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WATER STORAGE IN THE VADOSE ZONE EVALUATED FROM TDR SOIL MOISTURE MEASUREMENTS*

Urszula Somorowska

Faculty of Geography and Regional Studies, Warsaw University
ul. Krakowskie Przedmieście 30, 00-927 Warszawa
e-mail: usomorow@uw.edu.pl

A b s t r a c t. This study focuses on dynamic soil water resources evaluated by the TDR soil moisture meter in selected experimental sites in central Poland. The analysis is based on field measurements of volumetric soil moisture conducted since 1995 till 2004. The portable Time Domain Reflectometry meter (Easy Test) is applied to track the characteristic stages of the soil water storage of shallow soil layers. Evolution of the soil moisture vertical profiles has been highlighted on seasonal time scale. The range of natural variability of soil water storage in ten years period was derived from the soil moisture profiles detected under extreme atmospheric conditions.

K e y w o r d s: TDR technique, soil moisture, water storage

NOMENCLATURE

θ – volumetric soil moisture ($cm^3 \cdot cm^{-3}$),
θ_z – volumetric soil moisture at the depth of z cm ($cm^3 \cdot cm^{-3}$),
$\bar{\theta}_i$ – mean value of the volumetric soil moisture within the i-layer ($cm^3 \cdot cm^{-3}$),
Δz – depth of the soil layer (cm),
n – number of soil layers within the soil profile,
W – water storage (mm),
W_i – water storage in the i-layer (mm),
WS_{10} – water storage in the 0-10cm soil layer (mm),
WS_{50} – water storage in the 0-50cm soil layer (mm),
WS_{100} – water storage in the 0-100cm soil layer (mm).

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INTRODUCTION

The TDR technique is presently routinely used in a broad range of field experiments and environmental studies [1-5]. It allows nondestructive, *in situ* measurements of the moisture of the soil layers along its profile depth. Therefore, soil moisture measurements can be used in the parameterization of the soil surface properties. An assessment of the water resources in the vadose zone is a key aspect for the understanding of the moisture exchange in the soil-vegetation-atmosphere system. Thus, it can contribute to the better understanding of the land surface hydrological processes. Although considerable progress has been achieved in the description of soil moisture at a point, there is still much to be investigated, among others, in data collection and analysis as a feedback to the theory [7].

The state of the soil moisture, as described by volumetric soil moisture or the level of saturation relative to the soil field capacity, is strongly governed by rainfall and potential evapotranspiration. Rainfall recharges the upper soil layers, whereas evapotranspiration is the main depletion mechanism of the available water storage. Both these processes control the evolution of the soil moisture status which, on the other hand, is highly dependant on the physical characteristics of the soils. Changes in the soil moisture and groundwater storage have their consequences in the groundwater outflow which dominates the runoff in humid temperate environments.

The preliminary aim of the soil moisture measurements reported here was to detect present wetness conditions in the lowland basin of the Łasica channel [8]. This basin was influenced in the past by agricultural intensification and, in particular, by artificial drainage schemes. Currently it is situated within the boundaries of the Kampinoski National Park. Present environmental targets for this area comprise maintaining and restoring the ecological values by sustaining biodiversity, and ensuring that water policies reflect requirements imposed by different ecosystems. Restoration of wetlands involves in particular the necessity of maintaining a high moisture content of the sites involved. Managing favorable hydrological conditions supports habitat restoration of environmentally sensitive areas. To assure this, an understanding of the primary natural controls of the water regimes and hydrological functioning of the basin was required. The TDR soil moisture measurements conducted in the Łasica basin constitute the basis of the assessment of soil water resources for environmentally sensitive management [10].

In this paper selected soil moisture data measured by the portable TDR meter are highlighted and analyzed. The TDR Field Operating Meter produced by Easy Test [2] was used for the determination of the volumetric soil moisture content in the field during different seasons of the years 1995-2004. Evolution of the soil moisture vertical profiles has been presented for selected experimental sites. The range of natural variability of soil water storage was derived from the soil moisture profiles determined for extreme atmospheric conditions.

SOIL MOISTURE MEASUREMENTS

Fourteen experimental sites are regularly observed in different seasons of the year within the boundaries of the Łasica basin [9]. Observations have been conducted since spring 1995 till 2004. In this paper four experimental sites are chosen for analysis, located in Grabnik, Łubiec, Ąleksandrów and Truskaw. The Grabnik and Łubiec sites represent conditions of soil moisture fields influenced by very shallow groundwater level, whereas the Truskaw and Aleksandrów sites are characterized by shallow groundwater level.

