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Assessment of Geothermal Gradient in Bogala Area, Sri Lanka

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Abstract: ***Geothermal gradient gives important assessment to geothermal potential in an area. This study aimed to study geothermal potential in Sri Lankan crust using measurement from available deep mines. Bogala Graphite mines is one of accessible deep mine available and located 124 km away from the well demarcated tectonic boundary in Sri Lanka. In this research, 476 m deep Bogala Graphite mines was selected to study the geothermal gradient in Sri Lankan crust. Drill holes made in the bed rock horizontally, temperature sensors placed approximately in the same direction and kept continuously around 72 hours period. All the places selected to install sensors were far ends of long run abandoned tunnels/ adits in the mine. The average values of temperatures in those levels were computed, and then geothermal gradient was calculated as 28.046 ^{0}C/km. This method gave some reliable information about, how temperature gradient varies at different levels of Sri Lankan crust.***

Keywords: Sri Lanka, Geothermal potential, earth crust , abandoned mines.

1. Introduction

Use of green energy sources for power generation is increasing rapidly. Significant research in many countries are carried out on geothermal resources. Their main aim is to find out rich geothermal resources in their countries. Most of the methodologies used to find out geothermal potential at present are very expensive. Due to high initial and running cost third world and developing countries are not in a position to do such investigations without assistance of developed countries and international organizations. The world geothermal potential for electricity generation is about 22,400 TWh / year (224 x 10^{11} KWh / year) and for other uses is 392,000 TWh / year (ie. 392 x 10^{12} KWh / year) [1].

Most of the countries in the world including Sri Lanka face energy crisis at present. The energy demand increases 10 % annually. Ceylon Electricity Board (CEO) is the government owned supply authority in Sri Lanka , which generate, transmit and distribute electricity to the consumers. According to CEO the present power generation in Sri Lanka account for approximately 38% hydro power, 56% thermal power and the balance 6% is generated by wind mills. Furthermore, there are several off grid solar power plants and private mini hydro plants, which feed to houses and tea factories, respectively.

Power capacities of those power plants depend upon external factors, like rain fall, wind speed, sun shine and fuel supply. According to Ministry of Petroleum Industries, country spent large amount of foreign exchange to import fossil fuel and coal to generate power.

According to reports, Sri Lanka imports 100% crude oil requirements and imports 50% of petroleum products requirements at present. Over the last 15 years or so, the demand for petroleum products has risen at an annual average rate of about 5%. The current annul requirement of crude oil in the country stands at around 2 Million Mega Tons. A large amount of foreign exchange is required for crude oil and petroleum products imports.

The thermal power plants pollute the environment creating many adverse effects due to emission of an asphyxiate gas like Carbon dioxide (CO_2, an asphyxiate gas is non toxic or minimally toxic gas, which reduces or displaces the normal oxygen concentration in breathing air. Breathing of oxygen depleted air can lead to death by suffocation), and Carbon monoxide (CO) this is odorless, colorless gas that can cause sudden illness and death. Coal power gas plants emit gases, such as carbon dioxide, nitrogen dioxide and sulfur dioxide in to the environment. Acid rain is caused by the emission of nitrogen dioxide and sulfur dioxide. They react with atmosphere and form sulfurous, nitric and sulfuric acids and they fall as rains.

2. Research Background

For the development of any country, they should have suitable energy development and management plan. This is a big challenge for developing countries like Sri Lanka. Importing fuel and coal and burn them to generate electricity are not a viable solution most of the times. Then the deciding factor for unit cost of energy will be again cost of fuel and coal. To minimize usage of fossil fuels, another natural power resource should be needed. However, this natural source should be able to supply power continuously without interruption. Geothermal energy is one of the most reliable power sources in this regard. This can supply heat to the system without break and round the clock continuously.

The underground temperature gradient of a country is the main deciding factor of geothermal energy potential. This is very high in volcanic areas and less for inactive areas. Though Sri Lanka, has no single volcano or not placed in an active tectonic zone, there are several hot water springs and

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located along a major litho tectonic boundary of Highland Complex and Vijayan Complex which well-defined minor tectonic boundary in the metamorphic terrain of Sri Lanka (Figure 1). Presence of several thermal spring places near this boundary implies some heat sources are available under this zone.

