DESIGN METHODOLOGY FOR ASSESSMENT AND RANKING OF GEOTHERMAL RESOURCES: A CASE STUDY OF SOUTHERN THAILAND

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ABSTRACT

Low-temperature geothermal systems are widespread in sedimentary formations of continental regions of the Earth's crust, and through efficient low enthalpy technology nowadays these renewable geothermal energy resources can be accessed and utilized. However, as the potential of different geothermal sites might vary an evaluation and ranking is necessary, which requires reliable estimates about heat source and reservoir characteristics. In case well data for a site are already available, a relatively straightforward and established methodology is available to develop these estimates. But for many sites adequate well or subsurface data in general, like temperature gradient, reservoir temperature, and hot water flow rates, for example, is often not available, like for all hot spring sites in Southern Thailand. Hence, for these sites, a preference analysis via a positive attitude factor analysis was applied that uses all available data and information classified into four fractions combining altogether 20 factors: (1) all available exploration efforts, (2) available heat sources and reservoir data, (3) land use parameter, including geological hazards, and (4) market factors, including proximity to possible market. Ranking criteria are given to each factor to indicate its relative importance in the assessment. Normalized scores of the positive attitude factors method are given from 3 (highest) to 1 (lowest), which are independent variables that relate to the characterization of each factor. Subsequently, the scores of all factors will be summarized into a total score, which is an indication if a site has a good potential to be developed or not; a higher total score is better than a lower one. A final ranking for the hot springs in Southern Thailand shows that out of 30 sites currently two hot springs sites have a good potential, both in terms of geothermal resources and economic availabilities for further development.

Keywords: hot spring; assessment; ranking; net generated electric power; Southern Thailand

1. Geothermal Resources in Southern Thailand

At least 30 hot spring sites in Southern Thailand are located in eight geothermal systems which consist of Chumphon (CP), Ranong (RN), Surat Thani (SR), Phang Nga (PG), Krabi (KB), Trang (TR), Phatthalung (PL), and Yala (YL) shown in Figure 1, Figure 2, and Table 1. Surface discharge temperatures are between 40 and 80 °C. A summary of information for each geothermal system in the southern region is briefly given as followed.

Chumphon Geothermal System (CP)

CP system is located in Chumphon Province, northern part of Surat-Thani geothermal system represented by Figure 1 and 2a, and Table 1. Natural hot springs of more than three pools developed for tourist attractions have surface discharge temperatures ranging from 45 and 50 °C. Local geology at the hot spring and surrounding area is represented by Permian dolomitic limestone (Bhongsuwan and Auisui, 2015).

Ranong Geothermal System (RN)

RN system as one of the larger geothermal systems in the southern region is located in Ranong Province and famed for natural hot springs, thus drawing attention to local visitors and foreign tourists as shown in Figure 1 and 2b, and Table 1. Altogether seven hot spring sites are located in the RN system, which have the surface discharge temperatures between 40 and 75 °C (Khoonphunnarai et al., 2007; Chaturongkawanich and Leevongchareon, 2000). RN1 and RN6 sites have the highest temperature of this system. RN1 site is praised as a famous landmark of Ranong City, also providing spa and hot massage therapy nearby. RN6 site was discovered in deep forest of Kapoe District located about 60 km south of Ranong City; the site is protected by the Ranong Forest Preservation and Protection Division. All hot spring sites of the RN system are located close to the Ranong Fault Zone, a major NNE-SSW trending strike-slip fault (Khoonphunnarai et al., 2007; Sanmuang et al., 2007).

Surat Thani Geothermal System (SR)

SR system is located in the western part of the southern region with altogether nine hot spring sites recorded. The surface discharge temperatures range from 40 to 70 °C, while SR3, SR7, and SR9 sites show the highest surface discharge temperature of this system as presented in Figure 1 and 2c, and Table 1. SR3 is in Tha Chang District located on public land in close proximity to the main railway line from Bangkok to HatYai, and also relatively close to the Gulf of Thailand. SR7 is in Phunphin District and it is already developed for tourism; its larger pond is already visible from the main road, while SR9 in Khian Sa District is located in a national park. The general geology surrounding the SR system is characterized by isolated steep sided hills of Permian limestone tower karsts and granitic mountains on western margins (Khawdee et al., 2007).

