International Journal of Hydrological and Environmental for Sustainability
Volume 4, Issue 1, 42-54.
e_ISSN: 2828-5050
https://www.journal.foundae.com/index.php/ijhes

B-Li-Cl Trend Line Can Distinguish The Dominance of Hydrothermal Water and Surface Water: A Case Study of Geothermal in Tengchong, Southwestern China

Feng-Yun Huang
Department of Medical Imaging and Radiological Sciences, Central Taiwan University of Science and Technology,
TAIWAN, PROVINCE OF CHINA

Shakal Khan Korai*
Department of Biology, School of Life Sciences, Hubei University, CHINA

***Correspondence: E-mail:** shakal.khan.korai@gmail.com

Article Info

Article history:

Received: December 25, 2024
Revised: February 20, 2025
Accepted: February 28, 2025

Abstract

The Boron-Lithium-Chlorine (B-Li-Cl) trend line serves as a valuable geochemical tool for distinguishing the dominance of hydrothermal water and surface water in geothermal environments. In this study, we applied the B-Li-Cl trend line to analyze the geochemical characteristics of water samples from the Tengchong geothermal area in Southwestern China. Our results reveal distinct patterns that differentiate hydrothermal water from surface water, offering insights into the geochemical processes and interactions occurring in this region. The lower Cl/Li and Cl/B ratio values of meteoric water with a Cl concentration of <10 (mg/L) indicate that mixing occurs not only when migrating upwards, but also inwards. The absence of a trend formed at a Cl concentration of <10 (mg/L) proves that the Cl concentration can be diluted by mixing with meteoric water. Meanwhile, the concentrations of Li > 100 (μg/L) and B > 1 (mg/L) form a downward trend from magmatic water, while the concentration of B < 1 (mg/L) has a downward trend from meteoric water. Both interpretations confirm that the behaviour of Lithium and Boron towards temperature changes has the same tendency, which can illustrate the origin of hydrothermal water formation.

Keywords: boron; chlorine; geothermal; hydrothermal water; lithium; surface water

To cite this article: Huang, F, Y., and Korai, S, K. (2025). B-Li-Cl Trend Line Can Distinguish The Dominance of Hydrothermal Water and Surface Water: A Case Study of Geothermal in Tengchong, Southwestern China. *International Journal of Hydrological and Environmental for Sustainability*, *4*(1), 42-54. https://doi.org/10.58524/3r1t2184

INTRODUCTION

Understanding the geochemical processes in geothermal systems is crucial for the efficient exploration and management of geothermal resources. One of the most promising tools for this purpose is the Boron-Lithium-Chlorine (B-Li-Cl) trend line, which can distinguish between hydrothermal water and surface water. This study focuses on the application of the B-Li-Cl trend line in the Tengchong geothermal area, located in Southwestern China, a region known for its rich geothermal activity and diverse hydrothermal features (Guo & Wang, 2012). The Tengchong geothermal area is an ideal location for studying the interactions between hydrothermal water and surface water due to its unique geological setting and abundant geothermal manifestations (Meju & Le, 2002). These features provide an excellent opportunity to apply and validate the B-Li-Cl trend line as a geochemical tool for understanding the subsurface processes and water interactions in geothermal environments (Amita et al., 2014).

Hydrothermal systems are complex and dynamic, with various factors influencing the geochemical composition of water. The B-Li-Cl trend line allows researchers to analyze the concentrations of boron, lithium, and chlorine in water samples, providing valuable insights into the sources and behaviors of these elements within the geothermal system (Yan et al., 2024). By distinguishing between hydrothermal and surface water, the B-Li-Cl trend line helps to identify areas with significant hydrothermal activity and potential geothermal resources (Tanimizu et al., 2021). Geothermal systems offer a unique window into the complex interplay of hydrothermal processes and surface water interactions. Understanding these interactions is crucial for effective geothermal resource management and exploration. The Tengchong geothermal area in Southwestern China is a prime location for studying these dynamics due to its rich geothermal activity and diverse hydrothermal features. The Boron-Lithium-Chlorine (B-Li-Cl) trend line has emerged as a powerful geochemical tool for distinguishing between hydrothermal water and surface water (Umam et al., 2024). By analyzing the concentrations of these elements, researchers can gain insights into the source and behavior of water within geothermal systems. This method provides a clearer picture of the subsurface processes and helps in identifying areas with significant hydrothermal activity.