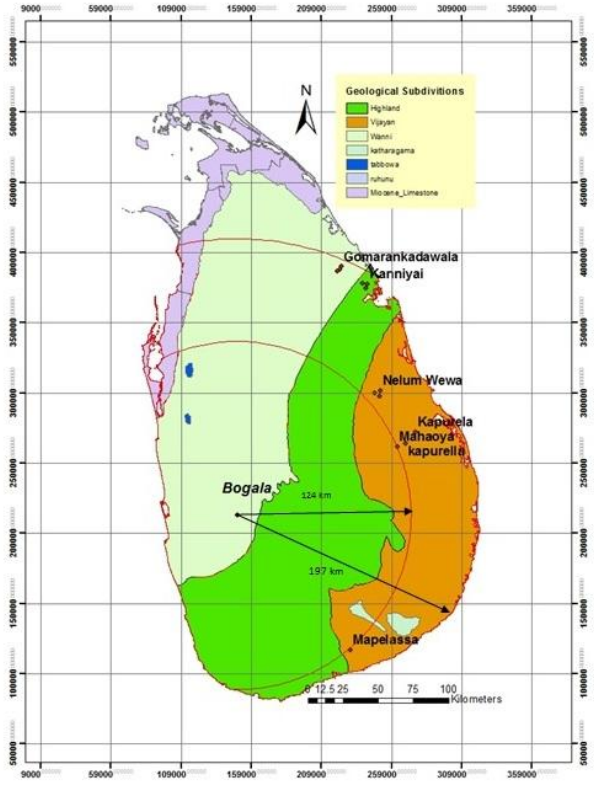


Figure 1: Boundary between lithotectonic complexes in Sri Lanka, and locations of some hot springs

Two hypotheses have been proposed to explain the existence of thermal springs in Sri Lanka. Above normal geothermal gradient is proposed by [2] while some researchers proposed a deep penetrating fracture system [3]. Seven geothermal springs from the Precambrian high-grade metamorphic terrain of Sri Lanka were investigated to assess their formation processes and to determine reservoir temperatures based on their chemical compositions. Silica-based geothermometric calculations for the Marangala and Nelumwewa springs showed the highest average reservoir temperatures of 122^0 C and 121^0 C, respectively. The temperature of the spring waters varies from place to place (Table 1). Some Sri Lankan researchers conducted studies about their behavior, physical and chemical properties etc[25].

Table 1: The water temperatures of some hot springs in Sri Lanka

No.	Location	Temperature ^{0}C
01	Kapurella (Ampara)	55
02	Maha Oya	56
03	Marangala (Padiyathalawa)	44
04	Mahapelessa (Soorirya Wewa)	46
05	Meda Wewa	45
06	Nelum Wewa (Polonnaruwa)	62
07	Kanniya (Trincomalee)	42
08	Kiwulegama (Jayanthiwewa}	34
09	Rankihiriya (Gomarankadawala)	42

The temperature of water is higher in those hot springs, which indicates high temperature inside the earth. To find out the energy potential, one of the well known methods used by various countries which use geothermal resources is to measure temperature gradient by drilling a bore hole and measuring the temperature at different depths of earth for long periods. This can be done by using thermal sensors and temperature loggers. However, drilling deep vertical bore holes on the earth is a difficult task and very expensive. Many researchers [4][5][6] have used abandoned mines to collect temperature data. These researchers argue that those abandoned mines could be used for energy generation [7].

There are two graphite mines in Sri Lanka and namely Bogala and Kahatagaha mines. Although, these mines are still in operation, there are number of abandoned tunnels /adits as associated with mines. In this research, initial investigations were carried out in few of those abandoned tunnels /adits at Bogala Graphite mines. Since these tunnels were not operated for a long period, the inside temperatures were higher than those in operation.

3. Geothermal Temperature Gradient Measurements

In the Earth, temperature generally increases downwards as depth increases. The geothermal gradient is therefore taken as difference in temperature with depth in the Earth. Different countries in the world use various methods to assess geothermal potential in their territories. Some commonly used methods at present are;

Magnetotelluric (MT) method which is an electromagnetic geophysical method of imaging the earth's interior by measuring natural variations of electrical and magnetic fields at the Earth's surface. This can be used to investigate depth ranges from 300 m below ground by recording higher frequencies down to 10,000 m or deeper with long-period soundings. This was developed in Russia and France during the 1950s, MT is now an internationally recognized for academic discipline and is used in exploration surveys around the world [8] 9] [10]. Commercial uses include hydrocarbon (oil and gas) exploration, geothermal exploration, mining exploration, as well as hydrocarbon and groundwater monitoring. MT geothermal exploration measurements used to detect resistivity variations associated with productive geothermal structures, including fractures and the presence of a cap rock, and allow for estimation of geothermal reservoir temperatures at various depths.

