Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 13, No. 4, p. 63-72, 2018
http://www.innspub.net

INNSPUB
RESEARCH PAPER

OPEN ACCESS

Development and validation of portable electronic sensor to detect the soil moisture for geotechnical investigations

Mian Sohail Akram[1], Kamran Mirza[1], Asim Iqbal[2], Muhammad Zeeshan[1*]

[1]*Institute of Geology, University of the Punjab, Lahore, Pakistan*

[2]*Department of Civil Engineering, FAST-NUCES, Lahore, Pakistan*

Article published October 06, 2018

Key words: Soil, Moisture content, Portable Electronic Instant Soil Moisture Sensor.

Abstract

The aim of this study is to develop and validate the Portable Electronic Instant Soil Moisture Sensor for the measurement of soil moisture, which is a basic step towards the soil characterization and used frequently as part of geotechnical investigations. In laboratory, soil moisture is determined by the oven-dry method and in the field generally by speedy moisture tester. The development of Portable Electronic Instant Soil Moisture Sensor is motivated to find soil moisture instantly without using any chemicals or split arrangements in the laboratory as well as in the field. The basic methodology and principle behind the moisture determination with this sensor is the application of electrical capacitance. The moisture content of 1200 soil samples from a north-east region of Pakistan (Lahore, Punjab) were determined by Portable Electronic Instant Soil Moisture Sensor and correspondingly laboratory Oven Dry Method results according to the standard American Society for Testing Materials to validate the sensor by comparison of results conducted by both methods. The comparison was made on various soil types and varying degree of moisture salinity. The results show that it has the accuracy level up to ± 2.5% to 3.0% as compared with the conducted results of Oven Dry Method, and it may be used with confidence in the field and laboratory for instant moisture determination.

***Corresponding Author:** Muhammad Zeeshan ✉ sohail.geo@pu.edu.pk

Introduction

The soil moisture determination is one of the basic and foundation tests carried out in both laboratory and field. Due to this importance, it has always been a necessity to obtain the soil moisture in quick time with accurate value, various methods/techniques have been developed to do the same like oven dry method (for laboratory) and speedy moisture test (for the field). The speedy moisture tester has been widely recognized and practiced. Besides this, the use of indirect methods like NMM (Neutron Moisture Meter), Thermal sensor, TDR (Time Domain Reflectometer), capacitive sensors etc. which give an indirect estimation of the soil moisture has also been promising hence inducing an encouragement to develop something based on one of these.

The main aim of this study is to develop a capacitive sensor to determine the moisture content of soil rapidly. The material used to develop this instrument is easily available with low cost and most importantly the controllable size of the instrument. The capacitance method uses the dielectric constant of the soil which is reliable property, also the varnish around the sensor keep it unaffected by the salinity of the water. Hence, it was tested to report the results correctly even in saline conditions. Total 1200 samples from a north-east region of Pakistan (Lahore, Punjab) were tested to compare the results for validation of an instrument. The horizontal and vertical analysis of the device has been done in order to make sure that it makes up to the satisfaction level as required and the obtained results present good correlation factor.

Materials and methods

In general water content or moisture content is the quantity of water contained in a material, such as soil where it is called soil moisture. Soil moisture determination is carried out using two methods, classified as Direct and Indirect methods (Hignettand Evett, 2008). Among direct methods, oven dry method (ASTM D-2216, 2010) and the speedy moisture test using calcium carbide (ASTM D-4944-11)are common. Whereas among Indirect methods, Neutron Moisture Meter (NMM), Time Domain Reflectometer (TDR) and capacitance probe methods are usually undertaken consideration.

Development of Portable Electronic Instant Soil Moisture Sensor (PEISMS)

The development of the PEISMS involves soil moisture content sensor from a vegetronix corporation (Fig.1), which is a capacitance-based sensor using transmission line techniques and Table 1 provides technical specifications of the sensor. The sensor was later connected with a locally developed circuit based on the calibration data. The instrument was setup by connecting the LCD panel and circuit board to the sensor probe and a 12-volt battery for power supply, the surface of the probe was wiped every time for a clean reading value. Taking readings from PEISMS was the process of penetrating the sensor probe into the soil directly, and the readings for the moisture content in percentage were displayed on the attached LCD Panel.

