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Simulation of soil water in space and time using an agro-hydrological model and remote sensing techniques

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ABSTRACT

Complete knowledge of all components of the water balance is essential to optimize water use in irrigated agriculture. However, most water balance components are very difficult to measure in terms of the required time interval and due to the complexity of the processes. An unsaturated zone model is a useful tool for predicting the effects of agricultural management on crop water use and can be used to optimize agricultural practices in view of minimizing the agricultural water use. For the irrigated areas in Minqin County of northwest China, the physically based one-dimensional agro-hydrological model SWAP (Soil, Water, Atmosphere and Plant) for water movement and crop growth was applied to reveal all the components of the water balance at multiple sites. This model has a varying level of abstraction referring to simulated processes in time and space. A combination of field, meteorological and aerial data was used as input to the model. Inverse modeling of evapotranspiration (ET) fluxes was followed to calibrate the soil hydraulic functions by using the parameter estimation package PEST. Surface Energy Balance System (SEBS) was used to estimate actual ET fluxes from NOAA AVHRR satellite images. Simulations were carried out for 15 different sites in Minqin County by using wheat (*Triticum aestivum* L.) as a test crop, but only three sites were selected for model calibration and evaluation. The period of simulation for the whole wheat growing season was from 1 April 2004 to 30 July 2004 and detailed analyses were performed for all sites. SWAP simulated soil water dynamics well and the distributed SWAP model is a useful tool to analyze all water balance components.

1. Introduction

Water is a renewable but limited resource. Future demands of this limited resource and the demands to adequately feed and clothe an expanding population in the world require that irrigation efficiency and crop productivity from irrigated lands be improved. There is an increasing competition in water use as the demand for water increases with the growing population (Molden, 1997; Seckler et al., 1998). Therefore, a rational approach to water use is needed to balance water supply and demand. One approach to check if the supply is adequate to meet the demand is to account for the respective components in the water balance. Doing so provides an opportunity to search for possible ways to save water from one application and allocate it to another. This is termed water trading (Seckler, 1996). Droogers et al. (2000) analyzed the water trading issue in irrigated agriculture. The approach was implemented by defining the components of the water balance through simulation models and analyzing the effects of water saving.

When dealing with efficient utilization of water in agriculture it is important to tackle the issue of optimal water use (Tuong and Bhuiyan, 1999; Ines et al., 2002). An irrigation system should be managed to achieve an optimal performance with respect to the system complexity and availability of resources. Most studies of irrigation planning problems, however, are based on an area allocation approach, i.e., based on socio-political considerations rather than technological ones (Paudyal and Das Gupta, 1990; Raman et al., 1992).

For the application of unsaturated soil water theory, relationships between soil water pressure head h, hydraulic conductivity K, and volumetric soil water content θ, must be known. The unsaturated soil hydraulic parameters are critical input parameters in models for variably saturated flow and contaminant transport, and often serve as integrated indices for soil quality (National Research Council, 1993; Lin, 2003).

According to Xevi et al. (1996) and Ma et al. (2009), for example, proper evaluation of the water balance in the unsatu-

