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Determination of soil moisture content using wavelet analysis, the case of Bule Hora wored Borena zone, Ethiopia

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Abstract

In this study by designing SMS a moisture contents of different soil samples were determined using computer technique. The soil moisture sensor has been developed using the basic property that the resistance of the soil between two points decreases with the increase of water content. The SMS sensor designed to give sound signal and the signals produced were recorded and analyzed using continuous wavelet transform with MATLAB software

Five 50 gm Oven–dried soils samples were used for the experiment from the collected soil samples of Bule hora wored. The samples were watered in the range of 0ml to 50ml at 5ml interval. The result obtained show that as the water level added to the soil increases all parameters such as frequency, Amplitude and energy of the signal increased except the scale parameter of the wavelet coefficients. Correlation relation between soil water contents with electrical conductivity, maximum amplitude with electrical conductivity, frequency with electrical conductivity, and frequency with soil water contents for all the sampled soils were studied using regression with matlab. The relation between dependent variable and independent variable shows that a high correlation relation with R^2 greater than 0.97 and with 95% confidence level. In general the research tried to show how wavelets can be used to analyse the variation of soil moisture content in any soil types which appear to be more useful than using traditional method of soil moisture determination.

Keywords: Soil moisture sensor, wavelet transform, Electrical conductivity, soil moisture Content, Amplitude, Frequency, scale, energy.

1. INTRODUCTION

Monitoring soil water content is essential to help growers optimize production, conserve water, reduce environmental impacts and save money. Soil moisture monitoring can improve irrigation decisions, such as how much water to apply and when to apply it. It can also match irrigation water applied with crop water requirements, avoiding over- or under-irrigating the crop. Over irrigation can increase energy consumption and water cost as well as leaching of fertilizers below the root zone, erosion, and transport of soil and chemical particles to the drainage ditches. Under-irrigation can reduce crop yields (Juan *et al*, 2007).

There are different techniques to determine soil moisture contents. Using direct and indirect methods that are time consuming and costly. Each crop requires some amount of water and there should be a moisture control mechanism so that crops obtain optimum moisture level which is used to grow and to give good yields. A valuable attempt to overcome these problems is by using soil moisture sensor. Identifying the most suitable and cost-time effective technique for studying soil wavelet analysis has been a challenge for many soil scientists. The changes in the spectral characteristics, according to Ben-Dor *et al*. (2003), occur due to changes in soil albedo and soil chromophores, where the former is strictly related to the physical soil properties, while the latter to the chemical.

Signal transmission is based on transmission of a series of numbers. The series representation of a function is important in all types of signal transmission. The wavelet representation of a function is a new technique (Perrier,et.al., 1995). The wavelet transform and more particularly the discrete wavelet transform is a relatively recent and computationally efficient technique for extracting information about non stationary signals like audio. Wavelet analysis has attracted attention for its ability to analyze rapidly changing transient signals. Any application using the Fourier transform can be formulated using wavelets to provide more accurately localized temporal and frequency information (Coifman, et.,al, 1994).

However, although Fourier inversion is possible under certain circumstances, Fourier methods are not always a good tool to recapture the signal, particularly if it is highly non smooth, too much Fourier information is needed to reconstruct the signal locally (Torrence,et.,al, 1998). In these cases, wavelet analysis is often very effective because it provides a simple approach for dealing with local aspects of a signal. Wavelet analysis also provides us with new methods for removing noise from signals that complement the classical methods of Fourier analysis.

This study is highly important because it introduces a new technique for the determination of soil moisture content and it has contribution for agriculture to use new technology, soil moisture sensor, that controls the water content of any crop so that maximum yield will be obtained. The study was performed by first designing a soil moisture sensor which gives sound as an output and by recording the sound produced at different water level added to the soil. A wavelet analysis of soil moisture content for different soil types were determined from the sound data recorded at different moisture content of different soil types.

