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STATISTICAL ANALYSIS OF DIRECT SUBSOIL TEMPERATURE DATA OBTAINED AT AND AROUND THE LAS PAILAS GEOTHERMAL PROJECT AND IN RINCÓN DE LA VIEJA NATIONAL PARK, GUANACASTE, COSTA RICA

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ABSTRACT

From June 2008 to September 2009, a field investigation for a Master's thesis in Natural Resource Management was carried out to identify the existence of subsoil thermal anomalies that may be correlated with local faults in the Pailas Geothermal Field, located on the Pacific slope of the Quaternary Rincón de la Vieja volcanic complex in northwestern Costa Rica. A total of 240 direct subsoil temperature measurements were made at fifty-seven one-inch diameter access holes equally spaced on a one-kilometer grid and drilled to depths ranging from 47 to 167 cm in iso-hyperthermal entisol to iso-hyperthermal inceptisol type soils. This study covers the area that will be directly impacted by the operation of a 35 MWe geothermal plant at the Pailas Geothermal field, part of the north bordering Rincón de la Vieja National Park and an area extending towards the northwest of the currently developed geothermal field. Soil temperature gradient data obtained in the non-hydrothermally altered areas of the field seems to be congruent with the results of mean monthly soil temperature data in other studies from non-hydrothermally altered soils, elsewhere in Costa Rica. However, throughout the field area there are important differences in soil type, geological formations, elevation, and geothermal activity, all of which may influence the measured subsoil temperatures. This paper presents statistical analyses of these data.

INTRODUCTION

This study was carried out on the Pacific slope of the Rincón de la Vieja volcanic complex at and around the Area of Direct Impact of the Pailas Geothermal Project (Figure 1).

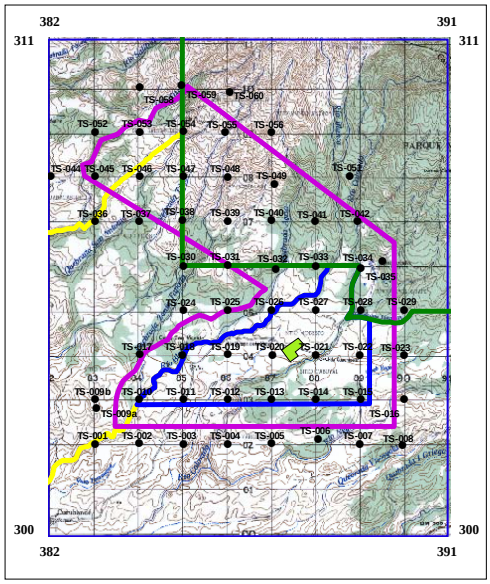

Figure 1: Location map of the study area. The Area of Direct Impact is outlined in blue (Insitituto Costarricense de Electricidad 2005).

Subsoil temperature measurements are used in a variety of applications ranging from agricultural disciplines to geothermal exploration. In general, soil temperatures increase conductively with depth although these temperatures are highly affected by sinusoidal daily and annual temperature waves as well as by elevation and vegetative cover. The daily temperature wave penetrates approximately one meter into the soil while the annual temperature wave penetrates down to up to 20 meters. Second in importance is the elevation of the measurement due to the adiabatic cooling at the surface and in third place is the vegetative cover. The mean annual soil temperature (MAST) has been defined as the temperature taken ad 50 cm depth by the Soil Science

Society. In this field area topographic aspect and slope, underlying geology and type of surficial deposit did not have an important influence on the subsoil temperatures. The effect of soil texture and relative humidity did not have a clear influence on subsoil temperatures either.

FIELD AREA

The field area covers approximately 3400 Ha (34 km^2) around the Area of Direct Impact defined for the Pailas Geothermal Field (Figure 1). Fifty-seven observation points were equally spaced in the field on a one kilometer grid and at each one a 1.5 inch hole was manually augered to an approximate depth of 1-1.6 meters and lined with a 1 inch PVC tube and capped so that water could not drain into the hole and also so that leaves and soil would not fall into the hole. Later, periodic subsoil temperature measurements were taken to observe the annual temperature wave and filter it out in order to amplify subsoil heat anomalies possibly related to a deep geothermal heat source.

