Variation of Soil Temperature with Time and Depth in Karbala Region

تغير درجة حرارة التربة مع الوقت والعمق في منطقة كربلاء

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Abstract

A theoretical investigation of factors affecting soil temperature variation with time and depth is presented. Annual soil temperature variation with time and depth declares that there is a considerable temperature variation in the upper few meters that is necessary to several application fields include agriculture, civil engineering, and environmental engineering. One-dimensional mathematical model is used to study the annual soil temperature variation. The model solution was calibrated with soil temperature measurements at Karbala region. The calibrated mathematical expression is a useful mean to describe the soil temperature variation with time and depth in Karbala region. Results show that at depth below about six meter the soil temperature is approximately constant.
Key words: Soil temperature; Karbala region; Mathematical model; Heat transfer

الخلاصة

تم في هذا البحث إجراء دراسة نظرية للعوامل المؤثرة في تغير درجة الجرارة داخل التربة مع العمق والزمن. اظهر التغير السنوي لدرجة حرارة التربة مع العمق والزمن إن هناك تغييراً مؤثرا في درجة الحرارة في بضعة الأمتار القليلة العليا من التربة وان هذا التغير مهم لعدة مجالات بضمنها الزراعة والهندسة المدنية والبيئية.تم اعتماد نموذج رياضي في بعد واحد لدراسة التغير السنوي لدرجة الحرارة داخل التربة. تمت معايرة نتائج الموديل الرياضي مع قياسات لدرجة حرارة التربة في منطقة كربلاء. يمثل التعبير الرياضي الناتج من هذه الدراسة أداة مفيدة للتعبير عن تغير درجة الحرارة مع الزمن والعمق في منطقة كربلاء. أظهرت النتائج أن درجة الحرارة في هذه المنطقة تبقى ثابتة على طول السنة عند عمق من ستة أمتار وأكثر من سطح التربة.

1. Introduction

The temperature regime of the soil surface has two cyclical periods, the diurnal and annual. Daytime heating and night-time cooling are responsible for the diurnal period, and the annual period results from the variation in short-wave radiation throughout the year. The manner in which heat flow through soil and the amplitude and phase of the temperature waves below the surface are of considerable importance in plant cultural practices and in engineering uses of soils [1]. Many physical, chemical, and biological processes that occur in soil are influenced by temperature [2].

Soil temperature greatly affects the plants and micro-organisms living in the soil. The rate at which organic matter is decomposed by microorganisms increases as the soil temperature increases from about 5ºC up to about 30º or 40ºC. The optimum soil temperature for the growth of plants varies widely with the species over the range of about 20º to 30º C as shown in data collected together by Voorhees, Allmaras and Johnson [3]. The growth rate of micro-organisms and plants may increase two- or three-fold with a 10º C increase in soil temperature up to the optimum.

Information on ground temperature is necessary for many construction projects. These include the design of airport and road pavement, the determination of the depth at which service pipes to buildings should he laid to avoid freezing, the excavation of foundations, and the design and construction of underground space for buildings. With the growing need for conservation, information on ground temperature is increasingly important for energy calculations such as those for determining heat losses from basements and the possible use of the ground as a source for heat pump applications. Engineering and architects concerned with these problems require a knowledge of the factors that determine ground temperatures as well as an understanding of how these temperatures vary with time and depth from the surface [4].

Due to limited amount of natural resources exploited for heating, and in order to reduce the environmental impact, people should strive to use renewable energy resources. For heating purposes, the ground can be used as a heat source. The ground-coupled heat pump (GCHP) can obtain heat from earth, using a ground heat exchanger (GHE). The GHE pipes of various shapes can also be placed into vertical boreholes which can be up to 200m deep. The temperature distributions in the ground are very important for calculations of heat losses of buildings to the ground, for design of thermal energy storage equipment and GHEs [5].

General behavior of soil temperature has been studied by many researchers. According to Marshall & Holms [1]; Williams & Gold [4]; Hillel [6] and Wu & Nofziger [7], for ground has constant thermal properties, the annual variation of daily average soil temperature at different depths is described with a sinusoidal function whose amplitude is decreases exponentially with distance from the surface. This study aims to obtain a mathematical expression for the temperature variation with time and depth in Karbala region. This expression will be useful to researchers and engineers in their studies.