In this study, we applied the B-Li-Cl trend line to water samples collected from various hot springs and surface water sources in the Tengchong geothermal area. Our goal was to determine the effectiveness of this geochemical tool in differentiating hydrothermal water from surface water. By comparing the geochemical signatures of these water sources, we aimed to enhance our understanding of the geothermal system in this region.

Boron (B)

Boron (B) is an invaluable element in the geochemical analysis of hot springs, serving as a reliable tracer for various hydrothermal processes. Its unique chemical properties make it an excellent indicator of water-rock interactions, and its isotopic composition can provide insights into the sources of geothermal fluids. The ability to distinguish between different sources of fluids, such as seawater, magmatic water, and meteoric water, enhances our understanding of the complex geochemical dynamics within geothermal systems (Oi et al., 1996; Purnomo et al., 2016; Williams & Hervig, 2004).

One of the primary reasons boron is so useful in geochemical analysis is its role as a tracer for hydrothermal processes. The isotopic composition of boron in hot spring waters can reveal the origin and evolution of hydrothermal fluids. By analyzing boron isotopes, researchers can determine whether the fluids are derived from seawater, magmatic sources, or meteoric water. This information is crucial for understanding the geochemical processes occurring within geothermal systems and for identifying the sources of geothermal fluids (Han et al., 2018; Wunder et al., 2005).

In addition to its role as a tracer, boron concentrations in hot spring waters can indicate the extent of water-rock interaction. High concentrations of boron often suggest significant interaction between geothermal fluids and the surrounding rocks. This interaction can lead to the release of boron into the water, providing valuable information about the geochemical processes occurring within the geothermal system. By examining boron concentrations, researchers can gain insights into the types of rocks and minerals present in the subsurface and the extent to which they influence the chemistry of the geothermal fluids (Meredith et al., 2013a; Oi et al., 1996; Purnomo et al., 2016).

Boron is also useful for estimating the temperature of geothermal reservoirs. The solubility of boron in water increases with temperature, so higher boron concentrations can indicate higher reservoir temperatures. This information is valuable for geothermal exploration, as it helps identify areas with high geothermal potential. By understanding the temperature distribution within a geothermal system, researchers can better assess the viability of geothermal resources and plan for their sustainable extraction. Furthermore, boron is an important indicator for assessing the environmental impact of geothermal activities. Elevated boron levels in surface waters can signal contamination from geothermal fluids, which is crucial for monitoring and managing the environmental effects of geothermal energy production. By tracking boron concentrations, researchers can detect and mitigate potential environmental issues, ensuring the sustainable and responsible use of geothermal resources (Han et al., 2018; Meredith et al., 2013b; Purnomo et al., 2016; Williams & Hervig, 2004; Wunder et al., 2005).

Lithium (Li)

Lithium (Li) is a significant element in the geochemical analysis of hot springs due to its distinctive properties and behavior in geothermal systems. One of the primary reasons lithium is highly valued in geochemical studies is its ability to trace hydrothermal processes. The concentration and isotopic composition of lithium in hot spring waters can offer valuable insights into the origins and pathways of geothermal fluids, helping researchers better understand the dynamics of geothermal systems (Meredith et al., 2013b; Tang et al., 2007; Umam et al., 2022).

In the context of geothermal exploration, lithium plays an important role in identifying the source and evolution of geothermal fluids. By analyzing lithium concentrations, scientists can differentiate between various fluid sources, such as magmatic water, meteoric water, and seawater. This differentiation is crucial for understanding the subsurface processes that influence the chemistry of geothermal systems and for identifying areas with significant geothermal potential.