Electrical Resistivity method is measuring electrical resistivity "ρ" of the subsurface is one of the most powerful geophysical method in geothermal exploration. The electrical resistivity of rocks is controlled by important geothermal parameters such as temperature, fluid type and salinity, porosity, the composition of the rocks, and the presence of alteration minerals. The reciprocal of resistivity is conductivity, σ (Sm^{-1}). However, in geothermal research, the tradition is to refer to electrical or resistivity measurements [11][12][13].

Seismic survey is one of geophysical survey that use to measure the earth's properties by means of principles of

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elastic properties. It is based on the theory of elasticity and therefore tries to deduce elastic properties of materials by measuring their response to elastic disturbances called seismic (or elastic) waves [14][15][16]. This method broadly used in various countries over the world for geothermal investigations.

Underground temperature gradient measurement is a popular method used to find geothermal gradient in an area. Initially drill boreholes vertically to the ground and placed several thermal sensors to at different heights of the boreholes. Then all sensors were connected to the temperature loggers to record real time temperature data. Those data were used to calculate the temperature gradient of the researched area. Many geoscientists were used this method to find out geothermal gradient, but this is expensive and difficult to make several hundreds of meters boreholes vertically on the earth. Some occasions several numbers of bore holes need to maintain the accuracy [17][18][19].

Other method is use of abandoned mines and petroleum wells [20][21] [22][23][24] to measure temperatures at different depths and calculate geothermal gradient and assess geothermal potential. Specially in Canada and Europe already use geothermal energy from abandoned mines[25],[26].Tunnels in mines filled with heat radiated from surrounding rock, hence temperature inside those tunnels are high.

The main objectives of this research is to determine geothermal gradient of the Sri Lankan crust using simple and feasible techniques. The secondary objective is to explore possibilities for use of geothermal energy for power generation as one of the alternatives solution for energy crisis in Sri Lanka.

4. Research Methodology

Location of the study

The Bogala situated in Aruggammana village, Kotiyakumbura area of Galigamuwa Division. Which is the one of the Divisional Secretary's areas of Kegalle District, Sabaragamuwa Province of Sri Lanka. This village is located 5 km away from Avissawella – Kegalle road. The famous Bogala graphite mines are in Aruggammana village (Figure 2).

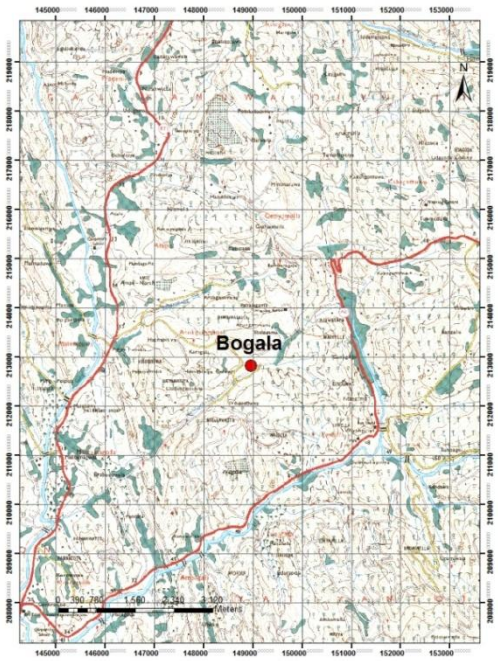


Figure 2. Map of Bogala area

Due to very high cost in drilling deep bore holes to measure temperatures inside the earth an alternative low cost method was selected. In this study, initially one deep graphite mine (Bogola mine having 476 m depth was selected to find out internal temperature gradient and internal temperatures at different depths were recorded for several days

The mines were discovered during the reign of the Dutch and later developed by the British in 1920.Complete depth of this mines is 476 meters from the ground level. GPS positions of Bogala Mines entrance is, 07.06'.86" N, 80.18'.60" E, Altitude of the mines entrance is 198 m above sea level. Bogala mine consists of network of adits, shaft and few tunnels.

In the mine entrance there are two shafts running to the earth. One tunnel runs vertically to 72 Fathoms (FM) or 124 meters (m) from the ground level. From that level, a second shaft runs vertically to 275 Fathoms or 476 meters depth. Cross sectional diagram is given in Figure 3.

