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Soil moisture response to environmental factors following precipitation events in a small catchment

H.D. Zhu [a], Z.H. Shi [a,b,*], N.F. Fang [b], G.L. Wu [b], Z.L. Guo [a], Y. Zhang [a]

[a] College of Resources and Environment, Huazhong Agricultural University, Wuhan 430070, China
[b] State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Institute of Soil and Water Conservation, Chinese Academy of Sciences, Yangling, Shaanxi 712100, China

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ABSTRACT

Moisture variation in upper soil layers following a precipitation event is recognized as an important process in the conversion of rainfall to soil water. To understand the variability of topsoil moisture following a period of precipitation, we explored changes in soil moisture after 12 precipitation events at 38 sampling locations in the Wulongchi catchment (1.92 km^2) located in the Danjiangkou Reservoir Area, China. Our results indicated that variation in soil moisture increased with decreasing soil moisture following each of the 12 precipitation events. Using a two-way indicator species analysis (TWINSPAN), the soil moisture measurement periods following each event were classified into three discrete groups: humid periods, moderate periods, and dry periods. For the humid periods, the total variance of soil moisture that could be explained by redundancy analysis was more consistent than those of the moderate and dry periods. For the humid periods on the first axis, soil thickness was the main significant factor, and the topographic wetness index, slope position and aspect were also significant environmental factors. For the moderate and dry periods, however, the effect of aspect on soil moisture decreased, whereas the effect of relative elevation increased. Each environmental factor that was tested for its influence on topsoil moisture variation presented different effects throughout all three of the studied soil moisture periods.

1. Introduction

Soil moisture plays an important role in the hydrological process of rainfall transitioning to soil water (Flugel, 1995), which is often the focus of hydrological research. Soil moisture controls the partitioning of energy and water related to infiltration, runoff, erosion, evapotranspiration, solute transport, and ecosystem dynamics (Qiu et al., 2001; Western and Blöschl, 1999; Yang et al., 2012a). Variation in soil moisture is of critical importance in many scientific and operational activities, such as groundwater recharge, climate studies, and numerical weather prediction (Seneviratne et al., 2010). Understanding soil moisture variability is also essential for quantifying relationships among hydrology, ecology, and physiography in a given region (Fu et al., 2003).

Soil moisture exhibits high spatial-temporal variability over multiple scales. Spatial patterns and temporal variability of soil moisture are influenced by a number of environmental factors, and the effects of these multiple factors are complex because the factors themselves may interact (Famiglietti et al., 1998; Guo et al., 2002; Qiu et al., 2001). Therefore, a considerable amount of research has been conducted on soil moisture to understand the mechanisms driving moisture variability and to accurately characterize its relationship to environmental factors (Owe et al., 1982; Landson and Moore, 1992; Sun et al., 2014; Fu et al., 2003; Zhao et al., 2011; Yang et al., 2012b). At a small scale, soil moisture is affected by local factors, including bulk density (Gómez-Plaza et al., 2001; Hill and Sumner, 1967; Ng and Miller, 1980), land use (Chen et al., 2010; Fu et al., 2003), relative elevation (Krumbach, 1959), slope gradient, slope position, slope shape, slope aspect, and soil depth (Famiglietti et al., 1998; Geroy et al., 2011; Gómez-Plaza et al., 2000).

In recent years, more studies have focused on the effects of microtopography on soil moisture variation. Slope gradient was found to have a negative correlation with soil moisture (Famiglietti et al., 1998; Kim et al., 2007; Moore et al., 1988; Nyberg, 1996; Western et al., 1999), but other studies found no significant correlation between soil moisture and slope gradient (Landson and Moore, 1992). Soils in intermountain basins and at lower slope positions consistently have higher water contents, whereas upslope soils have relatively low water contents (Afyuni et al., 1993). The higher soil moisture found in soils below a concave-shaped surface is attributed to the diversion of surface and subsurface water flow from the surrounding area. The downslope movement of water from convex-shaped surfaces most likely contributes to lower soil moisture in these areas. Soil can store rainwater temporarily and allow it to drain gradually. Deep soils have a

* Corresponding author at: College of Resources and Environment, Huazhong Agricultural University, Wuhan 430070, China. Tel.: +86 27 87288249; fax: +86 27 87671035.
E-mail address: shizhihua70@gmail.com (Z.H. Shi).

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greater water storage capacity during precipitation events. Topsoil moisture can be recharged by deeper soils during dry periods (Fu et al., 2011; Wang et al., 2013). Most previous studies have considered more than one environmental factor affecting soil moisture, but few studies have examined the effect of multiple environmental factors on variation in soil moisture following precipitation events. The objectives of this study were (1) to analyze variation in topsoil moisture following precipitation events and (2) to investigate the effects of environmental factors on topsoil moisture variation.