At each site, measurements of soil moisture have been taken at depths of 5 and 10 cm, and then with the increment of 20 cm, down to the first saturated layer. The installation scheme is presented in Figure 1. To assure accuracy of the measurements, the soil profiles have been exposed each time and then portable probes of different length were inserted in the soil, perpendicularly to the soil profile. In this way, readings of the volumetric soil moisture have been taken at specified depths from undisturbed soils. This way make the measurements time consuming, but still in situ. Accessing the soil profile from the surface, in the case of compact mineral soils, especially in dry conditions, is not possible using standard probes and therefore soil exposure is necessary. Speed of data processing of readings taken by Easy Test TDR meter could be improved if internal memory for storing readings were available, similar to that present in portable Minitrase TDR meter [6].

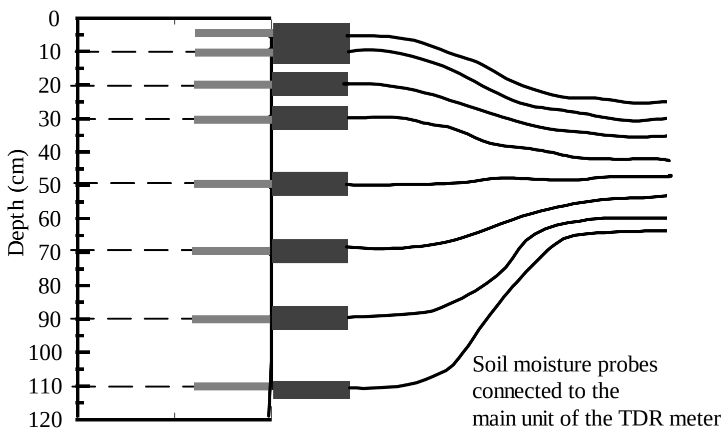

Fig. 1. Schematic installation of TDR soil moisture probes in the soil profile

VERTICAL SOIL MOISTURE PROFILES AND WATER STORAGE

From the soil moisture data set collected, the volumetric soil moisture profiles have been derived for each measurement period. Selected profiles are presented in Figure 2.