Phang Nga Geothermal System (PG)

PG system is located on the western side of the southern region, about 100 km north of Phuket City represented by Figure 1 and 2d, and Table 1. At least three hot spring sites can be found in this system, with surface discharge temperatures recorded from 45 to 78 °C (Ngansom et al., 2016; Ngansom et al., 2017) with only one site, PG1, has the surface discharge temperature of up to 78 °C. PG1 site can be found close to and at the banks of the Pai Phu River. Rocks in and around the PG1 site are dominantly granites, which are distributed in the southeastern part and sedimentary/metamorphic rock unit, which covers other parts (Duerrast et al., 2016; Ngansom et al., 2017).

Krabi Geothermal System (KB)

KB system located in the western part of the southern region, connected to the Andaman Sea, consists of at least five hot spring sites located in the system shown in Figure 1 and 2e, and Table 1. Surface discharge temperatures are recorded from 40 to 46 °C. Most of the hot spring sites are famous across the borders for their natural beauty such as the Saline Hot Spring Khlong Thom (KB4), the Hot Waterfall (KB5), and also Krabi Hot Spring (KB3). The geothermal system KB4 site has been identified for its complex geothermal setting (Ngansom and Durrast 2016), as it has both saline and hot water represented in one system.

Trang Geothermal System (TR)

TR system is located further south of the Krabi geothermal system, about 140 km, as shown in Figure 1 and 2f, and Table 1. Natural hot springs with at least three pools can be visited as they are developed as a tourist attraction and integrated with a Thai Massage School supported by the Local Administration Organization. Surface discharge temperatures range from 45 to 50 °C (Ramingwong et al., 2000). Surface geological surveys show sandstone outcrops both inside and outside the hot spring area.

Phatthalung Geothermal System (PL)

PL system is located in Phatthalung Province, about 84 km east of Trang geothermal system represented by Figure 1 and 2g, and Table 1. There are four hot spring sites with surface discharge temperatures between 41 and 57 °C recorded for this system. The general geological setting exposed rocks in the range from Cambrian to Quaternary. Cambrian rocks comprise of white to light gray colored fine grained sandstone and quartzite and Ordovician rocks compose of mainly gray colored, finely crystalline to coarse grain limestone (Jonjana et al., 2012).

Yala Geothermal System (YL)

Yala system is located in the southernmost part of Thailand near the border to Malaysia represented by Figure 1 and 2h, and Table 1. Detailed investigations of this site have been affected by continuous armed conflicts in this area since 2004; therefore geological and geophysical surveys data are limited. However, YL site is a famous tourist attraction, mainly for Malaysian guests; the surface discharge temperature is 80°C (Ramingwong et al., 2000).

