Geothermal Energy - Potential Applications in Sri Lanka

Bandara, H.M.D.A.H. [1,2] Sooriyarachchi, N.B. [1], Dissanayake, C.B. [1], Subasinghe, N.D. *[1]

[1]*National Institute of Fundamental Studies, Hanthana Road, Kandy, Sri Lanka*
[2]*Postgraduate Institute of Science, University of Peradeniya, Peradeniya 20400, Sri Lanka*
*Deepal.su@nifs.ac.lk

Abstract

Sri Lanka has seven major hot springs with outflow temperatures ranging between 35- 72 °C and possible reservoir temperatures ranging between 140 - 150 °C. Hence, they are categorized as low enthalpy geothermal systems. In the past research work, little attention was given to the geothermal energy potential, whereas priority has been given to study the origin of the geothermal systems. Hence this work focuses on understanding the potential of using geothermal energy in Sri Lanka. For geothermal energy exploitation, heat source and reservoir are vital to be located in depth, which is reachable economically. Recent studies carried out by our team using modern geophysical and geochemical techniques revealed that the heat sources of Nelumwewa, Mahapelessa, Kanniya and Kapurella hot springs are situated at depths which can be considered as suitable for economical drilling. Therefore, these sites can be earmarked as suitable locations for geothermal power plants supplying electricity. The other hot springs, which may not be suitable for electricity generation due to the high cost of drilling, can be used for direct heat utilization such as, drying of agricultural products (fish, rice, etc), steaming in sugar production from canes, direct use of heated water as recreation and medicinal applications.

Keywords: Geothermal Energy, Hot Springs, Low enthalpy, Sri Lanka, Geophysical

Introduction

The energy demand of the world is increasing day by day due to the growth of industrial and household requirements of energy. This is a common situation in Sri Lanka as well. According to statistics of Sustainable Energy Authority, Sri Lanka's total energy demand in 2012 was 38.3 PJ. A large amount of fossil fuel, biomass and hydropower had been used. The involvement of these energy sources has also made a considerable contribution to environmental pollution in Sri Lanka. Hence, the need for environmental-friendly, pollution-free, renewable energy is very important.

Geothermal resource is a reservoir inside the earth from which heat can be extracted and utilized for generating electric power. This contains heat both in solid rock and fluids that fill the fractures/ pore spaces within the rock.

Geothermal resources can be estimated based on geological and geophysical data such as: (1). Depth, thickness, and extent of geothermal aquifers. (2). Properties of rock formations (3). Salinity and geochemical fluids likely present in the aquifers. (4). Temperature, porosity, and permeability of rock formations.

In the earth the natural geothermal gradient is 20-60 °C/km. However, with the occurrence of geological boundaries and hotspots, heat locally transferred within a few kilometers from the earth's interior through the process of convection by magma or molten rocks. These hot magmas or molten rocks interact with near-surface rocks giving rise to geothermal activities such as; hot springs, geysers or fumaroles. Essential requirements for geothermal system exist are; (1). A large source of heat. (2). A reservoir to accumulate heat. (3). A barrier to hold the accumulated heat.

The main types of geothermal systems include vapor dominated, hot water, geopressed hot dry rock (HDR) and magma systems.

Though there are several types of geothermal resources, the ideal conventional geothermal system requires heat, permeability, and water. The heat from the earth's core continuously flow outward, sometimes as magma, coming out of the surface as lava or it remains below the earth's crust, heating nearby rocks and water. This hot water or steam can be trapped in permeable and porous rocks under impermeable rock and confined to form a geothermal reservoir. The important physical parameters in a geothermal system are; temperature, porosity, permeability, chemical content of the fluid and pressure [1].

Sri Lanka has seven major known hot springs with surface outflow temperatures varying from 35- 74 ^{0}C. Their source temperatures have been calculated and range from 140 – 170 ^{0}C [2],[3]. Hence those are categorized as low enthalpy geothermal systems. Even though most Sri Lankan hot springs have lower temperatures, some of the hot springs like Nelumwewa and Kapurella have much higher temperatures. Hence, they can be utilized to generate electricity. Even though other hot springs have lower temperatures they can be utilized as direct geothermal energy sources, like hot water for agriculture, food drying, recreational medicinal applications etc. Therefore with proper studies and infrastructure developments hot springs in Sri Lanka can be utilized as geothermal energy sources.

