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Quantitative Approximation of Geothermal Potential of Bakreswar Geothermal Area in Eastern India

Chiranjit Maji, Hirok Chaudhuri and Saroj Khutia

Abstract

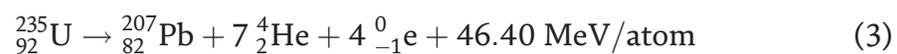
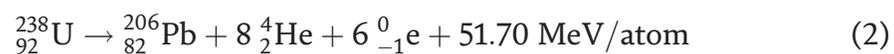
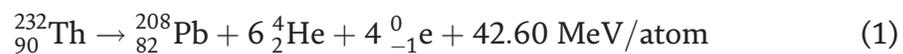
Proper utilization of geothermal energy for power generation is still overlooked in India even after having enough potential as much as the equivalent to its other nonconventional energy resources. The source of geothermal energy is the decay of the radio-nuclei present inside the Earth's crust apart from the primordial heat source. The noble gas ^4He is also produced during the radioactive disintegration process. Therefore, measuring the amount of ^4He gas along with some other geochemical parameters in an Indian geothermal area, the potential of the reservoir can be evaluated. Mathematical calculations relating to the radioactive disintegration to estimate the geothermal potential of Bakreswar geothermal reservoir utilizing the concept of the ^4He exploration technique has been described here. The study showed that the heat (radiogenic) energy generated by the radioactive decay of ^{232}Th , ^{238}U , and ^{235}U inside the reservoir was evaluated as 38 MW. This value raises to 76 MW when primordial heat is included. The detail calculations suggest that a Kalina cycle based binary power plant using ammonia–water mixture as working fluid is supposed to be installed at the identified locations with a drilling depth of about 1,100 m and the plant would be capable of delivering the power of 9.88 MW to 40.26 MW.

Keywords: hot springs, radioactive disintegration, helium generation, geothermal power, geothermal power plant

1. Introduction

The origin of the geothermal energy is connected with the internal structure of the planet and the physiochemical processes occurring therein. According to the current knowledge, geothermal energy is unevenly distributed throughout the globe near the surface to the deep interior of the Earth [1, 2]. Depending upon the accessibility as well as the opportunities for the utilization of modern technology, many nations in the world are exploiting this natural energy resources for the commercial production of electric power [3, 4]. Geothermal energy hence, geothermal areas are generally defined through the parameter, geothermal gradient, which is the rate of the increment of the temperature profile of underneath bedrock of the Earth. The average (global) value of the geothermal gradient is

typically 30 °C/km in the continental crust and 100 °C/km in the oceanic crust [1, 5]. However, in geothermal areas, its values are well above (>40 °C/km) the global average value [6]. It is so because of the magmatic intrusion. This intrusion is nothing but the molten magma, trapped within the Earth's crust at a depth of 5–10 km beneath the surface. This may still in a fluid state or the process of solidification and releasing heat constantly [2, 7, 8]. According to the origin of geothermal energy, it is categorized into two. One was from a relic of the Earth's accretion process, in which huge energy was trapped within the Earth's interior (~4.5 billion years ago) [7]. This one is named as the primordial heat source. Another one is the radiogenic heat source, which is produced by the natural decay process of long-lived radioisotopes such as ^{238}U , ^{235}U , ^{232}Th , and ^{40}K . These nuclei, of which the half-life ($T_{1/2}$) are comparable to the age of our planet, are found with significant abundance within the crust of the geothermal areas [9, 10]. A considerable amount of heat is contributed from the natural radioactive decay process. Eq. (1) to Eq. (3) represent the physicochemical processes and the heat energy released from the naturally occurring radioactive disintegration in each of the complete decay chain [11–14]. Moreover, it shows the produced crustal He (^4He) atoms and neutrinos during each decay process.



Moreover, within the deep Earth, the production rate of He from ^{232}Th and ^{238}U [and ^{235}U] radio-nuclei are encountered to be $2.43 \times 10^{10}\ \text{atoms}/\text{m}^3/\text{s}$ and $1.03 \times 10^8\ \text{atoms}/\text{m}^3/\text{s}$, respectively [10]. The fact of characteristics heat–helium coherence at any geothermal system (under the deep reservoir) is interpreted by such physicochemical processes [15]. This radiogenic heat, which is one of the main sources of the Earth's internal heat, powers all geodynamic processes underneath [16]. Generally, geothermal heat is transferred from the aquifer (reservoirs) to the Earth's surface by the conduction and convection process. Here, the geothermal fluid (meteoric water) acts as the carrier [1] and the radiogenic He, being highly diffusive gas, generated from the host mineral and mixes by diffusion with the fluid that circulates into the deep Earth [17]. The reservoir, which is nothing but a volume consisting of hot permeable rocks, is usually sandwiched by capping of impermeable rocks. And it is favourably connected to a recharge (surficial) area [18], from which geothermal fluids percolated to recharge the aquifer cyclically [18, 19]. The circulating fluids, to which the heat is transferred from the reservoir, escape through fracture and features from the deep reservoir and manifest through geysers, fumaroles, hot springs, etc. [8, 19]. Moreover, through diffusion and advection process, the radioactive inert gases (like ^{222}Rn & ^{220}Rn) including the stable and inert gases (such as He, Ar) are spontaneously migrating upward from the deep Earth to the superimposing atmosphere [20–22]. This process, known as 'Earth degassing', is non-uniform over space & time [23, 24]. The prominent signature of this degassing is generally noticed along active faults, fractures, oceanic ridges, geothermal fields, and even deep wells [25–27].

