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Temperature diffusion rate of weathered soil in a tropical area —A case study in surrounding Lembang, West Java, Indonesia—

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Abstract

Studies of ground surface temperature in tropical regions are rare. A case study has been carried out in the Lembang area, west Java, Indonesia, at an altitude of 1080 m to 1240 m above mean sea level. Measurements have been performed at four sites characterized by different soil with respect to grain size and surface properties such a bare soil and grass cover.

This study discusses the temperature amplitudes and the use of analytical models in order to obtain the variation of soil thermal diffusivity in depths and estimation of the depth of isothermal layer. It was observed that diffusion rates are different in the bare and grass cover sites. The temperature amplitudes in the grass cover sites are closer to one another than the temperature amplitude in the bare sites at depths below 10 cm. The fine-grained soil layer shows a diffusivity of 0.0024 to 0.0067cm^2/sec, indicating the stable temperatures around a depth of less than 1 meter. The soil layer with gravel-grains showed a thermal diffusivity of 0.0042 to 0.0073 cm^2/seconds. The stable temperatures are reached at more than 1 m in depth, ranging from 113.28 cm to 130.51 cm.

Key-words : Tropical area, Indonesia, shallow soil temperatures, thermal diffusivity, depths with isothermal layer.

1. Introduction

Scientists still commonly believe that rock/soil temperature distribution at any depth below the earth's surface is considered unchanged throughout the year. However, in the case of rocks and soil, temperatures at shallow depths, there is a significant fluctuation on a daily or on an annual basis. This temperature fluctuation is created almost entirely from heating by the sun and cooling through radiation, evaporation and various heat-absorbing processes. The previous investigations have also indicated that the real soil surface temperatures oscillate under field conditions and that these oscillations affect relatively the soil up to about 60 to 80 cm depths (Lovering and Goode, 1963; De Vries, 1975).

The temperature amplitudes are directly affected by external factors, such as the position of the sun, duration of heating, aspect and degree of cloud cover. The internal factors of major importance are the rock thermal properties, including the albedo, thermal conductivity and specific heat capacity (Kerr et al., 1984; McGreevy, 1985; Warke and Smith, 1996).

The initiative of the temperature measurement of ground surface on a case study in the vicinity of Lembang area comes from the results of trends in spring temperatures as reported by Hendarmawan (2002), Kumai and Hendarmawan (2002) in this area (Fig. 1). These papers have described the anomalous groundwater temperatures, the significant fluctuations of groundwater temperatures and the stable temperatures of groundwater gushing out from the springs. Concerning to these results, a more appropriate comparison to spring temperatures is the average ground temperature at the surface, as suggested by Nathenson (1990) due to the fact that springs generally occur at or near the surface. Another reason is the rarity of studies on ground surface temperature mainly in the tropical areas. In the tropical region, most observations focus more on a high altitude (more than 4000 meters) related with cold temperature and the analysis of weathering processes. Hence, identifying the ground surface temperature is necessary in the study area. This area is located on a volcanic slope where springs develop with very shallow watertables. The results of this study could be compared with the trends of groundwater temperature.

Therefore, the purpose of this paper is to demonstrate various temperature amplitudes and to determine the thermal diffusivity in order to estimate the depths which have relatively stable of temperatures. This study is the first to provide a database of the ground surface temperatures in the Lembang area, west Java, Indonesia.

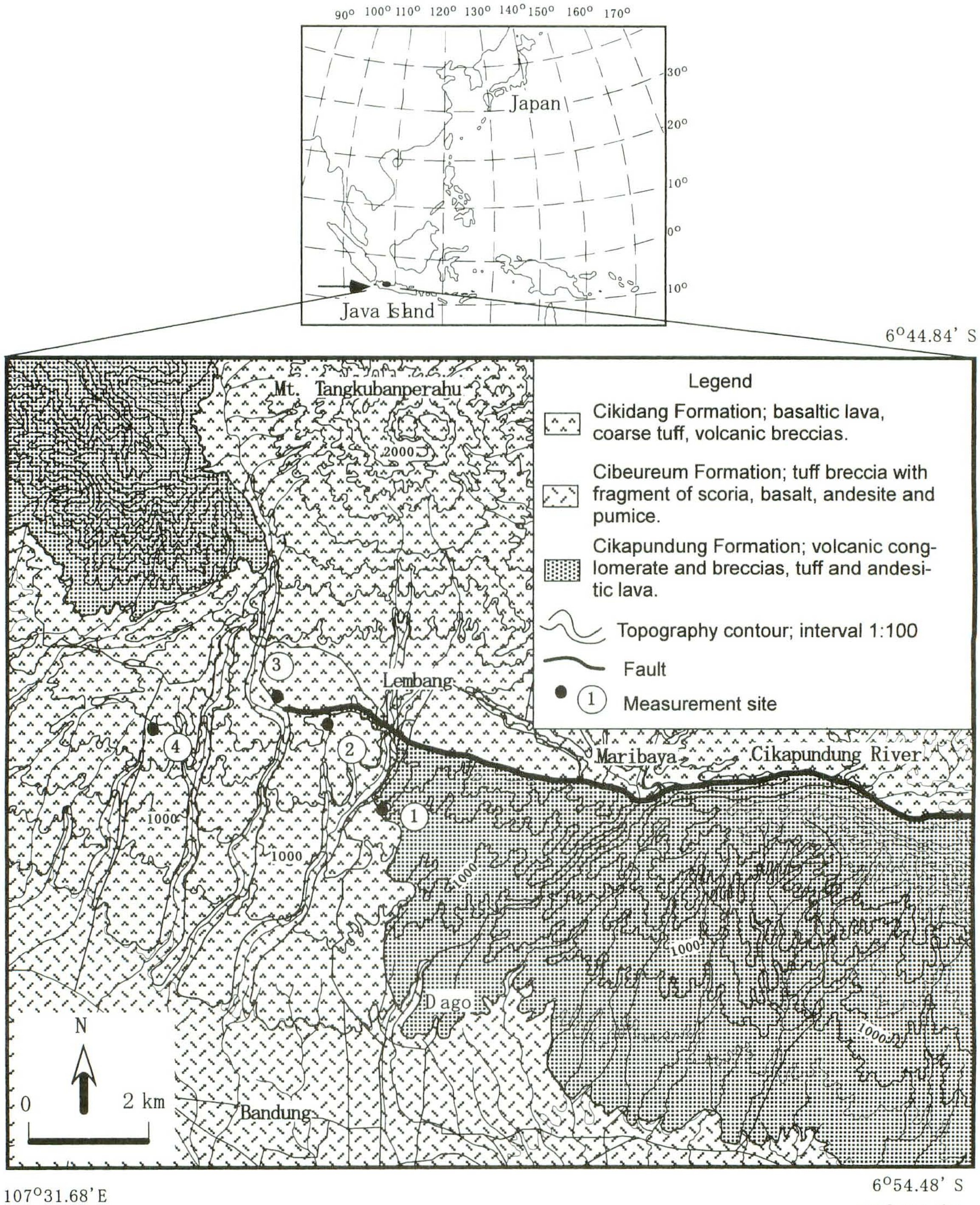


Fig. 1 Map showing the geology of the study area including the location and distribution of measurement sites.

2. Method

The depth where the effect of temperature oscillation approaches a minimum or close to the average temperature, will depend on properties of rock/soil surface such as the thermal diffusivity including the thermal conductivity, specific heat and density. The thermal diffusivity is a given quantity of heat which is inversely proportional to the specific heat and the density of the material and is directly proportional to the conductivity. The thermal diffusivity can be determined through collecting samples by testing the values of thermal conductivity, specific heat and density or by measuring the sub-surface temperature. However, Lovering and Goode (1963) suggested that the diffusivity determined by a laboratory method might be valid for small samples, but it could be somewhat in error for other conditions such as those surrounding the rock/soil mass. Therefore, the second method has been used in the present study, since not only the thermal diffusivity of soil layers on the study area can be determined but also a characteristic of the temperature oscillations can be obtained.

The sites chosen are those with characteristics of a flat land with a bare field or at least grass cover. Representative samples of soils from the various volcanic deposits were also considered carefully. Four sites were selected for measurements during the dry and the rainy seasons in 2003 to 2004. In these sites, the shallow wells were constructed with a 8 inch diameter and approximately a depth of 80 cm. Soon after the surface was drilled, the plastic casing was inserted into the well. Most of the shallow wells were completely dry. To prevent direct contact with air temperature, small holes in the casing and closer were insulated by wax (Fig. 2.a,b,c). A portable thermometer of the model IT 2000/IT-2100 was used to measure the temperature of the soil which has a resolution ±0.1℃. The reading of this thermometer was recorded on the daily observations with 2 hour intervals in a single day.