General Applications of Geothermal Energy

Geothermal energy is used in three main methods, (1). Direct use and district heating systems (2). Electricity generation power plants (3). Geothermal heat pumps. In Direct use and district heating systems. Hot water is used from geothermal springs or reservoirs located near the surface for bathing, and many people believe the hot, mineral-rich waters have natural healing powers. Ancient Roman, Chinese and Native American cultures used hot mineral springs for bathing, cooking and heating. Industrial applications of geothermal energy include food dehydration, gold mining, and milk pasteurizing. Dehydration, or the drying of vegetable and fruit products, is the most common industrial use of geothermal energy. To heat buildings through district heating systems, hot water near the earth's surface is piped directly into buildings for heating. The district heating system provides heat for most of the buildings in Iceland, Italy, and Greece.

Geothermal electricity generation requires water or steam at high temperatures (150 °C to 350 °C). Geothermal power plants are generally built where geothermal reservoirs are located, within a kilometer or two of the earth's surface. Geothermal power plants contribute a significant amount to the electricity demand in countries like Iceland, El Salvador, New Zealand, Kenya and the Philippines and more than 90% of heating demand in Iceland.

The main advantages are that it does not depend on weather conditions and has very high capacity factors; for these reasons, geothermal power plants are capable of supplying baseload electricity, as well as providing ancillary services for short and long-term flexibility in some cases.

In geothermal heat pumps, constant temperatures near the surface of the earth is used to heat and cool buildings. Geothermal heat pumps transfer heat from the ground (or water) into buildings during the winter and reverse the process in the summer.

Geothermal Springs in Sri Lanka

Hot water springs in Sri Lanka do not have any relationship with volcanic activities, in view of the fact that Sri Lanka is not situated in an active volcanic region or at an active plate boundary. Recent volcanism is not likely the heat source for the thermal springs [2] because the youngest igneous activity in Sri Lanka had occurred in Jurrasic or late Cretaceous time [4, 5]. Geothermal springs in Sri Lanka occur in Eastern part of the country along Highland Complex (HC) and Vijayan Complex (VC) boundary extending northward as ~350 km thermal spring line [8]. All geothermal water springs have variable flow rates and discharge temperatures, and springs are located in the lower altitude regions (<100m) of the island except the spring at Wahawa, Padiyathalawa which is located around 100 m altitude.

