Linking Soil properties, Vegetation, and Hydrology at Lincoln University’s Living Laboratory: Variability in Soil Thermal Properties

Willie Thomas, Faculty Advisor: Nsalambi Nkongolo

Abstract

Soil thermal properties are a very important factor in the biological process. Even though these properties are very important to the development of soil, they are still properties not widely used and analyzed as often as they should. This can be for various reasons such as cost, time. A very good case in point is the Lincoln University Living Laboratory. This lab has been in use by the university for over 5 years and the soil thermal properties have not been tested and recorded. In this study, the group will measure the soil thermal properties of the site using very practical instruments and measurements, and then use advancements in Geographic Information Systems to analyze, map, and possibly correlate the data collected through statistical, and visual interpretations.

Introduction

Soil thermal properties are also the most important factors in controlling the intensity of biophysical, biochemical and microbiological processes (Ghidyal and Tripatri; 1987, Brady, 1984). Knowledge of the soil thermal properties is required for accurate prediction of soil temperature and its influence on seed emergence and crop growth, soil water retention and the unsaturated hydraulic conductivity, and soil water vapor flow in coupled water (Hopmans, Bristow, and Simunek, 2002). Even after these properties are found, a problem will still remain in interpreting and analyzing the data. After the data is
collected distributing these amounts across vast soil acreages can be very tedious and error prone. However, the visual aspect of distributing these properties across an area of land can be interpreted and projected using geographic information systems (GIS). Using Lincoln University’s Living Laboratory as a test site, the objective of this project was to successfully integrate soil thermal property, including soil thermal conductivity, soil thermal temperature, soil thermal resistivity, and soil thermal diffusivity, calculations with advanced GIS techniques to display and characterize the properties of the lab.

**Materials and Methods**

**Study Site Description**

Lincoln University’s Living Laboratory was a portion of land that is apart of the Lincoln University campus that once was a rock quarry in the 1950’s. Since that time the quarry has been able to house various vegetations not typically conducive to a rock quarry areas. The site has not had any thermal properties calculated on the site, which make the lab a very good place to take thermal property readings. Integrating the GIS technology with the calculations would be very beneficial as well as practical for Lincoln University researchers.

**Data Collection**

Before the data was collected, the area and the sample points were mapped using Global Positioning Satellite Systems. Fifteen random sampling points were selected within the mapped were selected to collect data from the soil. KD2 thermal properties meter was used. KD2 calculates its values for thermal conductivity, resistivity, and diffusivity by monitoring the dissipation of heat from a line heat source given a known voltage. The equation for radial heat conduction in a homogeneous, isotropic medium is given by
\[ T - T_0 = \left( \frac{q}{4\pi \lambda_0} \right) E_i \left( \frac{-r^2}{4\kappa t} \right) \]

where \( T \) is temperature (°C), \( t \) is time (s), \( k \) is thermal diffusivity (m² s⁻¹), and \( r \) is radial distance (m). When a long, electrically heated probe is introduced into a medium, the rise in temperature from an initial temperature, \( T_0 \), at some distance, \( r \), from the probe is

\[ T - T_0 = \left( \frac{q}{4\pi \lambda_0} \right) E_i \left( \frac{-r^2}{4\kappa t} \right) \]

where \( q \) is the heat produced per unit length per unit time (W m⁻¹) and \( E_i \) is the exponential integral function

\[-E_i(-a) = \int_a^\infty \left( \frac{1}{u} \right) \exp(-u) du = -\gamma - \ln \left( \frac{r^2}{4\kappa t} \right) + \frac{r^2}{4\kappa t} - \left( \frac{r^2}{8\kappa t} \right) + ... \]

with \( a = r^2/4\kappa t \) and \( \gamma \) is Euler's constant (0.5772…). When \( t \) is large, the higher order terms can be ignored, so combining Eqs. (2) and (3) yields

\[-E_i(-a) = \int_a^\infty \left( \frac{1}{u} \right) \exp(-u) du = -\gamma - \ln \left( \frac{r^2}{4\kappa t} \right) + \frac{r^2}{4\kappa t} - \left( \frac{r^2}{8\kappa t} \right) + ... \]

where \( \lambda_0 \) is the thermal conductivity of the medium (W m⁻¹°C⁻¹). It is apparent from the relationship between thermal conductivity and \( DT = T - T_0 \), shown in Eq. (4), that \( DT \) and
\( \ln(t) \) are linearly related with a slope \( m = \frac{q}{4 \pi l h} \). Linearly regressing \( DT \) on \( \ln(t) \) yields a slope that, after rearranging, gives the thermal conductivity as

\[
\lambda_h = \frac{q}{4 \pi m}
\]

where \( q \) is known from the power supplied to the heater. The diffusivity can also be obtained from Eq. (4). The intersection of the regression line with the \( t \) axis (\( DT = 0 \)) gives

\[
\ln(t_0) = \left( \gamma + \ln \left( \frac{r^2}{4 \kappa} \right) \right)
\]

