HYDROLOGICAL AND THERMAL RELATIONSHIP BETWEEN GEOTERHMAL RESERVOIR AND NEARBY AQUIFER IDENTIFIED BY GEOCHEMICAL CHARACTERISTIC OF THE AQUIFER

Kasumi YASUKAWA[1] and Tetsuro NODA[2]
[1]Renewable Energy Center, AIST, 2-2-9 Machiikedai, Koriyama, Fukushima, 963-0298, Japan
[2]Institute for Geo-resources and Environment, AIST, 1-1-3 Higashi, Tsukuba, Ibaraki 305-8567, Japan
e-mail: kasumi-yasukawa@aist.go.jp

ABSTRACT

To estimate possible influence of geothermal development onto nearby hot spring aquifer, a criterion based on geochemical characteristic of the aquifer was developed. Hydrological and thermal connection of a geothermal reservoir to nearby aquifer may be expressed by five types of simplified structure models, which are, identical system, water supply system, steam supply system, heat conduction system and independent system. Recommended monitoring items for protection of hot spring resource are different for each type because possible interferences by geothermal development are different for each type. For volcanic resources, the relationship between a specific geothermal reservoir and a nearby aquifer may be roughly estimated by temperature and anion characteristics of the hot spring. In a former study, a criteria to judge such types was developed based on geochemical data. However, categorization into five types was not quite successful because geochemical characteristics of hot springs are not well represented by only five types although hydrological relationship is well described by five types. Consideration in geometrical setting of the aquifer and the geothermal reservoir is needed as well. Therefore in this study, a new criteria was developed by adding two new types, volcanic gas supply and CO_2 supply from rock, resulting in seven types in total. Geometrical settings is also taken in consideration. The threshold values in this criteria were set based on geochemical data taken from hot spring wells and natural manifestations all over Japan. Then a data set of hot springs in Kuju region, Oita, Japan was applied to the criteria, for which all seven types were identified. The new criteria, which enables protection of aquifer and geothermal development as well, may be applied for other volcanic regions.

Keywords: hot spring aquifer, geothermal reservoir, interference, criteria, anion, geochemistry, Kuju

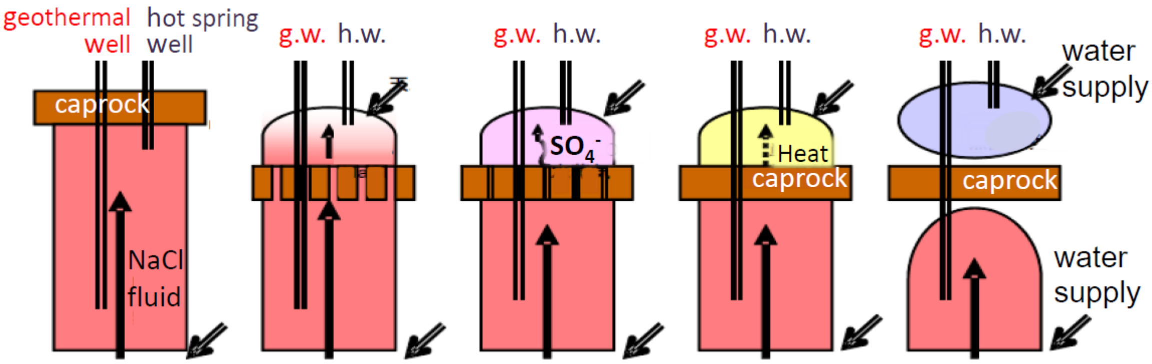
1. INTRODUCTION

Agreement with local society is essential for developments of a new geothermal power plant. For its achievement, environmental protection is a matter of importance and interference to nearby hydraulic system by should be avoided. Logically there should not be an interference if natural heat and fluid recharges and its utilization are well balanced or if a solid impermeable zone exists between a geothermal reservoir and its neighboring hydraulic systems. To materialize this idea, a three-year research project “Development of geothermal reservoir management system for harmonious utilization with hot spring resources” was conducted in FY2010-2012 (AIST, 2013).

In the project, relationship between geothermal reservoir and hot spring aquifer were carefully investigated for two model fields through geoscientific surveys (Yasukawa et al., 2013). However in real developments, such intensive site surveys may not be economically feasible and developers may want to know the possibility of interference before investing for exploration. Therefore a prototype software was developed to automatically estimate relationship between them by use of geochemical data of hot springs. The software identifies types of relationship to give advises on monitoring items. However, since the prototype software had problems in type identification, some improvements were made after the project was over. This paper describes those improvements in type identification method and shows its application to a real data set.