General objective

- To determine soil moisture content using wavelet analysis

Specific Objectives

To design soil moisture sensor that give sound as an output

- To develop a matlab code which records sound and which determine wavelet analysis of soil moisture contents'
- To find the relationship between frequency, amplitude and soil moisture content
- To find the relationship between soil electrical conductivity and soil moisture content

3. MATERIAL AND METHODS

3.2. Soil Sampling

Five soil sampling fields were randomly selected from Bule hora woreda. These are Gerba (soil A), Kilenso (soil B), Ropi-megada (soil C), Galenso-negeso (soil D) and Burka-ebela (soil E). From each site, ten soil sub-samples were collected from the depths of 0-20cm each in a randomly zigzag pattern using an auger. The collected Soil samples were dried using an oven at 105°C.

3.3. Soil Texture Analysis

Soil texture determines the rate at which water drains through a saturated soil; water moves more freely through sandy soils than it does through clayey soils. Differences in soil texture impacts organic matter levels; organic matter breaks down faster in sandy soils than in fine-textured soils, given similar environmental conditions, tillage and fertility management, because of a higher amount of oxygen available for decomposition in the light-textured sandy soils. The combined proportions of sand, silt and clay in a soil determine its textural classification.

Soil texture classification was done using hydrometer and the relative proportion of sand, clay and silt soil types will be determined.

3.4. Materials Used for Designing Soil Moisture Sensor

A soil moisture sensor circuits that gives sound as an output was designed and tested. Soil moisture sensors measure soil moisture at the root zone and regulate the existing conventional irrigation timer, resulting in considerable water savings when installed and used properly (Josh, 2009). The circuit will be constructed using;

- a transistor
- resistors
- Capacitors
- Buzzer
- connecting wires
- A variable resistance.

3.5. Experimental procedure

Experiments were conducted using the sensor on soil sampled. 50g oven dried soil for each sampled soils were used and keeping the mass of the soil constant water was added to the soil using a graduate cylinder starting from 0ml up to 30ml at 2.5ml interval. At each water level added to the soil different measurements were recorded. These are electrical conductivity, sound signal and soil water content.

3.6. Method of Data Analysis

.Electrical conductivity was measured using conductivity meter. The sound produced using SMS was recorded with matlab using wavrecord function and the sound recorded at each water level added to the soil was then analysed using continuous wavelet with Mexican wavelet and different out puts such as scale vs frequency, power spectral densities, and percentage of energy at each wavelet coefficient were determined using matlab. In this study, the dependent variables is soil moisture content and the independent variables are frequency, EC, amplitude

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4. Result and Discussion

4 .1Designing Soil moisture sensor

The sensor was designed based on the idea that the resistance between two points decreases when the water content increases. It was built using a transistor (CBC 184 LB), a variable resistance, 220 ohm resistor, two soil probes and buzzer as shown in fig below:

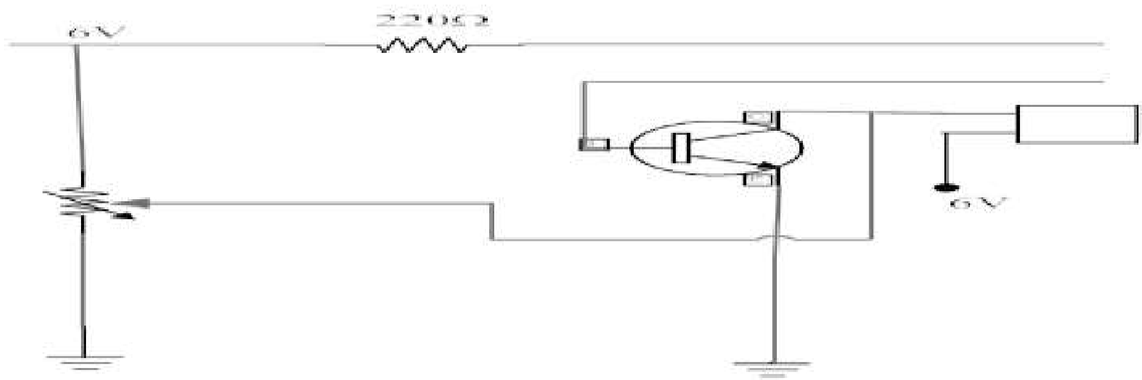

Figure 1. Soil moisture sensor circuit diagram

The soil probes consist of two thin copper wires each of 5cm length which can be immersed into the soil samples whose moisture content to be estimated. The circuit gives a sound output corresponding to the conductivity of the soil. The soil between the probes acts as a variable resistance whose value depends upon the moisture content in the soil. The input block is made from two components, moisture sensor and a resistor. They are connected in series between the power supply lines. The circuit gives a sound output whose tone corresponds to the conductivity of the soil. The transistor switches the output component (buzzer) on or off. If the input voltage is less than 0.6V, the transistor switches off. No current flows through the buzzer and it will not buzz. If the voltage is greater than 0.6 V, the transistor switches on. This allows current to flow through the buzzer and it buzzes.

4.2.1 Scale versus frequency

The relationship between scale and frequency were computed by first computing the center frequency F_c of the wavelet and using the following relation

$$Fa = \frac{Fc}{a.Sf} \quad (1)$$

Where

- a is a scale.

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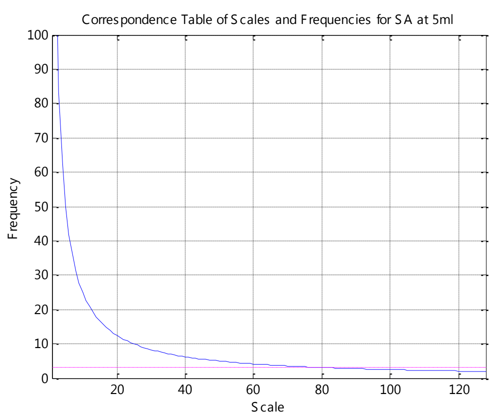
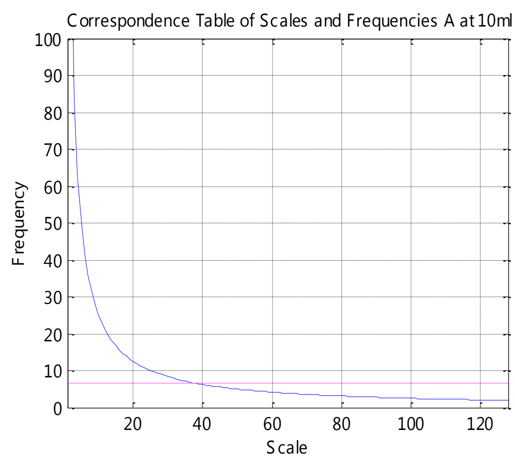
- Sp is the sampling period.
- Fc is the center frequency of a wavelet in Hz
- Fa is the pseudo-frequency corresponding to the scale a, in Hz

The result obtained show that scale and frequency have inversely proportional as shown in fig (3) below for soil sample A and for the signal recorded at different moisture of all soil samples. On figure the dominant frequency of the wavelet for soil A at 5ml is 3.25 and the scale is 77, at 10ml the dominant frequency is 6.5 and the scale is 38.





4.2.2 Power spectral density

The PSD estimated using spectral estimation of the signal recorded. PSD measures power per unit of frequency and has power/frequency units. This help to find the main frequency by looking at which the power/frequency reaches its maximum. The result obtained show that the dominant frequency at which the PSD reached maximum when 5ml water added to the soil samples was 3.25Hz, 3Hz, 2.5Hz, 3.9Hz, 3.9Hz for soil sample A, B, C, D and E, respectively. When the moisture content of the soil was 10ml the dominant frequency at which the PSD reached maximum was 6.5Hz, 7Hz, 5.8Hz, 7.8Hz, and 9Hz for soil sample A, B, C, D and E, respectively.

