

Estimating the Soil Water Content Using Electrical Conductivity, Oven Method and Speedy Moisture Tester

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Abstract—Soil samples were taken in order to investigate the spatial soil water content changes at 40 points in a field of 675 m² located on the old Istanbul-Izmit road in Kocaeli-Turkey. The water content values of soil samples collected were obtained using oven and Speedy Moisture Tester (SMT) in the laboratory to correlate with measured electrical conductivity of soil by electrical resistivity method with a 2-electrode system. The results showed a reasonably good correlation between electrical conductivity and water content. The determination coefficient between the water content and the electrical conductivity found by the oven method ($R^2 \approx 0.8$) was higher than that of the SMT ($R^2 \approx 0.6$). The correlation between the water content values of oven and SMT is quite affordable with the determination coefficient ($R^2 \approx 0.7$). Considering the results obtained from Oven and SMT method, it can be concluded that the resistivity method is also successful in measuring soil water content. It is foreseen that resistivity method can be preferred both because it is easy to use, and large areas are faster and economical in measuring soil water content.

Keywords: electrical conductivity, Luvisol, oven method, regression, Speedy Moisture Tester, water content

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INTRODUCTION

Water is the life source of all living things and a special material for living things. Soil water is necessary for the growth and development of the plant. Soil water content (SWC) defined by Rodríguez-Iturbe and Porporato [16] is one of the most important factors for plant growth, microbial decomposition of organic matter of soil, seed germination and plant nutrition.

The SWC is also an important parameter that determines the rate of decomposition of the soil organic material, such as soil respiration and soil carbon attachment rate. Currently, the estimation of SWC can be done in three techniques: (1) in situ measurements in the field, (2) remote sensing techniques and (3) soil water balance simulation [21].

In recent decades, much equipment was developed for SWC estimation in an indirect way [6, 24]. So far, many researchers have studied SWC in a variety of ways: Neutron moisture meters [23], cosmic-ray neutron probe [20], capacitance sensors [17], tensiometers [24], heat pulse sensors [6], fiber optic sensors [7] and GPS [18], Time Domain Reflectometry (TDR) [11, 13, 22] and resistivity meter [1, 5, 26].

Apart from the information on the distribution of the spatial water content of the soil in agricultural engineering, the vertical distribution profile of the water is also required. The above-mentioned TDR, remote sensing, cosmic-ray neutron probe: Neutron moisture

meters have a depth resolution of only a few centimeters. Gravimetric or TDR measurements of deeper soil layers are very demanding because they require excavation. These methods have limited use in water availability studies for deeper soil moisture storage and plant growth. With the electrical resistivity measurements of the soil, this problem can be eliminated on a vertical and spatial scale. The cheap, fast and time-saving feature of the resistivity method makes it superior to other methods. The resistivity of rock or soil varies with the water they contain. Since the groundwater has a good conductivity, it decreases the resistivity value.

In this study, it is aimed to compare the water content of the soil samples determined by oven method and Speedy Moisture Tester with the water content calculated by electrical resistivity method one of the geophysical methods.

DESCRIPTION OF STUDY AREA

The research area is located along the old Istanbul-Izmit road in Kocaeli (Fig. 1). The research area is underlain by the Atbasi formation aged from Paleocene to lower Eocene. The unit where sandstone and shale, marl and mudstones were intercalated was named as Atbasi formation by Ketin and Gumus [15]. The thickness of the unit varies between 50–500 m. Mechanical drillings in the area showed that 50–70 cm thick soft silty clay with less sand and gravel on the sur-

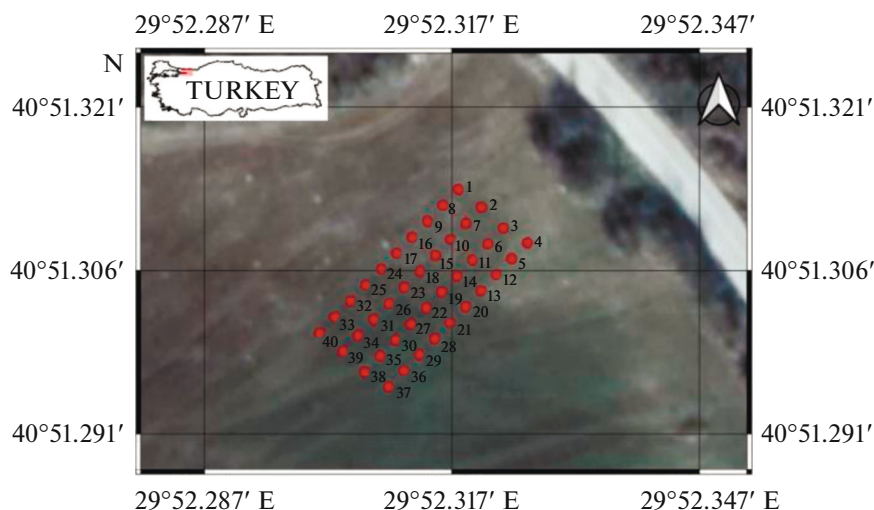


Fig. 1. Location map of the study area.