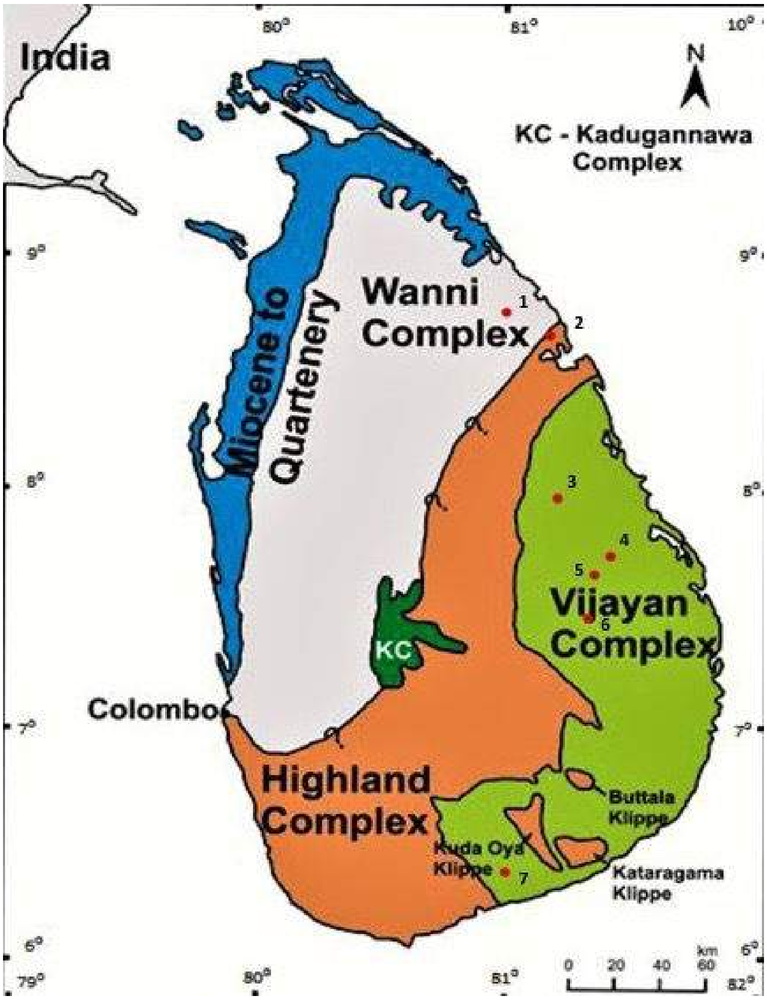


Figure 1: Geothermal hot springs in a generalized geological and tectonic map of Sri Lanka. The locations of hot springs are marked in red (Modified after [4]. The springs: 1-Rankiriulpotha; 2-Kanniya; 3-Nelumwewa; 4-Kapurella; 5-Mahaoya; 6-W W

The discharge temperatures of springs varied from 39.1 ^{0}C (Rankihiriya) to 74 ^{0}C (Kapurella). And pH vary from 5.7 (Kanniya) to 8.0 (Kapurella) [2],[7]. On account of the presence of a line of serpentine bodies, granites and anomalous uranium bearing regions, some considered them to be the source of heat for the hot springs. Chemical geothermometers reveal the temperatures of the heat sources of some hot springs near to 150 ^{0}C [8] From the chemical geothermometers of the Na- K-Ca and silica subsurface temperatures reported for the hot springs are, Kapurella, Mahaoya, Wahawa, Padiyathalwa ,143 ^{0}C and for others 102-131 ^{0}C [9], [10].

Table 1: Thermal springs identified in Sri Lanka, temperatures and lithological unit (After [6, 2, 7])

No	Hot spring	Temperature ^0C	Lithological Complex
1	Rankihiriya	39	Highland Complex
2	Kanniya	41	Highland Complex
3	Nelumwewa	62	Vijayan Complex
4	Kapurella	70	Vijayan Complex
5	Mahaoya	55	Vijayan Complex
6	Wahawa, Padiyathalawa	50 – 60	Vijayan Complex
7	Mahapelessa	45	Vijayan Complex

Most geothermal springs are closely associated with the Highland and Vijayan Complex boundary, which is a thrust zone based on the presence of shear zones, wrench faults and mylonites. The thrusting produces the heat in the nature of a deep mantle plume consisting crustal uplift and releasing a thermal flux, producing a high heat zone along the HC-VC boundary act as the source for the thermal spring line which appeared to align with the boundary line orientation [8] Multiple thrust zones and tectonically active zones which are connected with deep-seated mega lineament present in the area generate heat to increase the geothermal gradient [11]. Neo- tectonic activities along the HC – VC boundary, which is also evident by microseismicity observed in the Highlands and Sri Lanka due to the slow vertical movement in the Highlands [11] cause a thermal anomaly by increasing the geothermal gradient [12].

The Vijayan Complex is considered as a priority region as it consists of the youngest intrusions of dolerite dikes of K-Ar age of 150 Ma. The presence of thermal springs in association with dyke swarms indicate thermal components that have been added from relatively young intrusions. In the Wahawa and Padiyathalawa area, dolerite dykes having the K- Ar ages of 152± 7.6 Ma [13] are observed near westward of the thermal spring (Senaratne and Chandima, 2011). For the Wahawa and Padiyathalawa thermal springs, [14] were of the view that the meteoric water percolated from the Mahaoya River through the upper fractures of the shear zone to deep-seated fracture zones. This provides a continuous flow of water and the less fractured impermeable cap rock which over lies the reservoir, prevents the escape of hot reservoir fluids and acts as a barrier.

There is close proximity between HC- VC boundary and the Uranium anomalous regions reported in Sri Lanka and the Serpentinite occurrences. [8], suggested that the decay of uranium and highly exothermic reaction of serpentinization of ultramafic rocks may also act as the heat source for some of the hot springs in Sri Lanka.