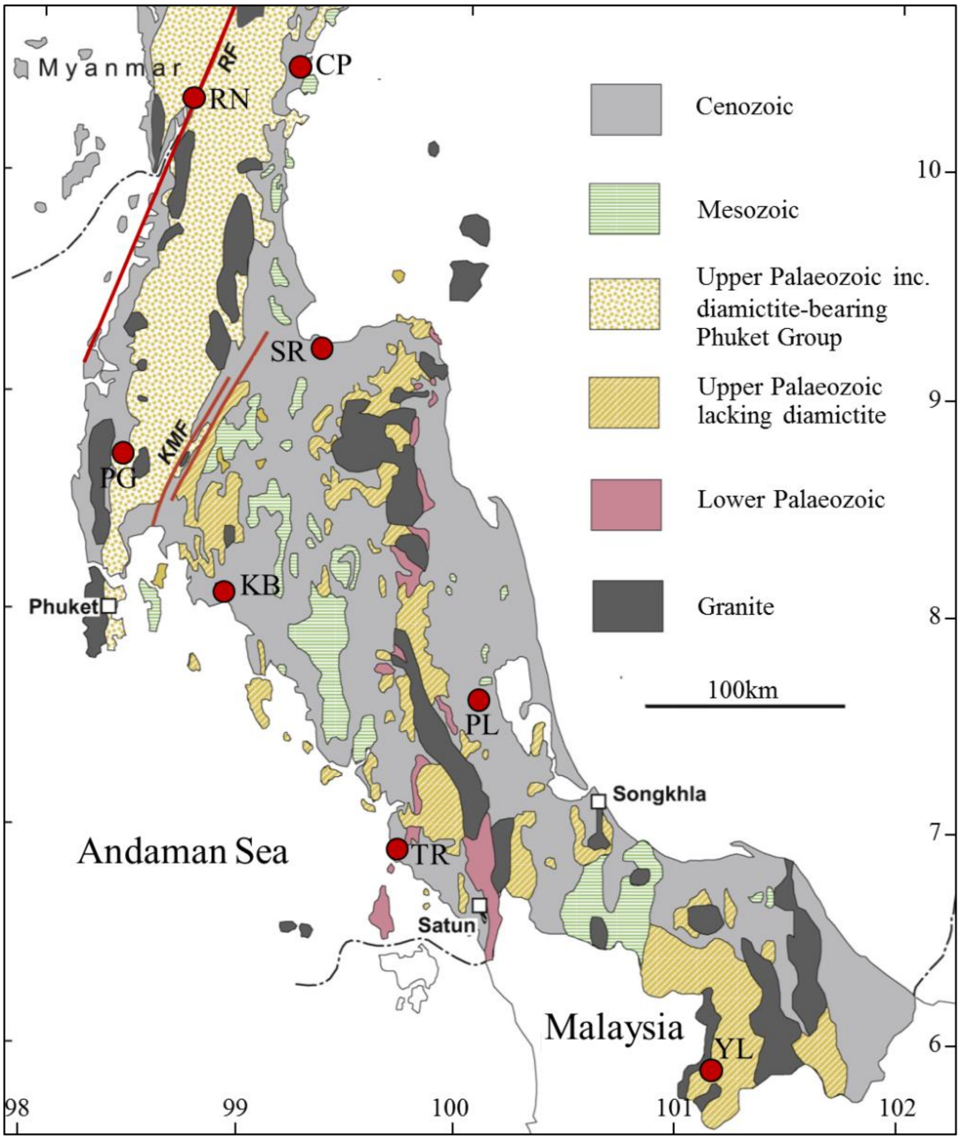

Figure 1 Simplified geological map of and locations of geothermal hot spring systems in Southern Thailand (modified from DMR, 1975; Ridd and Watkinson, 2013);

CP – Chumphon Geothermal System
RN –Ranong Geothermal System
SR – Surat Thani Geothermal System
PG – Phang Nga Geothermal System
KB – Krabi Geothermal System
TR – Trang Geothermal System
PL – Phatthalung Geothermal System
YL – Yala Geothermal System
RF – Ranong Fault Zone
KMF – Khlong Marui Fault Zone.

Figure 2 Geothermal hot springs in Southern Thailand; (a) Chumphon hot spring, (b) RN1 site of Ranong system, (c) SR7 site of Surat Thani system, (d) PG1 site of Phang Nga system, (e) KB4 site of Krabi system, (f) Trang hot spring, (g) PL1 site of Phatthalung system and (h) Yala hot spring.

Table 1 Locations and surface discharge temperatures of geothermal hot spring systems in Southern Thailand

Hot spring system	**UTM (WGS-84), Zone 47**		**Surface Temp. (°C)**
	East (m)	North (m)	
Chumphon: CP	512222	1075014	50
Ranong			
RN1	462169	1100516	65
RN2	460000	1094700	40
RN3	461030	1093400	45
RN4	462290	1094275	50
RN5	456192	1080300	46
RN6	470810	1060430	75
Surat Thani			
SR1	521107	1034893	45
SR2	520518	1033905	40
SR3	522412	1031459	60
SR4	555129	1009502	41
SR5	545897	972938	42
SR6	503522	979890	53
SR7	529417	991895	70
SR8	530806	991094	56
SR9	524947	977116	62
Phang Nga			
PG1	441455	960807	78
PG2	437870	975306	55
PG3	420496	918037	45
Krabi			
KB1	499622	900439	45
KB2	500183	891731	47
KB3	510462	888220	45
KB4	512329	873475	47
KB5	523171	876867	47
Trang: TR	551391	818787	52
Phatthalung			
PL1	625096	823266	57
PL2	608944	810077	46
PL3	604490	816432	50
PL4	615661	850513	41
Yala: YL	729730	646758	80

