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Temporal stability of soil water storage in diverse soil layers

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ABSTRACT

Knowledge of soil water storage (SWS) within soil profiles is crucial when selecting appropriate practices for the restoration of vegetation. To study the temporal stability of SWS and identify representative locations in diverse soil layers, an analysis of temporal stability was performed using Spearman rank correlation coefficients and relative differences. From July 2008 to October 2010, the SWS of three soil layers (0–1, 1–2, and 2–3 m) were measured using a neutron probe at 91 locations on a hillslope on the Loess Plateau, China. A total of 20 SWS datasets were collected over the period of measurement. The results showed that the variability of SWS decreased over time and increased over space with the increase in soil depth. High Spearman rank correlation coefficients ($p<0.01$) indicated a strong temporal stability of spatial patterns for all soil layers. Temporal stability increased with increasing soil depth. Furthermore, the closer two soil layers were within a given profile and the deeper any two adjacent soil layers were, the more similar were the temporal patterns. A significant negative correlation ($p<0.01$) existed between the status of soil moisture and temporal stability, and the dependency increased with soil depth. With increasing soil depth, more locations were able to estimate the mean SWS of the area. None, however, represented the mean values for all three soil layers separately.

1. Introduction

Soil water storage (SWS) is an important state variable in hydrologic and biologic processes (Choi and Jacobs, 2007). It has important effects on runoff, erosion, and transport of solute (Georgakakos, 1996). SWS, especially in upper soil layer, plays a key role in controlling water and energy fluxes in soils (Vereecken et al., 2007), influencing the partitioning of rainfall into infiltration and runoff and the partitioning of net radiation into sensible and latent heat (Pachepsky et al., 2003). Additionally, SWS plays an important role in the production of vegetation, especially in semi-arid environments, which is a limiting factor for the restoration of vegetation on the Loess Plateau, China (Hu et al., 2009).

Soil moisture, however, is highly variable in space, due mainly to soil variability, and in time, due to climate. In the past several decades, many studies have endeavoured to understand the spatio-temporal dynamics of soil moisture (Brocca et al., 2009; De Lannoy et al., 2006; Green and Erskine, 2011; Henninger et al., 1976; Hills and Reynolds, 1969; Mohanty and Skaggs, 2001; Moore et al., 1988; Nyberg, 1996; Thierfelder et al., 2003). The large variability of soils requires the collection of many samples from an area to extract sufficient information of soil moisture, which is costly in time and money.

Vachaud et al. (1985) were among the first to show that spatial patterns of soil moisture changed little with time despite large variation over time and space in the field. This phenomenon has been called temporal stability. The concept of temporal stability was thereafter extensively used to judge whether the spatial pattern for soil moisture in an area was persistent. For example, Comegna and Basile (1994) found no indication of temporal stability when the spatial patterns of soil moisture were investigated, and Kamgar et al. (1993) reported that the time-stable patterns of soil moisture could be observed only to a depth of 2.85 m. The temporal stability for soil moisture, however, is widely recognised by most authors (Brocca et al., 2009; Coppola et al., 2011; Cosh et al., 2004, 2008; da Sivaro et al., 2001; Martínez-Fernández and Ceballos, 2003).

Identifying time-stable locations to estimate the status of mean soil moisture for an area of interest has been one of the most important applications of the concept of temporal stability. Monitoring representative locations can determine the mean soil moisture of large areas at a small cost. This strategy is advantageous because it can significantly reduce the required number of samples while maintaining a high accuracy of prediction. Schneider et al. (2008) further pointed out that the selected locations were appropriate to estimate mean soil moisture of the study area for multiple years. More studies thus focused on identifying representative locations

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(De Lannoy et al., 2007; Fernandez and Ceballos, 2003; Grayson and Western, 1998). In addition, temporal stability of soil moisture was shown to be linked to many other factors, such as soil depth (Cassel et al., 2000), soil-water conditions (Martínez-Fernández and Ceballos, 2003), scale of interest (Gómez-Plaza et al., 2000), and soil texture (Mohanty and Skaggs, 2001). Biswas and Si (2011) further examined the controlling factors of SWS at different scales of measurement using wavelet coherence.

Many studies only examine a single soil layer (usually the upper 20 cm) (Cosh et al., 2008; Famiglietti et al., 1998; Gómez-Plaza et al., 2000; Goovaerts and Chiang, 1993; Hu et al., 2009; Schneider et al., 2008; Van Wesenbeeck and Kachanoski, 1988), and some only observe the soil profile within 0–1 m layer (Comegna and Basile, 1994; Guber et al., 2008; Hu et al., 2010a; Hupet and Vanclooster, 2002; Kachanoski and de Jong, 1988; Martínez-Fernández and Ceballos, 2003; Starks et al., 2006). Few, however, investigate the profile beyond 1 m (Hu et al., 2010b; Kamgar et al., 1993; Tallon and Si, 2004). More research on the temporal stability of SWS in different soil layers is therefore needed to determine whether the temporal stability of SWS is dependent on depth.