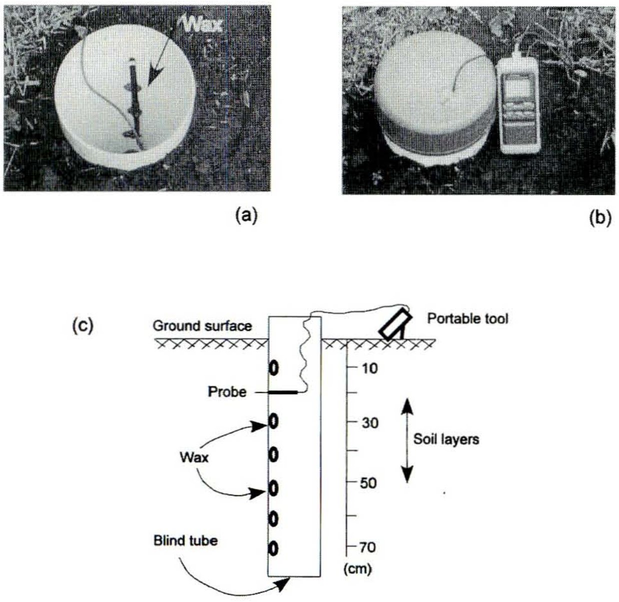


Fig. 2 Two photographs showing the shallow well and measurement tool, (a) the use of wax for reducing perturbation by the wind or air temperature, (b) the well always closed during and after measurements and (c) profile of the thermal sensor setting.

In the present study, the soil diffusivity will be determined through the approach of an analytical model as described in the previous studies. Carslaw and Jaeger (1959) proposed a one-dimensional vertical analytical model. In this model, soil thermal conductivity, λ (W m^{-1} ℃$^{-1}$), and soil volumetric heat capacity, C (J m^{-3} ℃$^{-1}$), are supposed to be constant in the time t (s) and depth z (m), and therefore soil temperature T (℃) is described by:

$$\frac{\partial T}{\partial t} = K_T \frac{\partial^2 T}{\partial z^2} \tag{1}$$

Where K_T (m^2 s^{-1}) is the soil thermal diffusivity defined as;

$$K_T = \frac{\lambda}{C} \tag{2}$$

Eq. (1) is only valid for a particular situation where λ and C, are constants. In the general situation, the correct equation becomes:

$$C\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(\lambda \frac{\partial T}{\partial z}\right) \tag{3}$$

Cichota et al. (2004) suggested that the Eq. (3) could not be solved analytically for a general situation. Eq. (1) can be solved for the following boundary conditions:

$$T(0,t) = \overline{T} + A_0 \sin(\omega t) \tag{4}$$

Which means that the surface temperature varies sinusoidal with, having a time-average value $\overline{T}$ (℃), amplitude A_o(℃) and radial frequency ω (s^{-1}); and

$$\lim T(z,t) = \overline{T} \tag{5}$$

The solution is:

$$T(z,t) = \overline{T} + A_0 \exp\left(\frac{-z}{D}\right) \sin\left(\omega t - \frac{z}{D}\right) \tag{6}$$

Where D (m) is the invariable depth defined as:

$$D = \sqrt{\frac{2K_T}{\omega}} \tag{7}$$

By making $t = 0$ in Eq. (6), the model implies the following initial conditions:

$$T(z,0)=\overline{T}+A_0\exp\left(\frac{-z}{D}\right)\sin\left(\frac{-z}{D}\right) \tag{8}$$

However, the Eq. (8) can be made simpler for any temperature oscillations in the daily observations, corresponding to the equation as described by Lovering and Goode (1963) as follows:

$$T_x = T_s e^{-x\sqrt{\frac{\pi}{\alpha P}}} \tag{9}$$

Where T_x is temperature range at depth x; T_s is amplitude of temperature about the mean at the surface; x is depth in centimeters; α is diffusivity; P is period in seconds (1 day=86,400 seconds).

3. Hydrogeological setting

The study area lies in a humid tropical climate having two seasons i.e. the rainy (wet) season and the dry season. The rainy season goes on from November to April and the dry season falls from June to September. Meanwhile, May and October are the months of the seasonal transition. The mean rainfall varies from 1700 mm/year in the central part of the Bandung region, up to 3600 mm/year on the mountain slopes north of Bandung (IWACO, 1990).

The study area has three volcanic formations e.g. the Cikapundung Formation, the Cibeureum Formation and the Cikidang Formation (Silitonga, 1973; Koesoemadinata and Hartono, 1981). The Cikapundung Formation is the oldest formation that crops out and covers the east-southern part of the study area. This formation consists of the intercalation of volcanic conglomerates and breccias, tuff and andesitic lava layers with the age of lava from 1.1 Ma to 0.16 Ma (Sunardi and Kimura, 1998) and with a thickness of approximately 350 m. The soil layers generally consist of the weathered volcanic breccia and tuff.

The Cibeureum Formation overlies the Cikapundung Formation in the southwest and the north. The Cibeureum Formation consists of repetition of alternating tuff-breccia beds with fragment scoria, basalt pumice and pumice. This formation is expected to have similar ages of lacustrine sediments, because of interfingering. The lacustrine sediments indicated ages of 40000-50000 years BP (Dam and Suparan 1992). The Cibeureum Formation has the thickness of 10-100 m.

The Cikidang Formation is the youngest formation in the study area, consisting of volcanic conglomerate, coarse tuff with parallel bedding volcanic breccias and basalt lava. This formation has an age of 0.04 Ma. The Lembang normal fault extends east to west and separates clearly between the Cikidang Formation and the Cikapundung Formation in the field.

The surface geology is mostly comprised of the soil that is developed on weathered volcanic ash. The presence of clayey soil or saprolith material is common phenomenon. In some parts, soil is also developed on weathered volcanic breccia layer. Stony soils prevail on the steep terrain at shallow levels, while the semi-weathered coarser volcaniclastic material occurs in almost all soils of the study area.

4. Results

Four locations were chosen for the measurement on the three formations. These locations as denoted sites 1, 2, 3 and 4 are situated between latitudes 6°49′58″S, 6°49′03″S, 6°48′55″S, 6°49′07″S and longitudes 107°36′26″E, 107°35′24″E, 107°34′56″E, 107°33′36″E, respectively. The elevations of sites 1, 2, 3, and 4 are 1,080 m, 1,190 m, 1240 m, and 1170 m, respectively (see Fig. 1). There are two wells in each of the sites. These sites are characterized by the flat surfaces with their slopes less than 2°. The sites 1 and 3 are a bare soil, while the sites 2 and 4 exhibit a dominant grass cover on the surface.

In the case of the bare surface, site 1 is composed of the uniform soil from the weathered volcanic breccia (laharic deposits) as associated with the Cikapundung Formation. The soil layer consists mostly of gravelly sand to sandy gravel with clayey silt. The fresh layer of this

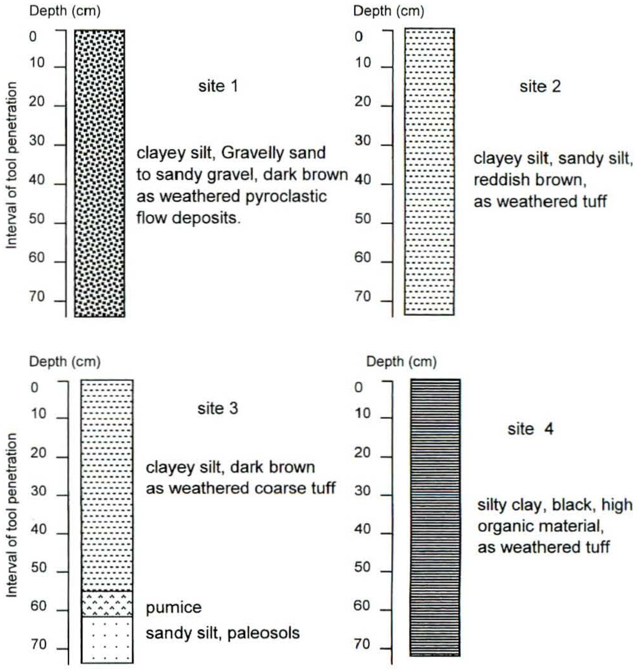


Fig. 3 Columnar section and descriptions of soil layer on the sites. Sites 1, 3 and sites 2, 4 are characterized by the bare soil and grass cover, respectively.

deposit indicated very compact and low permeability. At or near the surface, the moisture soil layer was observed in the field. Site 3 consists of the soil from weathered tuff of the Cikidang Formation. The soil layer indicated humus and silt loam, pumice layer and paleosoil layer, at depths of 0 to 53 cm, 53 cm to 61 cm, 61 to 71 cm, respectively.

