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# TREND ANALYSIS OF CHANGES IN SOIL MOISTURE FROM THE DIFFERENT DEPTHS IN THE MARTEW FORESTRY

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***Abstract***

The paper presents trends in average annual soil moisture in the area covered by the sixty-year old pine stand. The area of analysis is located in the Tuczno Forest District, the Martew Forestry, in the north-western part of Poland. The calculations were based on the measurements of soil moisture at seven different depths below the ground level. A set of probes was installed for measuring the moisture using TDR method in order to calculate retention changes in the unsaturated zone. Humidity measurements used in this work were carried out at daily intervals throughout the year 2014. Designated trends were analysed using the non-parametric Mann – Kendall test, which is used for detecting trend of hydrological and meteorological parameters. Negative values of the Mann-Kendall statistics point to a declining trend for most – six out of the seven, analysed levels of measurement. The tendency toward dryness was not confirmed by the data set of precipitations. Although precipitations are considered to be the main driver of variations in soil moisture their impact severity seems to be controlled by other characteristics of the catchment area and components of the water balance, such as evapotranspiration.

**Keywords:** Mann-Kendall test, soil moisture, the Martew Forestry

## INTRODUCTION

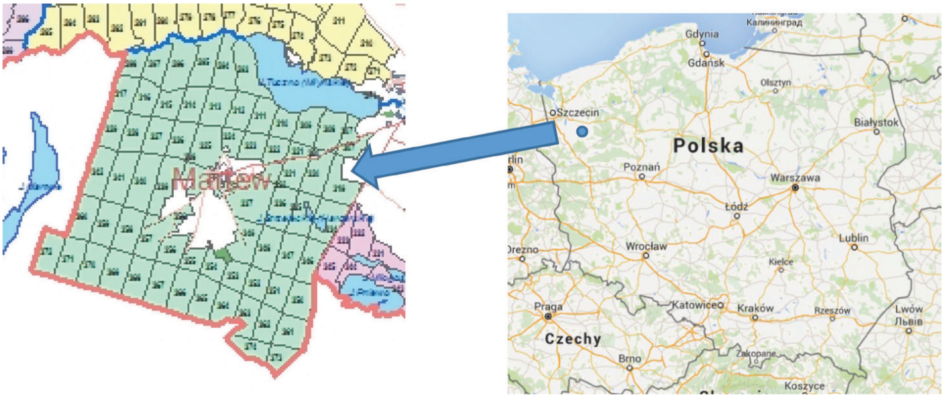
Soil retention results from water storage in the aeration zone of the soil profile (Mioduszewski 1996). It is especially important for plants. Its amount is determined by the quantity of water stored in the soil profile of a given thickness. It is not free water, but moisture available to plants (Chełmicki 2001). The value of water reserve in soil reveals short-term and long-term changeability. Short-term changes are a response to the weather conditions: the increases follow the precipitations whereas the losses are connected mainly with water consumption by tree stands for transpiration and evaporation from the soil (Suliński, Kucza 1987, Suliński 1989). Long-term changes are associated with biometric characteristics of the stand changing at its subsequent development stages (Suliński, Jaworski 1998). Tyszka and Stolarek (2003) write that the amount of soil water resources that recharge depends on the degree of precipitation transformations and potential water absorption by the substratum. This process may be disturbed in the winter months by soil freezing and snow retention. During the vegetation period (at its initial stage), soil moisture content results from post-winter retention. In June and July a considerable rainfall yield and its violent course favour a recovery of soil water resources. In August and September the low state of resources is conditioned by the amount of current rainfall. The precipitation lower than the usual monthly yields are mainly used for evapotranspiration and only to a low degree have an impact on the soil moisture content. There is some literature evidence, that linear trends concerning soil moisture for the data analysed over the recent years reveal downward tendencies (Robock et al. 2005, Keshavarz et al. 2011, Dorigo et al. 2012).

The aim of this paper is trend analysis of average daily soil moisture at different depths below the ground level in the Martew Forestry in 2014.

## DESCRIPTION OF THE RESEARCH AREA

The research area is situated in the north-western part of Poland in Tuczno Forest District, in the area of the Martew Forestry (Figure 1). Administratively, the terrain is located in the area of Wielkopolskie and Zachodniopomorskie provinces in the buffer zone of the Drawa National Park. No major urbanization occurs here and the forest complexes are coherent (http://www.tuczno.pila.lasy.gov.pl).