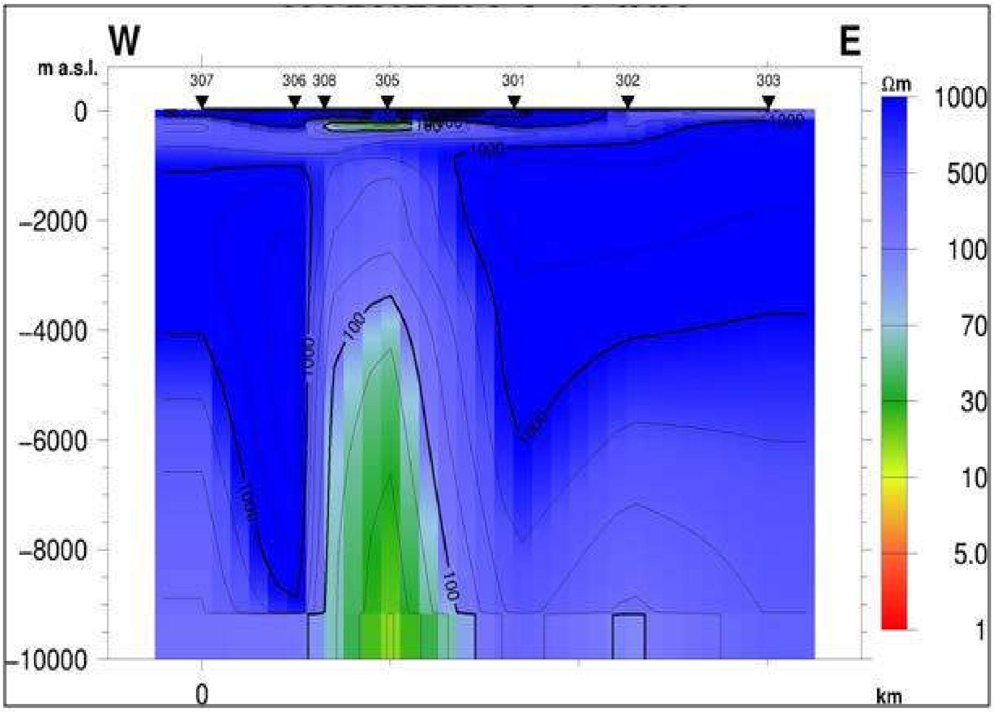
Geothermal Exploration in Sr Lanka

Geophysical Explorations

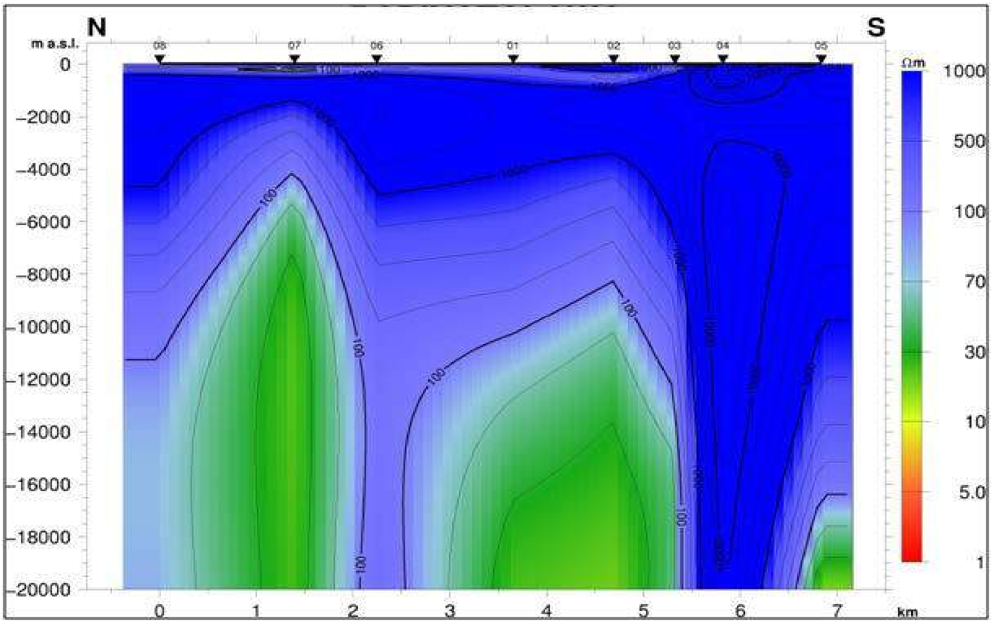
An imager resistivity, self-potential, magnetic and gravity survey carried out by [15], at the Mahapalessa and Mahaoya hot springs in Sri Lanka suggests, near subsurface resistivity structure to a maximum depth of a few hundred meters indicating no evidence for the existence of a sizable thermal water accumulation, but evidence for an upward flow path with the results of low resistive ground at the surface and very high resistivity at the depth. Very low resistivity regions (<30 Ωm) have been detected by the magnetotelluric (MT) method at many thermal springs within very high resistive rocks with the resistivity greater than 10,000 Ωm [7], Low resistivity regions at depths greater than 10- 12 km, and of a few square kilometers in cross sections occur at Padiyathalawa, Mahaoya and Kinniya. MT computed 2D resistivity models indicates connection from low resistivity regions at the depth towards the hot springs through the less resistive bands [7].