The calibration of the sensor was performed by installing in PVC recipient of cylindrical shape that was filled with soil and both sensor and soil were humidified with capillary (Atkins *et al.*, 1998). In the lower end of the PVC pipes, 5 holes with diameters of 6mm were created. These holes allowed the system (soil and sensor) to be humidified by capillarity, for 24 hours. Water accumulated in excess inside the recipient is dropped by the holes in the bottom of the PVC recipient. Additionally, caution was taken to install the sensors appropriately in the sample of soil. The set (sensor and soil) was also weighed daily, in the same moment of the reading of the output voltage by using an electronic balance, with a solution of 0.01 gram were also noted. The soil moisture was determined by Equation 1.

$$U\% = \frac{P_1 - P_2}{P_2 - P_3} \times 100 \qquad (1)$$

Where U% is the soil moisture expressed in terms of dry weight, P_1 is the weight of the humid sample soil,

P_2 is the weight of the drying sample soil and P_3 is the weight of the recipient. The weight of the drying sample soil was obtained before the beginning of each experiment. In each experiment, the sensor was weighed so that its weight could be subtracted in the results. In these capacitance systems, the frequency of oscillation is also affected by clay content, bulk electrical conductivity, and temperature (Baumhardt *et al.*, 2000).

Trial testing

It was necessary to test the adequate amount of samples and compare the results with standard oven dry to validate the instrument setup of PEISMS. The objective of the trial testing was to find and eliminate the mistakes which can compromise the quality of the final testing, also if some mistakes are found they could be corrected by making necessary adjustments. The trial testing helped to evaluate the estimated time and duration for the final testing planned with around 1200 samples(Fig. 2). Few problems regarding connections of ports were faced during the trail testing but these were eliminated by keeping the backup connecting wires. It was decided after multiple readings that five readings should be taken for each sample and an average was taken to mark the reading for the sample, this gave better results during the comparison (Iqbal, 2015; Akram and Iqbal, 2017).

Validation of PEISMS

After successful calibration and initial trial testing, validation of PEISMS was conducted on more than 1200 (700 natural moisture, 300 with 10% saline water and 200 with 15% saline water) samples. These samples belonged to various soil types by comparing the results of PEISMS and oven dry method conducted in the laboratory. In order to test PEISMS against the oven dry method which is a standard test in order to determine the moisture content; around 1200 samples of different soil gradations were prepared out of which 700 by adding 0%, 300 by 10% and 200 by 15% saline water made under controlled conditions(Adachi, 2004). The soil for the samples was acquired from different vicinities of Lahore and other districts of Punjab Province. The samples for the test were prepared in the laboratory, initially, the whole soil was oven dried overnight for the particle size analysis, and later the graded soil was wetted by adding water and kept overnight again for homogenous absorption and better results, the process was repeated and various samples were prepared for onward testing.

PEISMS was set up by connecting the LCD panel and circuit board to the sensor probe and a 12-volt battery for power supply, the surface of the probe was wiped every time for a clean reading value. Taking readings from PEISMS was the process of penetrating the sensor probe into the soil directly and the readings for the moisture content in percentage were displayed on the attached LCD Panel. The readings were taken at five different points in a single sample and an average was recorded. The readings were taken for 25 days and around 40-50 samples were tested every day, after reading values from PEISMS the sample was weighted and was placed in the oven for the determination of soil moisture through the oven dry method for comparison. Some variations were observed when the sensor probe was inserted into the soil sample at different depths, these variations were caused by the bulk electric conductivity (BEC) altered by the soil dielectric permittivity. Hence, the depth of penetration of sensor probe was not increased much and readings were taken at shallow depth mainly for quick and accurate readings. This variation issue can also be minimized by providing the access tubes having a standard diameter and wall thickness and keeping the soil sensor in self-centered position, the tube was wiped every time before insertion into the soil sample to avoid the liquid moisture around the tube which may have a significant impact on the readings of the sensor. This process kept the measurement volume small and increasing the precision, a 40 PVC pipe may be recommended solution to the problem. The sensor probe was also normalized by taking readings in air and water for comparison, the readings in air and water may also be taken with shorter length access tubes (Iqbal, 2015).

Results and discussion

The 1200 soil samples were tested with both PEISMS and oven dry methods subjected to soil type. Initially, all the test results of the samples without having saline water were analyzed.