face (top cover) was present and solid silty sandy clay continued to be below 7–8 m depth. Soil texture of the soft silty clay is given in Table 1.

Atterberg limit tests of soil samples taken from silty clay were performed on the surface and the results are given in Table 2. In the Atterberg Limits tests performed on the undisturbed (UD) sample taken from the main research drillings in the field, the mean soil plasticity was found as $PI = 26.865$. When these values were evaluated according to [12] the plasticity of the soft silty clay (top cover) was determined as “plastic” and dry strength as “medium”.

These data were evaluated according to the Unified Soil Classification System (USCS) and were determined as ground class CL (low plasticity clay) for fine grained soils. The soil is salt-free $Ec < 4 \text{ dS m}^{-1}$ [19].

MATERIAL AND METHODS

Soil Sample Collection for Laboratory Tests

Soil samples and resistivity measurements were taken at 40 points with 5-m intervals. The soil samples at each measuring point were collected using tubular soil sampler. The soil samples were immediately put into plastic bags and their mouths were closed tightly and they were taken to the laboratory without waiting.

Determination of Water Content of Soil by Oven Drying Method

The soil samples collected from top soil (Luvisol), 30 cm of depth, were analyzed for water content (W_n , %) with the oven method and Speedy Moisture Tester in the laboratory. 40 g soil is taken at each of measuring points. 20 g of this was used in the oven method and 20 g in the Speedy Moisture Tester. In the oven method collected 20 g soil samples were placed in jars

and weighed. The Jars and soil samples were kept at room temperature until ready to process. When they were ready, they were placed in the oven at 105°C and dried for 24 h. After they were removed from the oven and dried, their weights were measured again. Their water content was found by dividing the difference between weights before and after drying by soil weight.

$$W_n = [(m_1 - m_2)/(m_2 - m_0)] \times 100, \quad (1)$$

where m_1 —mass of the container with wet soil, m_2 —mass of the container with dry soil, m_0 —mass of empty container.

The moisture map of the key plot obtained from the oven water content values is demonstrated in Fig. 2. While the water content in the southern part of the field varies between 14–18% (blue colored), it reaches to the north and west of it, reaching to 24–28%. Water content varies between 20–22% in the middle of the key plot.

Table 1. Sieve analysis values

Parameter	Minimum	Maximum	Mean
Gravel, %	0.00	9.95	4.975
Sand, %	20	29.5	24.75
Silt and Clay, %	69.8	79.64	74.72

Table 2. Atterberg limit values

Parameter	Minimum	Maximum	Mean
Liquid limit LL, %	38.42	56.72	47.57
Plastic limit PL, %	16.86	24.55	20.75
Plasticity index PI, %	21.56	32.17	26.865

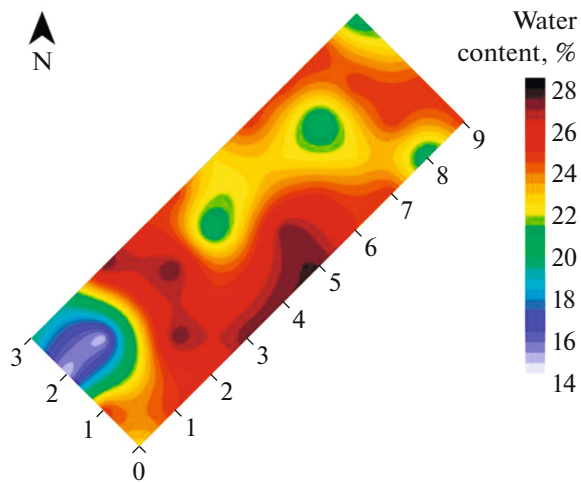


Fig. 2. 2D water content map of key plot.