Formerly the area was an agricultural land, currently following the afforestation; a sixty-year old tree stand is growing in this place on a mixed forest site. The proportion of pine (*Pinus sylvestris* L.) in the stand species composition is 99%. The other 1% is composed of an admixture of silver birch (*Betula pendula* Roth.). The underbrush is composed of beech trees (*Fagus sylvatica* L.) and the hornbeam (*Carpinus betulus* L.) (Chojnicki et al. 2009). The soil type was identified as rusty soil, in places as rusty ground-gley soil, deposited on loamy sand (Urbaniak et al. 2014). Detailed physical, chemical and water properties of soils are provided in tables 1 and 2.




(http://www.tuczno.pila.lasy.gov.pl, https://www.google.com/maps/place)

**Figure 1.** Location of the research area

**Table 1.** Soil properties on the test bench

| Diagnostic levels | Depth | Fineness | Solid phase density [g/cm$^3$] | pH | | C |
|---|---|---|---|---|---|---|
| | | | | $H_2O$ | KCl | [g/kg] |
| 1Oi | 0-5 | | | 4.37 | 3.38 | 309.4 |
| 1A1 | 5-10 | loose sand | 1.425 | 4.45 | 3.78 | 1.92 |
| 1A2 | 10-22 | loose sand | 1.544 | 4.53 | 4.14 | 0.82 |
| 1Bv | 22-53 | loose sand | 1.647 | 4.96 | 4.44 | 0.17 |
| 1B2 | 53-85 | loose sand | 1.557 | 5.20 | 4.11 | 0.05 |
| 1B3 | 85-94 | loose sand | 1.571 | 6.68 | 6.55 | 0 |
| 1C | 94- | loose sand | | 5.82 | 4.99 | 0 |

## METHODS

A set of probes was installed in a well to estimate the moisture in the aeration zone. Moisture content measurements in the soil/ground were conducted using TDR time-domain reflectometry. The TDR method dielectric medium (eg. soil) is calculated by measuring the speed of propagation of electromagnetic pulse along a waveguide formed by electrically conductive electrodes, forming a probe placed in the test center. Permittivity determines the speed of propagation in the waveguide. Thus, by measuring the propagation speed of the electromagnetic pulse humidity medium can be estimated. For this reason a well of concrete rings, 1 m in diameter each, was dug to the depth of 7.5m, in which the openings for the probe installation were drilled. The measurements in the well were done by means of 7 CS616 reflectometers (Krzysztofiak-Kaniewska, Miler 2013, Urbaniak et al. 2014). The measurement was done every minute, whereas the ten-minute average was registered. Mean daily values were used for the analyses, of which annual trends were determined.

**Table 2.** Water properties of soils on the test bench

| Levels | Soil moisture [%] | | | | | | Porosity $[cm^3/cm^3]$ |
|---|---|---|---|---|---|---|---|
| | pF=1 | pF=1.6989 | pF=2 | pF=2.3979 | pF=2.6989 | pF=3 | |
| 1A(10-12) | 0.369 | 0.194 | 0.124 | 0.086 | 0.072 | 0.050 | 0.465 |
| 1A(5-7) | 0.433 | 0.266 | 0.167 | 0.120 | 0.096 | 0.080 | 0.498 |
| 1B1v(28-30) | 0.354 | 0.184 | 0.117 | 0.076 | 0.060 | 0.043 | 0.418 |
| 1B2v(48-50) | 0.323 | 0.159 | 0.108 | 0.073 | 0.056 | 0.039 | 0.432 |
| 1Bv3(80-82) | 0.220 | 0.109 | 0.088 | 0.071 | 0.059 | 0.046 | 0.374 |
| 1C(130-132) | 0.141 | 0.065 | 0.052 | 0.042 | 0.033 | 0.020 | 0.397 |

The determined trends were subjected to the analysis using the Mann-Kendall nonparametric test (Gilbert 1987), which is used for e.g. the estimation of the trends for hydrological and climatic parameters (Hirsch, Slack 1984, Chiew, McMahon 1993, Yue et al. 2002, Khambhammettu 2005, Banasik et al. 2013). The values of S statistics in the test were determined on the basis of the following formula:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn\left(x_j - x_k\right) \tag{1}$$

where:

$$sgn\left(x_j - x_k\right) = \begin{cases} 1\ for\ \left(x_j - x_k\right) > 0 \\ 0\ for\ \left(x_j - x_k\right) = 0 \\ -1\ for\ \left(x_j - x_k\right) < 0 \end{cases}$$

$x_j$, $x_k$ – values of data in j and k times
$n$ – the length (number) of data set.

