instance, ground penetrating radar (GPR) (Beres, 1991; Demirci et al., 2012) and electrical resistivity tomography (ERT) (Di et al., 2001; Jones et al., 2012; Song and Zheng, 2005; Wang, 2011) techniques are used to detect leak positions of subsurface; however, the application sphere of these two measurement techniques differs. GPR can precisely detect soil moisture but only at shallow levels (Mahmoudzadeh Ardekani, 2013); and ERT can be used in caves and deep underground areas (Daily et al., 2004). Because the leakage depth and width are unknown, both methods are adopted in this study.

Saturated hydraulic conductivity of paddies indicates soil permeability, which is often used to validate the results of geophysical exploration (Bagarello et al., 2012; Johnston et al., 2009; Reynolds, 2000). Field measurement of hydraulic conductivity is important for determining the characteristics of soil water flow such as rainfall infiltration and runoff, aquifer recharge, migration of nutrients, spatial and temporal variability of soil hydraulic properties, and pesticide and contaminant levels (Bagarello et al., 2012; Hu et al., 2009); thus, hydraulic conductivity is one of the most important soil properties that controls water infiltration and surface runoff in farmland (Bagarello and Sgroi, 2007).

The objectives of this study are twofold: (1) to detect water leak in paddies by using the combined geophysical exploration methods of GPR and ERT; and (2) to verify the detection methods by soil saturated hydraulic conductivity (K) with a simplified falling head (SFH) infiltrometric technique, which was also used in previous studies to determine the rate of water infiltration into the soil (Azam, 2008; Bagarello and Sgroi, 2004; Rojas, 2008).

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2. Materials and methods

2.1. Field site description

The study area is situated in a coal-mining region (Fig. 1) in Chongqing municipality, China, at longitude 106°48′08″E and latitude 28°42′08″N. The climate of this region is subtropical humid; the topographic relief is high. The average yearly rainfall is 1240.9 mm, and the annual mean temperature is 14.6–15.6 °C. The soil texture is clay. The thickness of the soil is limited to approximately 0.5–3 m and contains purple paddy soil and purple sandstone. The mean pH of soil is 7.0. The mean saturated paste extract electrical conductivity of soil is 253.1 μs/cm.

We study six leaking paddies (two at the foot of the mountain, two in the semi-sunny slope and two in the semi-shady slope) in this coal-mining region by GPR and ERT. We also investigate the saturated hydraulic conductivity of these six leaking paddies and three other paddies outside the coal-mining influence zone (one at the foot of the mountain, one in the semi-sunny slope and one in the semi-shady slope). The average of saturated hydraulic conductivity of the three paddies is 5×10^{-4} cm/s. There are 2–3 samples in every paddy; each paddy is about 700–3000 m^2. One leaking paddy (about 3000 m^2) in the semi-sunny slope is chosen as our in situ experimental area.

2.2. Methods

Two geophysical exploration techniques, ground penetrating radar (GPR) and electrical resistivity tomography (ERT), are used to detect the underground anomalies in our study paddy. GPR and ERT respectively focus on the detection of anomalies in shallow and deep layers. Because the image processing and interpretation of these two methods are usually experiential, the verification is necessary. Infiltration tests are then adopted to verify the exploration results obtained by these two methods.