It is notable that geothermal energy sources are still overlooked in India for power generation even after the existence of a lot of potential resources, which are seen in twelve geothermal zones of the country [19]. However, several of them could be well utilized for the generation of power by means of developing geothermal power plants. For the sake of investigation, the hot spring site at Bakreswar in

West Bengal, India, was selected as shown in **Figure 1**. Now, knowing the amount of by-product, He gas which is ultimately reaching the surface through the fracture, fissure and hot springs vents, etc., the associated heat energy (radiogenic) produced inside the reservoir can be estimated. The energy released per unit time from underneath bedrock at the study area was calculated by means of measuring the average amount of He emanated from Agni Kunda hot spring at Bakreswar. Here mainly the decay series of ^{238}U , ^{235}U , and ^{232}Th were considered, and the amount of heat energy contributed due to each series was evaluated. Here the question may arise that each decay series [Eq. (1) to (3)] takes a long period (in geological time scale) to complete its disintegration process and release a certain amount of heat and He discretely. But, heat and He generated due to each series were utilized to calculate the amount of heat production at the said reservoir at a certain instant of time. However, He emanation at the study area shows stable activities for a long-time-interval (5 years), as established by [19]. Therefore, He generation is also stabilized for a long period, i.e., He generation due to every radioactive decay series

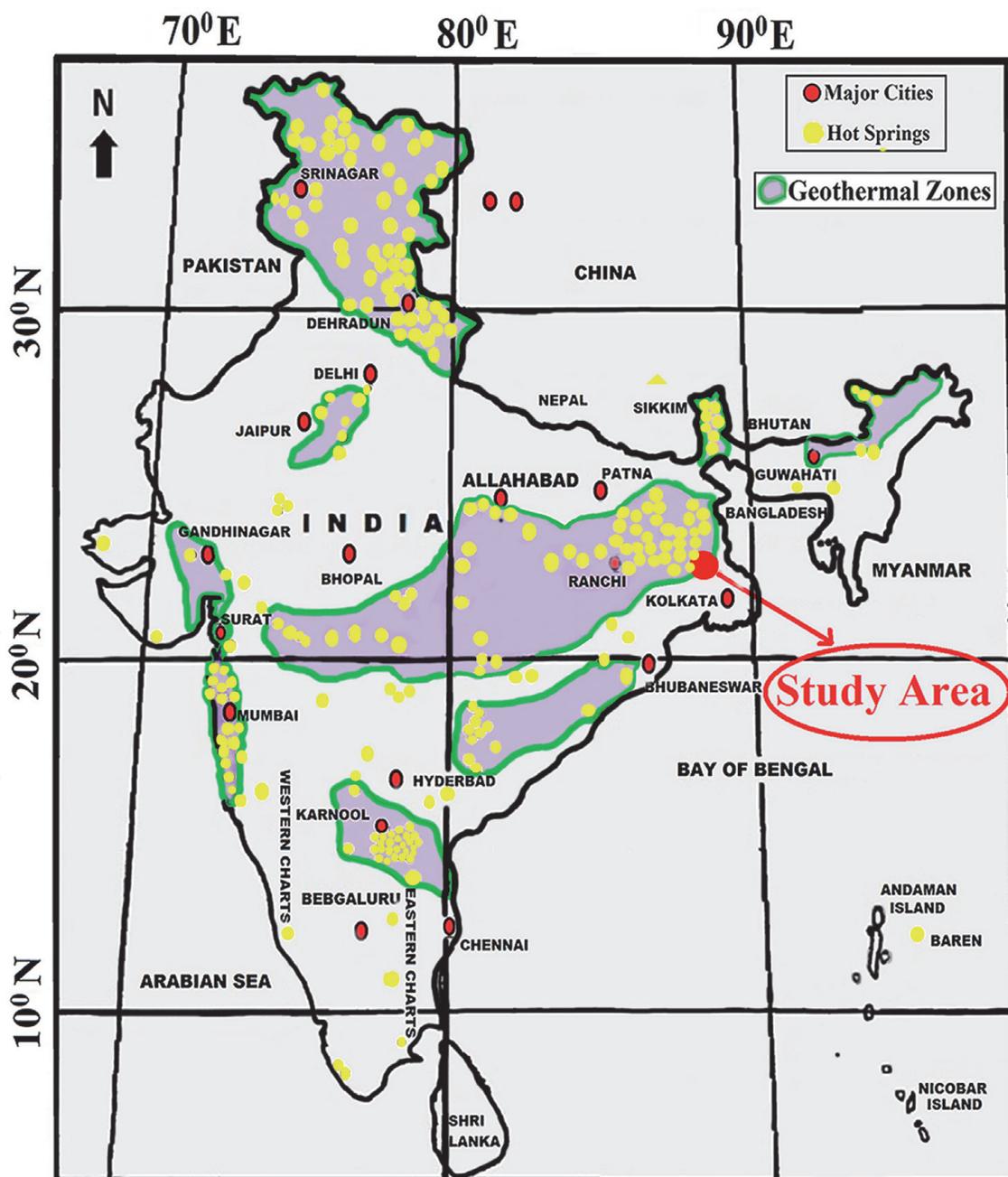


Figure 1.
Location of the study area Bakreswar in the map of India (modified after [19]).

and emanation of the said gas is in an equilibrium condition. Therefore, no He is being stored at the reservoir at the instant, and, therefore, the He emanation could be considered to be equal to the generation of the same due to the radioactive disintegration process.