2. HYDROLOGICAL CONNECTION BETWEEN A HOT SPRING AQUIFER AND A GEOTHERMAL RESERVOIR

The type of hot spring aquifer in relation with geothermal reservoir may be schematically categorized into five as shown in Fig. 2 (GRSJ, 2010**)**. Type 1 is an identical geothermal reservoir and aquifer system, in which only depths of geothermal well and hot spring well would be different. Type 2 has a cap rock beneath the aquifer, but it is slightly permeable so that the water in the aquifer is partly supplied from deep reservoir. Type 3 has more solid cap rock through which water may not permeate but steam and gas may, so that the aquifer has gas content supplied from deep reservoir. Type 4 has an impermeable cap rock through which only heat conducts from deep reservoir. Type 5 shows independent hot spring aquifer and geothermal system, which are geometrically separated, i.e., thermally and hydrologically insulated.



Type 1
Identical System

Type 2
Water Supply from Deep Reservoir

Type 3
Gas Supply from Deep Reservoir

Type 4
Heat Conduction System

Type 5
Independent Systems

Fig.1 Five types of hydrological relationship of geothermal reservoir to hot spring aquifer (GRSJ, 2010)

Table 1 shows possible interference of geothermal development to hot spring aquifer for each type. For Types 1 and 2, a geothermal development may seriously interfere hot spring aquifer if the amount of fluid extraction exceeds the natural recharge. For Types 3 and 4, a geothermal development may not affect hot springs at least in terms of flow rate. In case of Type 5, a development should not affect.

Table 1 Possible interference of geothermal development onto different types of aquifers (modified from Yasukawa et al., 2015)

Type	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type5**
Relation with geothermal reservoir	Identical system	Water supply from deep reservoir	Steam supply from deep reservoir	Heat conduction system	Independent systems
Possibility of interference	Large	Medium	Small	Very small	None
Possible major (quick) change	- Flow rate	- Flow rate - Dilution by natural recharge	- Chemistry	-	-
Possible minor (slow) change	- Temperature	- Temperature	- Temperature	-Temperature	-
Other conditional change	- Chemistry (If reinjection affects)	- Chemistry (If reinjection affects)	- Flow rate (If phase change occurs)	-	-

3. GEOCHEMICAL CHARACTERISTICS OF DIFFERENT TYPES OF HOT SPRINGS

Each type of hot spring fluid has different geochemical characteristics because of its relation with the geothermal reservoir. Hot spring water of Type 1 is NaCl dominant and has extremely high Cl^- content and high temperature. Type 2 is also NaCl dominant, but Cl^- content is lower than in Type 1. Type 3 shows SO_4^- dominant chemistry. Type 4 has low total dissolved solids (TDS) and is often HCO_3^- dominant. Type 5 shows chemical characteristics different from Type 1 to 4 and has low temperature.

In the proto-type software, hot springs are categorized into Types 1 to 5 based on the above geochemical characteristics. However in many cases of real data application, errors in type identification occurred. One reason is the lack of consideration in geometrical settings. Another reason is that hot spring fluid often contains high-concentration volcanic gas or CO_2, that makes type identification impossible. Therefore in a new criteria, two additional types are added for a better type analysis as shown in Fig. 2.

One is “CO_2 supply” from surrounding rock as shown in Fig. 2(a). In this case, HCO_3^- content is so dominant that ratio of Cl^- and SO_4^- cannot be evaluated. In terms of relation with deep geothermal reservoir, it could be any of Type 1-5 because mixture of CO_2 gas may occur for any of Type 1-5. Therefore interference of this type is not predictable.

The other one is “volcanic gas supply” from magma as shown in Fig. 2(b). This type may be identified by its low pH although it has Cl^- dominant chemistry as like Type 1 or 2. In terms of relation with deep geothermal reservoir, it is independent system in most cases. However, geothermal fluid of this type is so acid that a geothermal development is not feasible with current technology. Therefore no geothermal development would be proceeded for this type and no influence on hot spring occurs.

The chemical characteristics of hot springs are summarized with required and/or recommended monitoring items related to geothermal development in Table 2.

