Development situation and prospecting division of geothermal resources in Yangshan county, Guangdong Province

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Abstract. Yangshan County has abundant low-geothermal resources in its northeast, southwest, and midwest regions. These low-temperature geothermal resources in Yangshan County can prove to be beneficial for different purposes such as tourism, recuperation, sauna, and agriculture. Thirteen geothermal hot springs (spots) and seven geothermal anomalies have been discovered till now in this area. The geothermal resources are grouped on the basis of their conditions as follows: The Chengjia–Dianzhan and Dongguan–Jietan geothermal areas are classified as priority development zones, the Huangben–Mazishui and Qigongyuntankeng areas as sub-priority development zones, the Jiangying geothermal area as a general development zone, the Yangshan geothermal area as a potential development zone, and the Chengjia and Longfeng geothermal areas as restricted development zones.

1. Introduction
Geothermal energy is a pollution-free energy source. Few industries such as agriculture, cultivation, and tourism, have taken advantage of this energy source [1-3]. The geothermal resources in the Yangshan County follow the distribution of regional geothermal sources, which is related to the regional structure and batholiths. Yangshan County has relatively better geological conditions and geothermal resource distribution in its northeast, southwest, and midwest regions than in the remaining parts of the County. Thirteen hot springs (spots) and seven geothermally anomalous areas have been discovered till now in these areas. The Chengjia, Longfeng, Qigongyuntankeng, and Huangben hot springs are presently under development, whereas the rest are not in use or possess deep-seated geothermal resources, e.g., the Mazishui, Jiangyingyankou, Leigongkeng, Dongguan, and Jietan hot springs. Overall, the geothermal exploration in the Yangshan County has been limited to the discovery of only two sites till now. The development and utilization of these resources is limited to tourism and does not extend to industrial and agricultural activities or residential heating [4-8]. Environmental protection measures are not efficiently followed and there is a lack of environmental monitoring and protection measures.

2. Geothermal resource development and utilization
The utilization of geothermal resources depends on the temperature and the quantity and quality of the source water. Based on the temperature classification in the “Geological Exploration Standard of Geothermal Resources” (GB/T 11615-2010), the geothermal resources in the Yangshan County can be primarily classified as low-temperature geothermal resources. These resources can be used directly for...
tourism, recuperation, and agriculture after accounting for the environment, industrial structure, and economic development of the County.

1) Tourism
   Tourism is a major industry, pursued by the County, where the geothermal resources can be utilized. The 13th Five-Year Plan for the economic and social Development of the Yangshan County emphasizes upon the development of ecotourism and modern agriculture as well as the need to promote industrial development activities.

2) Agriculture
   The low-temperature geothermal resources in the County are suitable for the cultivation of vegetables, fungi, and flora and also for the hatching of bird eggs in greenhouses.

3) Geothermal water drilling, intake, and heating
   Geothermal water drilling and heating is a possible use of the geothermal water resources distributed in the County. The Chengjia Village in the Yangshan County has cold winters; hence, geothermal energy can be used for heating residences and industrial facilities. Further investigation of the geothermal resources and drilling for geothermal water intake and heating will improve the utilization of hot springs in the surrounding towns and villages.

3. Geothermal resources
   Multiple factors such as the scale, temperature, depth of geothermal reservoir, geothermal water yield, location of the field, and natural topography and environment are taken into consideration for evaluating the development and utility value of a geothermal field [9-10]. In this study, the geothermally anomalous areas of Chengjia, Dongguan–Shiluo, Huangben–Mazishui, Qigong, Jiangying, Leigongkeng, and Chengjiadi–Longfengdi were evaluated and divided into different categories.