2. Factors Affecting Soil Temperature

Factors that determine the temperature of the soil can be grouped in two general categories: meteorological and subsurface variables. Large-scale regional differences in ground temperature are determined primarily by meteorological variables such as solar radiation, air temperature and precipitation. Micro or local variations are caused by subsurface characteristics and ground thermal properties.

The properties of soil that determine its response to temperature changes at the surface are volumetric heat capacity, $\rho_s C_s$, thermal conductivity, $k_{t,eff}$, and water content. The ratio, $k_{t,eff}/\rho_s C_s$, known as thermal diffusivity, is important in calculating rate of heat flow in the soil. Detailed simulation of soil temperature includes complex interrelationships. Fortunately, in nature many factors tend to compensate each other so that it is usually possible to use relatively simple formula to estimate the limits within which soil temperatures will fluctuate [4].

3. General Behavior of Soil Temperature

The principal features of air and ground surface temperature variations can usually be described by an equation of the form [4]:

$$T_s(t) = T_{av} + A \cdot \cos\left(\frac{2\pi t}{t_o} - \beta\right) \qquad \text{.....................(1)}$$

where

$T_s(t)$ = Ground surface temperature at a given time (θ)

T_{av} = The average temperature for the period, involving one or more complete cycles of variation (θ)

A = The difference between the maximum and minimum temperatures for the period. (θ)

t = Time (T)

t_0 = Time for one complete cycle (T)

β = Phase shift (-)

If the ground has constant thermal properties, the temperature induced in it by cyclical variation is given by Hillel [6]:

$$T(z,t) = T_{av} + A \cdot \exp\left(-z \cdot \sqrt{\frac{\pi}{\alpha t_o}}\right) \cdot \cos\left(\frac{2\pi t}{t_o} - z \cdot \sqrt{\frac{\pi}{\alpha t_o}} - \beta\right) \qquad \text{.....................(2)}$$

Where,
z = Depth below the surface (L)
α = Thermal diffusivity ($k_{t,eff}/\rho_s C_s$) ($L^2\ T^{-1}$)

This sinusoidal temperature model was derived by solving the following partial differential equation [1, 6]:

$$\frac{\partial T(z,t)}{\partial t} = \alpha \frac{\partial^2 T(z,t)}{\partial z^2} \quad \text{.................. (3)}$$

The following assumptions are employed in the derivation of the temperature model:

1. A sinusoidal temperature variation at the soil surface (z = 0) follows equation (1).
2. At infinite depth, the soil temperature is constant and is equal to the average surface soil temperature.
3. The thermal diffusivity is constant throughout the soil profile and throughout the year.

4. Method

The measurement of soil temperature with time and depth in Karbala region had been obtained from Iraqi meteorological office and seismology organization. They had been done by meteorological directorate in Karbala which is located in hai Al-Husain district. These measurements were obtained using special two long mercury thermometers with their bulbs buried inside the soil at soil surface and 0.5 m depth respectively. The daily average temperature for each location was obtained from arithmetic average of four temperature measurements by each thermometer at deferent times during the day separated by a period of 6 hr. These times are 00 (mid night), 06, 12, and 18.

From observing soil surface temperature data, we have realized that the principal features of daily average amplitude, can be described reasonably well by equation (1). This equation was adjusted using the least-square method [8]. A simple computer program was developed for this purpose. This program was written in BASIC programming language. Predicted results, P_i, were compared with observed data, Q_i, by root mean square error, or RMSE:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(P_i - O_i)^2} \quad \text{...........(4)}$$

where
n = number of data points

5. Soil Temperature in Karbala Region

Figure (1) illustrates annual daily average temperature variation at soil surface and soil subsurface at a depth of one meter for Karbala region. The soil surface temperature can be described by equation (5) with reasonable accuracy.