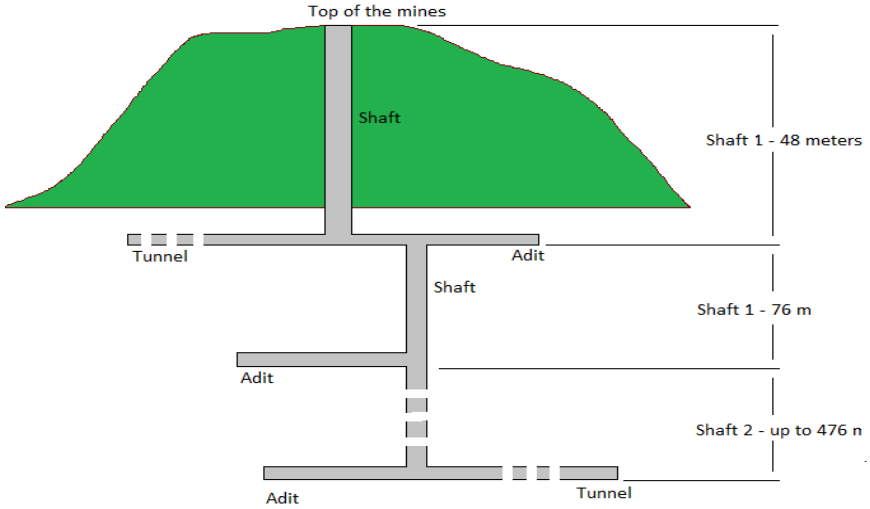


Figure 3: Cross section of Bogala mines

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There are some abandoned tunnels /adits in different depths. These tunnels do not have ventilation mechanism for many years. Therefore inside temperatures of these tunnels are higher than places close to shaft. Areas near shaft properly ventilated to provide fresh air for mines workers.

several abandoned tunnels which were not ventilate many years were selected for the study. The temperature inside far end of such places were higher than normally ventilated tunnels.

Horizontally driven bore holes were drilled on the walls of selected abandoned tunnels to place temperature probes. The dimensions of them were 32 mm diameter and 180 mm in depth. All drill holes make far ends of the abandoned tunnels. These holes used to measure inside temperature of bed rock. Opening of all drill holes were properly closed by cork plugs, and thermocouples inserted through center of cork plug to the center line of the drill holes.

Five numbers of temperature loggers are installed inside the mines at the different depths. All bore holes made at the depth of 72 FM or 124 m, 109 FM or 191 m,170 FM or 302 m, 205 FM or 361 m, 275 FM or 476 m.

All thermocouples connected to the temperature loggers and activated them to record temperature data. The arrangement given in Figure 4 was kept continuously 72 hours period to record data from 25th February 2011 to 28th February 2011.

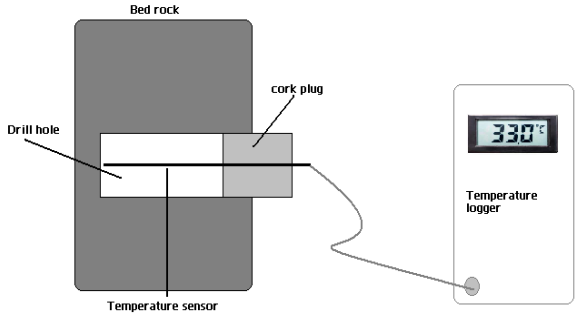


Figure 4: Arrangement used to measure bed rock temperature

Before installing the temperature loggers, temperatures at starting point of the tunnel and end point of the tunnel were measured. That shows the temperatures close to shaft is less than tunnel end. This happens due to lack of ventilation. Temperatures near shaft and far end of the tunnel were measured by using digital thermometer to confirm the difference as showing in Figure 5.



Figure 5: Direct reading of temperatures

Temperature data were recorded at one hour interval and the average temperature at each point is given in table 6. Different columns show the recorded temperature data for the selected depths, approximately, 124 m, 190 m, 300 m, 360 m and 470 m.

Ground temperature variation

Variation of ground temperature with time is a natural phenomenon. When the sun rises ground temperature increases and it reaches to maximum value at 12 o'clock. Again reduces when the sun sets. The outside temperature depends upon rainfall pattern and behavior of wind.

From 25th February.2011 to 28th February 2011 temperature variation of ground surface near shaft mouth was also measured and average value of the same was 25.12 ^{0}C (Table 6).

Table 6: Averaged Temperature at ground level.