Table 1. Soil Moisture probe specifications (Ravi *et al.*, 2004).

Contents	Details
Power Consumption	< 7mA
Supply voltage	3.3V to 20 VDC
Power ON to stable time	400 ms
Output Impedance	100K Ohms
Operational Temperature	-40 °C to 85 °C
Accuracy upto	< 1%
Output	0 to 3V related to moisture content

The soils types were grouped into five categories (Table 2) based on the particle size. In order to compare the results between the two methods, the difference of the values from results was calculated. The results were later compared in a graph where the slope of the graph and the y-intercept of the best fitting line was calculated.

Table 2. Group – A soil (A1-A5) mixed with normal water for sample preparation.

Sr. No.	Group soil description	Sieve sizes
1	Soil – A1	#40 Passing #60 Retained
2	Soil – A2	#60 Passing #80 Retained
3	Soil – A3	#80 Passing #100 Retained
4	Soil – A4	#100 Passing #200 Retained
5	Soil – A5	#200 Passing

Table 3. Group–B Soils mixed with 10% saline water for sample preparation.

Sr. No.	Group soil description (10% Saline)	Sieve sizes
1	Soil – B1	#40 Passing #60 Retained
2	Soil – B2	#60 Passing #80 Retained
3	Soil – B3	#100 Passing #200 Retained

The initial samples were made from the soil passing through the sieve #40 and retaining on the sieve #60, this soil was named as Soil-A1, the soil was then mixed with tap water and samples were obtained to perform the final testing, after the results from the PEISMS and the oven dry method were obtained they were compared with a graph, which showed the data correlation factor R^2 of line being 0.9371 and the slope of line being 1.02, the results were good to go as shown in the Fig. 3a. Secondly, the samples obtained from the soil passing through the sieve #60 and retaining on the sieve #80, this soil was named as Soil-A2, the soil was mixed with tap water and samples were obtained to perform the final testing, after the results from the PEISMS and the oven dry method were obtained they were compared with a graph which showed the data correlation factor R^2 of line being 0.9591 and the slope of line being 1.06 (Fig. 3b).

Table 4. Group – C Soils mixed with 15% Saline water for Sample Preparation.

Sr. No.	Group soil description (15% Saline)	Sieve sizes
1	Soil – C1	#40 Passing
		#60 Retained
2	Soil – C2	#80 Passing
		#100 Retained
3	Soil – C3	#200 Passing

For Soil-A3, the samples were made from the soil passing through the sieve #80 and retaining on the sieve #100, this soil was named as Soil-A3, the soil was then mixed with tap water and samples were obtained to perform the final testing, after the results from the PEISMS and the oven dry method were obtained they were compared with a graph which showed the data correlation factor R^2 of line being 0.9371 and the slope of line being 1.02 (Fig. 3c).

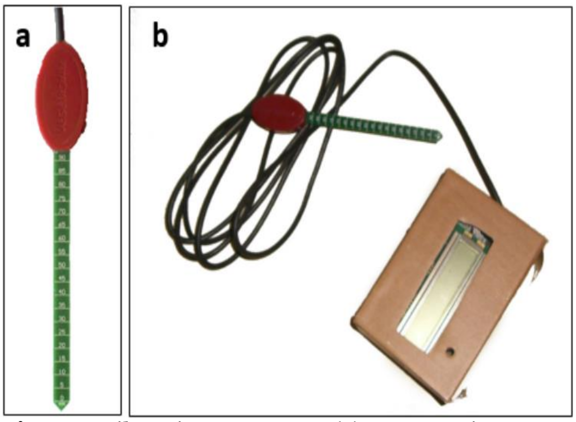

Fig. 1. Soil Moisture Sensor (a) Vegetronix Sensor (vegetronix.com) (b) Instrument Setup of PEISMS.

The Soil-A4 samples were made from the soil passing through the sieve #100 and retaining on the sieve #200, this soil was named as Soil-A4, the soil was then mixed with tap water and samples were obtained to perform the final testing, after the results from the PEISMS and the oven dry method were obtained they were compared with a graph which showed the data correlation factor R^2 of line being 0.9745 and the slope of line being 1.05 (Fig. 3d).