In the grass cover on the surface cases, site 2 consists of uniform soil from weathered coarse tuff of the Cibeureum Formation. Site 4 is composed of uniform soil from weathered coarse tuff of the Cikidang Formation. The columnar sections of soil layers are shown in Fig. 3.

4.1 Temperature oscillations

Data records of the diurnal temperatures are derived from four sites during two seasons, as shown in Table 1. All measurements were performed precisely every day. Consequently, the temperature oscillations on the topsoil will be different at every site and season. Figure 4 shows representative oscillations of temperature from site 1 to site 4.

The temperature curves on graphics show that the amplitudes of these oscillations become smaller and smaller as the amplitudes decrease in the deeper soil. The temperature time curves are relatively regular curves of symmetrical periodic and the similar sine curves. However, the temperature curves on the top of soil are asymmetric. This is expected due to the differing daily weather conditions. Nevertheless, these asymmetric curves decrease with increase in depth and become sinusoidal curves.

In general, the temperature curves show that the soil warms up during the sunny portion of the day and cools off at night after 12 hours, either in the dry season or the rainy season. Practically, a movement of heat downward occurred when the sun's rays strike the soil, and a movement of heat towards the surface occurred during the night. The wave of temperature oscillations becomes clearly plane or at least with a small amplitude with increasing depths and are relatively perpendicular to the main surface. Hence, the smallest amplitude of

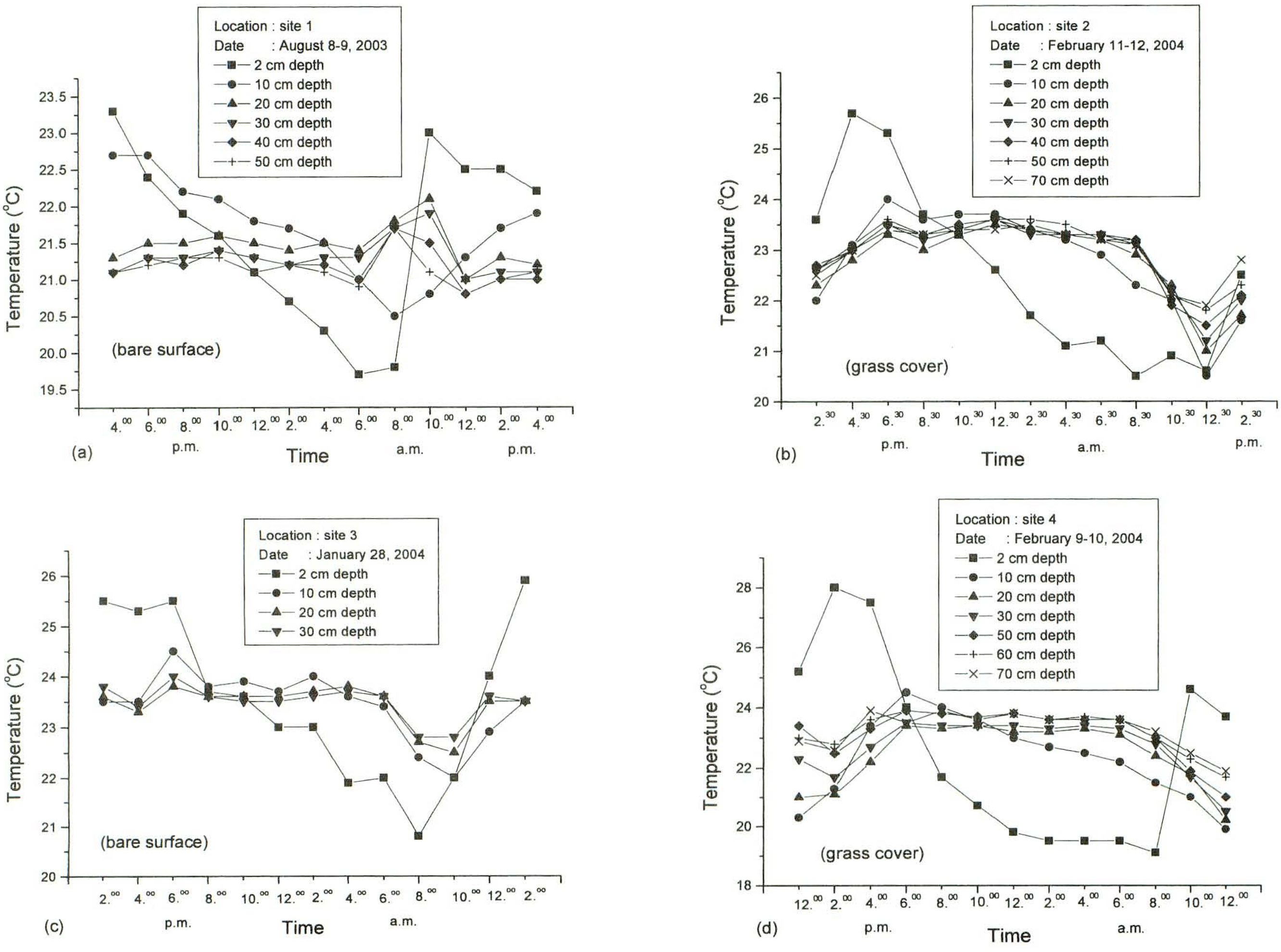


Fig. 4 Representatives of temperature oscillations, (a) and (c) do not show complete temperature oscillations at depth due to perturbations.

Table 1 Data of the ground surface temperatures in daily observation collected from 4 sites.