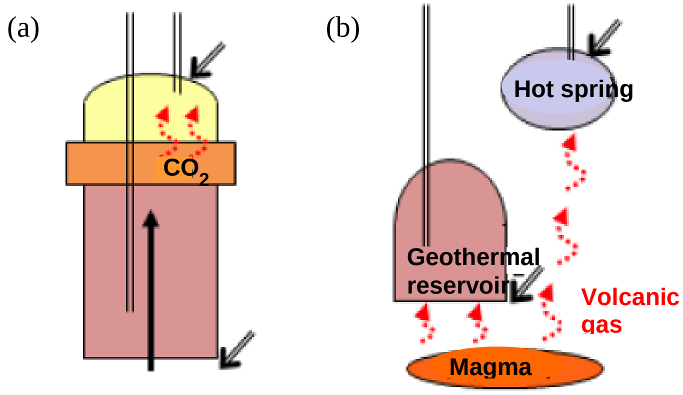


Fig. 2 Additional types: (a) CO_2 supply and (b) Volcanic gas supply from rock

Table 2. Chemical characteristic of different type hot springs and required monitoring

Type	Name of the system	Possibility of Interference	Chemical characteristics	Required (recommended) monitoring item
Type 1	Identical system	High	Cl^-/total anion >80% Temperature >90°C	Flow rate (Temperature)
Type 2	Water supply from deep reservoir	Medium	Cl^- type Temperature >60°C	Flow rate (Temperature) (Electric conductivity)
Type 3	Steam supply from deep reservoir	Low	SO_4^- type	Chemical Component (Temperature)
Type 4	Heat conduction system	Very low	Not Cl^- or SO_4^- type and TDS < 1000 mg/L	(Temperature)
Type 5	Independent system	None	Temperature <60°C and not Cl^-, SO_4^- or HCO_3^- type	None
new	CO_2 supply (from rock)	unpredictable	HCO_3^- type	All (Type should be judged by experts)
new	Volcanic gas supply (from rock)	None	pH<3 and $Cl^->SO_4^-$	None (No geothermal development)

In the new criteria, geometrical setting was also considered as follows:

1. If the horizontal distance from the center of the aquifer to that of the geothermal reservoir is 5 km or longer, it is Type 5.
2. Vertical separation of the aquifer and the reservoir in Type 1 should be shorter than 100 m.
3. Aquifer in Types 3 or 4 overlies geothermal reservoir with vertical separation of 100 m or longer.

Geometrical analysis 1 should be done before type identification by geochemical data while those 2 and 3 should be done after the type identification to confirm its result is appropriate.

Fig. 3 shows the new flowchart of type identification process. The threshold values shown in both Table 2 and Fig. 3 are based on Noda and Takahashi (1992).

