Geothermics 66 (2017) 101–109

Contents lists available at ScienceDirect

Geothermics

journal homepage: www.elsevier.com/locate/geothermics

Thermal geological model of the city of Guayaquil, Ecuador

Guillermo Soriano[a,*], Tania Espinoza[a,b], Ruben Villanueva[a,b], Inmaculada Gonzalez[b], Andres Montero[b,e], Mauricio Cornejo[c], Katthy Lopez[d]

[a] Escuela Superior Politécnica del Litoral, ESPOL, Centro de Energias Renovables y Alternativas (CERA), Campus Gustavo Galindo Km 30.5 Vía Perimetral, P.O. Box 09-01-5863, Guayaquil, Ecuador

[b] Instituto Nacional de Eficiencia Energetica y Energias Renovables (INER), Av. 6 de Diciembre N33-32 e Ignacio Bossano, Quito, Ecuador

[c] Escuela Superior Politécnica del Litoral, ESPOL, Centro de Nanotecnologia (CIDNA), Campus Gustavo Galindo Km 30.5 Vía Perimetral, P.O. Box 09-01-5863, Guayaquil, Ecuador

[d] Facultad de Ciencias Naturales, Universidad de Guayaquil, Av. Raúl Gómez Lince s/n y Av. Juan Tanca Marengo, Guayaquil, Ecuador

[e] Universidad Regional Amazónica IKIAM, km 7 vía Muyuna, Tena, Ecuador

ARTICLE INFO

Article history:
Received 7 December 2015
Received in revised form
22 September 2016
Accepted 4 November 2016

Keywords:
Thermal response test
Mineralogical analysis
Ground source heat exchangers
Heat sink

ABSTRACT

A thermal-geological model of the city of Guayaquil, Ecuador is presented, by thorough drill core studies and thermal response tests (TRTs) at ten representative locations. The aim of the project was to complete an analysis of the geological and thermal properties to define their suitability for ground source based heating ventilating and air conditioning (HVAC) systems. The first task consisted of performing mineralogical and geotechnical analysis of the samples using X-ray diffraction, optical microscopy, and grain size analysis tests to identify the litho-stratigraphy of ten points or areas in the city of Guayaquil. Simultaneously, field thermal response tests were completed to collect data on thermal properties of the soil in the ten locations. The geological and thermal response test results were used to develop representations of the city lithography as well as its thermal conductivity, resistivity, and undisturbed ground temperature results. These maps constitute a tool to design geothermal cooling systems and define the suitability of using the soil as a heat sink for cooling systems.

1. Introduction

A current problem for large cities with tropical climates is the large energy demand generated by mechanical cooling systems in buildings (Lu et al., 2013; Aldossary et al., 2014). In Malaysia, for example, building annual energy consumption is approximately 6090 GWh where 57% of which is due to air conditioning systems (Yau and Hasbi, 2013). In 2006, air conditioning and refrigeration accounted for 33% of electricity consumption in Hong Kong (Fong et al., 2010). The Gulf States (Bahrain, southern Iraq, Kuwait, Oman, Qatar, eastern Saudi Arabia and the United Arab Emirates) consume more than 70% of their energy production on air conditioning systems (El-Dessouky et al., 2004). A number of possible approaches to solving this problem have recently been discussed such as solar cooling systems (Anand et al., 2014; Chan et al., 2010), thermal storage materials (Pintaldi et al., 2015), passive solar cooling via evaporative effects (Best and Rivera, 2015; Chan et al., 2010), hybrid solar thermo-mechanical cooling with conventional cooling systems (Zeyghami et al., 2015), and geothermal-based cooling systems (GBCSs) (Florides and Kalogirou, 2007; Tsai et al., 2014; Ruiz-Calvo and Montagud, 2014; Kharseh et al., 2015). In the case of Guayaquil, Ecuador, a city with a tropical wet climate (average annual temperature is around 27 °C and average annual relative humidity is around 77% (INAMHI, 2015) with little variation through the year) and close to one of the largest estuarine systems in Latin America, i.e. the Guayaquil Gulf, the application of geothermal-based cooling systems is promising. The implementation of GBCSs requires knowledge of the thermal properties of the ground obtained by thermal response tests (TRTs) (Banjac et al., 2012; Shim and Park, 2013; Boukili Hacene et al., 2012; Esen and Inalli, 2009; Sharqawy et al., 2009; Sanner et al., 2003).

As GBCSs are used to exchange heat with the soil, its technical characteristics such as mineral composition, moisture content, particle size analysis, bulk density, and Atterberg limits can be related to its thermal performance. Previous studies had proposed thermal conductivity predictive models based on mineral composition, bulk density and water content (De Vries, 1963; Johansen, 1977; Kasubuchi, 1984). However, few studies reported the relationship between soil characteristics and its thermal properties. In this sense, Abu-Hamdeh et al. (2001) performed a comparison of two methods in order to evaluate thermal conductivity for four types of soils (sand, sandy loam, loam and clay loam). The authors

* Corresponding author.
E-mail address: gsorian@espol.edu.ec (G. Soriano).