$$T_s(t) = 25 + 22\cdot\cos\left(\frac{2\pi t}{365} - 1.02\pi\right) \quad \text{...........(5)}$$

where, t is time in days beginning from 1^{st} January

Similarly, we have realized also that the principal features of daily average amplitude at a depth one meter from soil surface can be described reasonably well by equation (2). So, the soil surface temperature can be described by equation (6) with reasonable accuracy.

$$T(z,t) = 25 + 22\cdot\exp(-0.83)\cdot\cos\left(\frac{2\pi t}{365} - 0.83 - 1.02\pi\right) \quad \text{............(6)}$$

So, the general form of equation (2) as applicable to Karbala region for any time and depth from soil surface will be:

$$T(z,t) = 25 + 22\cdot\exp(-z\cdot 0.83)\cdot\cos\left(\frac{2\pi t}{365} - z\cdot 0.83 - 1.02\pi\right) \quad \text{.............(7)}$$

6. Results and Discussion

Equation (7) was applied to different depths from the soil surface. The result is presented in figure (2), which shows the calculated underground temperature distribution for the months of January, April, July and October. For example, the temperature increases with depth for the month of January, while it decreases for the month of July. However, the temperature at a depth of about 6 m and deeper positions remains constant at about 25º C throughout the year. On the other hand, the temperature distribution of the underground soil around the year for different depths is presented in figure (3) for year round. Results from the model are consist with those obtained experimentally in other regions in the world [1]. The temperature fluctuation amplitude decreases exponentially with depth.

7. Conclusions

In this work it has been realized that, in Karbala region, the principal features of ground surface can be described by a sinusoidal function and that the principal features of subsurface temperature variations can described by the solution of one dimensional heat transfer model.

A mathematical expression was obtained to the temperature variation with time and depth in Karbala region. Such expression is useful to soil subsurface researches. The expression shows that the amplitude of temperature variation is exponentially decreasing with depth. The temperature at a depth of about 6 m and deeper positions remains constant at about 25º C throughout the year. This depth is reasonable for temperature variation in dry soil [4]. The soil depth above 6m experienced a considerable temperature variation throughout the year that is significant to the plants and micro-organisms living in the soil, organic matter decomposing and many engineering applications.

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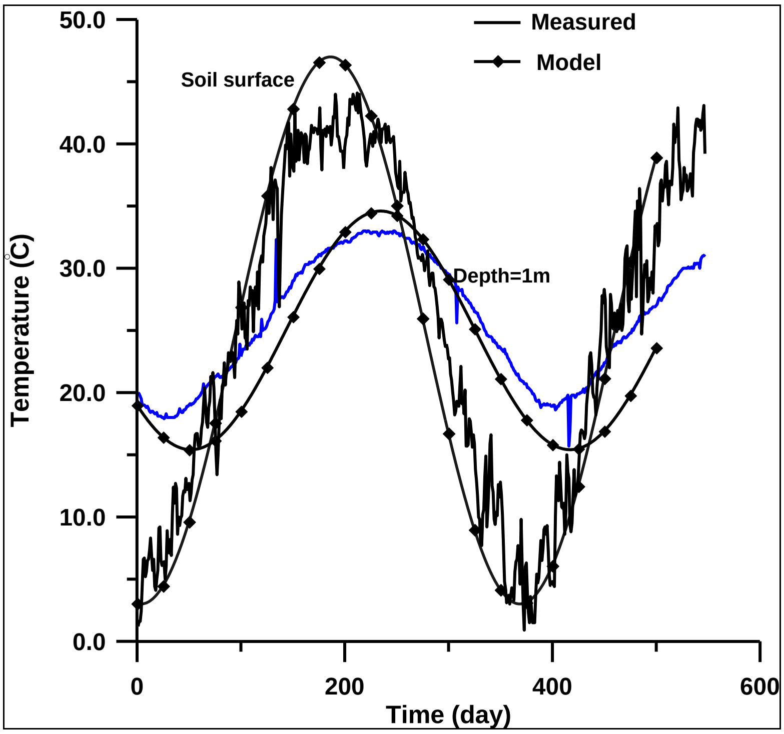

Fig.1: Soil temperature in karbala region: a comparison of measured values and best fit expression values for the period between 1/1/2007 (day 1) and 30/6/2008 (day 548).