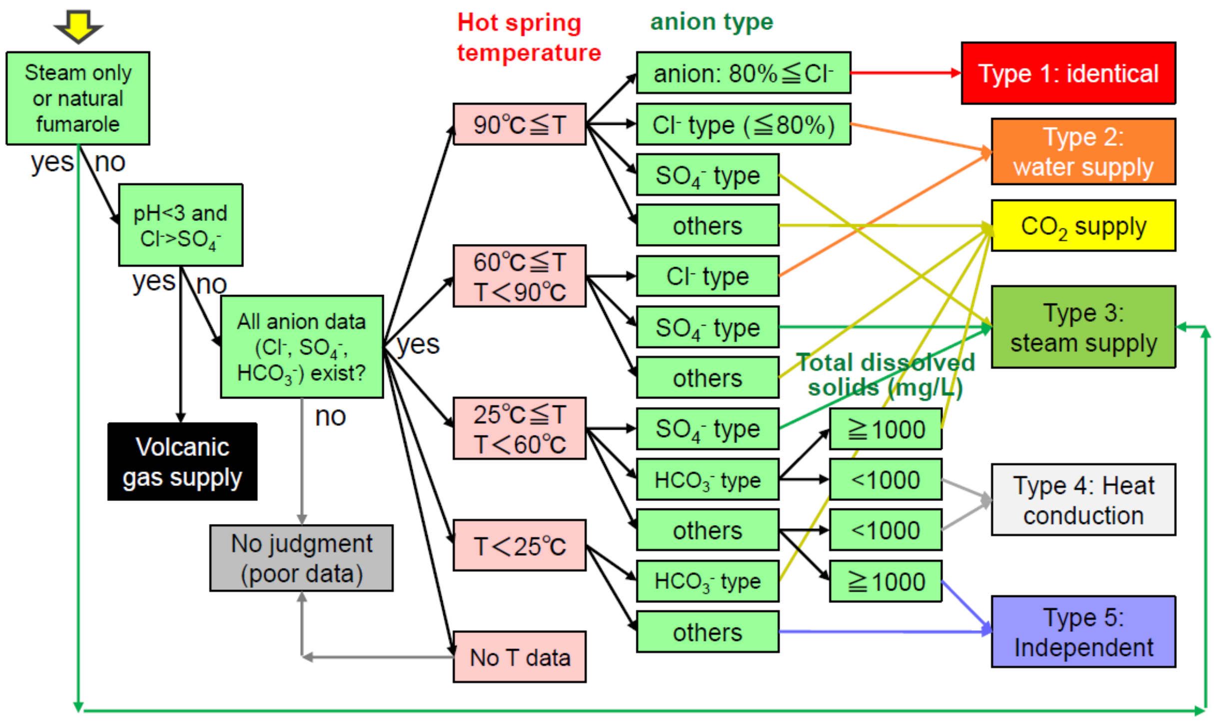


Fig. 3 Flow chart of type identification in the new criteria

4. APPLICATION OF DATA SET FROM KUJU REGION, OITA, JAPAN

Fig. 4 shows a ternary diagram of anions in hot springs in Kuju region, Oita, Japan with their type classification based on Fig. 3. All hot spring data in this region are plotted in this figure no matter of the distance from geothermal reservoir in order to show the variety of geochemical characteristics. In Kuju region, all seven types of aquifer are identified. The size of the circle indicates temperature while the color indicates the type shown in Fig. 3.

From Fig.4, it is clear that identical system and water supply systems (Types 1 and 2) are Cl^- dominant, Steam supply system (Type 3) is SO_4^- dominant, and CO_2 supply system is HCO_3^- dominant. Hot springs with temperature higher than 90ºC are all identified as Type 1 (Nos. 1-11) except for two (Nos. 46 and 41), that are Type 2. A predominant difference of Cl^- concentration in Type 1 and Type 2 is observed, suggesting that the threshold between them, Cl^-≧80% of total anion, is appropriate.

Heat conduction (Type 4) and Independent systems (Type 5) are classified by lower temperature and/or low TDS. Therefore the plots of these two types distribute in wide range of the ternary diagram. SO_4^- concentration is generally low for Type 4 while that is high for Type 5. Both Types 4 and 5 have extreme ratio of Cl^- and HCO_3^-: almost 100% Cl^- or more than 90 % HCO_3^-.