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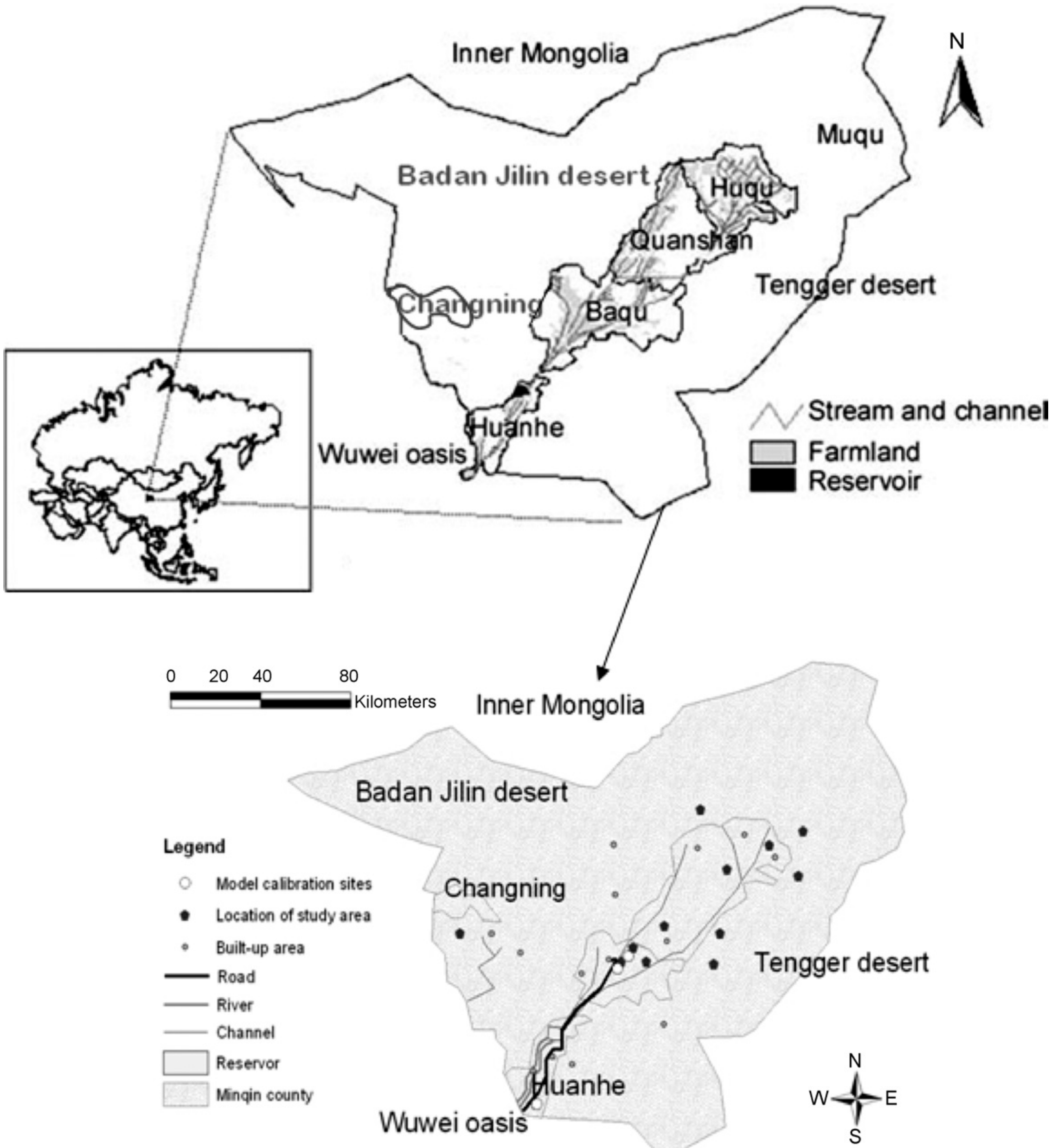

Fig. 1. Location of the study area and sites within China.

rated zone depends strongly on the appropriate characterization of the soil hydraulic functions. Therefore, proper definition of the soil hydraulic parameters under field conditions should be taken into consideration. However, accurate in situ determination of hydraulic properties of unsaturated soil is often not feasible because of natural variability of most field soils, and because instrumental limitations make measurement and analyses time-consuming and costly. Because of these problems, the unsaturated hydraulic properties are frequently determined in the laboratory, or estimated indirectly from other soil properties, which can be measured more easily and accurately. Direct measurement in the laboratory using soil core samples is the classic way to determine the soil hydraulic functions (van Genuchten et al., 1991). Unfortunately, direct measurement of these functions is impractical for most applications in research and management, especially for large-scale problems. For this reason, many applications rely on pedotransfer functions (PTFs) to indirectly estimate the hydraulic properties from more easily measured or more readily available information, e.g., soil texture, organic matter and bulk density (Wösten and van Genuchten, 1988; Wösten et al., 1998; Droogers et al., 2000).

The inverse modeling approach is applied where the measured soil hydraulic data are used as fitting criteria to estimate the soil hydraulic parameters. Kool and Parker (1988) solved the inverse problem in unsaturated transient flows using the indirect approach with the Levenberg–Marquardt algorithm. The Richards' equation was solved inversely for water infiltration and redistribution in a hypothetical soil profile to determine the soil hydraulic functions simultaneously. The soil water content and hydraulic head were used as fitting criteria. Based on their work (Kool et al., 1985; Kool and Parker, 1988), several studies were conducted to investigate further the inverse problem in unsaturated flows. The method has been applied with reasonable success in the laboratory using outflow experiments such as the one-step (van Dam et al., 1992) and multi-step outflow approaches (van Dam et al., 1994; Zurmühl and