Determination of Water Content of Soil Samples Using a SMT

The water content of the soil samples taken from the field was also found with the Speedy Moisture Tester. This device consists of a low-pressure vessel equipped with a pressure gauge and an electronic scale and test accessories and is used to measure practically moisture content of various materials such as soil, aggregate, dust and powders. Moisture measurements are made by mixing the soil sample of a certain weight with a calcium carbide reagent in a closed pressure vessel. Reagent reacts chemically with water in the soil sample producing acetylene gas that in turn increases the pressure within the vessel. The pressure increase in

the chamber is proportional to the amount of water in the sample and the moisture content is read directly from the pressure gauge of the device. The accuracy of the device is 0.5% for most materials and can be calibrated from 0–20% moisture, based on wet weight. Test speeds range from 45 s to 3 min.

To obtain the water content with the Speedy Moisture Tester, 20 g soil sample was poured into the chamber of Speedy vessel. After that pulverizing balls were placed into the chamber and was added two full scoops of reagent to the Speedy cap cavity. The sample was mixed with the reagent holding the Speedy horizontally and shaking it in an orbital motion to make the balls spin around inside the Speedy vessel for 20 s. After resting 20 s, this process repeated two or three times. Water content was read directly from the pressure gauge, keeping the Speedy horizontal and at eye level (Fig. 3). The water content map of the key plot obtained using the SMT values is given in Fig. 4. As can be seen from the figure, there is a close relationship between the water content map found by the Oven method and the water content map from the SMT.

Determination of Water Content of Soil Using a Resistivity Meter

The studies were performed using two electrodes the pole-pole system. In this system, a current (C1) and a potential (P1) electrodes are placed at 1m intervals to determine the resistivity of the soil at least 30 cm of depth and the other current (C2) and potential (P2) electrodes are placed 100 m away from these electrodes (Fig. 5). The distance of these two electrode systems from the research line must be at least 20 times

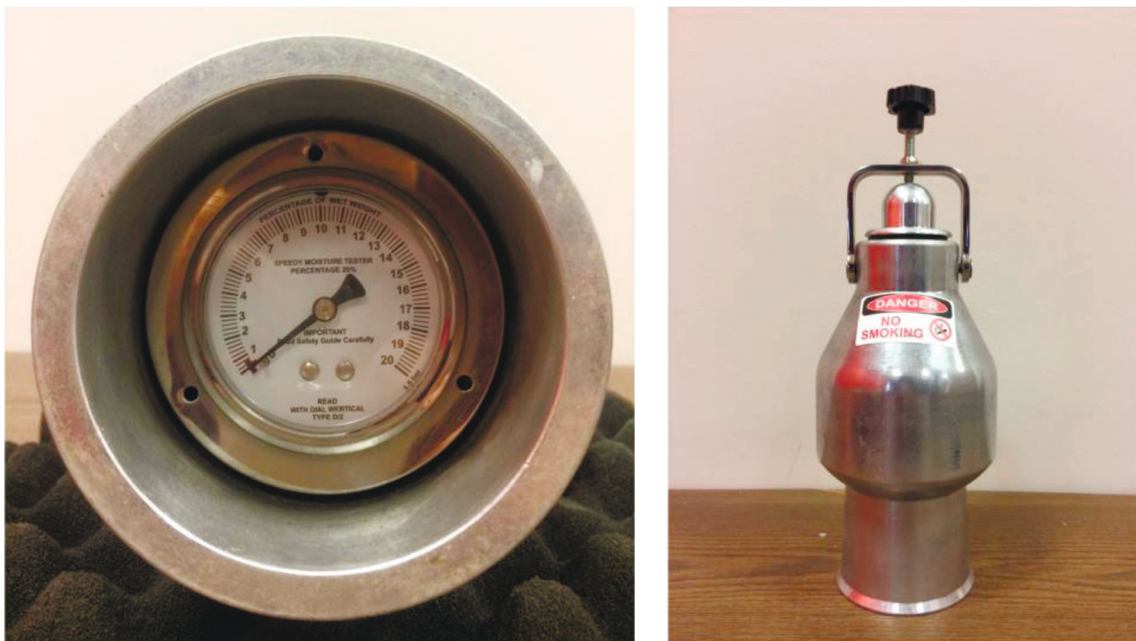


Fig. 3. Speedy Moisture Tester (SMT).