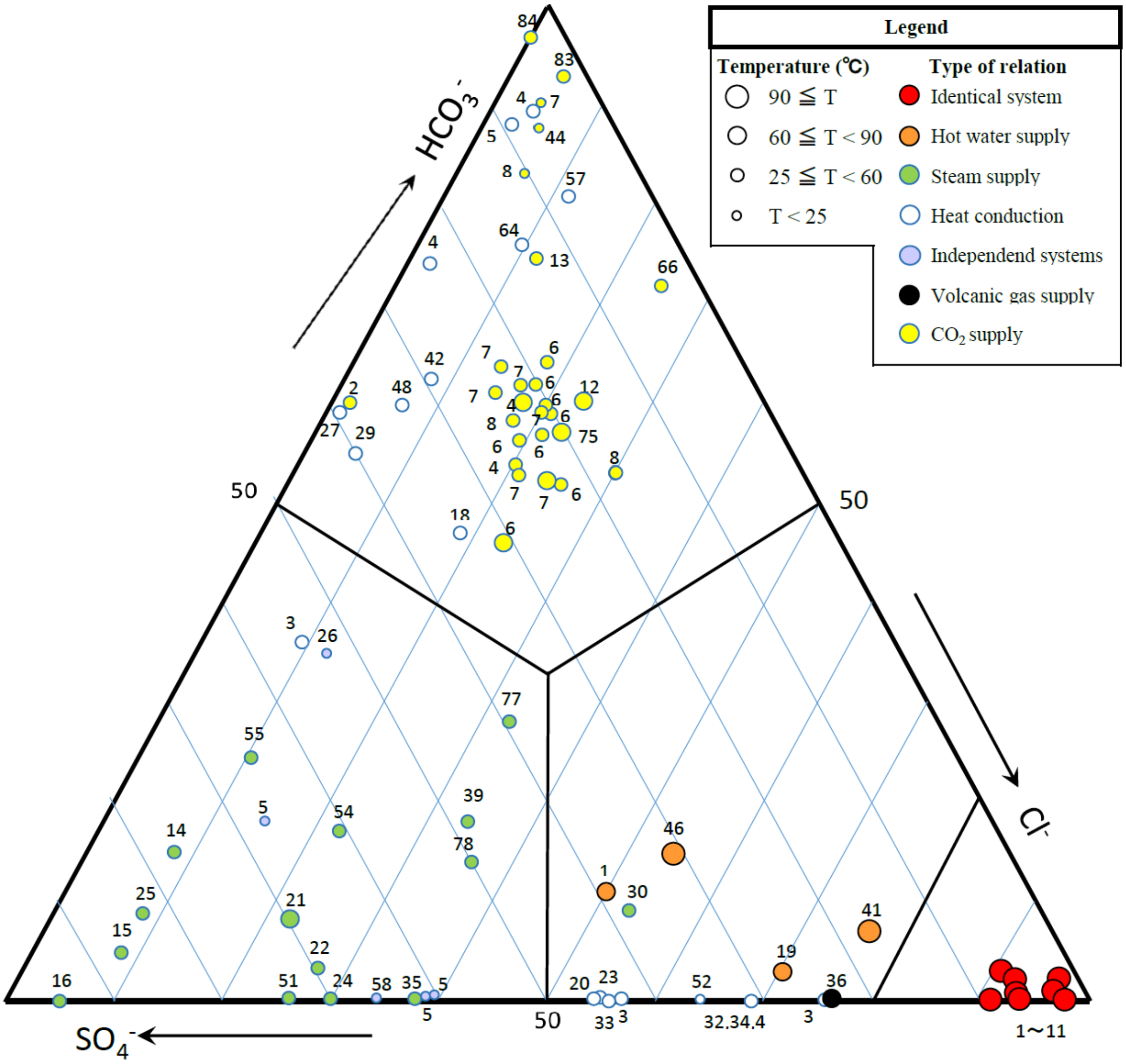


Fig. 4 Ternary plot of anions in hot springs in Kuju region with their type classification

Fig. 5 shows plots of hot spring temperature against TDS, for the identical hot spring data as shown in Fig. 4. Types 1 and 2 have high temperature and high TDS. Type 3 has intermediate temperature but its TDS is widely distributed. Both temperature and TDS is widely distributed for CO_2 supply type. Type 4 has low TDS and intermediate temperature. In this region, all plots of Type 5 shows lower temperature and TDS than Type 4, although Type 5 with higher TDS is possible according to Fig. 3. Thus the characteristic of this region is shown in the figure.