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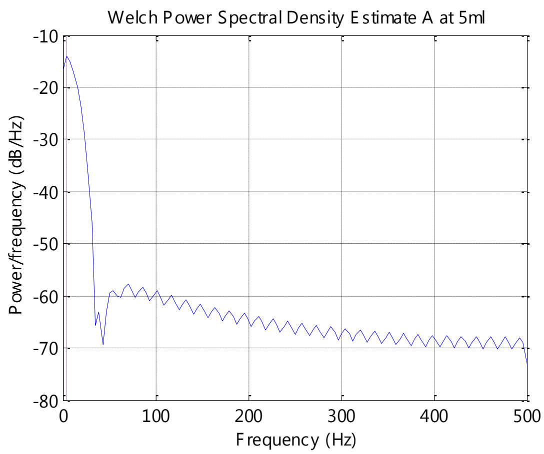
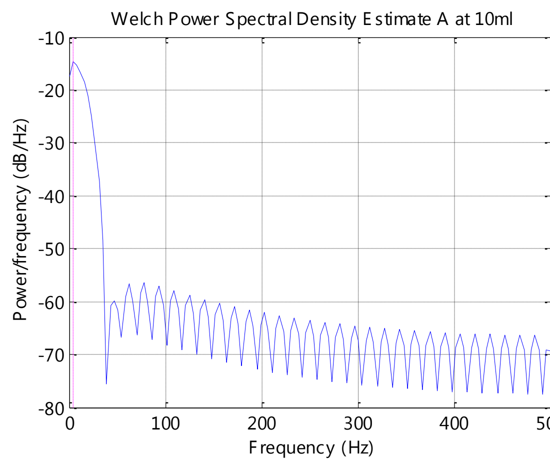
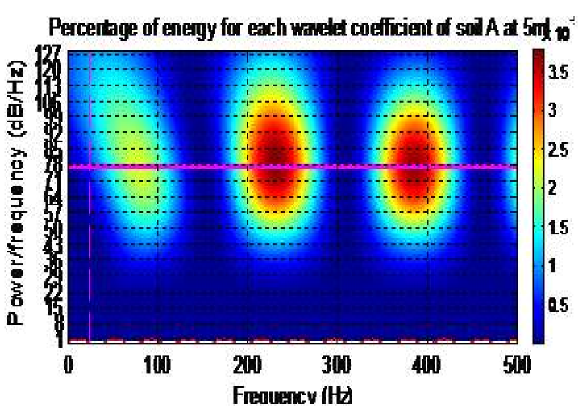
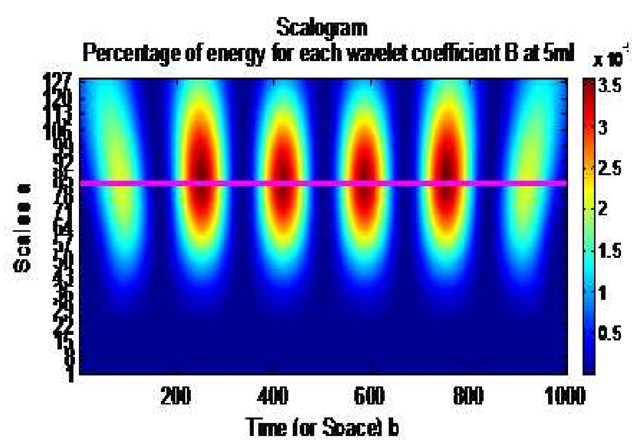




4.2.3 Scale, time and enegy

To detect maxima of energy at corresponds scale and frequency a continuous wavelet analysis with Mexican hat wavelet was used. The scalogram and horizontal line corresponding to the scale associated with the frequency were plotted. We can see that this line connects the maxima of energy in the scalogram. In the scalogram, at 5ml water added to the soil the maxima of energy are detected at scale 77, 83, 100, 63, and 50 which corresponds to frequency 3.25Hz, 3Hz, 2.5Hz, 3.906Hz, and 3.603, for soil A, B, C, D and E ,respectively.