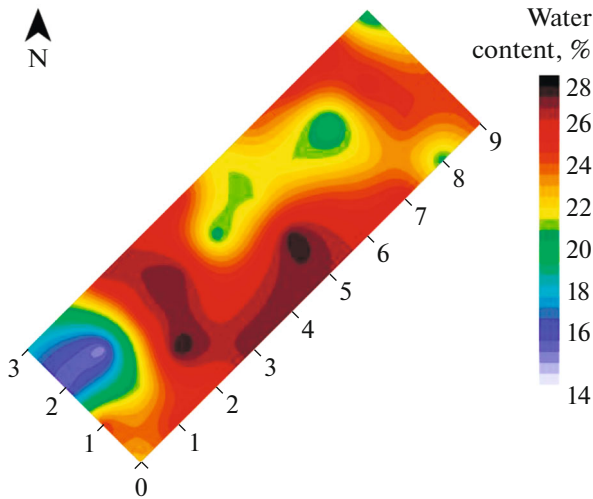


Fig. 4. 2D SMT water content map of key plot.

the largest C1–P1 distance to ensure that the error is less than 5% [27].

The two electrodes array gives useful information for subsurface layers [4, 14, 25]. The geometric factor k for two electrodes array is given by

$$k = 2\pi a, \tag{2}$$

where a is the spacing between the electrodes. The apparent resistivity is calculated by the following equation

$$\rho_a = k(V/I) = 2\pi a(V/I) \text{ [Ohm m]}, \tag{3}$$

where k = array geometric factor, V = voltage (mv), I = DC current (mA). The electrical conductivity is found by E

$$C_a = 1/\rho_a \text{ [Siemens per metre (S m}^{-1}\text{)]}. \tag{4}$$

The soil apparent conductivity map of the key plot is shown in Fig. 6. As can be seen from the figure, the electrical conductivity values in the south of the study area where the water content varies between 2 and 4% range from 0.0016 to 0.002 S m⁻¹ and just to the north of this area and to the west of the key plot rises to

0.0026–0.0028 S m⁻¹. Electrical conductivity and water content values are in harmony with each other.

Regression Analysis

Simple regression analysis was conducted to determine the relationships between conductivity (EC_a) versus water content (W_n) with the oven method (Fig. 7) and EC_a versus W_n with Speedy Moisture Tester (SMT) (Fig. 8). As seen from Fig. 7 that there is a reasonable linear relationship between EC_a and the W_n determined by oven method with the determination coefficient $R^2 = 0.7852$. Electrical conductivity increases with increasing water content. The same situation was determined between EC_a and water content determined by SMT with the determination coefficient $R^2 = 0.5596$. The linear relationship determined between water content determined by oven method and Speedy moisture tester with the determination coefficient $R^2 = 0.6935$ (Fig. 9). There is a linear relationship between W_n (SMT) and W_n (oven method).

DISCUSSION

The spatial soil content variability of the key plot was analyzed at 40 points at a distance of 5 m in key plot located along the old Istanbul-Izmit road, in Kocaeli, NW Turkey. For this purpose, soil water content values were determined by using oven method and SMT. Geophysical resistivity method was applied to find the electrical conductivity of the soil at each points, where the soil samples immediately after collection to correlate the results of oven and SMT. The ranges of water content values determined with the oven method vary between 15 and 27.5% while those determined by SMT method change between 15.5 and 27.5%. The conductivity values range from 0.0016 to 0.0028 S m⁻¹. Oven and SMT measurements do not show a significant change. Oven water content and electrical conductivity measurements indicated a rather strong linear correlation with determination coefficient $R^2 = 0.7852$. SMT water content and electrical conductivity measurements showed a slightly



Fig. 5. Resistivity data acquisition by two electrodes array.

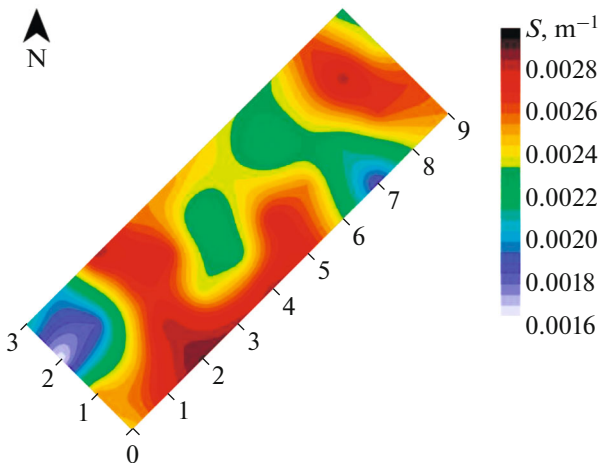


Fig. 6. 2D electrical conductivity map of key plot.