The extremely low resistive conditions observed around 150 m depth at the Kapurella area has been interpreted as an indication of water accumulation or aquifer. By the study using time domain electromagnetic (TDEM) method, the occurrence of vertical low resistive regions starting right below the Wahawa hot spring has been interpreted as the deep fractures circulating the thermal water to the surface.

One vertical line represents a regional fault [16], In Mahaoya, nearly vertical low resistive zone is attributed to the composite results by the three structural discontinuities, one lineament and two faults [16]. The geophysical study using magnetotellurics (MT) method in the Kapurella thermal spring, near subsurface indicated a low resistive pocket and SW dipping extension interpreted as the feeding fracture zone. Here the higher resistive impermeable metamorphic basement occurs in both sides of the fracture and reservoir of the kapurella thermal spring is suggested to have occured at the 7.5 km depth [3]. Many hot springs are close to the eastern flanks of the garben, river Mahaweli and topographic channels through Badulla and Ella flank the western side of the garben (Hatherton et al, 1975). As the hotspring waters are of meteoric origin [17],[2] and if deep normal faults are interconnected, the garben water enters through the western garben and returns upward as heated water along the eastern garben. In most locations dolerite dykes closely occur with the hot springs in the Kapurella and Padiyathalawa, and magnetic and resistivity surveys reveal that they are interconnected by deep fractures [18].



(a)



(b)

Figure 2: Deep resistivity profiles of kapurella and Padiyathalawa hot spring fields. (a). Resistivity profile for 10,000 m (10 km) depth, Kapurella area. (b). Resistivity profile up to 20,000 m depth, Padiyathalawa hot spring area.

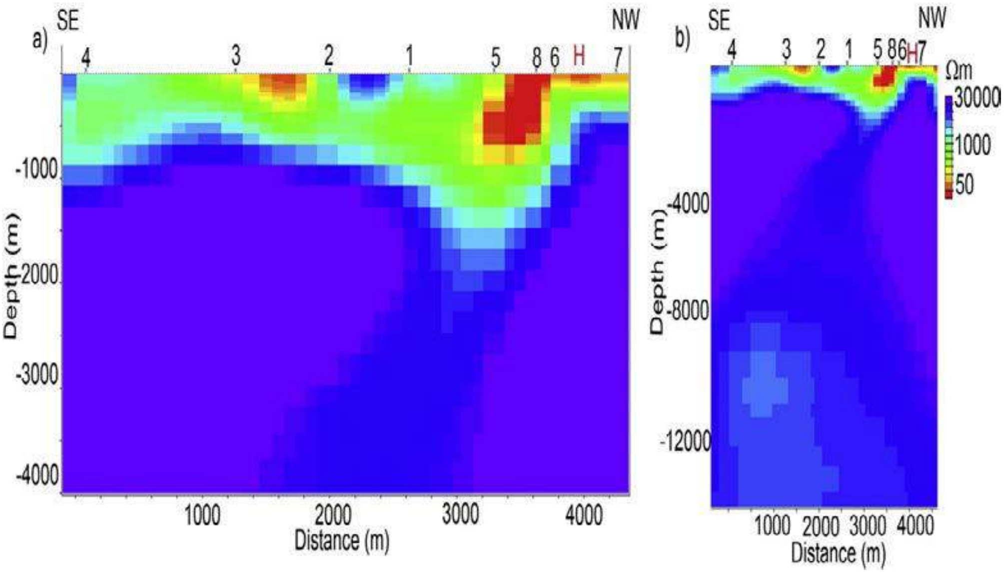


Figure 3: Deep resistivity profiles of Kapurella hot spring field. (a). 4000m deep profile. (b). 12000m deep profile [3].