For a deeper insight into these questions, the SWS of three layers (0–1, 1–2, and 2–3 m) were observed at 91 locations on 20 occasions from July 2008 to October 2010. The specific objectives of this study were: (i) to study the temporal stability of spatial patterns for SWS at three soil layers and analyse how those patterns vary with increasing soil depth; (ii) to observe the relationships between the status of soil moisture and temporal stability and test whether they further show a depth dependency; and (iii) to identify representative locations of each soil layer for future prediction of the mean SWS of this area.

2. Materials and methods

2.1. Description of field site

The study area is located on a hillslope (~14°) in the Liudaogou watershed (110°21′–110°23′ E, 38°46′–38°51′ N) of Shenmu County, Shaanxi Province, China (Fig. 1). This area is characterised by a large number of deep gullies and undulating loessial slopes. The climate is

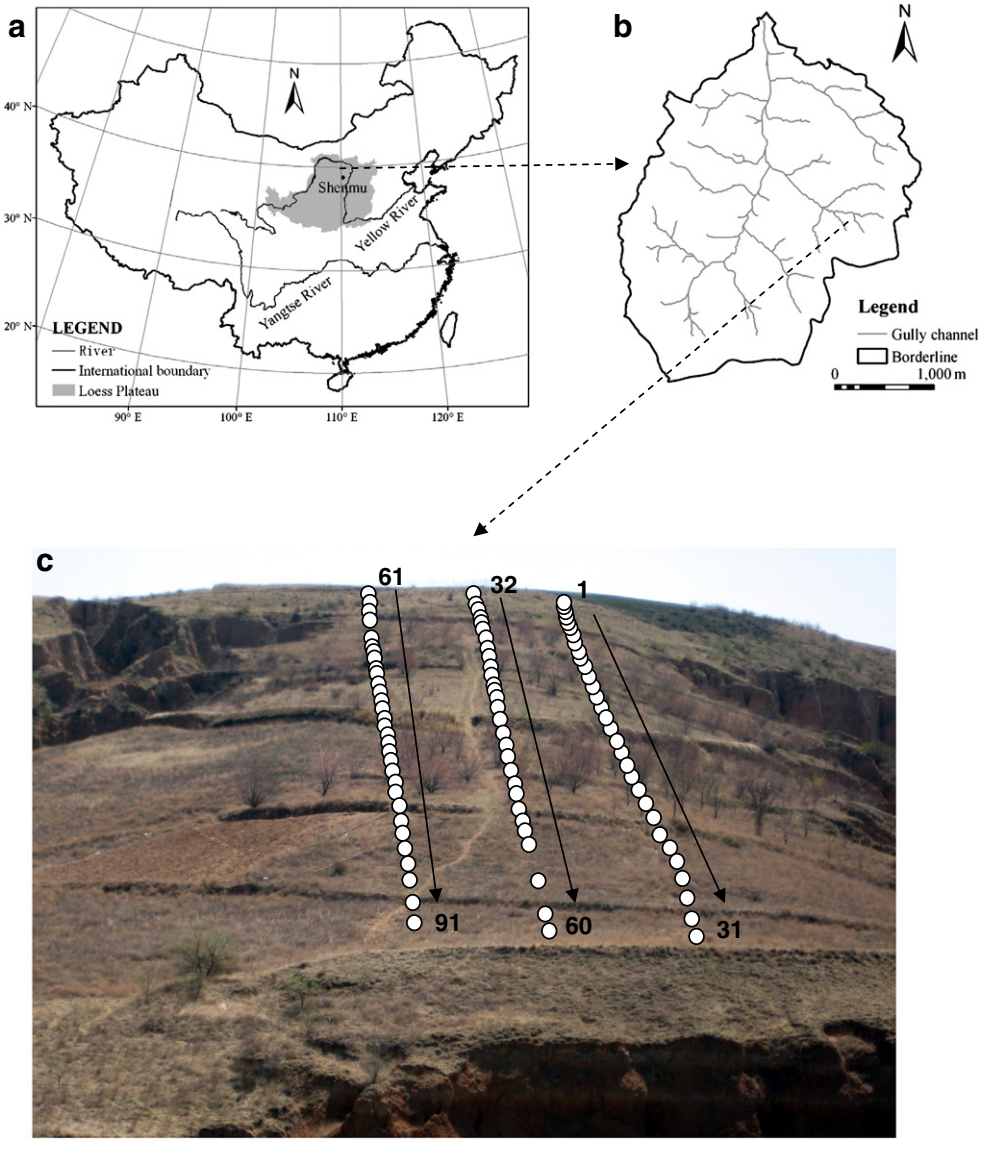

Fig. 1. The distribution of 91 neutron access tubes across the hillslope (c) located in the Liudaogou watershed (b) on the Loess Plateau of China (a). Intervals between adjacent transects and the spaces between adjacent locations are both approximately 10 m.