The values of data were compared in relation to all subsequent data values. The initial value of S Mann-Kendall statistics was assumed as 0 (lack of trend). If the value of a subsequent element of the series was higher than the preceding value, S increased by 1. On the other hand, if the value of the subsequent element of the series was lower than the preceding value, S decreased by 1. In result of the computations, the final value of S was obtained. Computations of S (Var(S)) variance were conducted considering the corrections regarding the number of data per series above 40 with repeated values in the data group (Gilbert 1987).

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p-1)(2t_p-5)}{18} \quad (2)$$

where:
$n$ – length (number) of data set
$g$ – number of data groups with repeated values
$t_p$ – number of repeated data values per group.

Using standardized Z test statistics calculated on the basis of the following formula:

$$Z = \begin{cases} \frac{S-1}{[(Var\ (S)]^{1/2}} & dla\, S > 0 \\ 0 & dla\, S = 0 \\ \frac{S+1}{[(Var\ (S)]^{1/2}} & dla\, S < 0 \end{cases} \quad (3)$$

The probability connected with Z test statistics was computed. It has been assumed that the trend is declining if Z is less than zero, whereas the probability is lesser than the assumed significance level α=0.05. At the same time the trend is regarded as increasing if Z is higher than zero while the probability is lower than the assumed significance level α=0.05.

## RESULTS

The annual precipitation total analysed for the researched area over the year 2014 was 484.3 mm. The highest daily precipitation total (27.7 mm) was registered on 22.12.2014 (Figure 2). A lack of precipitation was registered on almost 60% of days per year. The month with the highest rainfall was August (on average 83.1 mm) whereas November was characterized with the lowest precipitation (9.1 mm). In analyzed period the trend line for the precipitations was growing.

The greatest changeability of moisture content was registered in the measurements conducted at the depth of 0.85 and 2.00 m bgl (below ground level) – respectively 0.06008 and 0.03300 (Table 1, Figure 3). The 6.55 and 7.25 m (bgl levels revealed the least changeability, which was 0.00500 for both levels

(Figure 5). The wells from the intermediate depths (3.15-5.50 m bgl with the difference between the measured extreme values between 0.01000 and 0.00783 occupy an intermediate position (Figure 4).

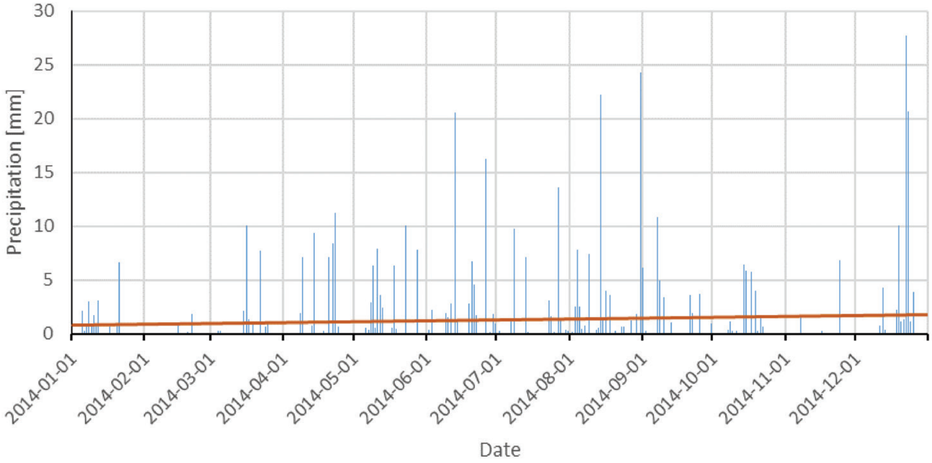



**Figure 2.** Distribution of daily precipitation sum in 2014

**Table 3.** The basic parameters describing soil moisture data measured at different levels below the ground surface in 2014

| Depth of measurements [m b.g.l.] | Minimum [%] | Maximum [%] | Mean [%] |
|---|---|---|---|
| 0.85 | 4.400 | 10.408 | 7.293 |
| 2.00 | 4.200 | 7.500 | 5.097 |
| 3.15 | 3.300 | 4.100 | 3.639 |
| 4.30 | 3.817 | 4.600 | 4.145 |
| 5.50 | 4.000 | 5.000 | 4.345 |
| 6.55 | 4.200 | 4.700 | 4.346 |
| 7.25 | 3.300 | 3.800 | 3.445 |