Figure 4 represents the recent studies on the Mahapelessa hot spring field and its relationship to the HC/VC boundary [20]. This resistivity image clearly shows the low resistivity zones extending, starting from the hot spring and to the deep subsurface. Another very low resistive one interpreted as [20] geothermal water accumulation zone can be identified in 500 m depth. Therefore, the Mahapelessa geothermal field can be utilized for electricity generation as geothermal water accumulation has occurred at shallow depths from the surface. It is

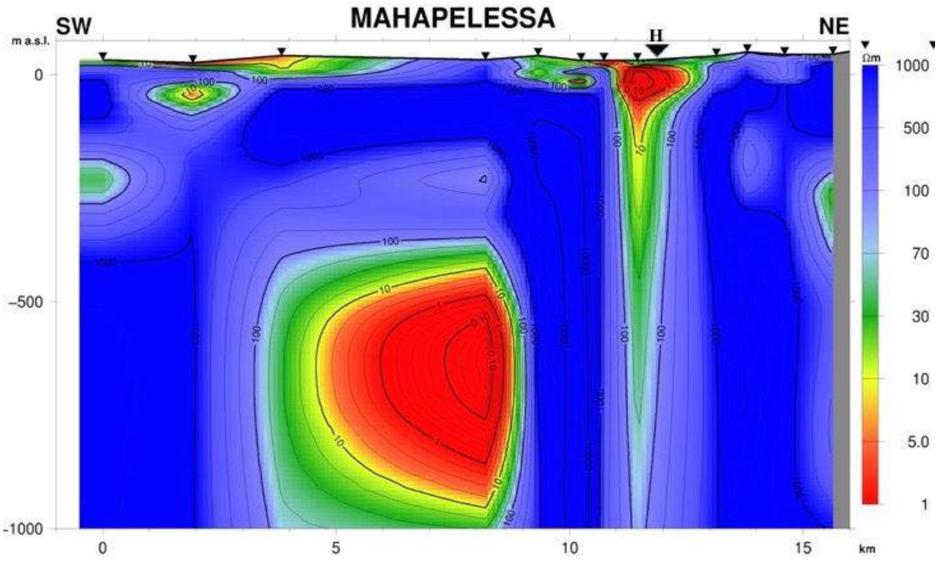


Figure 4: 1 km deep resistivity structure of the Mahapelessa hot spring field generated from MT method

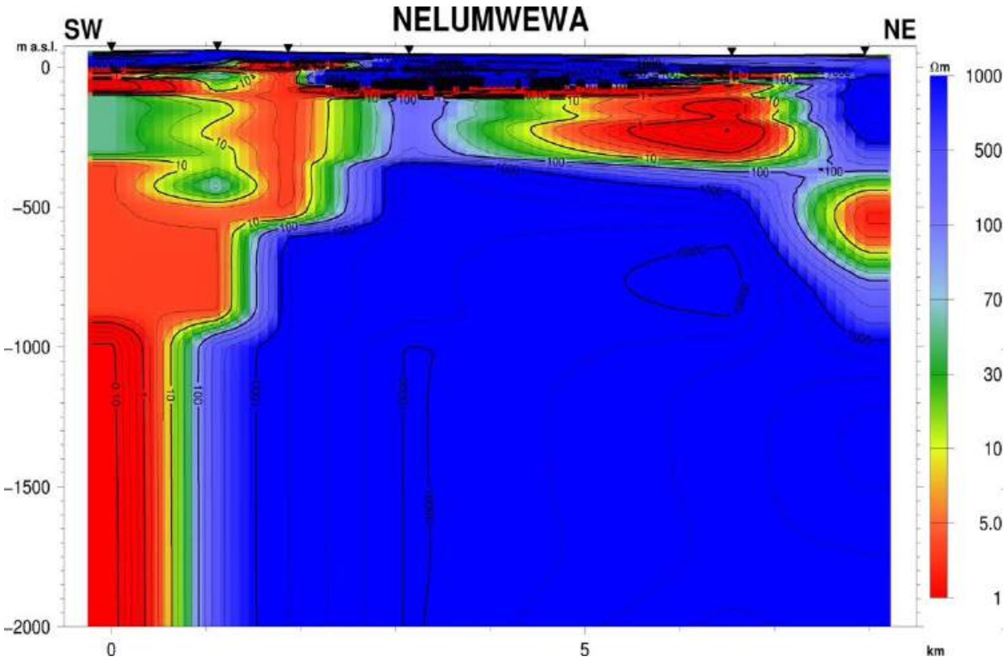


Figure 5: 2 km deep resistivity structure of the Nelumwewa hot spring field generated from MT method

therefore economically suitable for deep drilling.