Location	Date	No	Time	Temperature (°C) at depth of								Air temperature (°C)	Weather
				2 cm	10 cm	20 cm	30 cm	40 cm	50 cm	60 cm	70 cm		
Site 1 (well 1)	Jan 6-7, 2003	1	15.30	25.5	25.6	23.2	22.7	22.6	22.5	22.4		27.5	clear
		2	17.30	24.5	24.5	23.1	22.2	22.1	22.0	22.1		24.0	overcast
		3	19.30	23.7	24.1	23.0	22.3	22.0	21.9	22.0		22.0	overcast
		4	21.30	22.7	23.7	23.2	22.5	22.0	22.0	22.0		20.5	overcast
		5	23.30	22.4	23.5	23.3	22.6	22.4	22.2	22.2		19.0	clear
		6	1.30	21.3	23.1	23.0	22.7	22.4	22.2	22.2		17.5	clear
		7	3.30	20.5	22.5	22.8	22.5	22.4	22.3	22.2		17.0	clear
		8	5.30	19.7	22.2	22.8	22.6	22.4	22.3	22.2		16.0	clear
		9	7.30	19.0	21.4	22.2	22.1	22.0	21.8	21.7		21.0	clear
		10	9.30	21.6	18.6	19.3	19.4	19.6	19.9	20.0		35.0	clear
		11	11.30	27.2	21.3	20.9	21.1	20.9	21.3	21.0		35.0	clear
		12	13.30	29.5	23.9	22.5	22.4	22.3	22.2	22.2		30.0	clear
		13	15.30	26.1	24.5	22.5	22.4	22.3	22.3	22.3		26.5	clear
Temperature range (°C)				10.5	7.0	4.0	3.3	3.0	2.6	2.4			
Site 1 (well 1)	Aug. 8-9, 2003	1	16.^{oo}	23.3	22.7	21.8	21.3	21.1	21.1	21.1	21.0	24.5	overcast
		2	18.^{oo}	22.4	22.7	22.0	21.5	21.3	21.3	21.2	21.3	21.0	clear
		3	20.^{oo}	21.9	22.2	22.0	21.5	21.3	21.2	21.3	21.1	20.5	overcast
		4	22.^{oo}	21.6	22.1	21.9	21.6	21.4	21.4	21.3	21.2	19.5	overcast
		5	24.^{oo}	21.1	21.8	21.7	21.5	21.3	21.3	21.1	21.0	18.0	overcast
		6	02.^{oo}	20.7	21.7	21.7	21.4	21.2	21.2	21.2	20.9	17.5	clear
		7	04.^{oo}	20.3	21.5	21.6	21.5	21.3	21.2	21.1	20.9	17.0	clear
		8	06.^{oo}	19.7	21.0	21.4	21.4	21.3	21.0	20.9	19.8	18.0	clear
		9	08.^{oo}	19.8	20.5	21.6	21.8	21.7	21.7	21.7	21.3	25.0	clear
		10	10.^{oo}	23.0	20.8	21.4	22.1	21.9	21.5	21.1	21.0	27.0	clear
		11	12.^{oo}	22.5	21.3	21.1	21.0	21.0	20.8	20.8	20.7	27.0	clear
		12	14.^{oo}	22.5	21.7	21.3	21.3	21.1	21.0	21.0	20.9	26.0	clear
		13	16.^{oo}	22.2	21.9	21.4	21.2	21.1	21.0	21.1	21.0	24.0	clear
Temperature range (°C)				3.6	2.2	0.9	1.1	0.9	0.9	0.9	1.5		
Site 1 (well 2)	Feb. 2-3, 2004	1	12.^{oo}	24.6	22.4	22.5	22.9	22.8	22.8	22.7	22.7	27.0	overcast
		2	14.^{oo}	25.0	23.8	23.5	23.7	23.7	23.6	23.6	23.4	23.0	drizzle
		3	16.^{oo}	23.1	24.1	23.6	23.6	23.6	23.6	23.4	23.0	19.0	rain
		4	18.^{oo}	22.4	23.5	23.4	23.3	23.2	23.2	23.1	22.7	19.0	drizzle
		5	20.^{oo}	21.2	23.2	23.3	23.3	23.3	23.2	23.0	22.9	19.0	drizzle
		6	22.^{oo}	21.0	23.0	23.3	23.3	23.3	23.1	22.9	23.0	19.0	drizzle
		7	24.^{oo}	20.5	22.5	23.1	23.1	23.2	23.0	22.6	22.8	17.0	drizzle
		8	02.^{oo}	20.0	22.3	22.8	23.1	23.1	23.0	23.0	22.9	18.0	drizzle
		9	04.^{oo}	19.7	21.9	22.6	23.0	22.9	23.0	22.9	22.8	18.0	drizzle
		10	06.^{oo}	19.8	22.0	22.8	23.1	23.1	23.1	23.1	22.9	17.0	drizzle
		11	08.^{oo}	19.9	21.6	22.4	22.8	22.9	22.9	22.7	22.7	19.0	drizzle
		12	10.^{oo}	20.1	20.9	21.6	22.5	22.7	22.5	22.4	22.2	22.0	drizzle
		13	12.^{oo}	21.3	19.7	20.5	21.1	21.2	21.4	22.5	23.0	26.0	clear
Temperature range (°C)				5.3	4.4	3.1	2.6	2.5	2.2	1.2	1.2		
Site 2 (well 1)	Jan. 13-14 2003	1	13.30	21.3	20.7	21.0	21.1	21.3	21.5	21.6	21.6	29.5	clear
		2	15.30	21.6	20.9	21.0	21.1	21.2	21.3	21.4	21.5	26.5	clear
		3	17.30	21.6	21.1	21.1	21.1	21.3	21.4	21.6	21.6	25.0	overcast
		4	19.30	21.2	21.3	21.2	21.3	21.5	21.5	21.6	22.0	23.0	overcast
		5	21.30	21.0	21.2	21.0	21.1	21.3	21.6	21.6	21.8	22.5	overcast
		6	23.30	20.5	21.2	21.1	21.1	21.3	21.5	21.7	21.6	22.5	clear
		7	1.30	20.5	21.3	21.2	21.3	21.8	21.8	22.0	22.1	20.5	clear
		8	3.30	19.5	21.5	21.7	21.6	21.9	22.0	22.1	22.1	19.5	clear
		9	5.30	19.4	21.2	21.5	21.4	21.8	21.8	21.8	22.0	19.0	clear
		10	7.30	17.9	19.8	20.2	20.2	21.0	21.2	21.3	21.5	25.5	clear
		11	9.30	19.6	19.8	20.3	20.5	20.9	20.9	20.9	21.1	29.5	clear
		12	11.30	20.5	20.0	20.5	20.7	21.0	21.2	21.3	21.5	30.5	clear
		13	13.30	22.4	20.3	20.5	20.5	21.1	21.3	21.4	21.6	27.0	clear
Temperature range (°C)				4.5	1.7	1.5	1.4	1.0	1.1	1.2	1.0		
Site 2 (well 1)	Aug. 13-14 2003	1	12.oo	20.8	20.1	20.8	20.7	21.0	21.0	20.8	20.7	26.0	clear
		2	14.oo	22.5	20.8	20.3	20.6	20.5	20.7	20.9	21.1	23.5	overcast
		3	16.oo	22.1	21.3	20.8	20.8	20.9	20.9	20.9	21.3	22.0	clear
		4	18.oo	21.6	21.8	21.3	21.1	21.0	21.0	21.0	21.0	18.0	overcast
		5	20.oo	20.4	21.1	20.9	21.0	21.0	21.0	21.0	21.1	19.0	overcast
		6	22.oo	19.6	21.0	21.1	21.0	21.0	21.0	21.0	21.0	19.0	overcast
		7	24.oo	20.0	20.7	21.0	21.0	21.0	21.0	21.0	21.0	18.5	overcast
		8	02.oo	19.6	20.6	20.6	21.0	21.0	21.0	21.0	21.0	18.0	overcast
		9	04.oo	20.2	20.7	21.1	21.1	21.0	21.0	21.0	21.0	15.5	clear
		10	06.oo	18.2	20.2	20.7	20.7	20.6	20.7	20.7	20.8	15.0	clear
		11	08.oo	18.1	19.0	20.0	20.3	20.4	20.4	20.5	20.4	19.0	clear
		12	10.oo	18.6	19.3	20.6	20.6	20.4	20.4	20.6	20.2	23.5	clear
		13	12.oo	22.6	20.0	20.0	19.5	20.5	21.0	21.1	21.3	25.0	overcast
Temperature range (°C)				4.5	2.8	1.3	1.6	0.6	0.6	0.6	1.1		