In general the result obtained show that for each wavelet coefficients of signal recorded at different moisture content of all soil samples the maxima energy increases with moisture content while the scale of the wavelet coefficients decreases very rapidly.

p-ISSN: 2348-6848
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Volume 04 Issue 02
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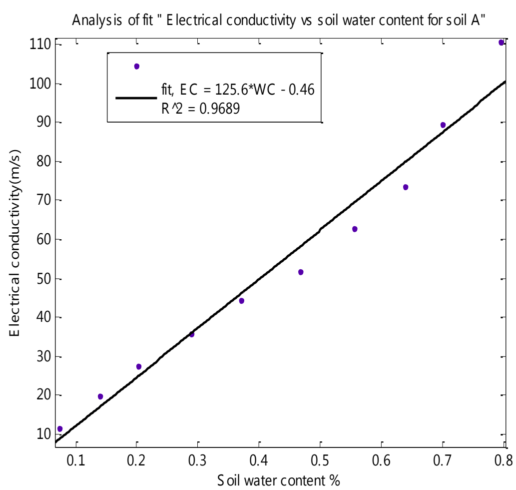
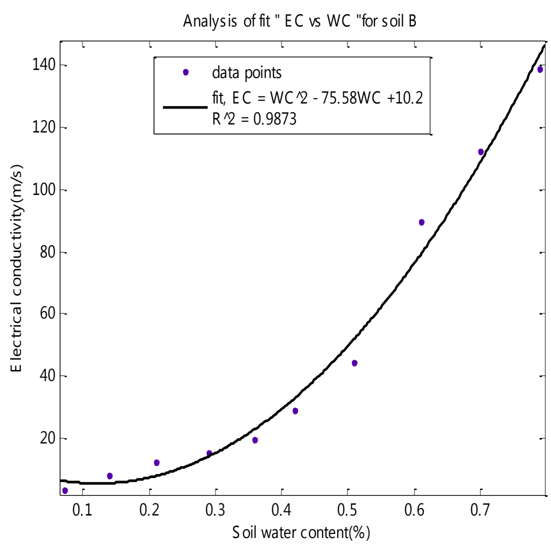
4.3. The Relationships Between Electrical Conductivity and Soil Moisture

As Robain *et al* (2003) and Ozcep *et al* (2005) point out that soil solid components are generally electrical insulators. However, the conduction of electrical current only lies on phenomenon occurring in water. The electrical properties of soils are the parameters of natural and artificially created electrical fields in soils influenced by distribution of mobile electrical charges, mostly water content, in soils.

It was found that as shown in figure (6) below the electrical conductivity increases as the moisture level of the soil increases. Therefore, there is a linear relationship exist between soil moisture contents and electrical conductivity. Similar result obtained by Cristine *et al*, (2007).





4.4. The Relationships between Amplitude of Signal and Electrical Conductivity

When the conductivity of the soil increases the output voltage of the soil moisture sensor circuits also increases this makes the buzzer to buzz. This leads to increase the amplitude of the signal to be increased and as shown in the fig 7 below a significant correlation obtained between amplitude and soil conductivity. Amplitude is measured from zero or from the origin.