The moisture level at 0.85m in depth bgl proved to be the most sensitive to precipitations, which is obvious, however its response is different in various seasons of the year. A strong increase in moisture at the beginning of the year is undoubtedly the result of spring snowmelt and the value of moisture content after this period was among the biggest over the whole studied year. In the subsequent months the moisture level was generally decreasing with increases during precipitation periods. It was undoubtedly affected by growing evapotranspiration during the spring-summer period. Since September the moisture was responding more strongly to precipitation, as evidenced by the increases at the beginning of September, in October and December. A similar course of changes in moisture content was registered on the depth of 2.00 m bgl The direction of changes has been maintained on the higher situated layer but the moisture content did not reveal any rapid growths. Two obvious increases were noted in September and December when daily precipitations oscillated around 25 mm. The subsequent three depths did not reflect the changes from the depths of 0.85 and 2.00 m bgl. The moisture courses at the depth of 3.15 and 4.30 m bgl are almost parallel with the lower moisture content on a higher level. At the depth of 5.50 m bgl the moisture values were higher than at the depth of 3.15 and 4.30 m bgl and its course as the only one in the whole profile revealed an upward trend. In two of the deepest layers the moisture values were the most aligned and their courses are approximate to each other.

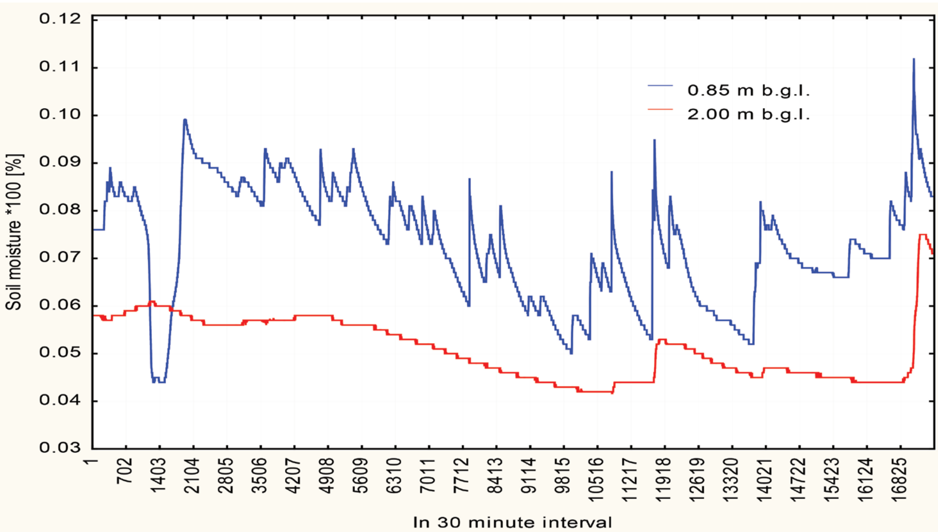



**Figure 3.** Distribution of average daily soil moisture at the depth of 0.85 and 2.00 m below ground level in 2014

Negative values of Mann-Kendall statistics (Table 4) indicate the occurrence of decreasing tendencies regarding a majority, six out of seven analysed measurement levels.