2. The study area: Bakreswar geothermal province

A cluster of seven¹ hot springs is scattered over Bakreswar geothermal area within a confined zone of the surface area of about 3350 sq. m [19, 28]. The area, which is a geologically complex, heterogeneous, and extensively faulted region, is situated at the eastern end of the SONATA (Son–Narmada–Tapi) geothermal province (**Figure 2**, window a) [19, 28]. The area lies in the West Bengal Basin (WBB), the extension of the Chotanagpur Gneissic Complex [29]. Furthermore, it is linked with a 1.2-km-long shear zone, which is characteristic by 50 m wide breccia/cherty quartzite aligned through the almost north–south trend-line [26] (**Figure 2**, window b). The springs here are connected with the extinct Rajmahal volcanic activity (115 Ma), and hence, are associated with the Precambrian granitic rocks [30] (**Figure 2**, window b). The highly permeable and porous subsurface of the site is facilitated due to the presence of the brecciated, highly sheared, and mylonitized rock here [26]. The association of the study area with the eastern edges of two major fault systems (the ONGC fault and the SONATA fault) made the region to be in a stressed state [31, 32]. This region is characterized by a very high geothermal gradient (~ 90 °C/km) and a high heat flow rate (~ 230 mW/m²) [19, 33]. The

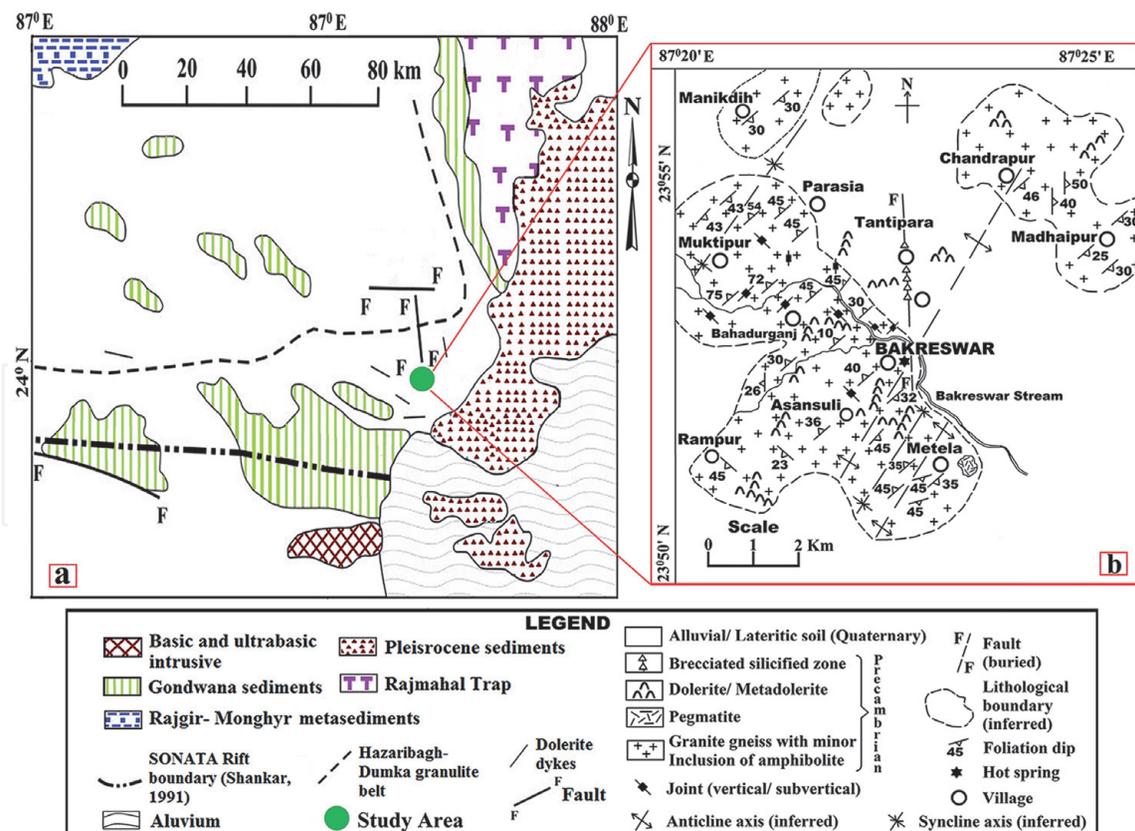


Figure 2. (a) Regional and (b) Local geological maps of the study area (modified after [19, 26]).