2. Southern Thailand Geothermal Assessment

2.1 Conceptual design

As the potential of the 30 different geothermal sites in Southern Thailand might vary an evaluation and ranking was necessary, which requires reliable estimates about heat source and reservoir characteristics. In case well data for a site would be available, a relatively straightforward and established methodology is available to develop these estimates. But for hot spring sites in Southern Thailand well or subsurface data, like temperature gradient, reservoir temperature, and hot water flow rates, for example, is often not available. Therefore, a preference analysis based on all available data was necessary as outlined in Fig. 3. A set of parameters, selection criteria utilizing positive attitude factors, has been established for this study to determine which sites have a good potential and thus should be further characterized in detail.

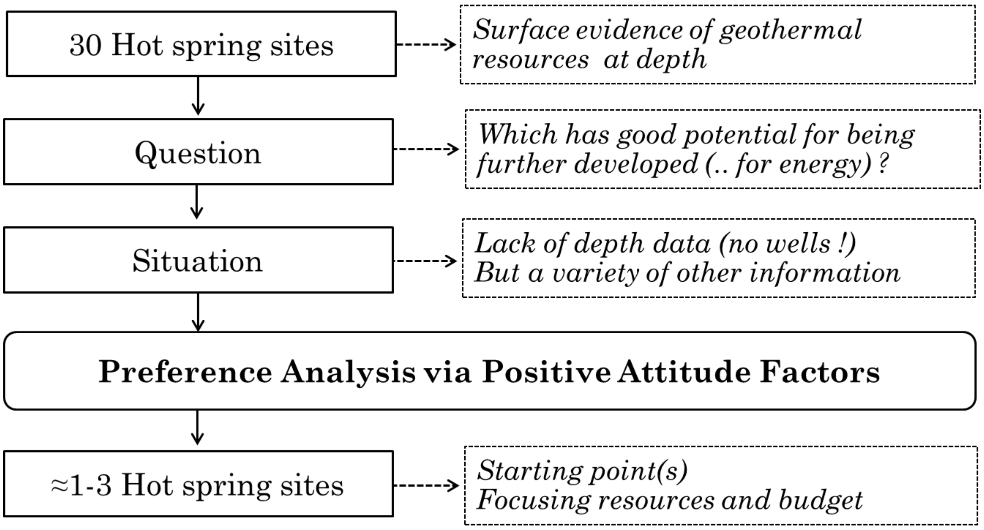

Figure 3 Conceptual design of Southern Thailand geothermal assessment

2.2 Preference Analysis

The preference analysis was designed in three steps: Step 1 initially separates favorable hot springs by using a surface discharge temperature of equal or more than 60 °C and a silica geothermometer of the reservoir temperature of equal or more than 100 °C (Fig. 4). For the remaining hot spring sites Step 2 with the positive attitude factors was applied (see Section 2.3). For Step 3, the percentage of each fractional score of the land and exploration factors was set ≥80%, whereas for reservoir and marketing factors the value was set lower, ≥60%, as for the latter two less data were available (Fig. 4). After Step 3 all hot spring sites were separated in sites currently favorable for geothermal resource based electricity generation and in sites currently only possible for direct use (Fig. 4).

