The Relationship between Soil Temperature and Volumetric Soil Water Content in Iraq using ECMWF Data for the Period (1980-2016)

Osama T. Al-Taai1, Wedyan G. Nassif2
1,2Department of Atmospheric Science, College of Science, Mustansiriyah University, Baghdad, Iraq
E-mail: osamaaltaai77@uomustansiriyah.edu.iq

Abstract. The Volumetric Soil Water Content (VSWC) and Soil Temperature (ST), are important factors in determining the phenomenon of desertification and agricultural drought, where soil temperature plays an important role in determining the date of flower growth. Surface evaporation and water leakage are also associated with climate-related evolution in terms of precipitation production and in the development of weather patterns. The methods adopted in the study depend on the monthly and annual mean of the four levels (L1, L2, L3, and L4) of the volumetric soil water content and soil temperature, taken from the European Centre Medium Weather Forecasts (ECMWF) for the time period thirty seven years (1980-2016), for selected stations in Iraq (Mosul, Baghdad, Rutba, and Basrah). The greatest value of the volumetric soil water content was recorded in Mosul, and the lowest value was recorded in Basrah. The greatest value of soil temperature recorded in Basrah, and the lowest value in Mosul. The relationship between volumetric soil water content and soil temperature is a very high negative correlation for thirty seven years for the selected stations (Mosul, Baghdad, Rutba, and Basrah).

1. Introduction
Soil water content is a major variable in many environmental studies, including meteorology, hydrology, agriculture and climate change. And affects the surface of the soil, especially at a depth of one to two meters, which is the key to the interaction between the earth and the atmosphere, and is one of the main variables that control the exchange of water and heat energy between the surface of the earth and the atmosphere through evaporation and plant transpiration. This variable has multiple correlations with other structural variables, which makes it highly predictive effective [1]. Although it forms a very minimal layer compared to the global total amount of water, it is very important in many basic processes of many hydrology, chemistry, and biologists, and it is an important variable used in many applications such as (numerical weather forecasts, global climate change monitoring, and prediction of surface runoff, and evaporation modelling, so it is important to carefully monitor and estimate the spatial and temporal differences of the soil water content [2]. Agriculture is the sector most economically affected by extreme weather phenomena such as drought, and many other economic sectors in society depend on agricultural ecosystems, which are a specific form of ecosystem adapted from humans to produce food, so drought can have many economic and social impacts The negativity is such as the loss of income in agriculture and the food industry and the high costs of water and production technologies such as irrigation systems [3]. Through continuous monitoring and modelling of hydrological processes, contrast and the influence of soil water content can be obtained and various practical applications are found. Examples of these applications include the following [4, 5]:

- Deviation between the actual and desirable values of the soil water content is critical to the process of water resources and political and administrative decision-making.
- Predicting climatic and climatic changes such as precipitation and temperature by estimating water and heat transfer between the Earth's surface and atmosphere by the flow process.
- Flood forecasting based on the spatial distribution of soil surface saturation.
Irrigation development by knowing the spatial and temporal distribution of the soil water content.

Rural and urban planning, which is before the choice of farms and the type of crops, which depends on the level of soil moisture level in order to achieve the maximum economic and environmental and social benefit.

Predicting global climate change through persistence or change in the rise or fall of the water content of the soil.

Agricultural applications by estimating grass growth with knowledge of the soil water content.

Other environmental processes through hydrological modeling and erosion prediction.

So this study came to analyse the behaviour of this variable and its changes during the months, and study the effect of nucleated factors on it and predict the relationship between the water content of the soil and some nucleation factors through some accurate statistical tests, see ‘Fig. 1’.

Figure 1. Water forms in the soil [6].