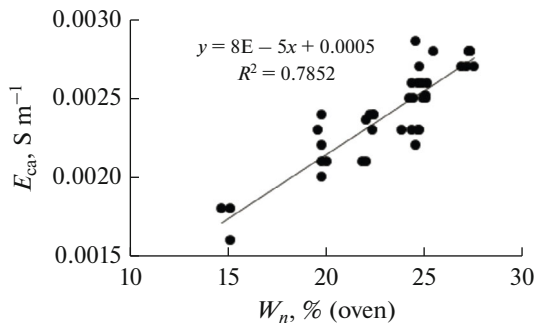


Fig. 7. Conductivity versus Oven water content values.

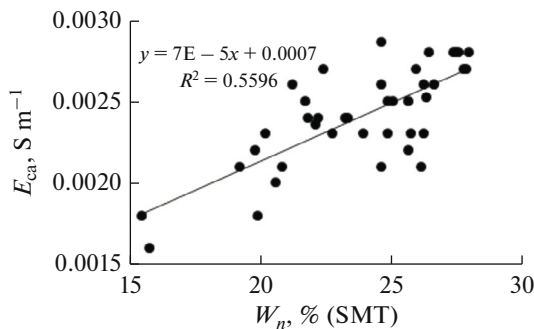


Fig. 8. Conductivity versus SMT water content values.

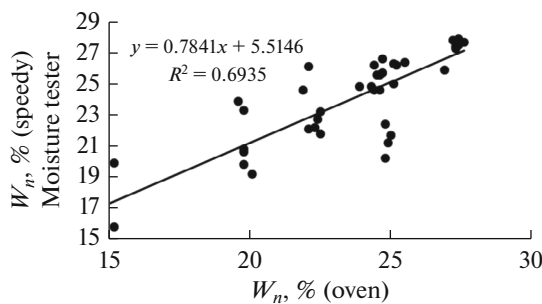


Fig. 9. Relationship between W_n with SMT method and W_n with oven method.

weak linear correlation with the determination coefficient $R^2 = 0.5596$. The electrical conductivity values increased with an increase in water contents of both determined with oven and SMT. The variability of the electrical conductivity and SMT water content values show more scattering than those of electrical conductivity and oven water content values.

The empirical formula determined from the relationship between the oven water content and electrical conductivity values for the soil specimens is given in (5) and that developed between SMT water content and electrical conductivity values is shown in (6).

$$ECa = 8 \times 10^{-5} (W_{n(Oven)}) + 0.0005 \quad (R^2 \approx 0.79), \quad (5)$$

$$ECa = 7 \times 10^{-5} (W_{n(SMT)}) + 0.0007 \quad (R^2 \approx 0.56). \quad (6)$$

From the regression line of oven and SMT water content values, the empirical formula is determined for the soil samples

$$W_{n(Oven)} = 0.7841(W_{n(SMT)}) + 5.5146 \quad (R^2 \approx 0.69). \quad (7)$$

As can be seen from Eqs. (5)–(7), the highest determination ($R^2 \approx 0.79$) was obtained between electrical conductivity (EC_a) and water content determined by oven method ($W_{n(Oven)}$). The correlation between the water content values obtained by SMT and the electrical conductivity is lower than the correlation between the water content values obtained by oven method and the electrical conductivity ($W_{n(SMT)}$). This means that if the water content of the soil is to be estimated by electric conductivity, it would be more appropriate to prefer the oven method for the correlation. When the determination coefficient ($R^2 \approx 0.69$) is taken into consideration, it is understood that the water contents of the soil samples found by the oven and SMT methods are not too much compatible with each other. The electrical conductivity increases with increasing water content values in the key plot which is salt-free. In the study area, the physical properties of the soil do not vary very much and the most important factor affecting the electrical conductivity is seen as water content of the soil samples. The results obtained in this study are consistent with the results of previous researches [1–3, 8–10, 28]. The results obtained in this study support the monitoring of soil water content by the use of electrical conductivity data. However, additional studies have to be done to determine which electrode systems have superiority in finding soil water content. In addition, the application of these studies through the soils showing changes in physical and chemical properties will be important to test the reliability of the electrical conductivity method.

CONCLUSIONS

The determination of the water content by the SMT and the oven method requires the removal of soil

samples from the land, and laboratory work which is time consuming and expensive. Because of this difficulty, the usage of resistivity method to estimate the water content from apparent electrical conductivity can be considered appropriate for a preliminary study.

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