In the resistivity profile of the Nelumwewa hot spring field generated from MT method, itis observed that low resistive zones occur at shallow depths from the surface (~500 m), which are interpreted as geothermal water accumulation zones [20] Even the magnetic surveys conducted in the same field reveal possible shallow geothermal water circulation paths in the area. Hence the Nelumwewa spring field is also a possible future geothermal electrical plant.

From geological studies and vertical electrical sounding (VES) carried out at the Nelumwewa thermal spring, a geostructural model has been proposed for the formation of Nelumwewa hot spring indicating deep percolating of groundwater through a regional fault zone, heated up by Hot Dry Rock beneath the Dimbulagala Mountain and returning to the surface through a regional vertical fault [19].

Geological and Geochemical Studies of Sri Lankan Geothermal Fields

According to the geological, geochemical and geographical settings, hot water springs in Sri Lanka can be divided into three groups;

Group 1: Mahapalessa
Group 2: Kapurella, Mahaoya, Padiyathalawa, Palanoya and springs around Mahiyangana and Ampara
Group 3: Kanniya, Rankihiriya and Adampane springs.

Group 1 is located in the Southern part of the Sri Lanka, near the HC- VC boundary and has a high salt content. Group 2 lies in the Eastern part and is mostly located in the VC, at a considerable distance from the HC- VC boundary and contain a low content of salt. Group 3 is located in the Northern part and in the HC having very low salt content [12].

The electrical conductivity of geothermal water varied from 532 µS /cm (Kanniya) to 7300 µS /cm (Mahapalessa), indicates the low mineralization of geothermal water except at the Mahapalessa spring [2].

Based on the major element compositions, hot springs can be classified in to three groups as, Na – Cl– HCO_3- type (Mahapelessa), Na – Cl – SO_4 type (Nelumwewa, Mahaoya, Marangala and Kapurella) or Ca–Cl–SO_4-type (Rankihiriya and Kanniya) [2].

Geothermal springs located in the Northeastern part (Rankihiriya and Kanniyai) are mostly dominated by high bicarbonate contents; Özler (2000) indicates that the HCO-3 content can increase with the time and travel distance in underground. Both these springs show lower discharge temperatures [2].

Table 2: Geothermometric calculations of geothermal heat sources in Sri Lanka (modified after, [8], [2])1 [8] 2 [2] a Temperature estimated by chalcedony geothermometer b Temperature estimated by chalcedony geothermometer based on field study

Geothermo meter	**Calculated Heat source temperatures (°C)**						
Thermal Spring	**Rankihiriya**	**Kanniya**	**Nelumwewa**	**Wahawa**	**Kapurella**	**Madunagala**	**Mahaoya**
Na-K-ca (1)	102-131	102-131	102-131	143	143	102-131	143
Silica geo thermometer (1)	102-131	102-131	102-131	143	143	102-131	143
Silica–quartz conductive cooling (2)	131	97	132	97	126	116	131
Silica quartz max. steam loss (2)	127	99	128	98	124	114	128
Silica–Chalcedony a (2)	92	57	92	57	87	76	92

Silica–Chalcedony b (2)	103	69	103	68	98	87	103
Modified silica geothermometer (2)	133	105	137	138	128	118	121
Na–Li f (2)	99	103	129	122	124	96	127

The springs in the middle part of the Sri Lanka (Nelumwewa, Mahaoya, Marangala and Kapurella) are concentrated in high sulfate water, while Mahapalessa in the Southern Sri Lanka with higher chloride- Sodium contents.