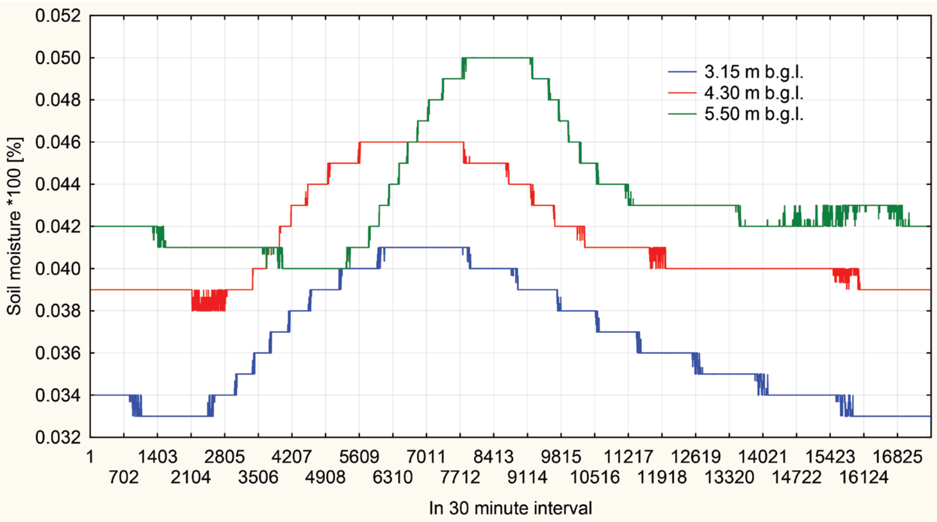



**Figure 4.** Distribution of average daily soil moisture at the depth of 3.15, 4.30 and 5.50 m below ground level in 2014

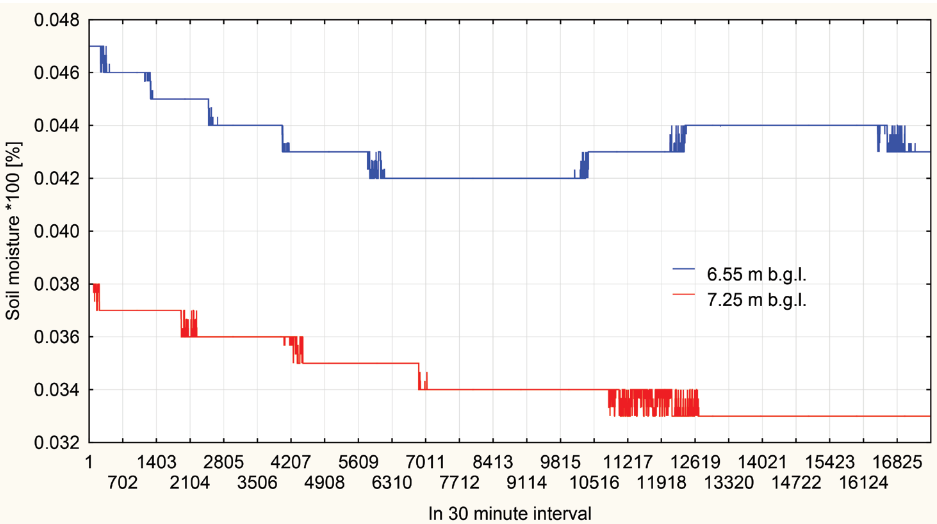



**Figure 5.** Distribution of average daily soil moisture at the depth of 6.55 and 7.25 m below ground level in 2014

**Table 4.** Trend analysis of average daily soil moisture at different depths below the ground level in the Martew Forestry in 2014

| Depth [m] | Range [%] | Mann-Kendall S | Test Z | p value | Trend on significance level 5% |
|---|---|---|---|---|---|
| 0.85 | 4.400-10.408 | -19780 | -8.4920 | 1.0157E-17 | Decreasing |
| 2 | 4.200-7.500 | -37515 | -16.1306 | 7.7718E-59 | Decreasing |
| 3.15 | 3.300-4.100 | -14192 | -6.1260 | 4.5058E-10 | Decreasing |
| 4.3 | 3.817-4.600 | -9727 | -4.2287 | 1.1752E-05 | Decreasing |
| 5.5 | 4.000-5.000 | 7771 | 3.3563 | 3.9494E-4 | Increasing |
| 6.55 | 4.200-4.700 | -7502 | -3.3046 | 4.7548E-4 | Decreasing |
| 7.25 | 3.300-3.800 | -55265 | -24.1700 | 2.2996E-129 | Decreasing |

## CONCLUSIONS

A drying tendency was not confirmed in the precipitation data set. Despite the fact that precipitation is regarded as the main factor for the shaping of the soil water resources, their amount does not seem to be controlled by the other characteristics describing the catchment area and the components of water balance, e.g. evapotranspiration. Dorigo et al. (2012) drew similar conclusions from their investigations. Seasonal changeability in the Mann-Kendall trend test after accumulating more data series seems worth analysing. Further research is necessary to point out the cause of decreasing trends in soil water resources of the investigated area.

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