¹ He emanated from other six hot springs and through the soil (soil gas) of the geothermal area are not included in the estimation due to the lack of other necessary information.

presence of a high heat-conducting zone in this area is confirmed by electrical resistivity studies. This conducting zone, which starts at a depth of around 2.8 km and goes down up to a depth of 4 km [34], is supposed to act as the heat feeder to the fault system linked with the Bakreswar hot springs. It is to be noted that the crustal thickness at the study area is only 24 km, whereas the average of the same throughout the country is 38 km [29, 35]. Besides, the average density of the crustal substance here is relatively low. Therefore, inert volatiles like He and ^{222}Rn gases can easily transmit to permeate through crustal constraints due to the presence of the thinner lithospheric overburden here. As a result, the spring and the soil gases here are dominated by the presence of high ^{222}Rn and He flux [29]. High ^{222}Rn and He gases are continuously conveyed and dispersed into the atmosphere via molecular diffusion and the formation of micro-bubbles at the hot spring vents. Here, temperature and He emanation profile of some sites of Bakreswar geothermal provinces are also tabulated in **Table 1** for a reference to attain the brief geophysical properties of the study area. Moreover, the reservoir temperature of the geothermal system underneath Bakreswar was predicted to be 100 ± 5 °C (at ~1 km depth) by [38]. The same was estimated to be in the range of 130 °C to 175 °C (by Na/K ratio) and 110 °C to 124 °C (by TSiO_2) by [39]. Furthermore, the range of the reservoir temperature was also evaluated as 212 °C to 124 °C, 118 °C to 120 °C, and 126 °C to 130 °C by means of silica geothermometry by [32, 38, 40] respectively. The audio-magnetotelluric (AMT) studies of the sub-surface beneath the Bakreswar geothermal area were conducted by [41] (**Figure 3**). The rapid relaxation inversion (RRI) for both transverse-electric (TE) and transverse-magnetic (TM) modes was carried out to figure out the resistivity profile of the subsurface of the site. Here, the suitable locations for drilling for the installation of a future geothermal power plant

Sl. No.	Test Site (distance from Agni Kunda)	Sample type	Temperature (°C)	He Conc. (vol %)	References
1	Bakreswar Agni Kunda (0 m)	HSG	69.0	1.72	[19]
2	Bakreswar Khar Kunda (16 m)	HSG	68.0	1.36	[36]
3	Bakreswar Bhairab Kunda (7 m)	HSG	62.0	1.12	[28]
4	Bakreswar Brahma Kunda (20 m)	HSG	46.0	1.26	[28]
5	Bakreswar Surya Kunda (18 m)	HSG	63.0	0.31	[28]
6	Bakreswar Reserve Tank (5 m)	HSG	52.0	0.91	[28]
7	PWD Bungalow at Bakreswar (987 m)	SG (1 m depth)	32.0 (Ambient)	0.35	[37]
8	PWD Bungalow at Bakreswar (988 m)	SG (3 m depth)	31.0 (Ambient)	0.02	[37]
9	PWD Bungalow at Bakreswar (990)	AA (1 m height)	33.0 (Ambient)	0.05	[29]
10	Bhabanipur (10 km)	AA (1 m height)	28.0 (Ambient)	0.07	[29]
11	Mallarpur (43 km)	BG (100 m depth)	58.0	1.20	RWA

Note: HSG = Hot spring gas; SG = Soil gas; AA = Ambient air; BG = Borehole gas; Conc. = Concentration; RWA = Recent work by the authors.

Table 1.
 Temperature and He emanation profile of some sites at Bakreswar geothermal province.