2.2.1. Ground penetrating radar (GPR)

GPR is used to detect abnormal details in shallow soil layers in our study. The used GPR system (GR-III), which is designed by the China University of Mining & Technology (Beijing), is composed of 4 parts: a computer system, a control system, a transmitter antenna, and a receiver antenna. Transmitter and receiver antennas are used to emit and receive electromagnetic waves (EM waves). The control and computer systems process the data images. When anomalies exist underground, the reflected waves appear irregular, and can be picked up by the receiver antenna to record abnormal information (position, structure, and shape). As Fig. 2(a) shows, during GPR detection, the antenna box, which contains transmitter and receiver antennas, moves along several planned routes in the detection area. A series of reflection signals are sampled, recorded into computer data files, and stacked into B-scan images. Due to noise and interference, these images are usually fuzzy and the anomalies are difficult to recognize. GPR image processing, which involves parameter setting, level tracking, level correction, time zero line setting, background clutter removal and low-pass filtering, can remove undesired noise and interference (Al-Qadi and Lahouar, 2005; Xu et al., 2012) and make the images readable. When the GPR antenna box passes above the anomalies, the waves appear distorted and the images contain void regions, i.e., the radar images become irregular where anomalies are located (Crocco et al., 2009; Demirci et al., 2012).

Critical parameters of GPR detection are radar antenna frequency and relative dielectric constant in soil (Neal, 2004).

The radar antenna frequency affects the depth of detection and the resolution of radar. The radar antenna frequencies of 100 MHZ, 200 MHZ and 400 MHZ are examined in our in situ test. The 100 MHZ frequency provides the deepest detection depth but lowest radar resolution. The 400 MHZ frequency provides the highest radar resolution but the lowest detection depth. Finally, the antenna frequency of 200 MHZ is chosen because it provides acceptable radar resolution and detection depth for our study.

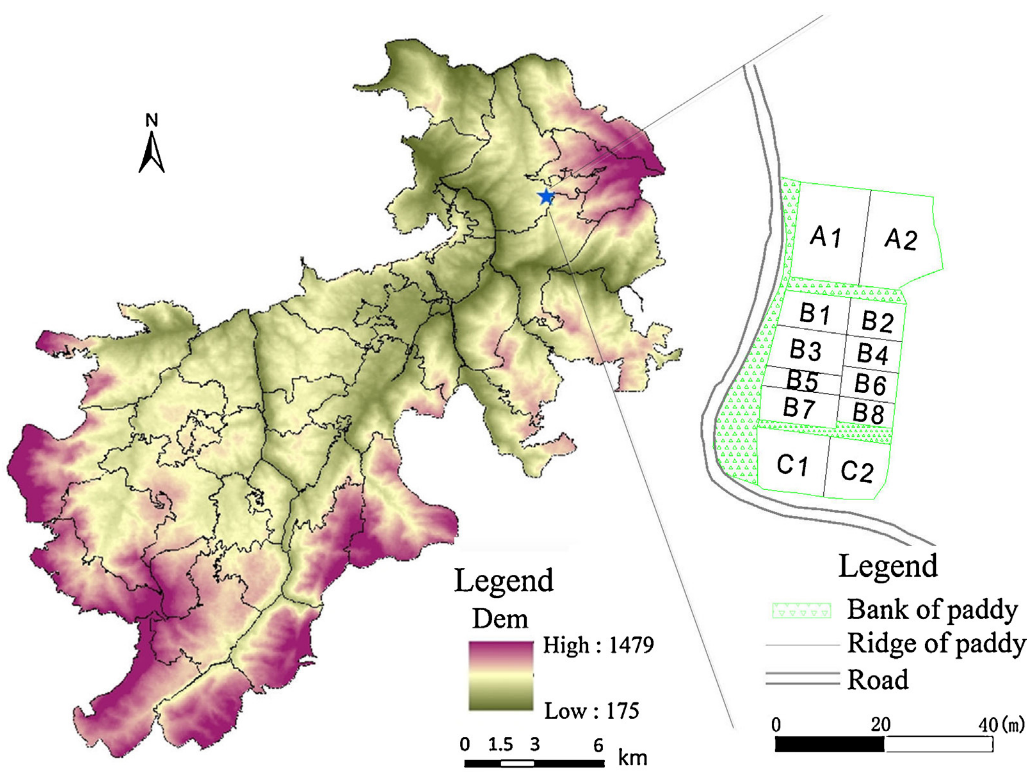

Fig. 1. Digital elevation map (DEM) of the coal-mining region and in situ experiment area.