METHODOLOGY

A type T thermocouple with a double spade mini male connector was lowered into each hole until the bottom hole temperature stabilized while the other end of the thermocouple wire was plugged into an EasyView 15 digital datalogger. A total of four pseudo-equally time spaced measurements were taken in the field in a 15 month period (3-5 month time span between measurements) and the time series temperature data was plotted out for each observation point during the data collection process.

DATA MANIPULATION

All data was tabulated according to site description, downhole pedalogic description, grain size analysis and time series temperature analysis. The field area was divided into fourteen sectors based on the topographic base map used. Furthermore, in the site description the coordinates, elevation, land use practice, underlying geology and topographic slope and aspect were taken into consideration.

In the downhole pedologic descriptions aspects such as field texture estimation, color, and rockiness were taken into consideration. Soil texture and relative humidity were determined in the laboratory following traditional oven drying, weight/weight percentages and sieving. Temperature data was recorded as time series for each observation point to observe the effect of the annual temperature wave and determine the Mean Annual Soil Temperature (MAST). The MAST is defined as being the subsoil taken at 50 cm depth however in this study a constant value was not observed, rather a time series of oscillating temperatures, however from at depths greater than 50 cm the temperature gradient was very low. Isolated these data did not seem to provide much information, although when ordered from lowest to highest elevation a trend of decreasing temperature could be observed with increasing elevation and approximately following the linear regression $y = 28.53-0.7x$ with an RMS of 2.7-6.1 depending on the season of the year (Figure 2). In general the MAST ranged from 20-26°C depending on elevation.

Table 1. MAST at different elevation belts.

Elevation Belt	N	MAST (°C)
400-500	3	26.06 +/- 1.91
500-600	15	24.61 +/- 1.26
600-700	13	24.01 +/- 0.89
700-800	10	23.21 +/- 1.19
800-900	6	22.50 +/- 1.10
900-1000	4	21.8 +/- 0.85
1000-1100	2	21.2 +/- 0.62
1100-1200	1	20.9
1200-1300	2	20.1 +/- 0.82

Time series data for the entire MAST at each elevation belt show the lowest temperatures in January and February and the highest temperatures in May and June (Table 2).

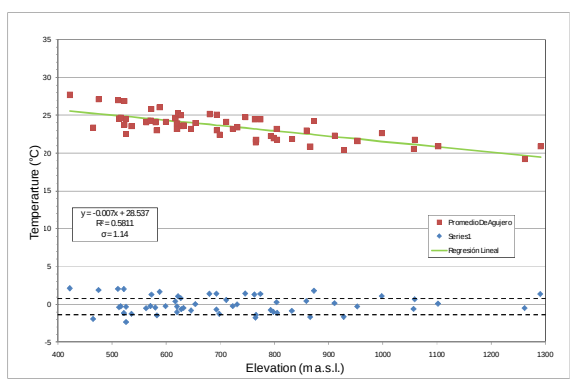

Figure 2: Linear regression of MAST data (orange scatter graph) and MAST data normalized to zero (blue scatter graph).

Table 2. Time series data of the MAST at different elevation belts.

	Elevation Belt (m a.s.l.)								
Month	400-500	500-600	600-700	700-800	800-900	900-1000	1000-1100	1100-1200	1200-1300
Jun		26,5	24,7	23,1					
Jul	25,2	24,3	23,4	23,7					
Aug	27,7	25,6	23,0	23,0	22,2	22,4			21,1
Sep			23,1	24,1	23,5	22,6	21,9	22,1	21,7
Oct		23,9	24,3	23,0	24,1	22,7	21,0		
Nov	25,3	24,1	23,6	23,0					
Dec	17,3	22,0		23,8					
Jan		19,1	19,0	20,3	20,0	17,5	19,1	16,2	13,7
Feb		23,2	24,2		23,3	21,6	21,4		19,3
Mar	29,1	25,9	24,0	23,3					
Apr		25,6	24,1	23,7	22,3	22,7	20,7		21,0
May	27,7	25,0	25,1	24,0	24,6	23,8	22,0	23,8	
Jun	28,2	25,5	25,0	24,0	24,7	23,2			21,3
Jul	24,6	25,2	26,8	23,3	22,5	22,4	21,4		21,1
Aug		25,2	24,4	23,5	23,4	21,1	21,9	21,6	
Sep		25,7	25,0	23,8	24,8	23,3			21,2
Oct		25,9	26,4						

Within each 100 m elevation belt there are differing categories of land use practices, namely: open pasture, forest, tree plantation and high grasslands. Separation of subsoil temperatures in each elevation belt by differing land use practices shows that in general forested areas are 2-3° cooler than open pasture areas. A similar exercise was done regarding underlying geology, topographic slope and aspect as well as surficial deposits however these variables did not seem to have an important impact on the measured subsoil temperatures.