From the calculated \( t_0 \) (from the intercept of \( DT \) vs. \( \ln(t) \)) and finite \( r \), the last equation gives the diffusivity (KD2 Thermal Properties Theory).

**GIS and Statistical Analysis**

The software used to finish the project was ARCGIS 8.3 and Statistix (statistical software). After the calculations were made for the samples and the site was properly mapped, the data from the GPS system was transferred into ARCGIS 8.3 and a polygon image of the field map was created (Fig. 1). The data stored in the GPS system included, the field map (LU Forest), coordinate points for the samples and soil thermal temperature. After the GPS transfer, an excel spreadsheet was created to store thermal temperature and the thermal property calculations. Excel was used because the data would be put into a table format that would be easily imported to ARCGIS and Statistix. Once the spreadsheet was finished the team performed an assessment of the spatial distribution of the soil thermal properties and created simple statistics table with the mean, variance, standard deviation, etc
The spreadsheet was converted into a delimited text format, which was joined to the already created ARCGIS project. Then using the ARCGIS spatial analyst extension, an inverse distance weighting (IDW) interpolated map of each property was created.

![Map of Lincoln University Living Laboratory with sample points and corresponding numbers.](image)

**Fig. 1**

**Results and Discussion**

**Statistical Assessment**

The summary of simple statistics table in for soil temperature, thermal conductivity, resistivity, and diffusivity are shown in Table A. The average temperature was 18.07 °C, which is about five units from both the minimum (12.97 °C and the maximum (23.30 °C). In comparison to other thermal properties, soil temperature showed the less variability show as shown by the coefficient of variation of 12.89 °C.
Table A. Summary of simple statistics for soil thermal properties at Lincoln University Living Laboratory

<table>
<thead>
<tr>
<th></th>
<th>T (°c)</th>
<th>K (wm⁻¹c⁻¹)</th>
<th>D (mm²s⁻¹)</th>
<th>R (m°cw⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>18.07</td>
<td>0.53</td>
<td>0.15</td>
<td>2.63</td>
</tr>
<tr>
<td>SD</td>
<td>2.32</td>
<td>0.25</td>
<td>0.06</td>
<td>2.15</td>
</tr>
<tr>
<td>C.V.</td>
<td>12.89</td>
<td>47.97</td>
<td>39.35</td>
<td>82.10</td>
</tr>
<tr>
<td>Minimum</td>
<td>15.20</td>
<td>0.11</td>
<td>0.10</td>
<td>0.98</td>
</tr>
<tr>
<td>Median</td>
<td>17.50</td>
<td>0.51</td>
<td>0.14</td>
<td>1.94</td>
</tr>
<tr>
<td>Maximum</td>
<td>23.30</td>
<td>1.01</td>
<td>0.30</td>
<td>9.52</td>
</tr>
<tr>
<td>Skew</td>
<td>0.81</td>
<td>0.25</td>
<td>1.18</td>
<td>2.36</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>-0.19</td>
<td>-0.63</td>
<td>0.23</td>
<td>5.10</td>
</tr>
</tbody>
</table>

T = soil temperature, K = soil thermal conductivity, D = soil thermal diffusivity, R = soil thermal resistivity

Spatial Distribution Assessment

The variability of the site was varied throughout the site, and very well distributed maps were made for each property. In the legend there is the class range of 5 created on a graduated color scale. This was done to remove overlapping of distribution due to numbers in only one of the categories and reduce the error. In figure the fairly warm spots that were the spatial distribution of the soil thermal temperature seems to be high in portions of the land that had been heated up on the land. The soil thermal conductivity map in figure 3 also seemed to follow the same pattern as the thermal temperature map.
Conclusion

By using an inverted weighted distance projection, the distributed the levels throughout the map very evenly. Hopefully this technology will become more useful and practical to gather information about soil thermal properties for land sites.
References