Finally, the Soil-A5 samples were prepared from the soil passing through the sieve #200 and collected over the pan, due to the constraint of time and proper handling of data the tests were limited to the study form samples obtained from sieve analysis only this soil was named as Soil-A5, the soil was then mixed with tap water and samples were obtained to perform the final testing, after the results from the PEISMS and the oven dry method were obtained they were compared with a graph which showed the data correlation factor R^2 of line being 0.9185 and the slope of line being 1.02 (Fig. 4a).

The overall comparison of the results from PEISMS and the oven dry method shows very low difference that is around ± 2.5 % in case of normal tap water, the results show that Slope of line remained to be 1.04 also that the correlation factor R^2 also remained 0.9602 (Fig. 4b) that justified the use of the sensor with capacitance probe.

The results from all soil samples using PEISMS were combined to get the overall picture and deviation from the Oven dry method; the following graphs present the results obtained from samples prepared using normal water.

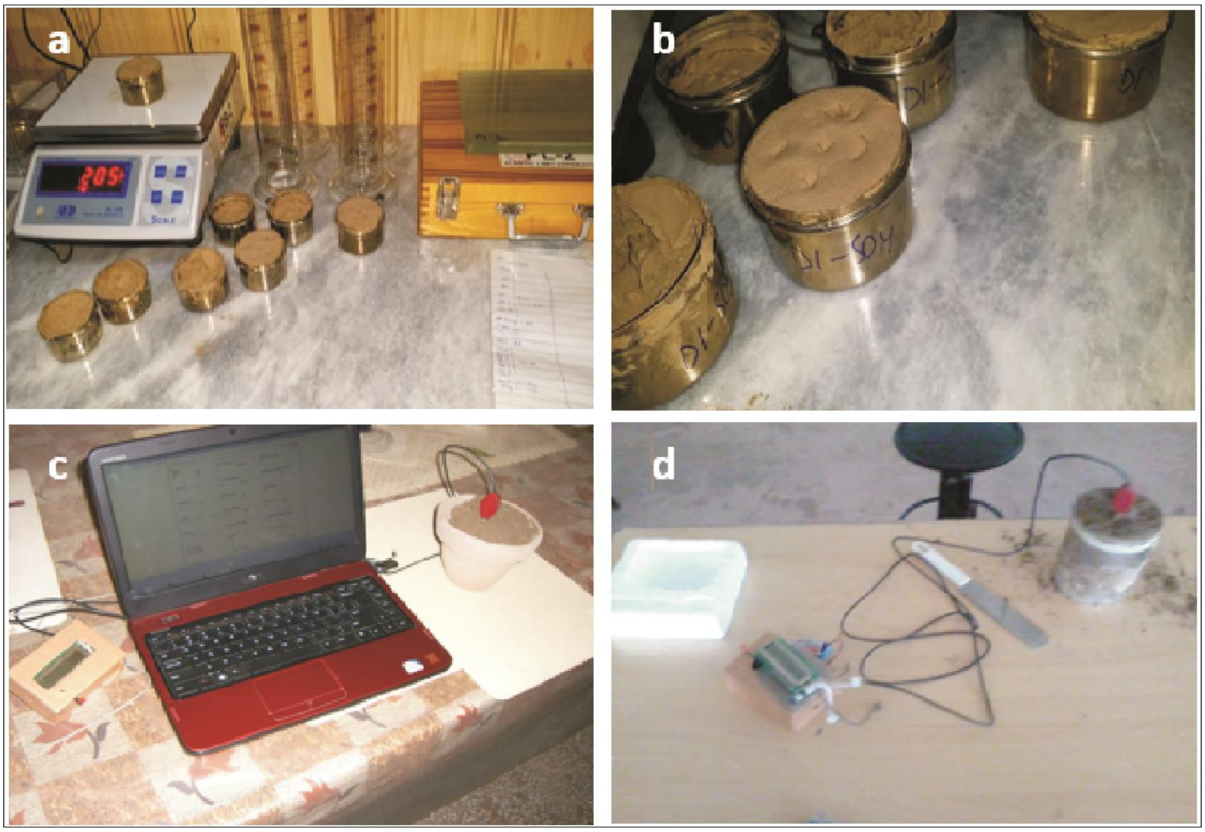

Fig. 2. Trial testing at Lab with PEISMS a) samples being weighted b) samples after oven drying c) PEISMS test 01 d) PEISMS test 02.