continued

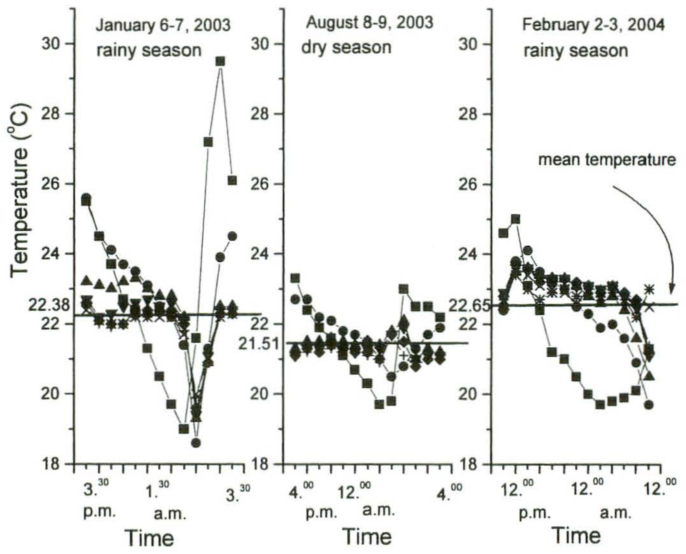
Location	Date	No	Time	Temperature (°C) at depth of								Air temperature (°C)	Weather
				2 cm	10 cm	20 cm	30 cm	40 cm	50 cm	60 cm	70 cm		
Site 2 (well 2)	Feb. 11 -12 2004	1	14.30	23.6	22.0	22.3	22.6	22.7	22.6	22.5	22.5	27.0	clear
		2	16.30	25.7	23.1	22.8	23.0	23.0	23.1	23.1	23.0	24.0	clear
		3	18.30	25.3	24.0	23.3	23.5	23.5	23.6	23.6	23.4	20.0	overcast
		4	20.30	23.7	23.6	23.0	23.2	23.3	23.3	23.3	23.3	20.0	clear
		5	22.30	23.3	23.7	23.3	23.4	23.5	23.5	23.5	23.4	20.0	clear
		6	24.30	22.6	23.7	23.5	23.6	23.6	23.6	23.5	23.4	20.0	clear
		7	2.30	21.7	23.4	23.4	23.3	23.4	23.6	23.5	23.5	17.0	clear
		8	4.30	21.1	23.2	23.3	23.3	23.3	23.5	23.4	23.3	17.0	clear
		9	6.30	21.2	22.9	23.2	23.3	23.3	23.2	23.3	23.2	18.0	overcast
		10	8.30	20.5	22.3	22.9	23.1	23.2	23.2	23.2	23.1	22.0	overcast
		11	10.30	20.9	22.0	22.3	22.2	21.9	22.1	22.2	22.1	28.0	clear
		12	12.30	20.6	20.5	21.0	21.2	21.5	21.8	21.1	21.9	36.0	clear
		13	14.30	22.5	21.6	21.7	22.0	22.1	22.3	22.6	22.8	34.0	clear
Temperature range (°C)				5.2	3.5	2.5	2.4	2.1	1.8	2.5	1.6		
Site 3 (well 1)	Aug. 7-8 2003	1	14.30	26.4	25.4	24.3	23.7	23.3	23.1	22.9	22.6	31.0	overcast
		2	16.30	26.6	25.5	24.2	23.9	23.4	23.2	23.0	22.9	25.0	clear
		3	18.30	25.8	25.3	24.3	23.9	23.4	23.1	23.0	22.6	20.0	clear
		4	20.30	23.6	24.3	24.0	23.3	23.1	22.9	22.6	22.5	18.5	clear
		5	22.30	22.5	24.1	23.7	23.4	23.3	23.1	23.0	22.7	17.5	overcast
		6	24.30	21.7	23.8	23.6	23.2	22.7	22.7	22.6	22.4	16.0	clear
		7	2.30	21.6	23.2	23.3	23.0	22.8	22.6	22.6	22.3	15.5	clear
		8	4.30	20.0	22.6	22.8	23.0	22.7	22.6	22.5	22.5	16.0	overcast
		9	6.30	20.9	22.2	22.8	22.9	22.9	22.8	23.1	23.2	19.0	overcast
		10	8.30	22.0	21.6	21.9	22.0	22.7	22.7	22.0	21.7	26.0	clear
		11	10.30	23.5	23.1	22.4	22.2	23.7	23.2	23.3	23.2	34.0	clear
		12	12.30	24.8	22.6	22.7	22.9	22.5	23.0	22.6	22.6	28.0	overcast
		13	14.30	25.4	23.2	23.0	22.8	22.9	22.9	22.7	22.8	29.5	overcast
Temperature range (°C)				6.6	3.9	2.4	1.9	0.7	0.6	1.3	1.5		
Site 3 (well 2)	Jan. 28 -29 2004	1	$14.^{00}$	25.5	23.5	23.6	23.8	24.6	23.8	23.8	23.7	25.0	overcast
		2	$16.^{00}$	25.3	23.5	23.3	23.4	23.6	23.6	23.6	23.6	24.0	overcast
		3	$18.^{00}$	25.5	24.5	23.8	24.0	24.1	23.9	23.9	23.7	21.5	drizzle
		4	$20.^{00}$	23.7	23.8	23.6	23.6	23.7	24.0	23.7	23.6	20.5	rain
		5	$22.^{00}$	23.6	23.9	23.6	23.5	23.6	23.7	23.7	23.6	20.0	drizzle
		6	$24.^{00}$	23.0	23.7	23.6	23.5	23.6	23.6	23.6	23.5	20.0	overcast
		7	$02.^{00}$	23.0	24.0	23.7	23.6	23.7	23.6	23.5	23.6	19.5	clear
		8	$04.^{00}$	21.9	23.6	23.8	23.7	23.6	23.7	23.7	23.6	18.0	clear
		9	$06.^{00}$	22.0	23.4	23.6	23.6	23.6	23.5	23.5	23.4	19.0	overcast
		10	$08.^{00}$	20.8	22.4	22.7	22.8	22.6	22.6	22.2	21.6	23.0	clear
		11	$10.^{00}$	22.0	22.0	22.5	22.8	23.1	22.9	22.7	22.6	24.5	clear
		12	$12.^{00}$	24.0	22.9	23.5	23.6	23.6	23.3	23.1	23.0	27.0	clear
		13	$14.^{00}$	25.9	23.5	23.5	23.5	23.6	23.6	23.5	23.4	23.5	overcast
Temperature range (°C)				5.1	2.5	1.3	1.2	2	1.3	1.7	2.1		
Site 4 (well 1)	Jan. 15 -16 2003	1	15.30	23.0	22.7	22.8	22.6	22.2	22.3	22.2	22.3	30.5	clear
		2	17.30	24.7	23.9	23.4	23.2	22.8	22.6	22.5	22.4	25.0	clear
		3	19.30	24.0	23.4	22.9	22.5	22.3	22.3	22.0	22.3	21.5	clear
		4	21.30	23.7	23.3	23.0	22.7	22.3	22.4	22.2	22.0	20.0	clear
		5	23.30	23.3	23.3	22.9	22.6	22.4	22.3	22.2	22.0	19.5	clear
		6	1.30	23.3	23.2	22.8	22.4	22.3	22.1	22.0	21.9	19.0	overcast
		7	3.30	22.8	23.0	22.7	22.4	22.2	22.1	22.0	21.9	19.0	overcast
		8	5.30	22.9	23.2	23.0	22.7	22.5	22.3	22.1	22.0	17.5	clear
		9	7.30	22.3	22.7	22.6	22.4	22.2	22.1	22.0	21.9	19.5	clear
		10	9.30	22.0	22.4	22.4	22.3	22.1	22.0	21.9	21.7	22.5	clear
		11	11.30	21.5	21.6	21.5	21.8	22.1	22.1	22.2	22.1	27.5	clear
		12	13.30	22.1	22.1	22.5	22.4	22.5	22.5	22.8	22.7	29.0	clear
		13	15.30	23.6	23.0	22.8	22.5	22.8	22.8	22.9	23.1	29.5	clear
Temperature range (°C)				3.2	2.3	1.9	1.4	0.7	0.8	1.0	1.4		
Site 4 (well 1)	Aug.15 -16 2003	1	13.30	20.4	20.4	20.0	20.6	20.7	20.7	19.4	21.3	27.5	clear
		2	15.30	20.6	20.6	20.8	20.8	20.9	21.1	21.1	20.9	25.0	clear
		3	17.30	21.2	22.0	20.0	19.8	19.8	20.0	20.2	20.2	20.0	clear
		4	19.30	20.4	21.9	20.6	19.8	19.7	19.6	19.8	20.0	19.0	overcast
		5	21.30	21.1	21.5	20.7	20.2	20.1	20.0	20.1	20.1	19.0	overcast
		6	23.30	20.7	21.2	20.7	20.3	20.1	20.1	20.2	20.2	19.0	overcast
		7	01.30	20.6	21.0	20.7	20.3	20.1	20.1	20.2	20.2	18.0	clear
		8	03.30	20.3	20.7	20.5	20.3	20.1	20.1	20.2	20.2	18.0	overcast
		9	05.30	20.0	20.4	20.5	20.3	20.0	20.1	20.1	20.2	17.0	overcast
		10	07.30	19.5	19.8	20.0	19.8	19.9	19.9	19.9	19.9	21.0	overcast
		11	09.30	20.5	19.9	20.2	20.1	20.2	20.3	20.4	20.4	24.0	clear
		12	11.30	19.6	20.6	20.4	20.0	20.1	20.0	21.0	21.0	27.0	clear
		13	13.30	22.6	21.1	20.2	20.8	20.8	20.7	20.8	20.8	28.0	clear
Temperature range (°C)				3.1	2.2	0.8	1.0	1.2	1.5	1.7	1.4		

Table 1 (continue)

Location	Date	No	Time	Temperature (°C) at depth of								Air temperature (°C)	Weather
				2 cm	10 cm	20 cm	30 cm	40 cm	50 cm	60 cm	70 cm		
Site 4 (well 2)	Feb. 9-10 2004	1	12.^{00}	25.2	20.3	21.0	22.3	23.0	23.4	23.0	22.9	25.0	clear
		2	14.^{00}	28.0	21.3	21.1	21.7	22.2	22.5	22.8	22.6	24.0	clear
		3	16.^{00}	27.5	23.4	22.2	22.7	23.0	23.3	23.6	23.9	24.0	clear
		4	18.^{00}	24.0	24.5	23.4	23.5	23.8	23.9	23.9	23.5	20.0	clear
		5	20.^{00}	21.7	24.0	23.3	23.4	23.7	23.8	23.8	23.9	18.0	rain
		6	22.^{00}	20.7	23.6	23.4	23.4	23.6	23.7	23.7	23.6	18.0	overcast
		7	24.^{00}	19.8	23.0	23.2	23.4	23.6	23.8	23.8	23.8	17.0	clear
		8	02.^{00}	19.5	22.7	23.2	23.3	23.4	23.6	23.6	23.6	17.0	clear
		9	04.^{00}	19.5	22.5	23.3	23.4	23.5	23.6	23.7	23.6	18.0	overcast
		10	06.^{00}	19.5	22.2	23.1	23.3	23.5	23.6	23.6	23.6	18.0	overcast
		11	08.^{00}	19.1	21.5	22.4	22.8	22.9	23.0	23.0	23.2	24.0	clear
		12	10.^{00}	24.6	21.0	21.8	21.7	21.8	21.9	22.3	22.5	29.0	clear
		13	12.^{00}	23.7	19.9	20.2	20.5	20.7	21.0	21.7	21.9	25.0	clear/wind
Temperature range (°C)				8.9	4.6	3.2	3.0	3.1	2.9	2.2	2.0		