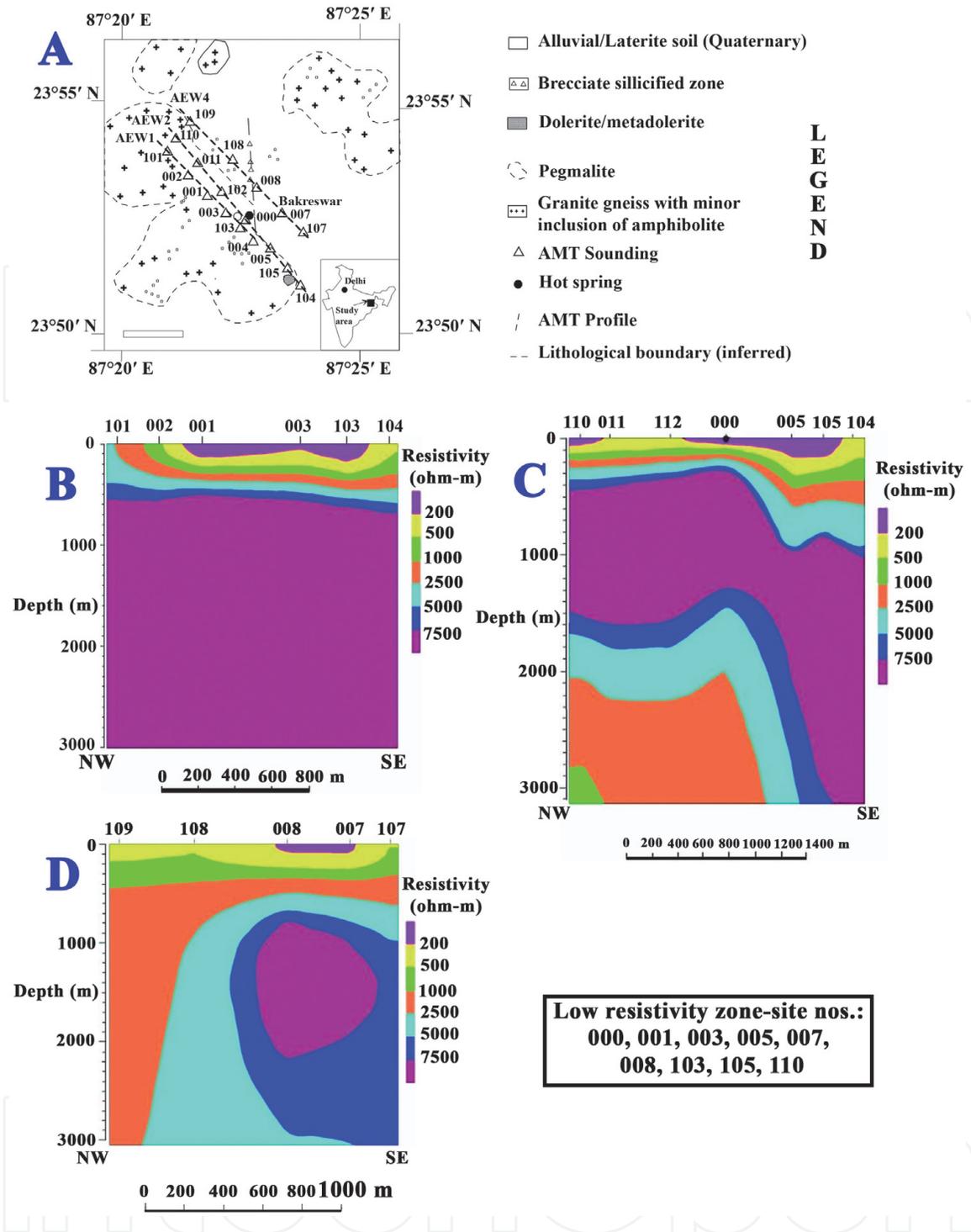


Figure 3. (A) AEW traverses (AMT sites) on the map of the study area; (B) 2D RRI (rapid relaxation inversion) along traverse AEW1; (C) 2D RRI along traverse AEW2; (D) 2D RRI along traverse AEW4 (modified after [41] [personal communication] and [42]).

at the study area were identified by the authors using the result of that AMT survey [personal communication] and the same is discussed later.

3. Methodology

3.1 Experimental techniques

In view of continuous monitoring of gases emanated from the hot spring Agni Kunda at the spring site of Bakreswar, a field laboratory was established. In this