http://dx.doi.org/10.1016/j.geothermics.2016.11.003
0375-6505/

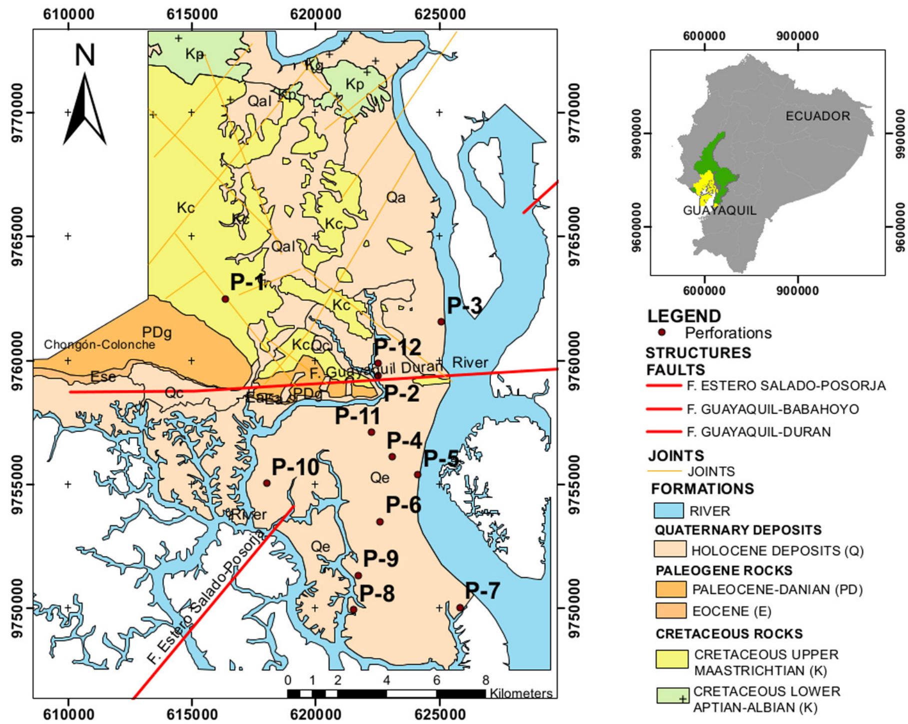

Fig. 1. Geologic map of Guayaquil, Ecuador.

varied the percentage of material, bulk density and moisture content of each type of soil and reported that clay loam soils had lower thermal conductivity than sandy soils. Barry-Macaulay et al. (2013) reported that the thermal conductivity of soil, tested in the laboratory, was influenced by the variation in moisture content, bulk densities, and particle size. This study also highlighted that thermal conductivity of the soil increased with particle size, bulk density, and moisture content. On the other hand, Bovesecchi and Coppa (2013) stated that the degree of consolidation also altered the thermal conductivity of the soil. They reported that consolidated soil showed higher thermal conductivity than their unconsolidated counterpart. Stylianou et al. (2016) analyzed 135 collected samples from 20 geological formations in Cyprus, determining that thermal properties change according to material composition and moisture content. Geological formations containing gypsum presented better thermal properties under dry conditions.

This study is an attempt to propose a geothermic model for the city of Guayaquil and to present suitable sites for efficient geothermal based cooling systems. The model relies on geologic and lithological characterization as well as thermal properties of soil at ten selected sites. There are a few studies in Latin America (Soriano et al., 2015), and this is the first survey of thermal properties of soil carried out in Guayaquil, Ecuador.

2. Methodology

2.1. Geological description of the site

The study area is the center-south of the city of Guayaquil, a part of the Guayas province, as observed in Fig. 1. The geology of this area is related to its geomorphology which consists of three macro-domains, namely: the alluvial plains of Daule and Babahoyo rivers, the deltaic-estuarine soils from the Guayas River and the Chongon-Colonche range.

In chronological order the study areas comprise Holocene deposits of Quaternary (Q), and the sedimentary rocks are from Eocene (E). The alluvial plains (Qa) from the Guayas river are located in the northeastern part of the city and is associated directly with the flooding plains from the Daule and Babahoyo rivers which form the Guayas River. The deltaic-estuarine complex (Qe) is located in the south-center area of the city composed by the Guayas river and Salado estuary flowing into the sea. The Chongon-Colonche range which belongs to the Cayo formation (P,K), is in the northwestern part of the city and shows a homoclinal structure of average direction N110° constituted by sedimentary rocks from the Cretaceous era.

2.2. Core drilling method and borehole heat exchanger installation

This study is an attempt to map the thermal properties of the soil at ten selected locations to propose a geological-thermal model for city of Guayaquil. Nine drilling sites were located on deltaic-estuary soils and one on rocks of the geological Cayo formation (Ordonez et al., 2006; Benitez et al., 2005). Specifically Table 1 provides the coordinates for each borehole in system UTM-WGS84 with the name of the location and depth of the drilling.

The drilling method was rotopercussion, with recovery of core samples. The drilling equipment was a TP50 core driller mounted on a truck and an ACKER TP-30 on wheels as seen in Fig. 2.

Table 1
Site coordinates (UTM-WGS84) and depth of the ten boreholes.

No.	Location	Depth (m)	Coordinate *X*	Coordinate *Y*
P-1	ESPOL	60.00	616350.25	9762495.55
P-2	Univ Guayaquil	60.00	622554.09	9759392.59
P-3	Base Naval Norte	60.00	625099.87	9761545.73
P-4	Centro Civico	50.00	623103.20	9756112.67
P-5	Astinave	50.00	624152.13	9755373.32
P-6	Hospital	60.00	622635.45	9753496.58
P-7	Esclusa	60.00	625843.68	9750023.04
P-8	Base Naval Sur	60.00	621556.55	9749922.25
P-9	Trinitaria	50.00	621732.95	9751321.83
P-10	Suburbio Militar	60.00	618037.44	9755050.60