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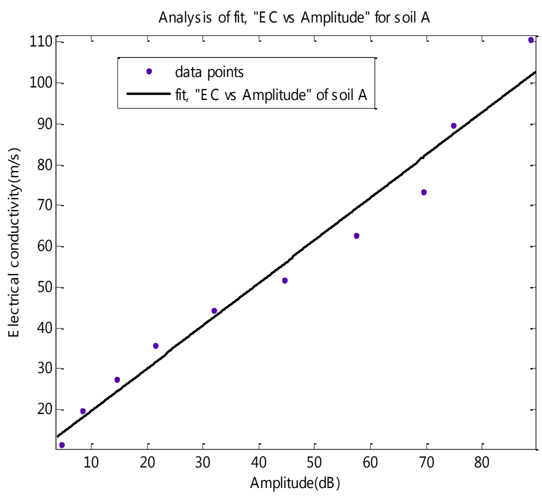
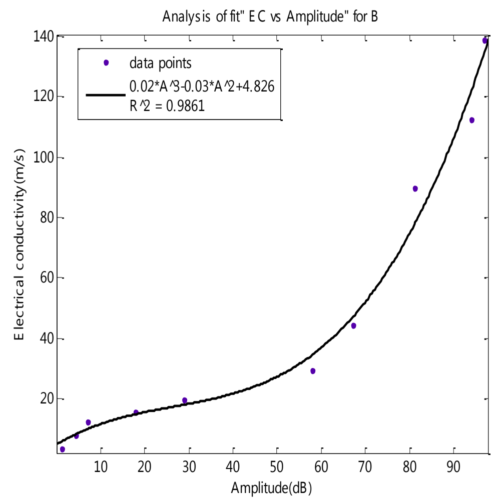
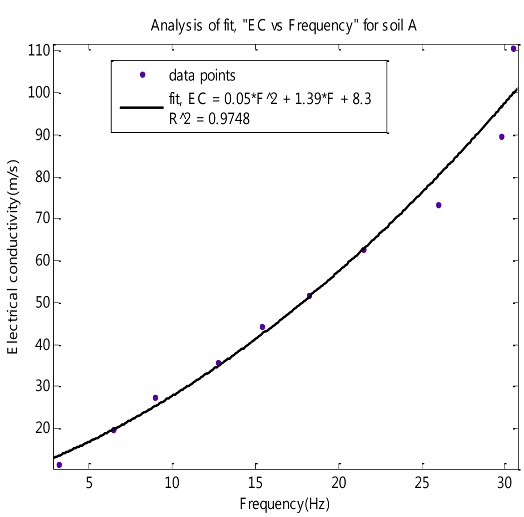
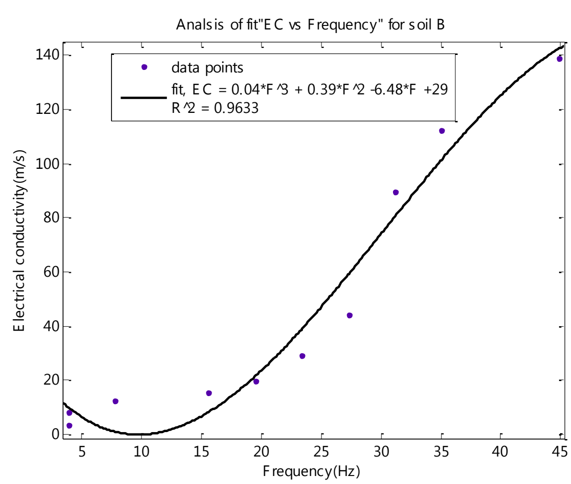




4.5. The Relationship between Frequency and Electrical Conductivity

Dissolved ions and minerals salts enhances charge mobility imply that large magnitude of electrical conductivity in a given soil material is an indication of high water content. The presence of water in the soil is the most significant factor that enhances the electrical conductivity of the material. Since frequency is depend up on the amplitude of a signal and the sound of a signal becomes large when the conductivity of the soil increases these results to an increase in the frequency of the sound signal as shown in figure 8 below.