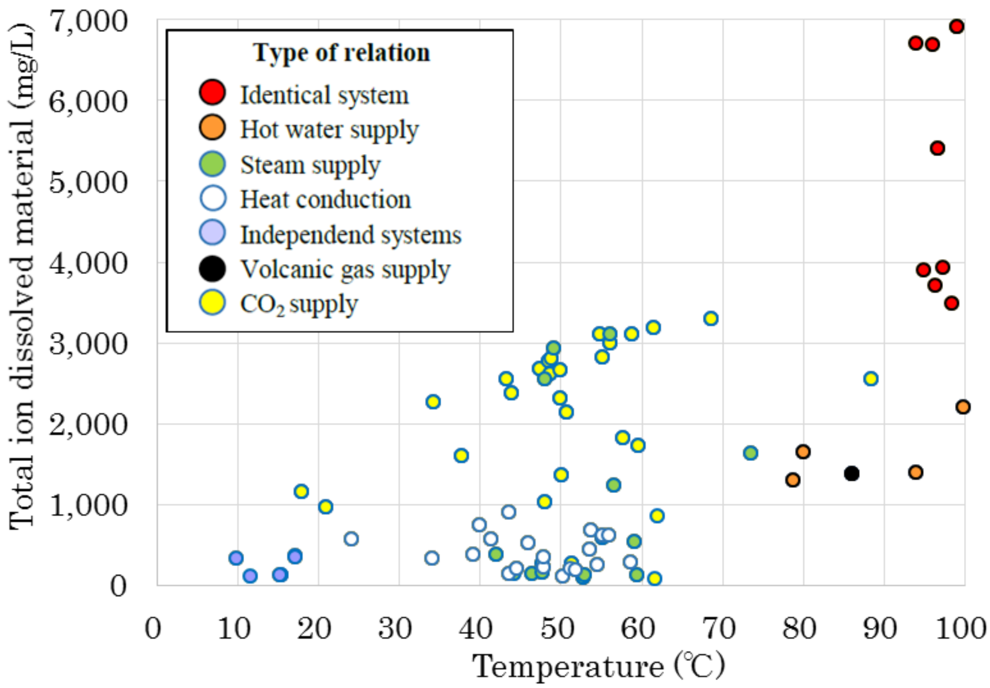


Fig. 5 Temperature-TDS plot of hot springs in Kuju region, Oita, Japan

5. DISCUSSIONS

Although a detailed type analysis through detailed geological, geochemical and geophysical surveys would be needed in some stage of geothermal development, a simplified type analysis based on geochemical data of the hot spring aquifer may be useful for small development or early stage of large development. It may also help hot spring owners to protect their own hot springs.

For the case of CO_2 supply type, more detailed survey and analysis should be done by the expert to determine the relationship between hot spring aquifer and geothermal reservoir. Nevertheless even in this case, type of relationship is roughly estimated by the temperature: if it is 60 °C or higher, it should be either Type 1, 2 or 3 and if lower than 60 °C, it should be Type 3, 4 or 5, according to Fig. 3.

Although the threshold values shown in Table 2 and Fig. 3 are based on hot spring and geothermal fluid data from igneous related systems in Japan only, it may be applicable for similar volcanic resources in other countries. For non-volcanic geothermal resources, these values may not applicable, but the idea of the flowchart shown by Fig. 3 may be applied to any systems in the world.

6. CONCLUSIONS

Hydrological and thermal connection between geothermal reservoir and nearby hot spring aquifer is expressed by five types of simplified structure models, which are identical system, water-supply system, steam-supply system, heat conduction system and independent system. The interference of geothermal development onto nearby aquifer should differ depend on the type. Therefore required and/or recommended monitoring for protection of the aquifer differs for each type of relation. Type of relation between a specific geothermal reservoir and a hot spring can be roughly estimated by geochemical analysis of the hot spring.

In a former study, a criteria to judge such types was developed based on hot springs' geochemistry. However, categorization into five types was not quite successful because geochemical characteristics of hot springs are not well represented by only five types. Consideration on geometrical configuration was necessary as well. Therefore a new criteria was developed in this study by adding two new types, volcanic gas supply and CO_2 supply, either from surrounding rock. Geometrical setting of the aquifer and the geothermal reservoir is also taken in consideration. Then a data set of hot springs in Kuju region, Oita, Japan was applied to the new criteria, for which all seven types were identified. The new criteria, which enables protection of aquifer and geothermal development as well, may be applied for other volcanic regions.

ACKNOWLEDGEMENTS

This study was triggered by a research project "Development of geothermal reservoir management system for harmonious utilization with hot spring resources" in FY2010-2012 supported by the Ministry of Environment. The criteria established in this study had been improved through discussions with H. Tokita, A. Uchiyama and Y. Kiyota of West JEC Ltd. The authors are grateful to these supporters.

REFERENCES

AIST, 2013. FY2012 Annual Report on Development of an advanced geothermal reservoir management system for the harmonious utilization with hot spring resources (in Japanese), National Institute of Advanced Industrial Science and Technology, Tsukuba, Japan, pp.350.

GRSJ, 2010. "For harmonious co-existence of hot springs and geothermal developments," Geothermal Research Society of Japan (in Japanese).

Noda, T. and Takahashi, M., 1992. Geochemical classification of source waters relating to geothermal system, Chikyukagaku (Geochemistry), 26, 63-82 (in Japanese with English abstract).

Yasukawa, K., Sakaguchi, K., Tosha, T., Uchida. T., Sasaki, M., Ishido, T., Yanagisawa, N., Nawa, K., Sugihara, M., Machida, I., Komazawa, M., Matsubayashi, O., Ioka, S., Matsuyama, K. and Noda, T., 2013. Results of the "harmonious utilization with hot spring resources" project, *Proceedings*, AGS10, Tagaytay, Philippines.

Yasukawa, K. Noda, T., Tokita, H., Uchiyama, N., Matsubayashi, O. and Sakaguchi, K., 2015. Advanced Software for Harmonious Geothermal Development with Nearby Hot Spring, Proceedings WGC2015, Melbourne, Australia.