2. Materials and methods

2.1. Study area

We conducted the study in the Wulongchi catchment (32°45′N, 111°13′E), located in Danjiangkou City in Hubei Province, China. The catchment covers an area of 1.92 km^2 (Fig. 1), and the elevation ranges from 310 to 420 m. The major soil type is classified as an Alfisol according to the USA Soil Taxonomy (Soil Survey Staff, 1999). Soil thickness was measured at each sampling point by driving a metal rod into the soil at four locations around the point and calculating the average depth. Soil thickness is heterogeneous across the catchment, particularly on the hillslopes. The tops of hillslope areas are mostly covered with thin soil layer, whereas the midslope or downslope sections are overlain by a medium or thick soil layer. The soil layer is deeper and more homogenous in intermontane basins. The region where the Wulongchi catchment is located has a typical subtropical monsoon climate. The mean annual precipitation is approximately 749 mm, and precipitation occurs mostly between April and October. The annual average temperature is 15.6 °C. The natural vegetation displays signs of long-term disturbance from human activity and land use. Land use types include open forest, forest, cropland, shrubland and grassland. The crops include maize (*Zea mays* L.) and wheat (*Triticum aestivum* L.), which are grown using a crop rotation system. The vegetation mainly consists of arborvitae (*Platycladus orientalis* L.), wild jujube (*Ziziphus jujuba* var. *spinosa*), Agnuside (*Vitex negundo*), and vetchleaf sophora (*Sophora davidii*).

2.2. Soil moisture measurement and analysis

Previous studies have found that three measurements are sufficient to characterize temporal patterns of soil moisture across a given area of up to 10 km^2 using mean soil moisture values (Brocca et al., 2009; 2010). Twelve measurement processes were taken, and each of them lasted for six consecutive days. Our sampling strategy aimed to include as much diversity of land use and topography as possible in our data collection and analysis. Similarities and differences among the five hillslopes were considered in detail, resulting in the selection of nine potential regulating factors of soil moisture (i.e., soil thickness, slope gradient, topographic wetness index, bulk density, relative elevation, land use, slope position, slope shape, and slope aspect). A total of 38 sampling points distributed across the five hillslopes and the intermountain basin were selected to measure soil moisture (Fig. 1). The hillslopes were covered with highly heterogeneous soils that ranged in thickness from 15 to 85 cm, but the soil in the intermontane basin was more homogenous and thicker. The distribution of land use types, including open forest, forest, cropland, shrubland, and grassland, differed among the five hillslopes. At the 38 sampling points mentioned above, soil moisture was measured daily at two depths (0–5 cm and 10–15 cm) using time domain reflectometry (TDR). At each sampling point, we used a soil auger to drill down to the designated sampling depth, and four soil moisture measurements were collected at that depth. To calibrate the TDR measurements, soil samples were collected during the in situ soil moisture measurements and dried in a forced-air oven at 105 °C to a constant mass. The following regression equation was used to relate the TDR values to gravimetric soil moisture, which was derived by

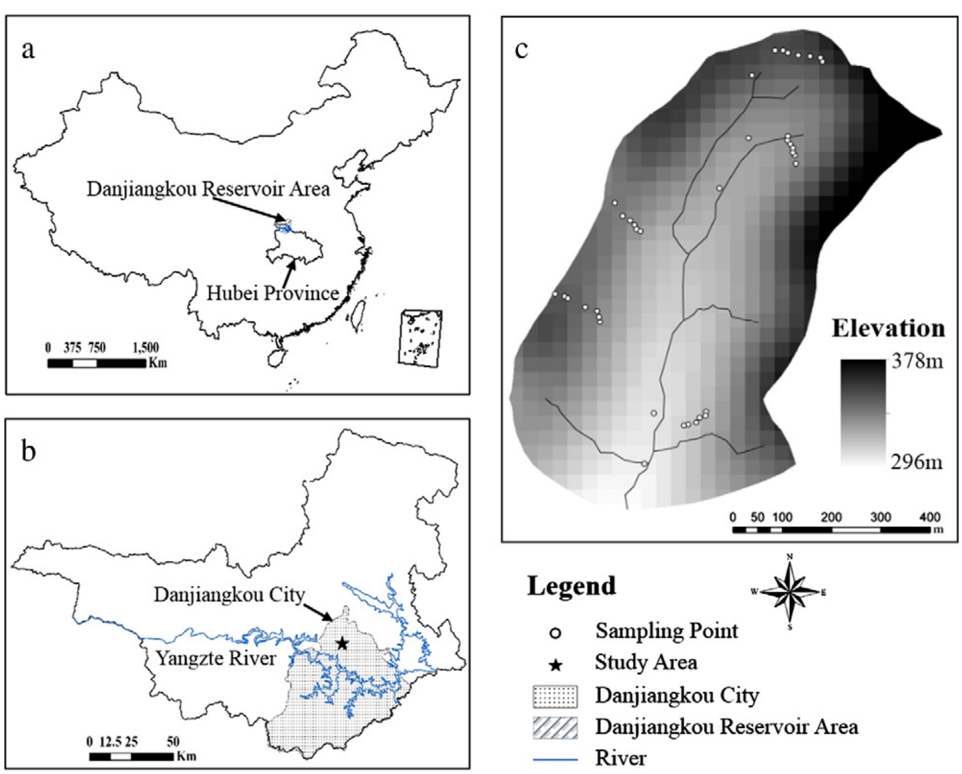

Fig. 1. Location of the study area and sampling points: (a) location of Hubei Province and the Danjiangkou Reservoir Area in China; (b) location of Danjiangkou City and the study area in the Danjiangkou Reservoir Area; (c) sampling points in the Wulongchi catchment.