Table 1 (continue)

(a) Location : Site 1 (bare surface)



(b) Location : Site 4 (grass cover)

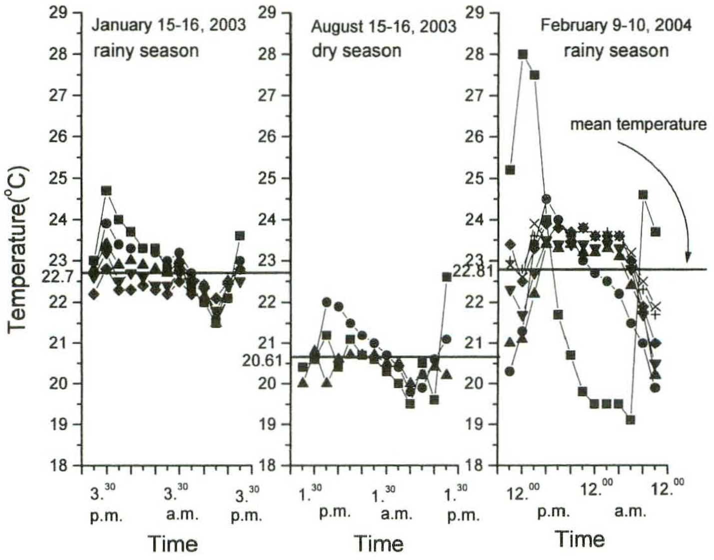


Fig. 5 The average of ground surface temperatures during the dry and the rainy season, (a) bare soil, (b) grass cover.

temperature oscillation will be close to the average temperature of ground surface at a certain depth.

The average of ground surface temperatures on the study area indicated that the average temperatures in the dry season are a little bit lower than the averages in the rainy season. This phenomenon can be illustrated for two seasons as shown in Fig. 5 and will be dealt with in the discussion. Two representative sites were selected for bare field and grass cover.

4.2 Thermal diffusivity

Before the thermal diffusivities of soil layers are determined, there are some considerations related with accurate data. The probe of tool is limited and hence the author could not install the probe permanently in the soil at the depth interval. Before the probe penetrated the soil, when the wax was picked up for measurements at depths of 40 cm to 70 cm, the penetration places opened for 4 to 5 seconds. Consequently, perturbation of air temperatures might have occurred in these depths. Perturbation could possibly be avoided for measurements from the top to a depth of 30 cm, because the probe directly penetrates the soil after the wax was picked up. For this stage it is possible to measure manually using two hands inside the well (see Fig. 2). Thus, the data from the top to 30 cm in depth can be expected to be accurate.

Further, some other steps had also to be performed. For example, the data of site 1 on February 2-3, 2004 and site 2 on February 11-12, 2004 had to be determined. These sites have different soil types in grain size i.e. gravel and clayey silt for sites 1 and 2, respectively.

Firstly, the mean temperatures and the range of total temperatures are calculated. The mean temperature can be obtained by calculating statistically, all results of measurement in a data set. The range of total temperature on a data set is derived from the temperature data on the topsoil where the maximum temperature is reduced by the minimum temperature. This total temperature range is usually twice the amplitude.

Secondly, every single temperature on times and depths are reduced by the mean temperatures, and the results are then divided by the total temperature range. The final results are made in percent unit as shown in table 2. Mathematically, the author can use Celsius degrees. However, when we calculate the depths with constant temperature, the values of 0.1% and 0.01% of the surface ranges are assumed by the researchers in the previous studies, as being the smallest amplitudes close to the stable

Table 2 Percent results of diurnal temperatures in materials of different depths, after reduced by the mean temperature and divided by range of total temperature.

Location : site 1 (well 2) : bare surface
Date : February 2-3, 2004

Mean temperature : 22.65 °C
Total temperature range : 5.3 °C

Depth	Results of reduced by mean temperature and divided by total range on the surface at every time of measurements (%)												
(cm)	12.00	14.00	16.00	18.00	20.00	22.00	24.00	2.00	4.00	6.00	8.00	10.00	12.00
2	36.79	44.34	8.49	-4.72	-27.36	-31.13	-40.57	-50.00	-55.66	-53.77	-51.89	-48.11	-25.47
10	-4.72	21.70	27.36	16.04	10.38	6.60	-2.83	-6.60	-14.15	-12.26	-19.81	-33.02	-55.66
20	-2.83	16.04	17.92	14.15	12.26	12.26	8.49	2.83	-0.94	2.83	-4.72	-19.81	-40.57
30	4.72	19.81	17.92	12.26	12.26	12.26	8.49	8.49	6.60	8.49	2.83	-2.83	-29.25

Location : site 2 (well 2) : grass cover
Date : February 11-12, 2004

Mean temperature : 22.82 °C
Total temperature range : 5.2 °C

Depth	Result of reduced by mean temperature and divided by total range on the surface at every time of measurements (%)												
(cm)	14.30	16.30	18.30	20.30	22.30	24.30	2.30	4.30	6.30	8.30	10.30	12.30	14.30
2	15.00	55.38	47.69	16.92	9.23	-4.23	-21.54	-33.08	-31.15	-44.62	-36.92	-42.69	-6.15
10	-15.77	5.38	22.69	15.00	16.92	16.92	11.15	7.31	1.54	-10.00	-15.77	-23.46	-23.46
20	-10.00	-0.38	9.23	3.46	9.23	13.08	11.15	9.23	7.31	1.54	-10.00	-10.00	-21.54
30	-4.23	3.46	13.08	7.31	11.15	15.00	9.23	9.23	9.23	5.38	-11.92	3.46	-4.23
40	-2.31	3.46	13.08	9.23	13.08	15.00	11.15	9.23	9.23	7.31	-17.69	-25.38	-13.85
50	-4.23	5.38	15.00	9.23	13.08	15.00	15.00	13.08	7.31	7.31	-13.85	-19.62	-10.00

temperatures. Therefore percent unit can make easily be made use of in the calculation. Concerning inaccurate results, table 2 shows that six temperatures at depth of 40 and 50 cm have large deviations (marked by a thick line in the table). They did not plot in the graph. However, this process does not influence in obtaining the range of temperature wave at 10 cm to 30 cm depths.

Thirdly, the values as shown in Table 2 are plotted in a graph as depth versus temperature ranges in order to determine the range of temperature waves at certain depths. The outside curves on graphs become important in view of the ranges of temperature wave, as shown in Fig. 6. These outside curves are termed "envelope curves". The ideal outside curves from field measurements are not achieved because of the asymmetric oscillations of the surface temperatures, the heterogeneity of the adjacent soil layers and uncontrolled perturbation from wind and dew during measurements. Statistically, two or three lines of outside curves are necessarily performed in order to obtain the appropriate envelope curve.