1) Chengjia geothermal zone
   It is located along the secondary EW-striking fault within the inner contact zone of the Dadongshan rock massif, which is a part of the northern extension of the NE-striking Chengjia–Qigong fault zone. The Paleozoic outcrop majorly consists of limestone and quartz-sandstone. Massive intermediate felsic intrusive rocks from the Yanshanian age are also observed. After the Palaeozoic outcrop, the sedimentation-cover layer is limited and represents the deposits of a long-lasting uplift. The major structures include the NE-striking structures, the contact zone of the rock massif, the EW-striking structures, and the Neo-Cathaysian structures. These structures form a complicated structural condition beneficial to the generation of geothermal fluids. In short, this zone has excellent geothermal conditions and shows good potential for further geothermal development. The hydrochemistry is of the HCO3–Na•Ca type with relatively high levels of fluorine that reach the concentration levels similar to that in mineral water used for physiotherapy. Thus, it can be named as fluorine water, with high physiotherapy-utilization value. There are two geothermal areas in this zone. The first is the Chengjia hot spring, which is developed and utilized, and the second is the recently discovered Dianzhan hot spring. This zone has a very high tourism potential as it is well-connected to the Shaoguan area in the east. There are many scenic areas such as the Chengjia natural reserve park and the Top Mountain of Guangdong. The geothermal resources of the Chengjia hot spring area are limited; hence, the existing scenic areas and parks need to be well-protected while undertaking the developmental activities by accounting for the natural flow of the geothermal waters in the design. Further geothermal exploration needs to be done to investigate the occurrence and characteristics of the geothermal resources in this zone without compromising on the protection measures for the existing Chengjia hot spring. A third industrial chain can be created with the hot spring at the opening by combining the development of saunas and outdoor adventure activities and using the residual geothermal water for agriculture.

2) Dongguan–Shiluo geothermal zone
   It is located at the upstream of the Xiaobeijiang River, in the middle of the NW-striking Shuikou–Shiluo fault and in the northern part of the NE-striking fault. The geothermal reservoir consists of Carboniferous limestone. The zone is located at the intersection of the NE- and NW-striking structures and has favorable geological conditions. The hydrothermal activity within the zone is vigorous.
There are four or five geothermal hot springs (spots) with warm geothermal waters having temperatures ranging between 40°C and 57°C. Only the Longfeng and Shiluo hot springs have been explored till now. The waters are of calcium-sulfate-type and rich in trace elements such as metasilicic acid, fluorine, and strontium. It can be named as fluorine water or strontium-rich spring. The water quality and degree of utilization are high.

The geothermal anomaly is 20–30 km away from the Yangshan area with relatively good accessibility. The Longfeng spring in the Reshui Village of the Yangshan County along the bank of the Xiaobeijiang River is a scenic spot and has a high tourism potential.

The other hot springs are not as well-explored and are in the deeper parts of the area. Overall, this zone can be developed for leisure, recuperation, and business tourism.

3) Huangben–Mazishui geothermal zone

It is located on the NW-trending fault zone and along the northern and southern parts of the NE-striking Chengjia–Qigong Fault. The outcrop of this zone, which is a part of a collapsed basin filled with Quaternary sediments, contains Late Paleozoic limestone and quartz-sandstone. The major structures in the area are the NW-trending Qinglian–Dadongshan Fault and the NE-trending Dadongshu–Ouwu structure belt. These relatively large-scale faults provide the necessary conditions for the occurrence and formation of geothermal fluids. The NW-trending Huangben–Lingbei–Mazishui belt intersects with the NE-trending Chengjia belt in the Lingbei area. It was initially thought that there were undiscovered geothermal resources in the NW direction, especially around the Lingbei area.

Three geothermal spots are found in this zone despite the lack of extensive geothermal exploration; the low-temperature (33–35°C) Huangben hot spring and the warm (43°C) Mazishui hot spring. The hydrochemistry of the Huangben and Mazishui hot springs is of the HCO₃–Ca type. The fluorine content of the Huangben hot spring is 0.664 mg/L, whereas that of the Mazishui hot spring is 0.89 mg/L. The low concentration of fluorine is attributed to the mixing with shallow cold water during surface water sampling. The fluorine concentration might change if water samples are obtained from deeper parts of the spring. The metasilicic acid content is higher in the Mazishui hot spring (38 mg/L).

The Huangben and Mazushui hot springs have no direct access to roads but trails are available. The geothermal potential of the hot springs needs to be investigated. The Huangben Gaolan and Huangben Linchang hot springs can be used for aquaculture, greenhouse cultivation, and irrigation activities. The Mazishui hot spring can be developed for recuperation and tourism with some modification of the existing facilities; however, new heat sources need to be identified.

4) Qigong geothermal zone

It is located in the inner contact zone of the Lianyang rock massif in the southern part of the Yangshan County. The NE-striking Chengjia–Qigong Fault is the largest fault in this area that controls the distribution of the geothermal hot springs. There are two geothermal hot springs (spots) in this zone. The Yuntangkeng hot spring with water temperatures of 46–47°C and the Huangshakeng hot spring, a seasonal hot spring located northeast of the Yuntangkeng hot spring and with better geothermal conditions. There is no exploration activity conducted in this geothermal zone till now.