A best fit third degree polynomial of subsoil temperature data plotted out on a temperature-time chart show an annual temperature wave with an approximate amplitude of 2.5°C and a wavelength of 6 months which when compared with the mean annual air temperature (MAAT) indicate an approximate 2 month lag time between MAAT and MAST.

This time series data was also compared with the different seasons common in Costa Rica to try to understand how the MAST fluctuates according to climatic changes. In Costa Rica the rainy season is typically six months long (from May to November) and the other six months cover the dry season.

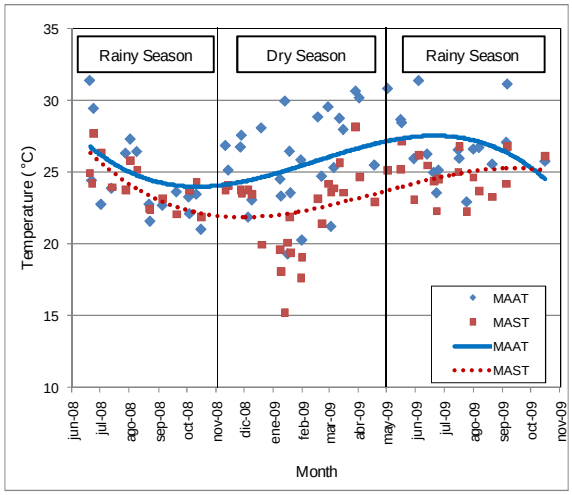

Figure 3: Mean annual soil temperatures (dotted line) and mean annual air temperatures (solid line) in the dry and rainy seasons.

Decomposition of the time series data into different land use practices shows that the annual heat wave has a similar effect on soil temperatures in open pastures and forested areas while it is more pronounced in the open grasslands (restricted to the higher elevations). Additionally, these data were normalized to zero so that the deviation from the mean value could be observed. Some sites had a MAST greater than one standard deviation from the best fit third degree polynomial curve and may be considered as having anomalously high subsoil temperatures.

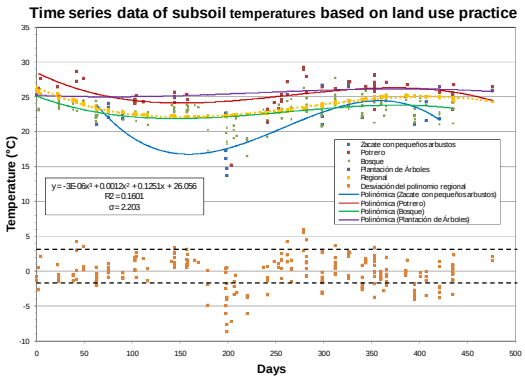

Figure 4: Graphical decomposition of the MAST as per land use practice and normalized to zero.

FINAL COMENTS

In this investigation subsoil temperatures were taken in iso-thermal to iso-hyperthermal entisols and inceptisols with temperatures ranging from 22-26°.

The standard deviation from the best fit third degree polynomial is 2.2.

Soil temperatures decrease with increasing elevation and follow a linear regression of approximately *28.53-0.7x* with an RMS of 2.7-6.1.

The annual temperature wave of the soil fluctuates in accordance with the seasonal changes (dry season to rainy season) with an amplitude of approximately 2.5°C and a six month wavelength, showing a two month lag time with respect to mean annual air temperatures.

The majority of the soil temperatures obtained in this field study are background temperatures.

Some sites in this field area, where a greater than one standard deviation from the best fit polynomial is observed, may have anomalously high subsoil temperatures that suggest a deep heat source and need to be further investigated.

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