Comparison of Test Results of Soil Samples with Salinity

In Group-A the soil was mixed with tap water and samples were prepared, Group-B had the soils mixed with 10% of Saline water and Group-C soil samples were prepared with 15% Saline water. The 10% Saline solution with water was made, the samples were tested, the soil was classified in Group-B based on gradations as shown in Table 3**.**

The saline samples were prepared in controlled conditions using the salt NaCl (Adachi, 2003), initial samples were made from the soil passing through the sieve #40 and retaining on the sieve #60, this soil was named as Soil-B1, the soil was then mixed with 10% saline water and samples were obtained to perform the final testing, after the results from the PEISMS and the oven dry method were obtained they were compared with a graph which showed the data correlation factor R^2 of line being 0.9823 and the slope of line being 1.048, the results were good to go as shown in the Fig.5a. Secondly, the saline soil samples were prepared using soil passing form the sieve #60 and retaining on the sieve #80, this soil was named as Soil-B2, the soil was then mixed with 10% saline water and samples were obtained to perform the final testing, after the results from the PEISMS and the oven dry method were obtained they were compared with a graph which showed the data correlation factor R^2 of line being 0.978 and the slope of line being 1.05 the results were good to go as shown in the Fig. 5b. Similarly, for 10% saline water sample the last soil samples were prepared using soil passing form the sieve #100 and retaining on the sieve #200, this soil was named as Soil-B3, the soil was then mixed with 10% saline water and samples were obtained to perform the final testing, after the results from the PEISMS and the oven dry method were obtained they were compared with a graph which showed the data correlation factor R^2 of line being 0.99 and the slope of line being 1.03 the results were good to go as shown in the Fig. 5c.