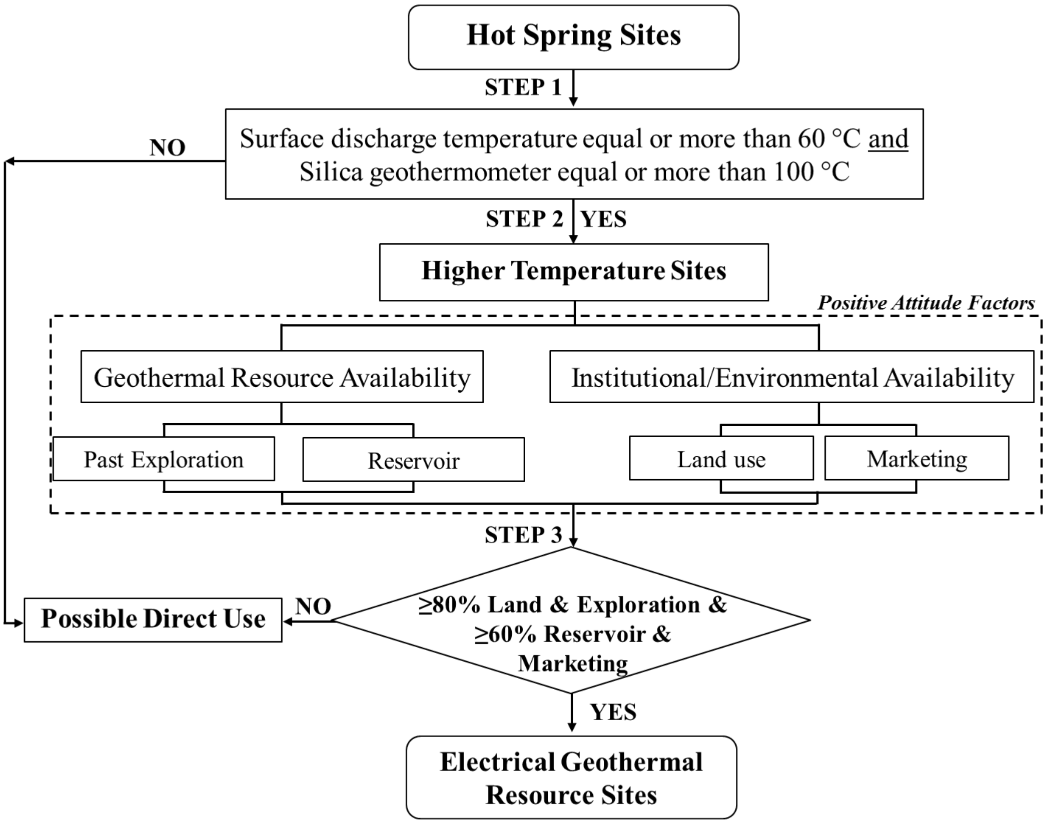

Figure 4 Preference analysis flowcharts

2.3 Factor Analysis and Normalized Scores

The preference analysis is using the co called "positive attitude factors" (Step 2), which can be divided into four broad concerns (fractions): (1) land use, (2) exploration, (3) reservoir, and (4) market factors; Table 2. Ranking criteria are given to each variable to indicate its relative importance in the assessment (Bignall and Sanders, 2016). Normalized scores of the positive attitude factors method are given from 3 (highest) to 1 (lowest), which are independent variables that relate to the characterization of each factor (Table 2). All scores should not be strictly interpreted because uncertainties may exist in the assignment of the numbers. In the following ranking criteria and weights procedure are given and explained in detail. Numbers in brackets are the normalized scores assigned to each factor.

Table 2 Factor analysis and normalized scores of the positive attitude factor analysis

Positive attitude factors list (total score: 60 points)	**Normalized scores** (3)	(2)	(1)
1) Land uses availability (15 points)			
1.1) Accessibility factors	main road or highway	paved road	rural non-paved road
1.2) Terrain factors	flat or almost flat topography	hilly, forest, or mangrove	mountainous
1.3) Risk of natural hazards factors	never	non-frequent events	more frequent events
1.4) Security factors	no security incidents	security incidents from time to time	security incidents occur monthly
1.5) Owner attitude factors	strongly agree	agree	indifferent
2) Exploration availability (9 points)			
2.1) Geological factors	complete data, surface, shallow, and deep	almost complete: surface or shallow or deeper	incomplete, or no data available
2.2) Geophysical factors	complete: surface, shallow, and deeper data	complete: surface or shallow or deeper data	incomplete, or no data
2.3) Geochemical factors	complete isotope data	cation/anion composition, geothermometer data	no data
3) Reservoir availability (21 points)			
3.1) Areal extension (surface) factors	large-surface; $\geq$ 1 km^2	medium-surface; >0.5 to <1 km^2	small-surface; <0.5 km^2
3.2) Exit temperature factors	high-surface discharge; ≥80 °C	intermediate-surface discharge; >70 °C to <80 °C	low-surface discharge; 60 °C to <70 °C
3.3) Reservoir temperature factors	high-temperature systems; ≥150 °C	intermediate-temperature systems; 150 °C to ≥90 °C	low-temperature systems; <90 °C
3.4) Surface fluid flow factors	higher flow rates; ≥1 L/s	lower flow rates; >0.1 L/s to <1 L/s	no data
3.5) Structural control (fault) factors	main large faults or fractures	subordinate faults or fractures	no faults or fractures
3.6) Heat source factors	only granite settings	granite and sedimentary /metamorphic settings	only sedimentary/metamorphic settings
3.7) Drilling depth factors	< 150m	> 150 m to < 500 m	≥ 500 m
4) Marketing availability (15 points)			
4.1) Distance to higher voltage power lines	close-less; <500 m	≥500 m to < 1,000 m	far-exceeding; > 1000 m
4.2) Terrain of power line corridor	flat or almost flat topography	hilly, forest or mangrove	mountainous terrain
4.3) Terrain of development site	flat or almost flat topography	hilly, forest or mangrove	mountainous terrain
4.4) Distance to heating load	close-less; <200 m	≥200 m to < 5,00 m	far-exceeding; > 500 m
4.5) Proximity to market	close-less; <20 km	≥20 km to < 50 km	far-exceeding; > 50 km