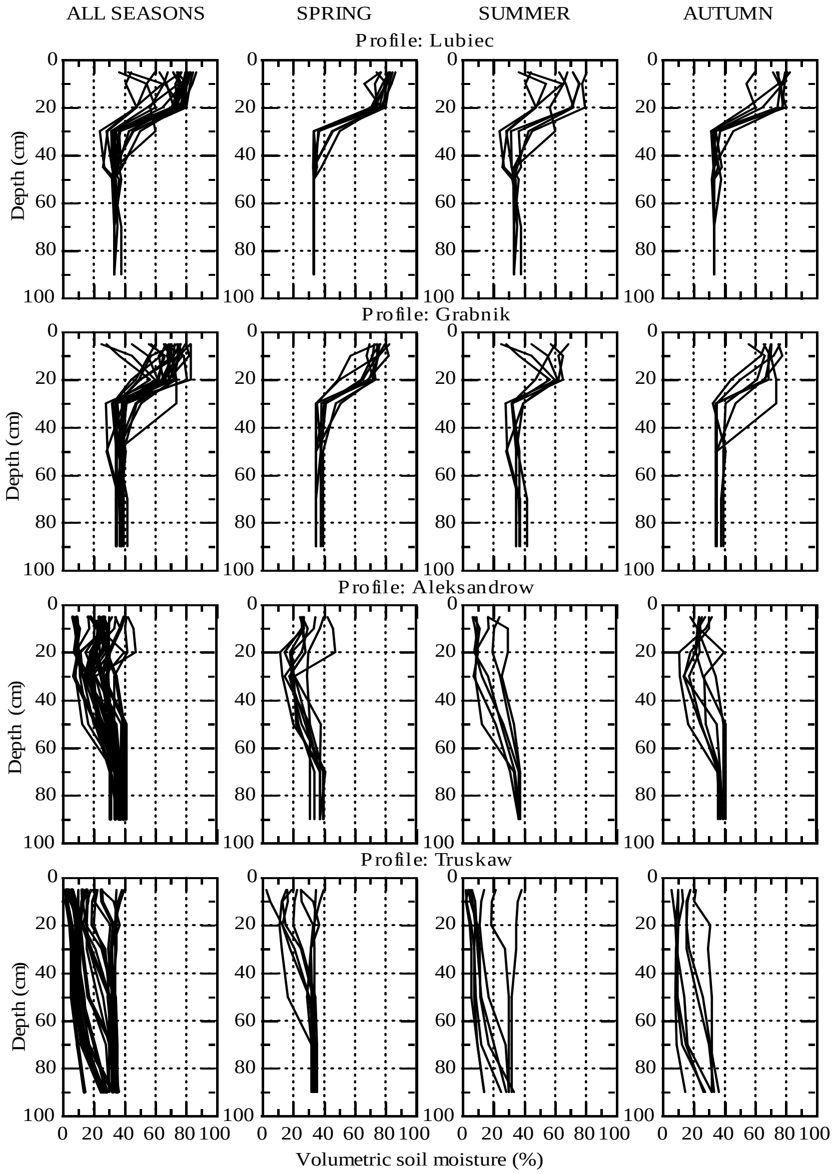

Fig. 2. Vertical soil moisture profiles in all seasons and separately for spring, summer and autumn

Soil moisture profiles have been gathered for each site to display the range of the soil moisture variability at a site. This range is determined by the edge curves representing extreme stages of the soil moisture content. Additionally, soil moisture profiles have been displayed for spring, summer and autumn season, for each site separately. In all cases, the evolution of vertical soil moisture profiles shows wetting and drying cycles. In spring, after the winter which is usually the wetting season, the soil moisture content is relatively high. During the spring-summer period which is usually the drying season, the decrease in soil moisture content with the depth of the soil profile is observed. At the Grabnik and Łubiec sites, the highest volumetric soil moisture values are found at the surface and they decrease with depth. At the Aleksandrów and Truskaw sites, relatively uniform soil moisture profiles are observed during spring and late autumn, whereas during summer the soil moisture usually increases with depth. In surface soil layers, a considerable decrease in soil moisture is usually observed during summer, with great water loss at the surface.

From volumetric soil moisture data the soil water storage can be calculated. The storage of water W in the soil for the layer from the depth z_1 to z_2 can be expressed as:

$$W = \int_{z_1}^{z_2} \theta \cdot dz \tag{1}$$

Thus the storage of water W in the layer of depth $\Delta z = z_2 - z_1$ can be obtained from the following expression:

$$W = \frac{\theta \cdot \Delta z}{10} \tag{2}$$

The water storage WS in the soil profile can be expressed as a sum of water storage in particular soil layers W_i and can be calculated as:

$$WS = \sum_{i=1}^{n} W_i = \sum_{i=1}^{n} \frac{\overline{\theta}_i \cdot \Delta z_i}{10} \tag{3}$$

In equation (3) the value of θ_i represents the mean value of soil water content within the i-layer and Δz_i is the depth of particular soil layer. Taking into account location of the TDR soil moisture probes installed at different depths, the soil profiles have been schematized in a number of soil layers. Then from equation (3) the water storage in the soil profiles of the depth of 10cm, 50cm and 100cm has been calculated according to the following expressions:

$$WS_{10} = 0.75 \cdot \theta_5 + 0.25 \cdot \theta_{10} \tag{4}$$

$$WS_{50} = 0.7 \cdot \theta_5 + 0.75 \cdot \theta_{10} + 1 \cdot \theta_{20} + 1.5 \cdot \theta_{30} + 1 \cdot \theta_{50} \tag{5}$$

$$WS_{100} = 0.75 \cdot \theta_5 + 0.75 \cdot \theta_{10} + 1 \cdot \theta_{20} + 1.5 \cdot \theta_{30} + 2 \cdot \theta_{50} + 2 \cdot \theta_{70} + 2 \cdot \theta_{90} \tag{6}$$

The temporal fluctuations of water storage in the years 1995-2004 are shown in Figure 3. Observed course of water storage confirms the thesis that fluctuations are formed by the wetting and drying cycles. The only exception was the situation observed in the summer of 1997, when high wetness conditions were caused by flood.