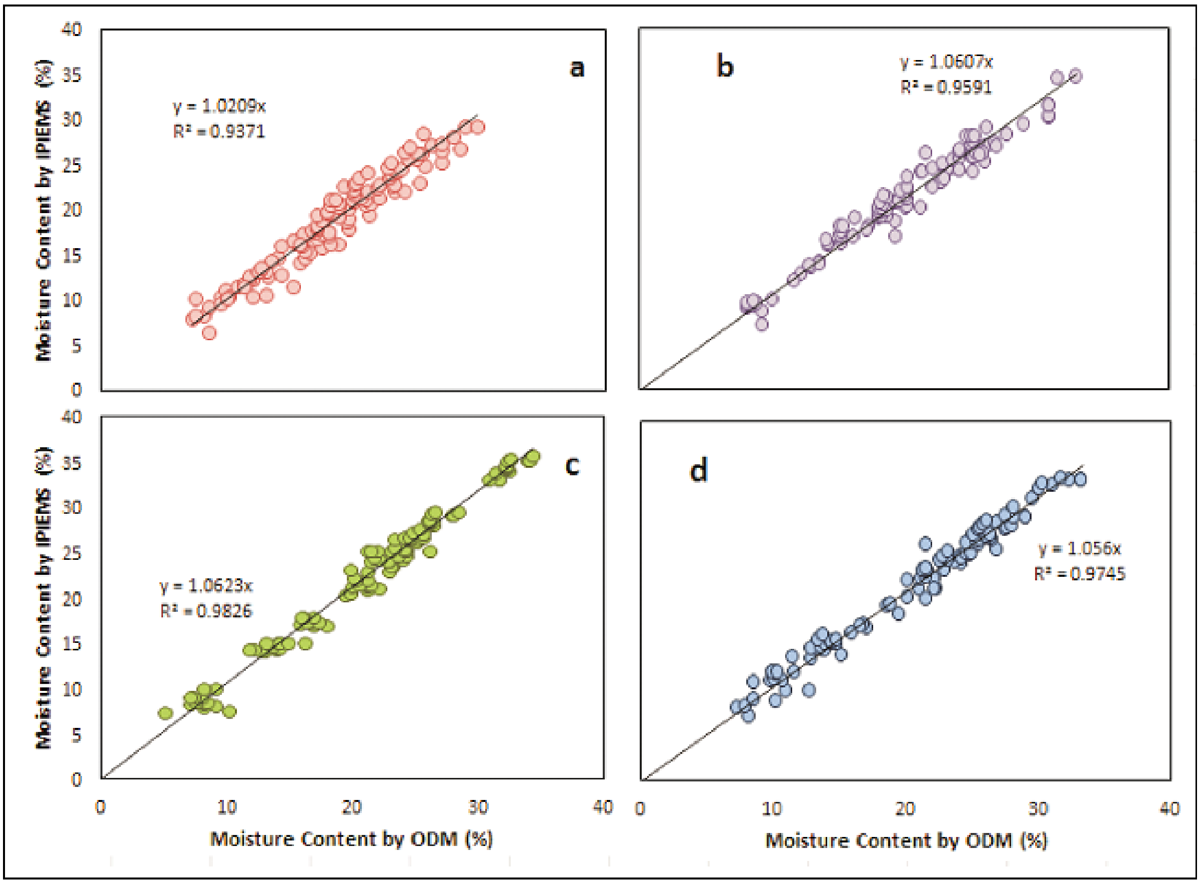

Fig. 3. Correlation of the test results of moisture contents by PEISMS and oven dry method, a) Soil A1, b) Soil A2, c) Soil A3 and d) Soil A4.

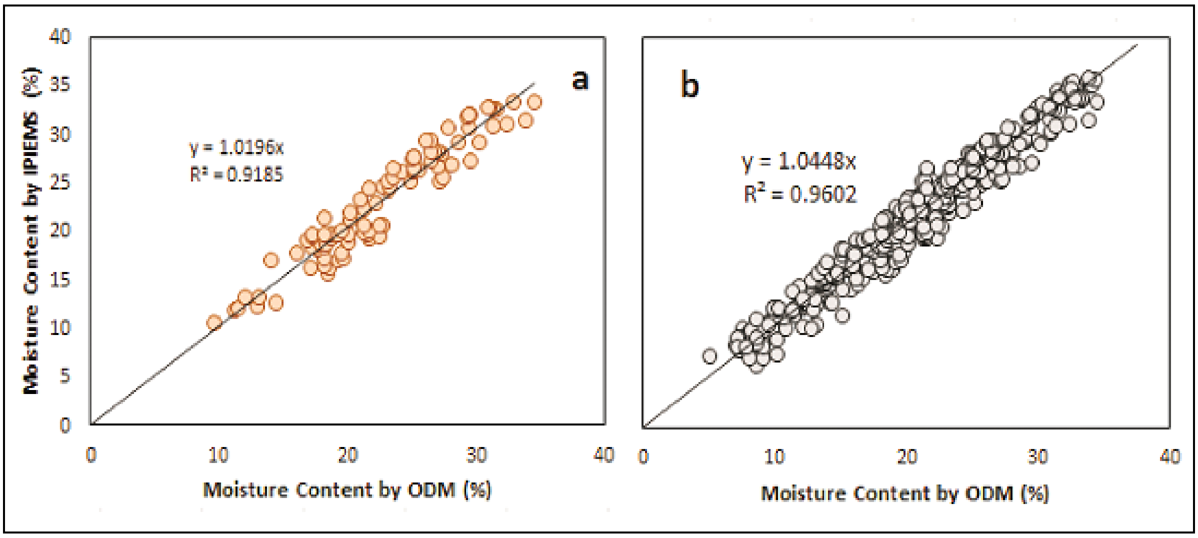

Fig. 4. Correlation of the test results of moisture contents by PEISMS and oven dry method, a) Soil A5 and, b) Cumulative results for all soils (i.e. A1-5).

The 15% saline water was used to prepare the sample for more accuracy check and data collection the first soil samples were prepared using soil passing form the sieve #100 and retaining on the sieve #200, this soil was named as Soil-C1 to C3 and was put in the 3rd and final group (Table 4) i.e. Group C, the soil was then mixed with 15% saline water and samples were obtained to perform the final testing.