3. Assessment Results

After applying the temperature criteria to all 30 hot springs in Southern Thailand (Step 1), seven remained for the positive factor analysis in Step 2 (see Fig. 5). After that for each fractional score a minimum value in percentage was assigned (Step 3). For land and exploration factors the value was set by ≥80%, whereas for reservoir and marketing factors the value was set lower, ≥60%, as for the latter two less data were available (Fig. 5). If values were above the threshold the site was given a positive mark and all marks were added. Results can be classified into three groups; hereinafter, RN1 and PG1 as good starting points for further work and potential sites for electricity production; RN6, SR3, and SR7 arbitrarily considered having an average or minor chance, and SR9 and YL1 show a poor chance (Fig. 5). However, if in the future more data might be available the assessment outcome might change, thus the assessment reflects the current situation.

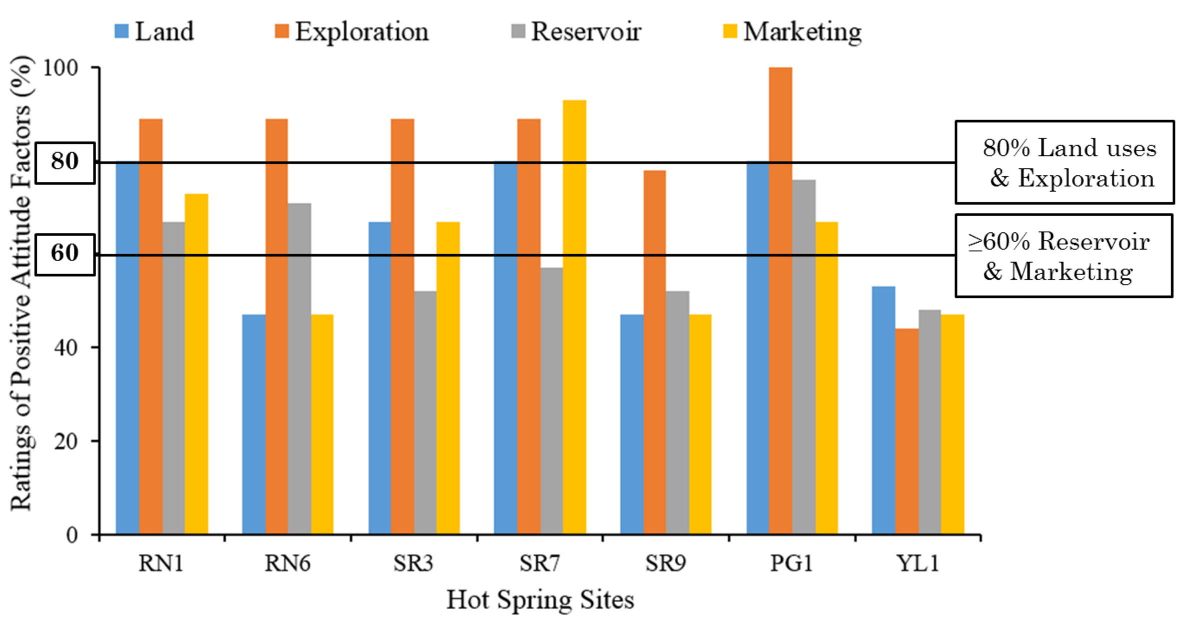

Figure 5 Ratings of geothermal hot springs with positive attitude factors; Ranong geothermal system, RN1 and RN6, Surat Thani, SR3, SR7 and SR9, Phang Nga, PG1, and Yala, YL1