The modified silica geothermometers of Verma and Santoyo (1993) yielded the highest reservoir temperatures that range from 105ºC (Kanniya) to 138ºC (Marangala) for all geothermal springs in Sri Lanka. Silica based geothermometers reveal the highest reservoir temperatures of 97 ^{0}C (Kanniya) to 132 ^{0}C (Nelumwewa) while Na – Li geothermometers reveals 96 ^{0}C (Mahapalessa) to 129 ^{0}C (Nelumwewa). The average reservoir temperatures vary from 88 ^{0}C (Kanniya) to 120 ^{0}C (Nelumwewa) [2].

The geochemical composition of natural shallow groundwater in nearby terrains closely matches with the hot spring waters, indicating that all water should stem from a common circulation. As the geochemical values, isotopic data from geothermal and non- geothermal water are almost identical; the hypothesis of a common source of recharge and internal circulation pattern can be confirmed [2].

From the isotopic and geochemical similarities of shallow groundwater and geothermal spring water, a fast circulating system, is indicated. Hence the hot springs are much likely to be heated at much shallow depths, because fast conduit circulation systems do not reach down to much higher depths. This suggests a much steeper geothermal gradient which may be related to the residual heat along the HC – VC boundary zone [2].

Potential Applications of Geothermal Energy in Sri Lanka

There are many potential applications using the geothermal hot springs in Sri Lanka. Even though the heat source or reservoir origins are not clearly identified, their temperatures have been calculated already. The temperatures of the sources indicate (~ 150-170 ^{0}C) which means t they can be utilized to generate electricity, as a direct use of a geothermal energy.

As Sri Lanka has many agricultural and tourism impacts, there are many direct uses of geothermal springs. some of the most common uses which can be applied to Sri Lanka are discussed in the following section.

Direct use

The areas around geothermal manifestations have a dry climate and the major economic activity in the areas is agriculture. It is also a popular tourist destination because of the wildlife and beach (specially Trincomale to Hambanthota). These sectors can be benefited immensely from the geothermal energy through direct utilization. The possible applications include drying of agricultural products (cereal), sugar processing, papermill operation and in recreational facilities such as warm pools, saunas and steam baths.

Steaming and drying of agricultural products

The geothermal springs have been located in Trincomale (Kanniya, Rankiriulpotha), Polonnaruwa (Nelumwewa), and Hambanthota (Mahapelessa) districts. The area is extensively agricultural especially, rice, maize, soya, peanut, etc. being grown. Forrice and cereal production industries, hot spring water can be used as thermal energy for steaming and drying. At least a part of energy consumption of this production can be supplied using these geothermal energy systems.

Sugar processing

geothermal energy can be used in sugar processing. Cane sugar production requires considerable amounts of steam; The geothermal heat energy can be used for evaporation in multiple effect evaporators. It is reported that natural heat is already used in several countries for brewing and distillation. Cane cultivation in the area can be used as a cost effective and easy process to manufacture sugar or other valuable products using this geothermal energy. In Sri Lanka cane sugar industry is limited to areas like Trincomalee and Moneragala . Hence Hot springs such as Kanniya, Padiyathalawa, can be used as geothermal energy sources for the cane industry in Sri Lanka.

Recreational and health applications

Hot springs and warm mineral springs have been used for recreational and health purposes form any countries, even in Sri Lanka. There are records of many geothermally heated swimming pools, mineral baths, mud baths, steam baths and specially organized recreational centers from several countries. In Sri Lanka, the tourism industry has shown great progress in recent times, including the areas where there are hot springs. There is a great potential for attention for herbal and local medicinal therapy by the tourists. Hence. Combining tourism and these local medicines would give much higher profits to the country. As in many other countries, hot spring waters can be used for herbal and steam baths before some medicinal treatments. Therefore, additional infrastructures such as hotels, recreational facilities have to be developed for better tourist attractions at such places.

Indirect use (electricity)

By assuming that the 350 km long highland Vijayan boundary zone a potential geothermal energy source, estimation to a thickness of 2 km and a width of 2 km, A potential of 1335 MWe generating capacity for 50 years and 723 MWe generating capacity for 100 years were concluded by a Monte Carlo simulation [6]. Even though [6] is the only comprehensive study done about potential electricity generation estimations, some of the assumptions cannot be justified. For example, assuming that the whole 320 km long HC/VC boundary as a geothermal belt may not be correct. Hence considering the hot spring fields as point sources rather than a continuous belt might be give a more accurate and precise estimations.

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