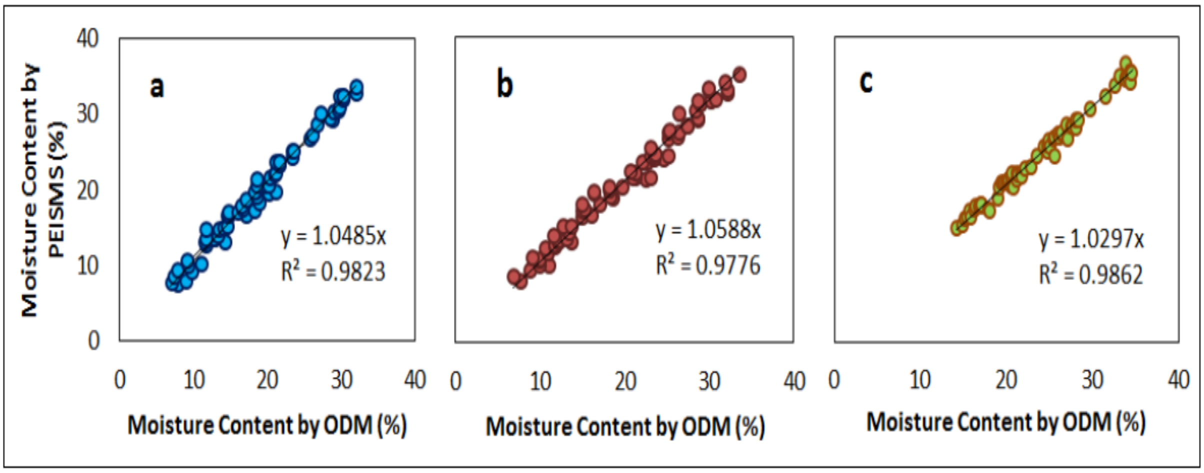

Fig. 5. Correlation of the test results of moisture contents having 10% salinity by PEISMS and oven dry method, a) Soil B1, b) Soil B2 and, c) Soil B3.

The first sample in this group was Soil-C1 passing form the sieve #40 and retaining on the sieve #60, after the results from the PEISMS and the oven dry method were obtained they were compared with a graph which showed the data correlation factor R^2 of line being 0.964 and the slope of line being 1.06 (Fig. 6a). In second step for 15% saline samples were prepared using soil passing form the sieve #80 and retaining on the sieve #100, this soil was named as Soil-C2, the soil was then mixed with 15% saline water and samples were obtained to perform the final testing, after the results from the PEISMS and the oven dry method were obtained they were compared with a graph which showed the data correlation factor R^2 of line being 0.93 and the slope of line being 1.04 (Fig. 6b).

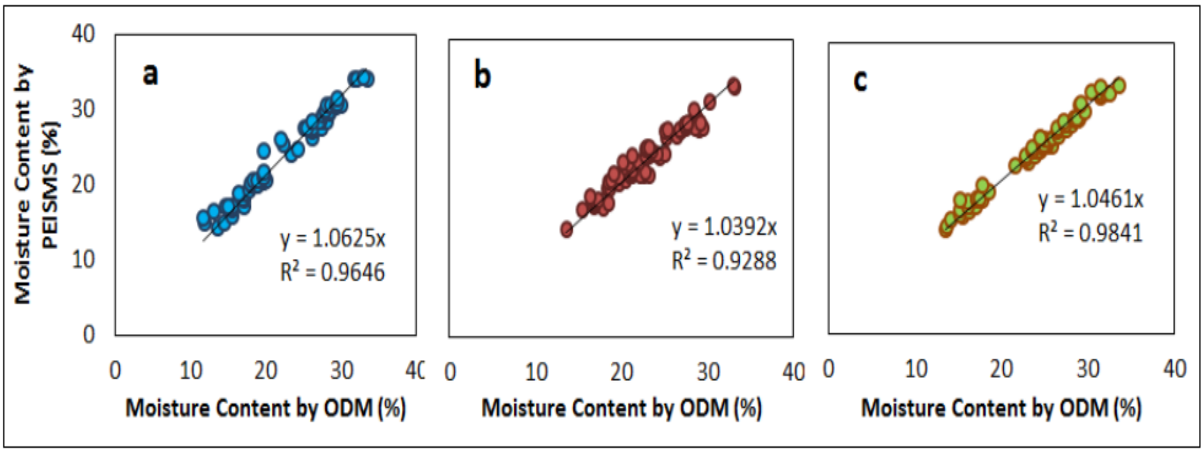

Fig. 6. Correlation of the test results of moisture contents having 15% salinity by PEISMS and oven dry method, a) Soil C1, b) Soil C2 and c) Soil C3.