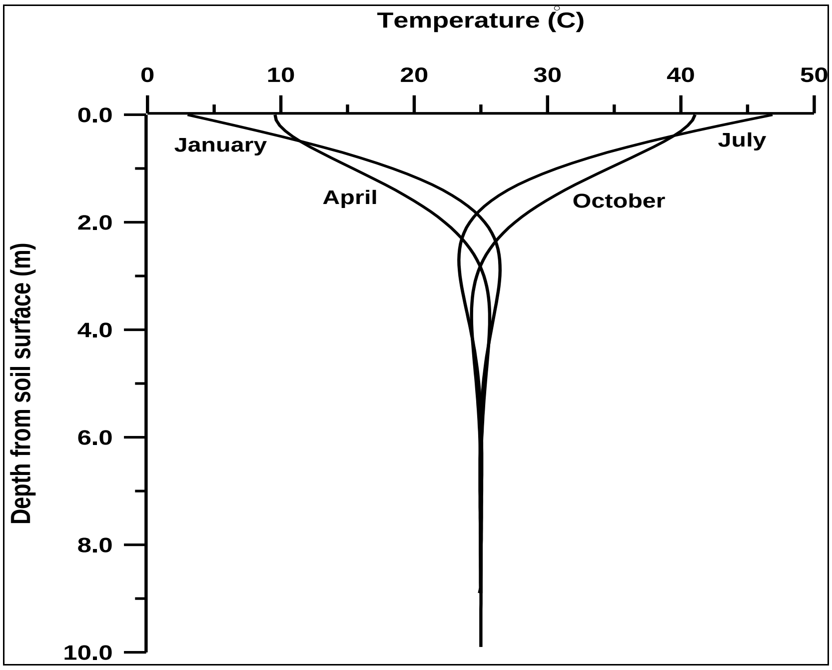

Fig. 2: Spatial underground temperature distribution in Karbala region**.**

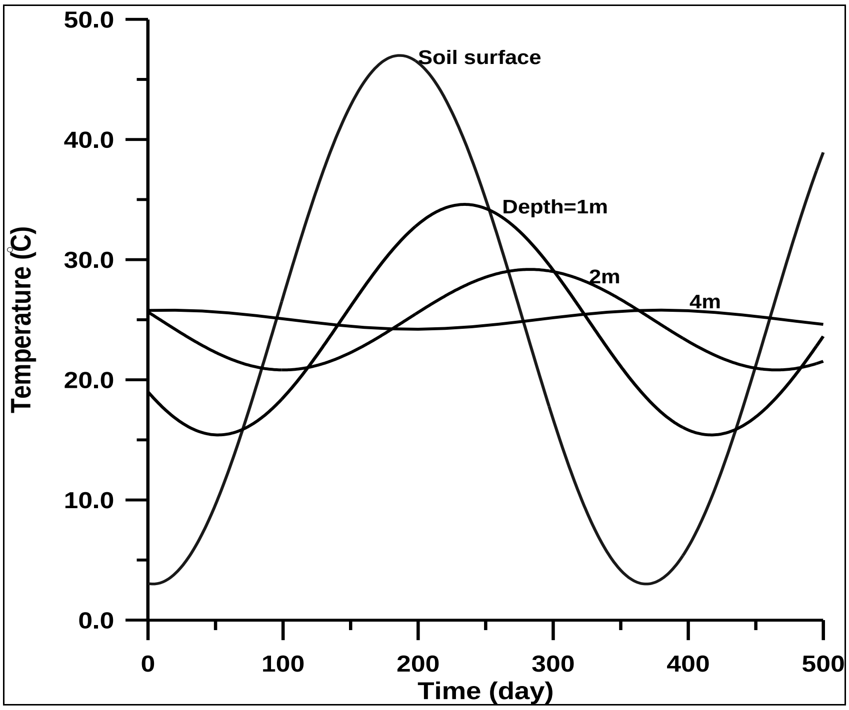

Fig. 3: The temperature distribution of underground soil around the year for Karbala region.