The hydrochemistry of the zone is of the HCO₃–SO₄–Na•Ca-type, and the concentrations of trace elements such as fluorine, metasilicic acid, and radon are similar to those of the thermal mineral water for physiotherapy; the waters thus have high physiotherapy value and are well utilized. The Yuntangkeng and Huangshakeng hot springs in the Qigong geothermal zone are 6 km from the town of Qigong and are connected by a country road.

5) Jiangying geothermal zone

It is located in the southern limb of the Yankou Syncline in the northeastern parts of the Jiangying Town. The bedrock consists of Carboniferous carbonates. A low-temperature (29–35 °C) hot spring is found in this zone. The permitted heat withdrawal and geothermal fluid withdrawal capacities are 6.10 × 1010 kJ/a and 132 × 104 m³/a, respectively. The hydrochemistry of the hot spring is of the calcium–magnesium carbonate type and it is suitable for aquaculture and irrigation activities.

6) Leigongkeng geothermal zone
It is located on the secondary EW-striking fault zone and on the southwestern side of the NE-striking fault belt in the Yangshan Basin. The EW-striking fault contains sandstone and quartz-sandstone in the north and limestone in the south. One geothermal hot spring is found in this zone, with water temperature in the range of 27–29°C. This zone has not been officially explored yet. The current potential is low as it might be a deep-seated resource. There is an investment risk involved because of the unfavorable geological conditions; therefore, it has been suggested to locally explore the area and investigate the current economic conditions before undertaking any developmental activities. Overall, the Leigongkeng geothermal zone has some potential.

7) Chengjia and Longfeng geothermal fields

The geological exploration of these geothermal fields has been concluded and the fields are already in use. They belong to a resource-protected mining area but are within the monitoring range of the groundwater and surface water environments.

In summary, the six geothermal anomalous zones were categorized into five groups, ranging from priority development zone to restricted development zone, on the basis of their hydrothermal fluid characteristics and according to the local economic status.

1) Priority development zone: The Chengjia geothermal anomalous zone (except the Chengjia hot spring) and the Dongguan–Shiluo anomalous zone (except the Longfeng hot spring) are rich in geothermal resources, have thick geothermal reservoirs, and large water withdrawal capacities. Moreover, they are evenly distributed and shallow, which facilitates their development. These two fields have huge geothermal potential, are accessible and scenic, and can be further developed. The priority exploration and development at the outbound areas is suggested to follow the heat-controlling structures and should proceed without affecting the Chengjia and Longfeng hot springs.

2) Subpriority development zone: The Huangben–Mazishui geothermal anomalous zone and the Qigong–Yuntangkeng geothermal field are relatively rich in geothermal resources, evenly distributed, and have a thick geothermal reservoir and large water withdrawal capacity. The shallow resources are easy to develop but they are placed in this group because they are not easily accessible.

3) General development zone: The Jiangying–Yankou geothermal anomalous zone has low water temperature and is inaccessible; however, it can be developed and utilized.

4) Potential development zone: The deep-seated Leigongkeng geothermal anomalous zone needs to be further studied prior to its development and utilization.

5) Restricted development zone: The exploration of the Longfeng and Chengjia geothermal fields has been concluded and they are already in the development and utilization stage. The exploration of the surrounding fields needs to be stopped to prevent duplication of activities.

4. Conclusion

The Yangshan County is rich in geothermal resources that can be utilized for tourism, recuperation, sauna, agriculture, and aquaculture activities. The geothermal resources are distributed in the northeastern, southwestern, and midwestern areas, with thirteen geothermal hot springs (spots) and seven geothermal anomalous zones discovered till now. The Chengjia and Dongguan–Shiluo geothermal fields are grouped into the priority development zone; the Huangben–Mazishui geothermal anomalous zone and Qigong Yuntankeng geothermal field belong to the subpriority development zone; the Jiangying–Yankou geothermal anomalous zone belongs to the general development zone; the Leigongkeng geothermal anomalous zone belongs to the potential development zone; and the Longfeng and Chengjia geothermal fields belong to the restricted development zone.

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