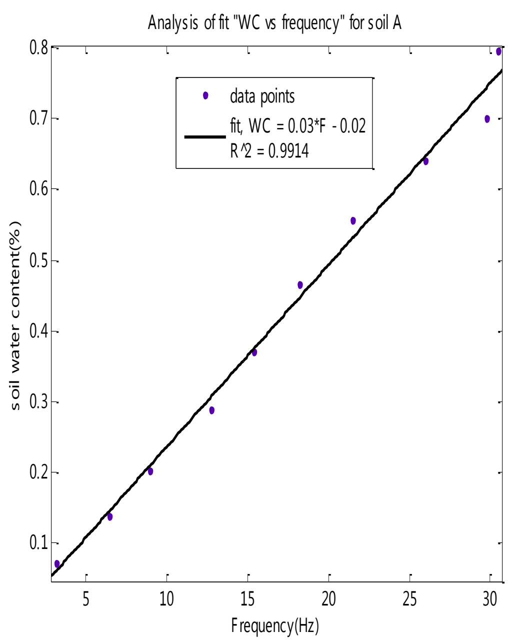


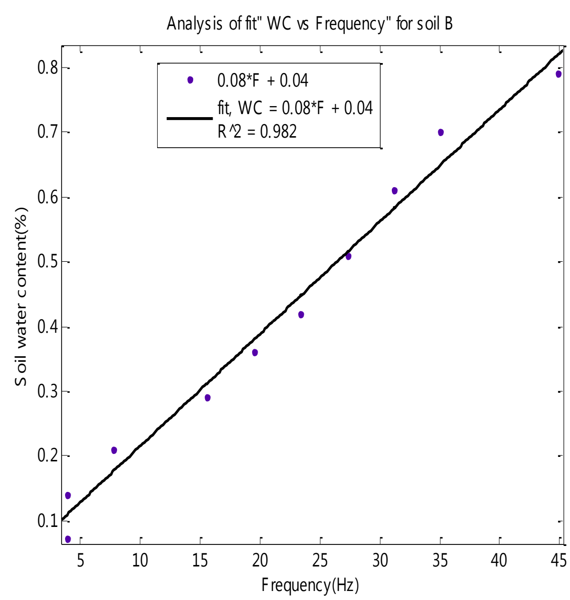


p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 04 Issue 02
February 2017

4.6. The Relationship between Frequency and Soil Water Content

Frequency domain analysis has been shown to be useful for more accurate water content determination, water content determination in saline soils, and determination of such difficult to measure soil properties as specific surface area and soil solution conductivity. Using the designed soil moisture sensor circuits the frequency of the sound signal obtained at different soil water contents for all soil types as shown in figure 9 below shows that the frequency is highly related with soil water. Due to the fact that EC of soil depends on the moisture of soil, the sound that obtained using the sensor varied as EC of the soil varied and this variation results in variation of the spectrum of the sound signal. In general the spectrum of soil affected by different factors such as soil texture, soil water contents, organic contents of soil, PH, soil water holding capacity, etc. Hence, the moisture content of the soil can be controlled by determining the frequency of soil moisture.





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p-ISSN: 2348-6848
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Volume 04 Issue 02
February 2017

CONCLUSSIONS and RECOMMENDATIONS

5.1. Conclusion

The development of soil moisture sensors has grown in popularity due to an increasing demand in precise irrigation. In this research a SMS was designed and used to collect data, and also wavelet analysis technique was used to estimate soil moisture content's. The wavelet coefficient is estimated for signals recorded at different water contents of the soil from within a scale specific window since the underlying wavelet function is obtained by a dilation of the basic wavelet.

Since soils differ in organic matter content, water holding capacity, porosity, salinity etc. the electrical conductivity was varied for different soil types and increased as soil moisture content increases. Because of the variation of the electrical conductivity of soils, the output signals were varied linearly. Therefore, the dominant frequency of the signal at the corresponds of soil water content were obtained using different approaches. The relation between dependent variable and independent variable shows that high correlation relation with R^2 greater than 0.95 and with 95% confidence level. In general the research show how wavelets can be used to analyse the variation of soil moisture content in any soil types which appear to be more useful than using traditional method of soil moisture determination.

5.2. Recommendation

Since the application of wavelet transformation in sound signal analysis is relatively new field of research, many methodological aspects (choice of the mother wavelet, value of the scale parameters) of the wavelet technique will require further investigation in order to improve the determination of soil moisture content using this novel signal processing techniques. In addition a wide range moisture sensor which output to be electrical signal or sound signal device need to be developed.

Because the wavelet analysis of soil moisture content was done for soils taken at a depth of 20cm the study didn't reveal the relation between soil depth, amplitude, frequency and energy. So, further study is necessary in this aspect.

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