The VSWC is considered one of the main factors used in environmental studies, as well as in agriculture, hydrology and climate changes. As a result of agricultural processes during the preparation of soils of various sizes in addition to the event of stacking of the surface layer during agricultural operations and this layer is characterized by lack of pores and high apparent density and lack of forgotten interstitial spaces, which affect the decrease of water conductivity of the soil and the speed of gas exchange in addition to the mechanical resistance of the soil with the change in thermal properties. The Soil water content is defined as the amount of water contained within most soil pores and around the surface of soil pellets relative to the density of dry soil. The temperature of the earth depends on the nature and characteristics of its surface, whether the presence of ice in the poles or over the tops of the mountains or moisture in the soil and water in the oceans that would not have raised the temperature of the earth, because the water absorbs most of the heat of the sun located on the ground, where the activity of plants is deeply affected by soil temperature, because of its impact on its biological and natural processes bad in the full plant phase or in the stage of primary germination and seed phase as well. The organisms in soils are affected by changes in soil temperature in addition to their impact on Surface air near the soil [3]. There are several direct (or soil-related) factors that affect soil temperature, including the specific water temperature, colour, composition, texture and vegetation. All these factors directly affect the Soil Temperature (ST). Soil temperature affects plant activity where water absorption decreases if the soil temperature decreases due to limited absorption, damaging the plant so-called physiological dehydration of its tissues [5].
2. Methodology
2.1. Data source and study stations
Work was carried out with monthly mean data of Soil Temperature (ST) and Volumetric Soil Water Content (VSWC) for four-levels (L1, L2, L3, and L4) of the soil, for the period (1980-2016), taken from the European Centre for Medium-Range Weather Forecasts (ECMWF) [7]. These data were converted into annual mean integrated set for the purpose of showing the effect of annual change. The stations (Mosul, Baghdad, Rutba, and Basrah) were chosen for this research (North, Centre, West, and South) respectively, as shown in Table 1, and ‘Fig. 2’.

Table 1. Longitude, latitude and elevations above sea level for study stations in Iraq.

| Study Stations | Longitude (°E) | Latitude (°N) | Elevations above sea level in meter |
|----------------|----------------|---------------|-----------------------------------|
| Mosul          | 43.2           | 36.3          | 223.5                             |
| Baghdad        | 44.5           | 33.3          | 34                                |
| Rutba          | 40.3           | 33            | 600.8                             |
| Basrah         | 47.5           | 30.5          | 5                                 |

Figure 2. The study stations in Iraq.

2.2. Statistical using
2.2.1. Simple Linear Regression (SLR)
Several available statistical operations were performed where Sigmaplot program was used to calculate the slope value and the P-value by Simple Linear Regression (SLR) method in order to predict the relationship between soil water content and soil temperature. SLR is the study of the relationship between two variables to arrive at a linear relationship between these two variables, where the data is supposed to be distributed naturally. To know the value of the regression, the slope is calculated from the following equation [8]:

\[
\bar{Y} = a + b\bar{X} \quad (1)
\]

\[
(2) b = \frac{\Sigma_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\Sigma_{i=1}^{n}(x_i - \bar{x})^2}
\]
Whereas: (b) is the slope and shows the slope of the straight line, (a) is constant and shows the value of the section of the unit of the line, Eq. 1.

As for the probability value, P-value is a statistical term, which is a number or number used to evaluate the statistics, and it is a value that appears if the factor is actually affecting or not?

After converting data from NC-file format to (TXT-file), the Fortran language (which is a multi-use programming language and after isolating and filtering data for each region separately in the form of (TXT-file)) is used and from which the calculations were performed and then using the Sigmaplot program which is a group among the scientific programs for charts and data analysis through which it is possible to draw time series charts for each introverted variable and find the relationship between each variable and the VSWC by calculating the slope value and the value of P-value [9, 10].

2.2.2. Pearson’s correlation coefficient (r)

The Pearson Moment Correlation matrix is a series of scatter graphs that plot the associations between all possible combinations of variables. The first row of the matrix represents the first set of variables or the first column of data, the second row of the matrix represents the second set of variables or the second data column, and the third row of the matrix represents the third set of variables or third data column. The X and Y data for the graphs correspond to the column and row of the graph in the matrix. For example, the X data for the graphs in the first row of the matrix is taken from the second column of tested data, and the Y data is taken from the first column of tested data. The X data for the graphs in the second row of the matrix is taken from the first column of tested data, and the Y data is taken from the second column of tested data. The X data for the graphs in the third row of the matrix is taken from the second column of tested data, and the Y data is taken from the third column of tested data, etc. The number of graph rows in the matrix is equal to the number of data columns being tested [11]. The Pearson correlation coefficient (r) is used to measure the strength of a linear association between two variables, where the value $r = 1$ means a perfect positive correlation and the value $r = -1$ means a perfect negative correlation. So, for example, you could use this test to find out whether people's height and weight are correlated [12]. Requirements for Pearson's correlation coefficient:

- Scale of measurement should be interval or ratio
- Variables should be approximately normally distributed
- The association should be linear
- There should be no outliers in the data.

$$ r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2} \sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}} $$

(3)

3. Results and Discussion

3.1. Analysis of the monthly mean of soil temperature for four-levels

‘Fig. 3’, shows that the soil temperature is in a state of variation for all soil levels. The greatest value of the monthly mean of soil temperature was recorded in the month of July at the first and second levels of the soil. As for the third and fourth levels, the greatest value of the soil temperature was recorded respectively in August and July. The lowest value was recorded at the first and second levels in December and January. The lowest value of soil temperature at the third and fourth levels was recorded in February and March, respectively.
Figure 3. The monthly mean of soil temperature for four-levels (L1, L2, L3, L4) of the Soil for Selected Stations in Iraq for thirty seven years.