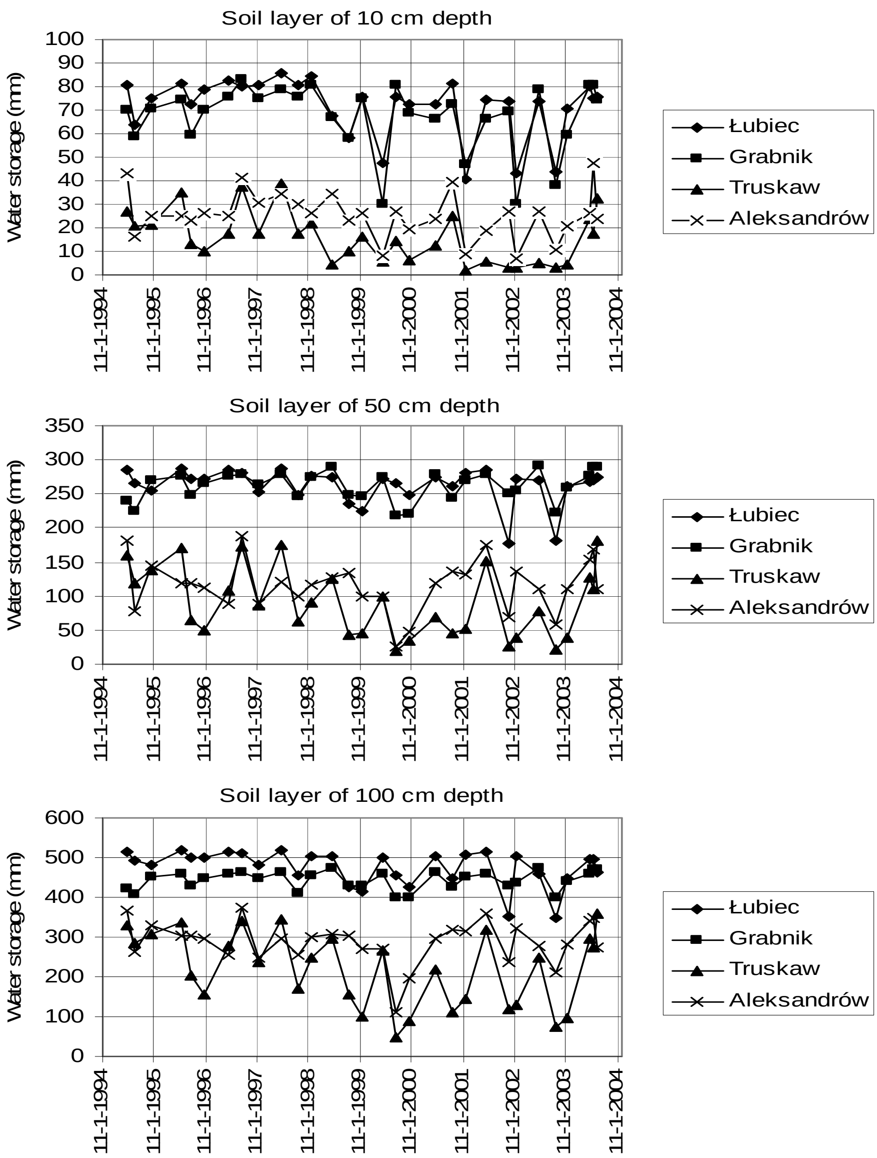

Fig. 3. Water storage in the 0-10 cm, 0-50 cm and 0-100 cm soil layers in hydrological years 1995-2004

CONCLUSIONS

The study provides ground true data on the soil moisture content and water storage in the top soil layers derived from the TDR soil moisture measurements. The soil moisture fluctuations have been detected based on field measurements conducted at representative sites during eight years of observation (1995-2004). Examples of fluctuations are presented for two different regimes of the soil moisture fields, separately for sites with very shallow groundwater levels (the Łubiec and Grabnik sites) and shallow groundwater levels (the Aleksandrów and Truskaw sites). Differences in soil moisture profiles characterize the dynamics of soil water storage that are the result of site-specific characteristics and atmospheric forcing (recharge by precipitation and evapotranspiration). Derived course of water storage fluctuations in three soil layers of the depth 10 cm, 50 cm and 100 cm shows the range of possible wetness conditions.

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OCENA ZAPASÓW WODY W STREFIE AERACJI NA PODSTAWIE POMIARÓW WILGOTNOŚCI GRUNTU METODĄ REFLEKTOMETRYCZNĄ (TDR)

Urszula Somorowska

Wydział Geografii i Studiów Regionalnych, Uniwersytet Warszawski
ul. Krakowskie Przedmieście 30, 00-927 Warszawa
e-mail:usomorow@uw.edu.pl

Streszczenie. Praca dotyczy zapasów wody w glebie ocenionych na podstawie pomiarów wilgotności gruntu metodą reflektometryczną (TDR) w wybranych profilach glebowych Polski środkowej. Podstawą analizy są polowe pomiary objętościowej wilgotności gruntu wykonywane w latach 1995-2004. Do identyfikacji charakterystycznych stanów wilgotności gleby wykorzystano przenośny miernik wilgotności Easy Test. Zmiany wilgotności w profilach glebowych przedstawiono w różnych sezonach roku. Przedstawiono naturalną zmienność glebowych zapasów wody w skali dziesięciolecia, kształtowanych przez zmienne w ciągu roku warunki atmosferyczne.

Słowa kluczowe: technika TDR, wilgotność gleby, zapasy wody