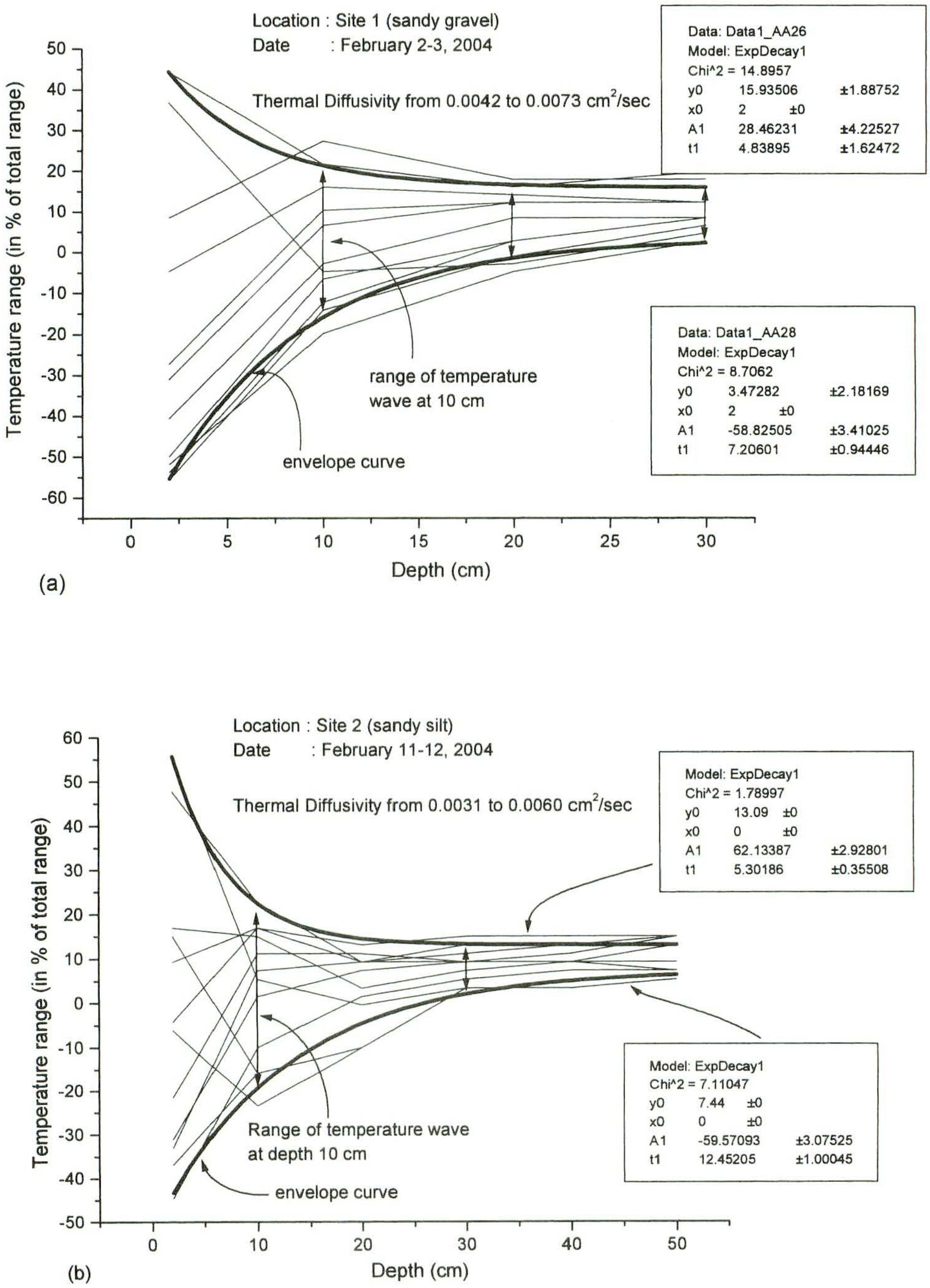


Fig. 6 The simulation results of envelope curve and temperature wave range at 10 cm to 30 cm depths through the graphs to obtain the thermal diffusivity.

Finally, after the range of temperature wave derived for depths of 10 cm to 30 cm, the thermal diffusivity of soil can be determined by Eq. (9). It was observed that the thermal diffusivities on site 1 are 0.0042, 0.0055 and 0.0073 cm^2/seconds for 10, 20 and 30 cm depths, respectively. Meanwhile, site 2 had the thermal diffusivities of 0.0031, 0.0060, and 0.0056 cm^2/seconds at 10, 20 and 30 cm depths, respectively. These results can be controlled by overlapping the ideal envelope curves of soil diffusivity known, as shown in Fig.7. The range value of 10 cm depth can correspond to the ideal curve of 0.0040 thermal diffusivity, while the range value of 30 cm depth may coincide with the range of temperature in the ideal curve of 0.0080 thermal diffusivity.

In the same way, calculations have been performed for all data. After obtaining the thermal diffusivity, the depth with the smallest temperature amplitude can also be estimated through Eq. (9). Where T_x is given the values of

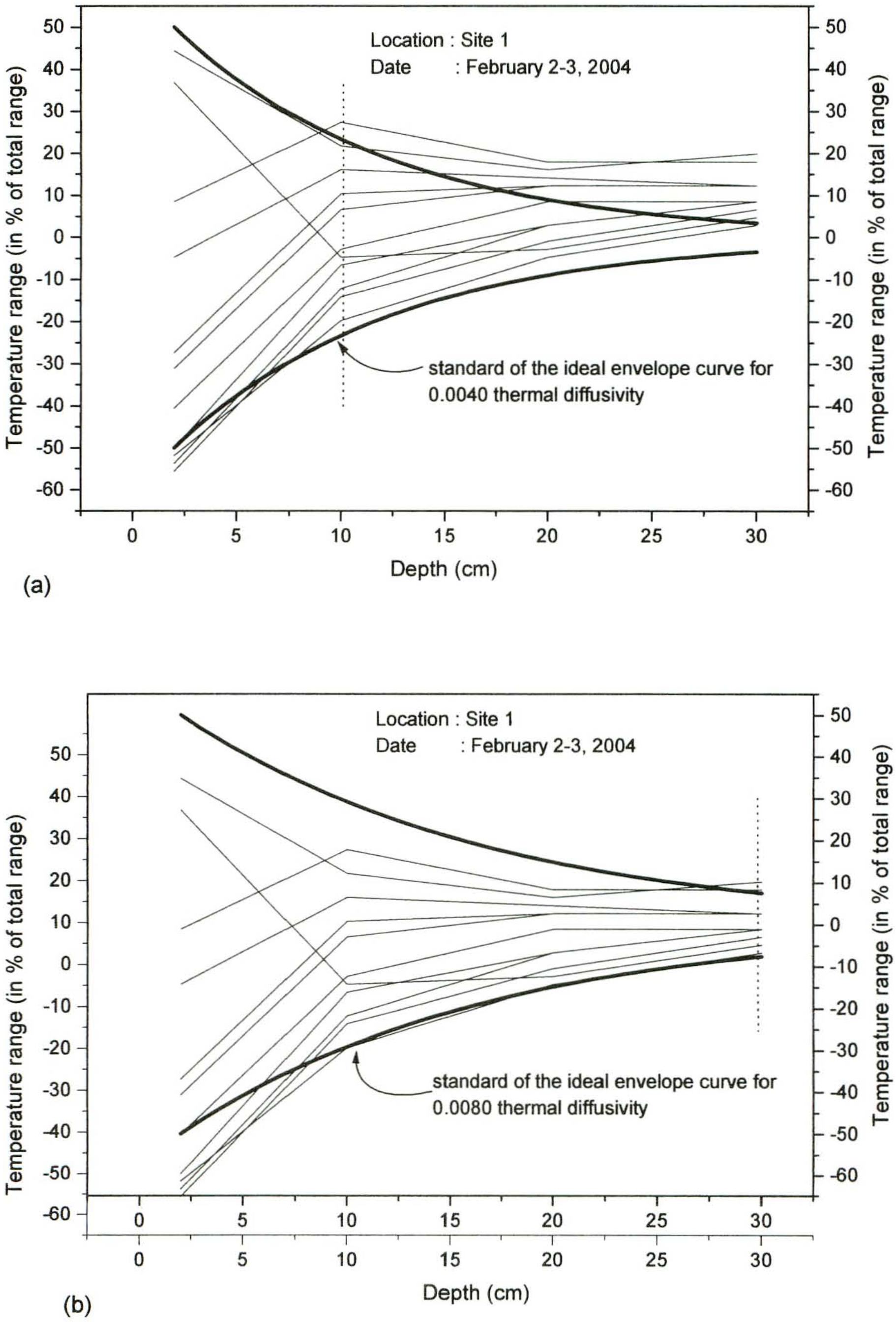


Fig. 7 Overlap of the envelope curves from certain standards of diffusivity known with the observed curves (a) for 10 cm and 30 cm depths.

Table 3 Results of simulation through Eq. (9), including the thermal diffusivity and the depths with relatively constant temperatures.

Location	Date	Diffusivity (cm^2/sec)	Depth in centimeter at which range is	
			0.1% of surface range	0.01% of surface range
Site 1	Feb. 2-3, 2004	0.0042	74.2368	98.9896
		0.0055	84.9539	113.2801
		0.0073	97.8732	130.5070
	Aug. 9-10, 2003	0.0048	79.1953	105.6519
		0.006	88.5002	118.0654
		0.0071	96.2888	128.4559
	Jan. 6-7, 2003	0.0025	57.2437	76.3321
		0.0033	65.8061	87.7497
		0.0049	80.1688	106.9018
Site 2	Feb. 11-12 2004	0.0031	63.6472	84.9000
		0.0060	88.5406	118.1058
		0.0056	85.5201	114.0663
	Aug. 13-14 2003	0.0097	112.2489	149.8501
		0.0130	129.9833	173.5252
		0.0122	124.8348	166.6299
	Jan. 13-14 2003	0.0035	67.7287	90.3181
		0.0071	96.4509	128.6181
		0.0120	125.4484	167.2864
Site 3	Jan 28-29, 2004	0.0025	57.3961	76.4845
		0.0024	56.2883	75.0083
		0.0030	63.3503	84.4189
	Aug. 7-8, 2003	0.0038	70.5601	94.0700
		0.0059	87.9199	117.2172
		0.0094	110.9696	147.9452
Site 4	Feb. 9-10, 2004	0.0025	57.2004	76.2888
		0.0042	74.1742	98.9269
		0.0067	93.6319	124.8781
	Aug. 15-16 2003	0.0054	84.1231	112.1685
		0.0065	92.3419	123.1275
		0.0081	103.0473	137.4019
	Jan. 15-16 2003	0.0067	93.7016	124.9476
		0.0088	107.4426	143.2708

0.1 percent and 0.01 percent as an arbitrary value of the minimum change. The complete results of diffusivity and depth are shown in Table 3.