4. Discussion and Conclusions

The assessment and subsequent ranking of all hot spring sites in Southern Thailand is based on scientific measurements as well as on qualitative judgments made by the researchers involved. Therefore, the positional ranking of geothermal sites might not be very robust (sensitive) to uncertainties and to the quality of data used for such an assessment, but it is relatively robust to provide a quantitative assessment, which can be easier translated into economic values and financial risks. It should be noted that the ranking presented here is somewhat subjective since it uses researchers for qualitative evaluations. To a certain extent this opinion may be incorrect or biased – minimized trough team approach - or does not fully reflect the actual conditions. As many assumptions are used for individual site assessments, such as depth of reservoir, flow rates, it would be preferable if more precise data were known. Generally, methods employed here might create a bias in favor of sites with more complete information since the certainty of the inputs is more favorable. There are specific sites where additional new data could alter some of the results presented here (Fig.6). Even though authors were aware of that the results presented here can be used as a guide for a future definition of sites that should receive further attention and study.

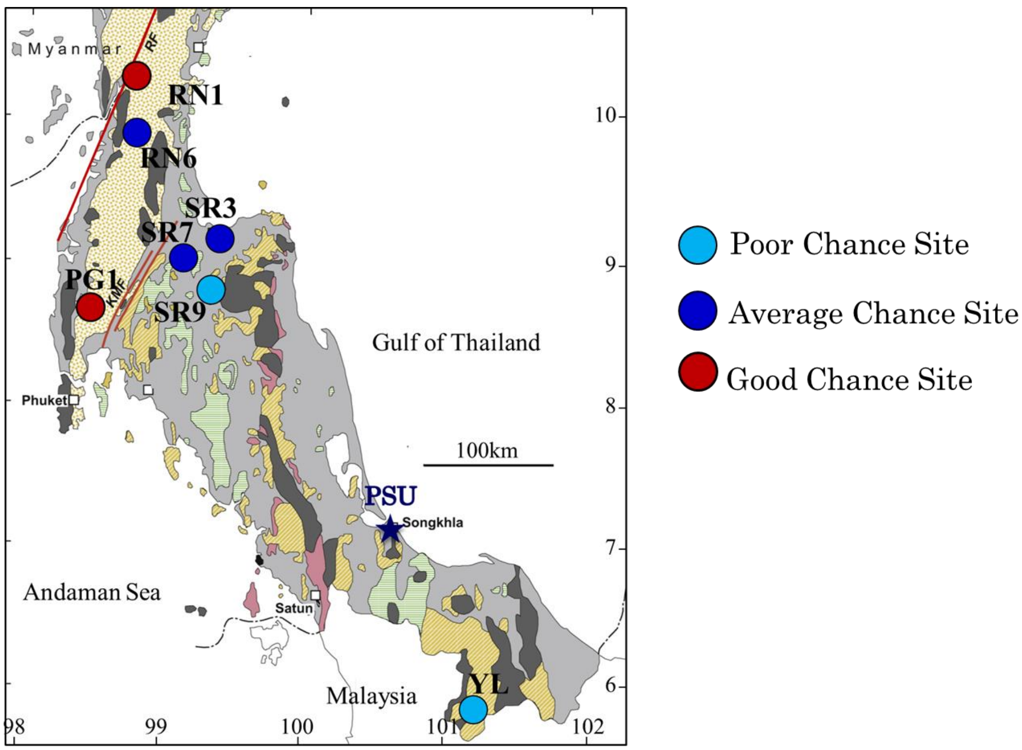

Figure 6 Results of geothermal hot spring assessment in Southern Thailand

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