Bogala Temperature - 25.02.2011 to 28.02.2011		
Date	Time	Temperature °C
2/25/2011	12:00:00 noon	27.68
2/25/2011	18:00:00	26.06
2/26/2011	12:00:00 night	24.03
2/26/2011	6:00:00 AM	24.12
2/26/2011	12:00:00 noon	27.02
2/26/2011	18:00:00	25.76
2/27/2011	12:00:00 night	23.61
2/27/2011	6:00:00 AM	24.06
2/27/2011	12:00:00 noon	27.11
2/27/2011	18:00:00	25.68
2/28/2011	12:00:00 night	23.03
2/28/2011	6:00:00 AM	23.39
2/28/2011	12:00:00 noon	26.87
	Total	328.42
	Average	25.26

The underground temperature of the bedrock of the mine varies with depth from the ground level. This is a natural process due to very high internal temperature level of the earth core. The collected temperature data averaged and calculated the daily average for different depths. And also temperature gradients for different levels of mines were calculated (Table 7).

Table 7: Averaged Underground temperature variation with depth at Bogala mines area.

No	Depth Z meters from mines entrance	Average Temperature t ^{0}C	Temperature Gradient G_t ($\Delta T/\Delta Z$) between two levels, ^{0}C / 100 m
1	124 (Z_1)	25.76 (T_1)	
2	190 (Z_2)	28.31 (T_2)	3.8 = (36 / Km)
3	300 (Z_3)	32.46 (T_3)	3.7 = (37 / Km)
4	360 (Z_4)	34.53 (T_4)	3.4 = (34 / Km)
5	476 (Z_5)	38.61 (T_5)	3.5 = (35 / Km)

The geothermal gradient is the difference in temperature with depth in the Earth. In the Earth, temperature gradually increases downwards with the increased depth.

The way to calculate a temperature gradient is to take the difference of the temperature and divide it by the difference of the depth. The general equation to show the temperature

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gradient of a system can be written as follows. Here T is temperature in degrees centigrade and Z is depth in meters.

The temperature gradient G_t, is ^{0}C / m is given by,

$$G_t = \frac{T_5 - T_0}{Z_5 - Z_0} \quad G_t = \frac{38.61 - 25.26}{476 - 0} = 0.028046\ ^0\text{C/m}$$

Here Z_5 = 476 m, Z_0 = 0 m, T_5 = temperature at 476 m and T_0 = temperature at ground level. From this research temperature gradient calculated as 28.046 ^{0}C /Km.

Underground temperature variations

Meantime it is observed that the underground temperatures of the different depths varied for few decimal points. Temperature variation in the inside the bed rocks for different depths were calculated (Table 8).

Table 8: Temperature variation inside the bed rock

No.	Depth m	Maximum Temperature ^{0}C	Minimum Temperature ^{0}C	Difference ^{0}C
1	124	25.8	25.1	0.7
2	190	28.1	28.6	0.5
3	300	32.8	32.1	0.7
4	360	34.8	34.2	0.6
5	476	38.9	38.4	0.5

5. Discussion and Analysis

Geothermal gradient measurement is one of the most essential tasks to assess the geothermal potential in a preferred area. One of the most reliable methods used for this is to continuous temperature logging in a deep borehole for a considerable time period. However, some researches use simple temperature logging in abandoned coal mines and oil wells for understanding the geothermal gradient. In this study, Bogala Graphite mines selected to study the geothermal gradient in Sri Lanka, it is approximately, excavated to depth of 476 m.

Several numbers of temperature sensors have been placed, at different depths towards the same direction after making horizontal drill holes in the bed rock at available depths. All sensors were placed in contact with the bedrock, *ie* bottom of the drilled hole and fully insulated using cork plugs and silicon to prevent contacting air in the surrounding area. They were far ends of long run abandoned tunnels in the mines that were not ventilated for several years resulting very high temperatures compared to the working area. These setups were kept continuously for 72 hours period and the time series temperature data were collected. Using the average temperature values of different levels, geothermal gradient were calculated. The calculated geothermal gradient is 28.046 ^{0}C/ km. Most of the places in the world shows geothermal gradient as 25 – 30 ^{0}C (77 – 86 ^{0}F) per kilo meter. Thus, this location is124 km away from the well marked tectonic boundary of Sri Lanka which comprising number hot water springs, the temperature gradient measured gives some guide lines to interpret geothermal gradient along that boundary. Researchers have observed that high gradients (up to 200°C/km) are along the oceanic spreading centers and along island arcs. Those places molten volcanic rock (magma) are available, therefore, more heat rising to the surface. Low gradients are observed in tectonic subduction zones because of thrusting of cold, water-filled sediments beneath an existing crust. The tectonically stable shield areas and sedimentary basins have average gradients that typically vary from 15–30°C/km.

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