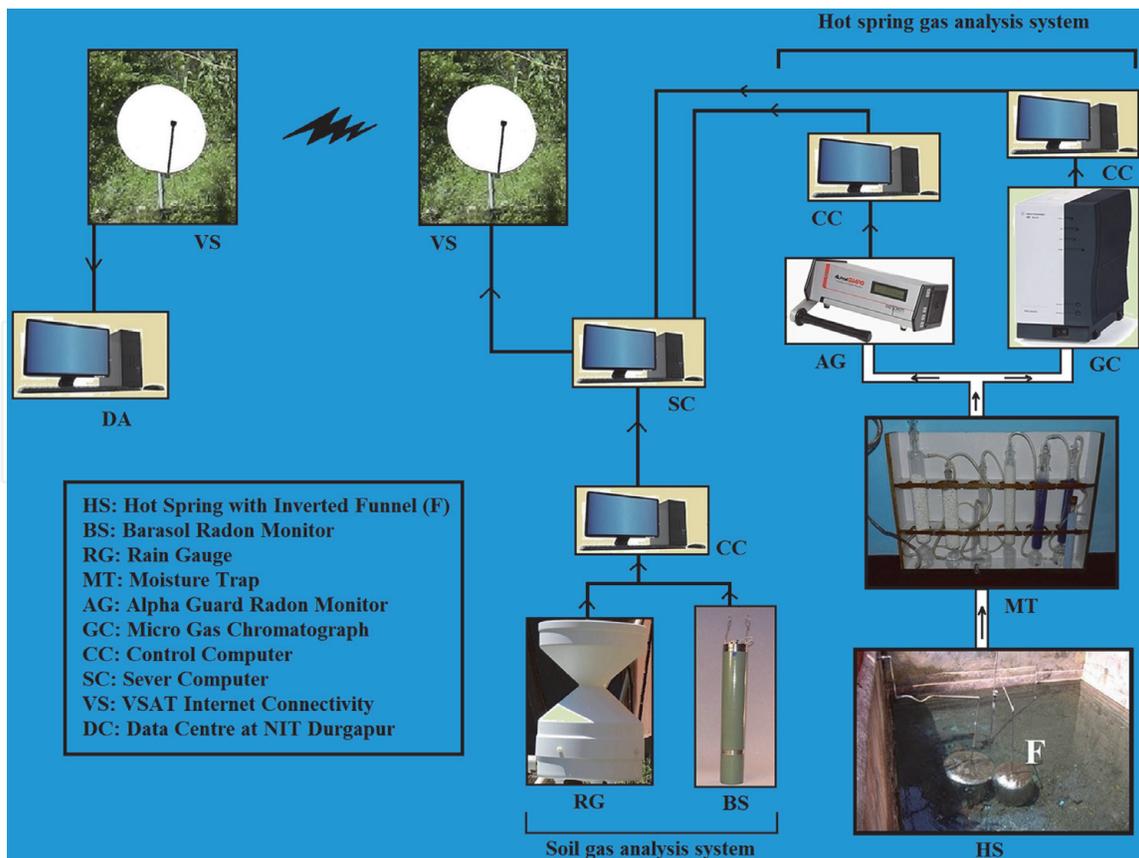


Figure 4. Schematic diagram of the experimental set-up installed at Bakreswar (modified after [19]).

regard, a giant inverted SS funnel was placed under hot water at Agni Kunda at a position where gas out flux was significantly high, to trap hot spring gases which were comprised of He, Ar, O₂, N₂, CH₄, CO₂, ²²²Rn, etc. A portable and programmable μ -GC (micro-gas chromatograph) CP 490 (make Agilent, Netherland) comprised of a μ -thermal conductivity detector, was utilized to detect the relative concentration of different gases present in the spring gas. Here, ultra-pure (>99.998 vol%) H₂ gas was utilized as the carrier gas for running the equipment. The entire measurement was carried out in-round-the clock (24 \times 7) measurement fashion for a continuous five-year (1st August 2005 to 31st July 2010). The back-up power supply was maintained to keep a stable and continuous power supply in case of a power failure. The schematic diagram of the experimental set-up is illustrated in **Figure 4**. Further details of the above-mentioned experimental procedure are already described by [19]. Here, the average value of the He concentration (vol%) of 5 years of continuous measurement was adopted in our study. Moreover, the flow rate of the emanated gases from the spring vent was measured by means of collecting the spring gases in a gas container (5 litres) from the main channel of the incoming gas line. The gas collection procedure was kept running up to a certain time until its pressure makes equilibrium with the pressure (1.58 atm) at the spring vent underwater. This type of measurement was done once every month for a continuous five years, and the average value of those was considered as the final value of the gas flow rate under consideration. The ambient temperature of the study area was monitored for the same interval at the time of measurement of gas flow rates.

3.2 Analytical techniques

To move towards the desired direction for calculation, the following steps were adopted.

The volume of He gas (V_{He}) emanating from the spring per second was estimated as

$$V_{He} = F \times C_{He} \quad (4)$$

Where F = average flow rate of He gas emanation (recorded); C_{He} = relative concentration of He in the gas mixture, which was expelled through the spring vent (recorded). The no. of moles of He gas emanated per unit second from the hot spring was calculated using the real gas equation as stated below:

$$(V - nb) \left(P + \frac{n^2 a}{V^2} \right) = nRT \quad (5)$$

$$\text{i.e., } \frac{ab}{V^2} n^3 - \frac{a}{V} n^2 + (bP + RT)n - PV = 0 \quad (6)$$

Where V (i.e., V_{He}) = volume of the He gas at temperature T and pressure P ; R = universal gas constant = 0.0821 litre atm/ mole K; n = number of mole (to be calculated); 'a' and 'b' are real gas constants and for He, $a = 0.03457$ atm litre²/mole²; $b = 0.02370$ litre/mole [43]. Solving the Eq. (6) and considering the real root for 'n', the corresponding total number of He atom (N_{He}) was calculated by

$$N_{He} = n \times N_A \quad (7)$$

Here, N_A = Avogadro's number = $6.022140857 \times 10^{23}$ [44]. The relative contribution of the individual isotope in the generation of He atoms was calculated according to their relative abundance in the natural resources because the total number of He atom is produced via the radioactive decay series of ²³⁸U, ²³⁵U, and ²³²Th. Here, the same was not applicable to the 40 K series as it disintegrates through only β emission. Therefore, for production of He atoms,

$$\begin{aligned} &\text{The relative contribution of Uranium } (C_U) \\ &= \frac{\text{conc. of Uranium (U)}}{\text{total conc. of Uranium (U) \& Thorium (Th)}} \end{aligned} \quad (8)$$

$$\begin{aligned} &\text{The relative contribution of Thorium } (C_{Th}) \\ &= \frac{\text{conc. of Thorium (Th)}}{\text{total conc. of Uranium (U) \& Thorium (Th)}} \end{aligned} \quad (9)$$

The basement of the study area is predominantly composed of granite gneiss belonging to the Precambrian Chotanagpur Gneissic Complex [26, 30]. Here the relative contribution of U and Th were evaluated according to their (average) content in granite type rock material, i.e., ²³⁸U [or ²³⁵U] content as 4.80 ppm and ²³²Th content as 21.50 ppm were considered [10, 45]. Moreover, natural Uranium is an admixture of ²³⁸U (99.28%) and ²³⁵U (0.71%) [10]. Therefore, for production of He atoms by radioactive decay,

$$\text{The relative contribution of } ^{238}\text{U } (C_{U-238}) = \frac{99.28}{100} \times C_U \quad (10)$$

$$\text{The relative contribution of } ^{235}\text{U } (C_{U-235}) = \frac{0.71}{100} \times C_U \quad (11)$$