3.2. Analysis of the monthly mean of VSWC for four-levels
‘Fig. 4’, shows that the greatest value of the VSWC has been recorded in Mosul and the lowest value recorded in Basrah, and it can be observed that there is a large variation in the amount of VSWC at the first and second levels for all study stations, while the third and fourth levels are their variation for most study stations with the exception of Mosul, it is possible to notice a large variation in the values of VSWC at the third and fourth levels compared to other regions, it can be observed that the amount of VSWC at the third and fourth levels of Baghdad station is fixed in the amount for all months compared to (Mosul, Rutba, and Basrah). We also note that the VSWC at the third level is greater than the fourth level in the stations (Baghdad, Rutba, and Basrah), except for Mosul, which is in a state of contrast and for all levels.
Figure 4. The monthly mean of volumetric soil water content for four-levels (L1, L2, L3, L4) of the soil for selected stations in Iraq for thirty seven years.

3.3. Analysis of the yearly mean of ST and VSWC for four-levels
In the ‘Fig. 5, 6, 7 and 8’ it was found that the greatest value of the VSWC was recorded in Mosul (0.24 m$^3$m$^{-3}$) for the first level, (0.25 m$^3$m$^{-3}$) for the second level, (0.26 m$^3$m$^{-3}$) for the third level, and (0.28 m$^3$m$^{-3}$) for the fourth level, for a period thirty seven years, due to the characteristics of this region in terms of large amounts of rain and low temperatures compared to other regions. The lowest value has been recorded in Basrah (0.17 m$^3$m$^{-3}$) for the first level, (0.19 m$^3$m$^{-3}$) for the second and third levels, and (0.20 m$^3$m$^{-3}$) for the fourth level. The reason for the decrease in this station is due to the lack of rain, which affects the soil. As for soil temperature, its greatest value was recorded in Basrah (32 °C) for the fourth level, (30 °C) for the first, second, and third levels, respectively, for a period thirty seven years, because this station is characterized by high temperatures. And the lowest value recorded in Mosul (17 °C) due to the climate of this region, which is characterized by low temperatures. Accordingly, the negative relationship between the soil temperature and VSWC, meaning that the higher the soil temperature, the lower VSWC.
Figure 5. The annual mean of ST and VSWC at the first-level (L1) for four selected stations for a period (1980-2016).

Figure 6. The annual mean of ST and VSWC at the second-level (L2) for four selected stations for a period (1980-2016).
Figure 7. The annual mean of ST and VSWC at the third-level (L3) for four selected stations for a period (1980-2016).

Figure 8. The annual mean of ST and VSWC at the fourth-level (L4) for four selected stations for a period (1980-2016).
3.4. The relationship between the monthly mean of the ST and VSWC for four-level
The relationship between the ST and VSWC is the negative relationship, as the soil temperature is directly affected by solar radiation and the surface air temperature, that is, when the air temperature increases, the soil temperature near the surface increases also, so the soil temperature relationship with the volumetric soil water content at the four levels of the soil becomes clear. In the ‘Fig. 9, 10, 11, 12’ and Table 2, shows the relationship between ST and VSWC is very high negative in most study stations.

![Figure 9](image-url) The relationship between ST and VSWC at the first-level (L1) for four selected stations in Iraq for thirty seven years.