The final testing was performed on the samples passing from sieve #200 and was collected in the pan, this soil was named as Soil-C3, the soil was then mixed with 15% saline water and samples were obtained to perform the final testing, after the results from the PEISMS and the oven dry method were obtained they were compared with a graph which showed the data correlation factor R^2 of line being 0.98 and the slope of line being 1.05 as shown in the Fig. 6c.The overall comparison of the results from PEISMS and the oven dry method shows very low difference that is around ±3.0% in case of saline water which is very near to the ±2.5% value which was obtained earlier with the case of normal tap water, the results show correlation factor R^2=0.98 for 10% salinity and R^2=0.96 for 15% salinity which justifies the use of the sensor with capacitance probe.

The comparison also indicates the effect of salinity to be very minimum on the readings, this was achieved by means of varnish around the sensor capacitance probe. The calibration also helped to improve the results, since the sensor was normalized before taking readings.

Conclusion

This research work was conducted by using 1200 samples of soil from Lahore, Pakistan to validate the Portable Electronic Instant Soil Moisture Sensor (PEISMS) for the measurement of soil moisture. This capacitance method for the determination of soil moisture is capable of producing results as good as the Time Domain Reflectometer (TDR) and transmission line (TL) techniques. Another important aspect of the sensor is that a characteristic graph can be drawn between volts and volumetric moisture content. Capacitance method for the measurement of soil moistures can and should be used for both laboratory and field measurement programs. It is economical and portable as compared with other conventional apparatus i.e. microwave oven and speedy moisture tester. The moisture content of collected samples was determined by PEISMS and oven dry method (ODM) with thestandard of American Society for Testing Materials. Firstly the soil samples were classified into five groups (A1-A5) on the basis of grain size of i.e. sieve no. 40, 60, 80, 100, 200 and prepared with normal water. The graphs were prepared to compare the results of PEISMS and ODM by y-intercepts of the best line fit method. The results gave good correlation between results of both testing methods with R^2 = 0.94, 0.96, 0.98, 0.97 according to the soil groups. Similarly, the soil was classified into two more groups on the basis of water salinity, soil groups (B1-B3) prepared with 10% saline water and group (C1-C3) prepared with 15% saline water. The correlation factor R^2 for samples with 10% salinity was 0.98, 0.97, 0.98 and similarly, samples with 15% saline water have a correlation factor of R^2=0.96, 0.93, 0.98. The overall comparison of the results from PEISMS and the oven dry method predict very low difference, the results depict correlation factor of R^2=0.98 for 10% salinity and R^2=0.96 for 15% salinity.

The above-mentioned correlation factors justify the use of the sensor with a capacitance probe. This method can and will be improved but in the meantime, further work on this study is needed for making it more easy to use and effective for a wide range of soils and even smaller in its physical size, so that it can fit in a pocket. The development of a computer application for computing different properties of soil is also to be done as continued progress.

References

Adachi K. 2003. Making Salt Water (Saline) Solutions. Website accessed 24th August, 2014. http://educateyourself.org/dc/saltwatersolutions.shtml,

Akram S, Iqbal A. 2017. Development of Portable Instant Soil Moisture Content Sensor. International In: Conference for New Challenges in Geo-technical Engineering (ICNCGE), FAST-NUCES Lahore Pakistan.

ASTM D. 2216. 2010. Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock Mass. Annual book of ASTM standards, West Conshohocken.

ASTM D. 4944-11. Standard Test Method for Field Determination of Water (Moisture) Content of Soil by the Calcium Carbide Gas Pressure Tester. West Conshohocken.

Atkins RT, Pangburn T, Bates RE, Brockett BE. 1998. Soil Moisture Determinations Using Capacitance Probe Methodology. Special Report 98-2, US Army Corps of Engineers.

Baumhardt RL, Lascano RJ, Evett SR. 2000. Soil Material, Temperature, and Salinity Effects on Calibration of Multisensor Capacitance Probes. Soil Science Society of America Journal **64**, 1940–1946.

Hignett C, Evett S. 2008. Direct and Surrogate Measures of Soil Water Content. International Atomic Energy Agency, Vienna, Austria, p. 107-109.

Iqbal A. 2015. Development and validation of portable electronic instant soil moisture sensor (PEISMS). M.phil Thesis, Institute of Geology, University of the Punjab, Lahore, Pakistan.

Ravi S, D'odorico P, Over TM, Zobeck TM. 2004. On the effect of air humidity on soil susceptibility to wind erosion: The case of air-dry soils. Geophysical Research Letters **31.** "H400 Soil Moisture Sensor Probes," (2008).