The no. of the He atoms generated (in a unit second) due to the decay of radio nuclei ^{232}Th , ^{238}U and ^{235}U are respectively $C_{\text{Th}-232} \times N_{\text{He}}$, $C_{\text{U}-238} \times N_{\text{He}}$ and $C_{\text{U}-235} \times N_{\text{He}}$. According to Eq. (1) to Eq. (3), it is reflected that 6 He atoms and 42.6 MeV/atom heat energy, 8 He atoms and 51.7 MeV/atom heat energy and 7 He atoms and 46.4 MeV/atom heat energy from the decay of ^{232}Th , ^{238}U and ^{235}U are releasing respectively. Therefore, the energy release (per unit second) from ^{232}Th , ^{238}U , and ^{235}U decay can be evaluated respectively by

$$E_{\text{Th}-232} = \frac{42.6}{6} \times C_{\text{Th}-232} \times N_{\text{He}} \quad (12)$$

$$E_{\text{U}-238} = \frac{51.6}{8} \times C_{\text{U}-238} \times N_{\text{He}} \quad (13)$$

$$E_{\text{U}-235} = \frac{46.4}{7} \times C_{\text{U}-235} \times N_{\text{He}} \quad (14)$$

And the total energy generated due to the decay of all these three radioelements were

$$E_{R(\text{Total})} = E_{\text{Th}-232} + E_{\text{U}-238} + E_{\text{U}-235} \quad (15)$$

An important issue to discuss is that the loss of generated heat energy may be considered to be negligible here as capping of the impermeable and insulating bedrock over the geothermal system prevents the heat transfer by means of conduction and convection [30, 41, 42]. Therefore, the heat energy would be stored inside the geothermal system, which may be subjected to break its dynamical stability after the accumulation of enough energy within it. However, that does not happen as excess heat is drained to the surface, along with the transfer of geothermal fluid through the spring vent [30, 42]. Moreover, here only radiogenic heat is accounted for, and the contribution of energy belonging to primordial heat sources is not included. However, [46] documented that heat from radioactive decay was contributed about half of Earth's total heat flux, and the rest was accounted for from the primordial heat source of the Earth. Considering the similar concept, we can also assume that the primordial heat source also would contribute as much as heat energy generated by radioactive decay of radio-nuclei at the reservoir of the study area.

Therefore, the heat generated by the primordial source,

$$E_{P(\text{Total})} = E_{R(\text{Total})} \quad (16)$$

Therefore, total energy contributed from the radiogenic and primordial source is

$$E_{\text{Total}} = E_{P(\text{Total})} + E_{R(\text{Total})} \quad (17)$$

Moreover, If the geothermal gradient $\left(\frac{d\theta}{dx}\right)$ is considered to be constant at least up to the depth of the reservoir (x) then the depth (x) of the reservoir could be calculated from the below stated linear relationship.

$$\theta_r = \left(\frac{d\theta}{dx}\right) x + \theta_a \quad (18)$$

Where, θ_r = reservoir temperature of the geothermal system; θ_a = average ambient temperature at the study area.

4. Result and discussion

The measured parameters as well as calculated parameters such as number of He moles emanating per second (n), the total number of He atoms emanating per second (N_{He}), the contributed relative concentration of ^{232}Th (C_{Th}), ^{238}U (C_{U-238}) and ^{235}U (C_{U-235}) including the energy contributed due to decay of ^{232}Th , E_{Th-232} , ^{238}U , E_{U-238} and ^{235}U , E_{U-235} etc. are listed in **Table 2**. The Table reflects that the heat energy generated per unit second by the radioactive decay of ^{232}Th , ^{238}U and ^{235}U inside the reservoir are 31.58 MW, 6.3585 MW and 0.0467 MW respectively and together contributed as approximately 38 MW [radiogenic source, $E_{R(Total)}$]. Considering the concept of [46], as mentioned above, total heat energy [E_{Total}] related to the radiogenic source [$E_{R(Total)}$] and the primordial source [$E_{P(Total)}$] is expected to be 76 MW. Moreover, the values would be likely increased whenever the He emanations through the others hot springs (where He emanation is comparably less than that of Agni Kunda) and the vast surface area (soil gas) at Bakreswar would be included in this estimation. However, this was a little bit difficult as well as complicated due to the technical coerces and geographical constraints. It is notable that Kalina cycle based binary power plant using ammonia–water mixture as working fluid (thermal efficiency: 13–53%) [47], is already proposed to be