---

**Figure 9.** The relationship between ST and VSWC at the first-level (L1) for four selected stations in Iraq for thirty seven years.
Table I: Volumetric Soil Water Content (m$^3$ m$^{-3}$) and Soil Temperature (°C) for Different Stations in Iraq for Thirty-Seven Years

| Station | Volumetric Soil Water Content L2 (m$^3$ m$^{-3}$) | Volumetric Soil Water Content L3 (m$^3$ m$^{-3}$) |
|---------|-----------------------------------------------|-----------------------------------------------|
| Mousl   | 0.20, 0.22, 0.24, 0.26, 0.28, 0.30             | 0.18, 0.19, 0.20, 0.21, 0.22, 0.23             |
| Baghdad | 0.18, 0.19, 0.20, 0.21, 0.22, 0.23             | 0.210, 0.215, 0.220, 0.225, 0.230             |
| Rutba   | 0.195, 0.200, 0.205, 0.210, 0.215              | 0.195, 0.200, 0.205, 0.210, 0.215              |
| Basrah  | 0.19, 0.20, 0.21, 0.22                         | 0.19, 0.20, 0.21, 0.22                        |

**Figure 10.** The relationship between ST and VSWC at the second-level (L2) for four selected stations in Iraq for thirty seven years.

**Figure 11.** The relationship between ST and VSWC at the third-level (L3) for four selected stations in Iraq for thirty seven years.
Figure 12. The relationship between ST and VSWC at the fourth-level (L4) for four selected stations in Iraq for thirty seven years.

Table 2. Pearson’s correlation coefficient test and Simple linear regression results for the ST and VSWC at the four levels (L1, L2, L3, L4) for four selected stations in Iraq (Mosul, Baghdad, Rutba, and Basrah).

| Stations | Relationship | Pearson’s correlation coefficient (SLR) | Simple Linear Regression (SLR) |
|----------|--------------|--------------------------------------|--------------------------------|
| Mosul    | ST&VSWC LI   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L2   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L3   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L4   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L1   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L2   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L3   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L4   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L1   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L2   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L3   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L4   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L1   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L2   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L3   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L4   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L1   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L2   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L3   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L4   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L1   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L2   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L3   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L4   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L1   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L2   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L3   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L4   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L1   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L2   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L3   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L4   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L1   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L2   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L3   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L4   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L1   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L2   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L3   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L4   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L1   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L2   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L3   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L4   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L1   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L2   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L3   | -0.9 | V. High negative | 0.0001 | Linear |
|          | ST&VSWC L4   | -0.9 | V. High negative | 0.0001 | Linear |
4. Conclusions

- The greatest value of the volumetric soil water content was recorded in Mosul, and the lowest value was recorded in Basrah.
- The greatest value of soil temperature recorded in Basrah, and the lowest value in Mosul.
- The relationship between volumetric soil water content and soil temperature is a very high negative correlation for thirty seven years for the selected stations in Iraq (Mosul, Baghdad, Rutba, and Basrah).

Acknowledgements

An acknowledgment to the European Centre Medium Weather Forecasts (ECMWF) on the data used in this study, and we would also like to thanks Mustansiriyah university for providing scientific support to accomplishing this research.

References

[1] Walker J. Estimating Soil Moisture Profile Dynamics from Near-Surface Soil Moisture Measurements and Standard Meteorological Data. Ph.D. dissertation, The University of Newcastle, Australia, 1999.
[2] Lingli W., and John J. Satellite remote sensing applications for surface soil moisture monitoring: A review. Journal of Front. Earth Sci. China. 3 (2):237–247, 2009.
[3] Commission of Agricultural Meteorology (CAGM). Report of the RA II Working Group on Agricultural Meteorology, Part IV: Drought and Desertification. Report No. 52. WMO/TD-No. 524:1-43, 1993.
[4] Fast J. D. Handbook on the Physics and Chemistry of Rare Earths. Amsterdam: Elsevier, 2:133, 1989.
[5] Entekhabi D., Nakamura H., and Njoku E. G. Retrieval of Soil Moisture by Combined Remote Sensing and Modelling. In: Choudhury, 1993.
[6] Nancy M. T., Keith S. Porter, and Robert J. W. Water and the Soil. Dept. of Agronomy, Cornell University, 2012.
[7] The European Centre for Medium-Range Weather Forecasts. ECMWF Overview, 2016. http://www.ecmwf.int/about/overview/.
[8] Seidenglanz A. Uni Bremen Panoply A Tool for Visualizing NetCDF-Formatted Model Output. NASA, 2012.
[9] David P. The FORTRAN I Compiler. University of Illinois, Urbana-Champaign, 2000.
[10] Williams F. Reasoning with statistics. How to read quantitative research 4th ed. Fort Worth. Harcourt Brace Jovanovich College Publishers, 1992.
[11] SigmaPlot From Wikipedia, 2011. http://en.wikipedia.org/wiki/SigmaPlot.
[12] Levesque R. SPSS Programming and Data Management: A Guide for SPSS and SAS Users, Fourth Edition", SPSS Inc., Chicago II, 2007.