5. Discussion

Concerning the doubt on the data below a depth of 40 cm, the accuracy of the data can be interpreted by checking the temperature ranges (usually twice temperature amplitudes) from top to a depth of 70 cm. Based on the analytical model as shown by Eq. (8), the amplitude in temperature oscillations will decrease with increasing depths. In general, the data from the top to a depth of 30 cm are consistent with the above model. However, the results of some data sets still exhibit temperature ranges that increase with increasing depths, specifically below 40 cm (see table. 1 marked by the thick line). This case causes doubt on the data. Moving the wax and probe may have caused the inaccuracy of the data. Therefore the use of the data set from the top to a depth of 30 cm is reasonable and appropriate for determining the thermal diffusivity as considered in the previous section. The author considers that the probe must be embedded in the soil at every interval of depth in order to derive the high accuracy of data at depths of 40 cm to 70 cm.

In fact, the interesting patterns of temperature oscillations reveal that the minimum temperatures at depths of 10 cm and below are reached about two hours after the minimum at the surface (see Fig. 4a,c). This is similar to some measurement results in the non-tropical areas. This needs some explanation. As we know, the heat always flows in the direction from warmer to cooler. During the night, the temperature gradient is upwards. It means that heat flows from the bottom to the top and is lost to the atmosphere because of the cooler air temperature. When the topsoil received the heat of the sun, the temperature gradient is downwards. Thus, the top soil receives heat coming from downwards and from upwards, and consequently the temperature of the topsoil would rise faster than the lower parts. However, characteristics of soil density can also possibly affect this case since soil layers between the top to 10 cm depth are generally characterized by loose soil. Thus, the diffusion rate of heat would be slow.

Meanwhile, sites 2 and 4 with grass cover show some differences. They need more than two hours to reach the minimum (see Fig. 4b,d). This configuration suggests that the vegetation cover can also be a factor affecting the pattern of temperature oscillations. Sites 1 and 3 are associated with the bare site and are unprotected from direct rays of the sun. Therefore it becomes very warm during the hottest time of the day. In the night, their heat may be rapidly lost to the atmosphere. On the other hand, at sites 2 and 4, the grass cover prevents the soil from becoming warm. The grass can act as a blanket to reduce the rate of heat loss from soil.

As mentioned in the previous description different temperature oscillations would be created due to changes weather on a single day and also due to grass cover. Nevertheless, based on the analytical model as described on Eq. (8), heat reaching the surface will not affect the thermal diffusivity and the average of temperature at a site. This model has been proved experimentally by Jury et al. (1991).

The average ground surface temperatures of the study area indicate that there are no values of significance that were observed during annual observations (see Fig. 5). Nevertheless, the temperature in the dry season is lower than in the rainy season both on the bare site and the grass cover site with the difference being about 1℃. External factors may however, affect this situation. The climate is one of the external factors. The humidity and minimum air temperature are the lowest in July and in August based on the climate data of 2002-2004 (Badan meteorology dan Geofisika/ Institute of Meteorology and Geophysics, Bandung, Indonesia, 2002-2004). With the low humidity, heat flows more quickly from soil layers and is lost to the atmosphere. Furthermore, the low air temperature can

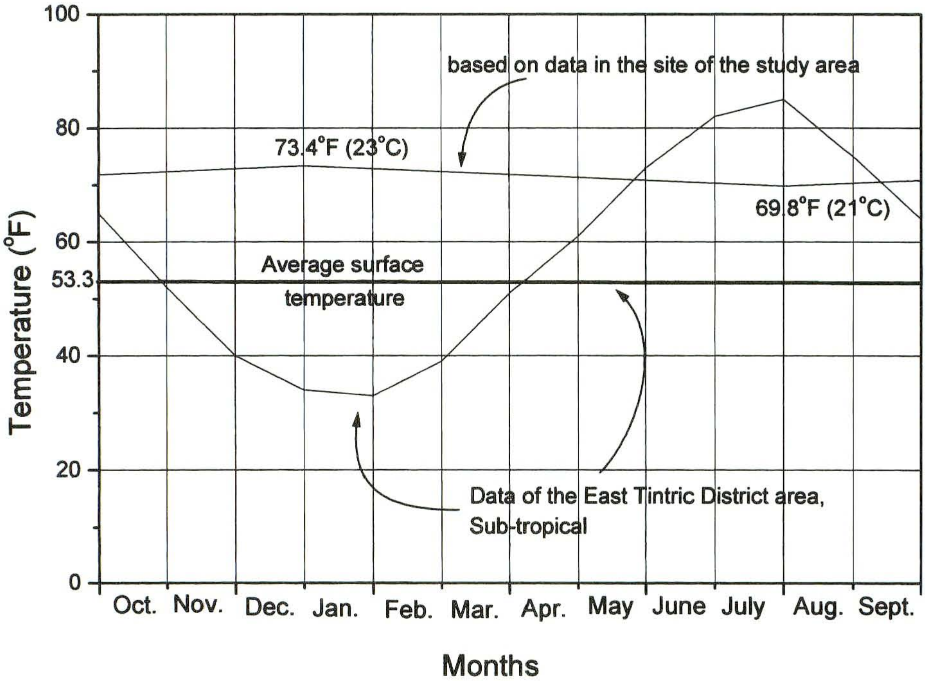


Fig. 8 Comparison the annual daily average surface temperature between the study area and the East Tintic District, Utah in the non-tropical area, (modified after Lovering and Goode, 1963).

enhance the values of the temperature gradient upward during the night. Hence, the average surface temperature would be lower in the dry season. These factors mentioned above in addition to the wind factor could also influence the diffusion rate of heat where soil temperature becomes not so warm due to the high amount of solar radiation.

If the author compares the annual ground surface temperature based on daily data in the study area with those of a non-tropical area, a significant difference of temperature will be seen during the winter and the summer in the non-tropical area (Fig. 8). The annual data may form sinusoidal curves that can be useful for determining accurately diffusivity of soil through Eq. (8). On the other hand, it is not possible to get significant sinusoidal curves from the annual data of the study area because the differences of averages of daily and seasonal temperatures are very small. Therefore, this configuration supports the use of daily data for determining the thermal diffusivity of soils as shown in the present study.

Concerning the increased values of thermal diffusivity in the lower part, some conditions may affect the values, such as composition of soil and density giving a certain heat conductivity and specific heat. Another major factor is the presence of a very shallow watertable at sites 2 and 4 and this can make the soil more moist through capillary processes. Heat conductivity of soil increases with the moisture content where the movement of water affects the transfer of heat.

Although isothermal layers are commonly described at 0.1℃ amplitude, for certain depths amplitude of 0.1℃ or 0.05 % of surface range is not appropriate for showing the stable/constant temperatures. Therefore the present study has taken the values of 0.1% and 0.01% surface range for calculation to ensure a relatively constant temperature, for the results calculated in Table 3.

6. Conclusion

The following conclusions are arrived at from the present study.

1. The data validity at depths below 40 cm in some data sets indicated some inaccuracy due to the limitation of portable tools. Installed probes of tools for every depth interval are required. Therefore, in all efforts in obtaining measurements of the ground surface temperature, no moving probe could avoid or at least reduce any perturbation by air temperature in order to obtain the accurate data.
2. The local variations in weather, soil moisture, soil with grass cover could generate different temperature oscillations. Based on these oscillations, there are no significant differences in average temperatures during the dry and the rainy seasons in the study area. Therefore, the use of daily temperature oscillations for determination of the thermal diffusivity is appropriate.
3. Based on the results during 2004, soil layers with fine-grains indicated thermal diffusivity from 0.0024 to 0.0067 cm^2/seconds. Soil layer with gravel-grains indicated thermal diffusivity from 0.0042 to 0.0073 cm^2/seconds. However, the soil moisture could affect significant values of diffusivity where the increased moisture caused increasing diffusivity, such as at sites 2 and 4.
4. The stable temperatures can be generally reached around less than depth of 1 meter for sites consisting fine grained. While, the stable temperatures on the site with gravel grains are reached at more than 1 m depth, ranging from 113.28 cm to 130.51 cm.

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