Sl. No.	Parameters	Parameters' value	References [Eq., if any]
1	He concentration, C_{He}	1.72 vol%	RA
2	Flow rate, F	3.5 L/min	RA
3	He emanation per minute, V_{He}	0.0602 L/min	EA [Eq. (4)]
4	Temperature inside the spring gas trapping funnel, T	342 K (69 °C)	[19]
5	Pressure inside the spring gas trapping funnel, P	1.58 atm	RA
6	Number of moles emanating per second, n	56.3877×10^{-6}	EA [Eq. (6)]
7	Total number of He atoms emanating per second, N_{He}	33.9623×10^{18}	EA [Eq. (7)]
8	The relative concentration of ^{232}Th , C_{Th}	81.7490×10^{-2}	EA [Eq. (9)]
9	The relative contribution of ^{238}U , C_{U-238}	18.1195×10^{-2}	EA [Eq. (10)]
10	The relative contribution of ^{235}U , C_{U-235}	0.1296×10^{-2}	EA [Eq. (11)]
11	Energy contributed due to decay of ^{232}Th , E_{Th-232}	31.58 MW	EA [Eq. (12)]
12	Energy contributed due to decay of ^{238}U , E_{U-238}	6.3585 MW	EA [Eq. (13)]
13	Energy contributed due to decay of ^{235}U , E_{U-235}	0.0467 MW	EA [Eq. (14)]
14	Energy accounted for radiogenic source, $E_{R(Total)}$	37.9834 MW	EA [Eq. (15)]
15	Energy accounted for primordial source, $E_{P(Total)}$	37.9834 MW	EA [Eq. (16)]
16	Total Energy accounted from radiogenic & primordial source, E_{Total}	75.9668 MW	EA [Eq. (17)]
17	Geothermal gradient, $\frac{d\theta}{dx}$	90 °C/km	[33]
18	Reservoir temperature, θ_r	130 °C	[40]
19	Average ambient temperature, θ_a	26 °C	RA
20	Depth of the geothermal reservoir, x	1155 m	EA [Eq. (18)]

Note: EA = Estimated by the authors; RA = Recorded by the authors

Table 2.
Experimental and calculated parameters.

installed at the spring site [48]. Accordingly, if such type of power plant is supposed to be installed, for say, the plant would be capable of delivering the power of 4.94 MW (minimum thermal efficiency 13%) to 20.13 MW (maximum thermal efficiency 53%) only considering the radiogenic heat source. These values are changed to 9.88 MW and 40.26 MW, respectively, when the primordial heat source is comprised of the radiogenic heat source.

Recently, the reservoir temperature [θ_r] of the Bakreswar geothermal system was estimated to be 126–130 °C by [40] by means of silica geothermometry. The average ambient temperature [θ_a] of the study area was recorded to be 26 °C. Our estimation using the mathematical relation [Eq. (18)] shows that the geothermal reservoir at the area is expected to be located at about [$x=$] 1,111 to 1,155 m beneath the surface. Moreover, the results of audio magnetotelluric (AMT) studies collected from [41] revealed the existence of a deep heat reservoir in the N–W part of Bakreswar. Observation sites 000, 001, 003, 005, 007, 008, 103, 105, 110, as marked in **Figure 3**, show low resistivity profile, and these are more favourable sites for deep drilling.

It is notable that no such work has been carried out to figure out the potential of Bakreswar geothermal region in terms of power harnessing capability. However, [42] estimated the geo-heat of the site to be 1158 KW-hr ($=416.88 \times 10^7$ Joule) by means of considering total water discharge through Agni Kunda hot spring and difference between the spring temperature and mean ambient temperature. Further, another approach may be considered here to get a comparative view in this regard. In this connection, the water discharges from the Agni Kunda and Khar Kunda hot spring were measured to be 790 L/min (~ 790 kg/min) and 680 L/min (~ 680 kg/min) respectively. The amount of the heat energy carried out (per second) by the hot water through these springs would be 10.29–10.70 MJ (equivalent to 10.29–10.70 MW in terms of power). However, the energy carried out by other springs is not included herewith due to technical difficulties. Furthermore, the energy carried out by the gaseous phase of the hot springs and the heat loss through the soil of the vast region is out of scope to be counted.

5. Conclusion

Using a simple technique by means of He exploration study at the field site, the probable energy generated inside the reservoir was estimated here. Considering the combined source of heat generation inside the reservoir system, the energy was expected to be generated from the source of power of 38 to 76 MW using the appropriate technology. The utilization of proper technology for power generation could facilitate to build a Kalina cycle based geothermal power plant (using ammonia–water mixture as working fluid) of power harnessing capability of 9.88 MW to 40.26 MW at the study area. Moreover, the values would be likely increased whenever, the He emanations through the others hot springs (where He emanation is comparably less than that of Agni kunda) and through the vast surface area (soil gas) at Bakreswar would be included in this estimation. However, this was a little bit difficult as well as complicated due to the technical coerces and geographical constraints. Furthermore, the deep drilling (production & injection well) of the proposed power plant to be rooted upto a depth of approximately 1,100 m at a location near to the hot spring area as indicated in the **Figure 3**. However, a detail geophysical survey may also be required for selecting the appropriate and exact location for drilling as well as the measurement of the horizontal (length & width-wise) and vertical (depth-wise) dimension of the geothermal reservoir at the area.

The same would be subjected to accurately calculate the possible capacity of the power plant to be installed at the site.

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Author details

Chiranjit Maji*, Hirok Chaudhuri and Saroj Khutia
Department of Physics, National Institute of Technology Durgapur, Durgapur,
India

*Address all correspondence to: chiranjit.nitdphysics@yahoo.in;
cm.15ph1102@phd.nitdgp.ac.in

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