Lithium is also useful for estimating the temperature of geothermal reservoirs. The solubility of lithium in water increases with temperature, making it a reliable indicator of high-temperature geothermal activity. By measuring lithium concentrations in hot spring waters, researchers can infer the temperature distribution within a geothermal system, which is essential for assessing the viability of geothermal resources and planning their sustainable extraction (Umam et al., 2025). Additionally, lithium can help in understanding water-rock interactions within geothermal systems. The presence of lithium in hot spring waters often indicates extensive interaction between geothermal fluids and the surrounding rocks. This interaction can release lithium into the water, providing valuable information about the types of rocks and minerals present in the subsurface and their influence on the geochemistry of geothermal fluids (Zandvakili et al., 2024). Studying these interactions enhances our understanding of the geological processes shaping geothermal systems (Arienzo et al., 2020; Tang et al., 2007; Toki et al., 2016).

On the other hand, lithium is an important element for monitoring and managing the environmental impacts of geothermal activities. Elevated lithium levels in surface waters can signal contamination from geothermal fluids, which is critical for detecting and mitigating potential environmental issues. By tracking lithium concentrations, researchers can assess the environmental effects of geothermal energy production and ensure the sustainable and responsible use of geothermal resources (Tang et al., 2007).

Chlorine (Cl)

Chlorine (Cl) is a crucial element in the geochemical analysis of hot springs due to its distinctive properties and its ability to provide valuable information about the hydrothermal system. One of the primary reasons chlorine is highly valued in geochemical studies is its conservative behavior in water, meaning it is less likely to participate in chemical reactions compared to other elements. This characteristic makes chlorine a reliable tracer for understanding the origin and evolution of geothermal fluids, helping researchers track the movement and mixing of these fluids within the geothermal system (Hendry et al., 2000; Jalili et al., 2019).

In geothermal exploration, chlorine plays a significant role in identifying the source and composition of geothermal fluids. By analyzing chlorine concentrations, scientists can differentiate between various fluid sources, such as magmatic water, meteoric water, and seawater. This differentiation is crucial for understanding the subsurface processes that influence the chemistry of geothermal systems and for identifying areas with significant geothermal potential. Additionally, the ratio of chlorine to other ions, such as sodium (Na), can provide insights into the mixing of different water sources and the extent of fluid-rock interactions (Iqbal et al., 2023; Tsay et al., 2017).

Chlorine is also useful for estimating the temperature and pressure conditions within geothermal reservoirs. The concentration of chlorine in geothermal fluids is often associated with the dissolution of chlorine-bearing minerals at high temperatures and pressures. By measuring chlorine concentrations in hot spring waters, researchers can infer the temperature and pressure conditions within the geothermal system, which is essential for assessing the viability of geothermal resources and planning their sustainable extraction. High chlorine concentrations can indicate areas with high geothermal potential, guiding exploration efforts and resource management (Iwamori, 2007; Vuataz, 1983).

Moreover, chlorine can help in understanding the processes of fluid circulation and recharge within geothermal systems. The presence of chlorine in hot spring waters often indicates the involvement of deep-seated fluids that have traveled through the geothermal system and interacted with various rock formations. By studying chlorine concentrations and isotopic compositions, researchers can gain insights into the pathways and mechanisms of fluid circulation, the rates of recharge, and the connectivity between different parts of the geothermal system. This information enhances our understanding of the geological processes shaping geothermal systems and contributes to more effective exploration and management strategies (Millot et al., 2012; Utama et al., 2021; Vuataz, 1983).

METHOD

This study relies on secondary data to analyze the geochemical characteristics of hot springs waters in the Tengchong geothermal area, focusing on the Boron-Lithium-Chlorine (B-Li-Cl) trend line to distinguish between hydrothermal water and surface water. Literature Review A comprehensive literature review was conducted to gather relevant information on the geochemistry of hot springs, the application of B-Li-Cl trend lines, and the geological and hydrothermal characteristics of the Tengchong region. Sources included peer-reviewed journals, research articles, geological surveys, and conference proceedings. Key studies on similar geothermal systems and methodologies provided a solid foundation for this research.

Data Sources Secondary data was collected from one of source by Guo & Wang, (2012) **(Table 1)**, including published research articles, geological surveys, and government reports. Specific data points included concentrations of boron, lithium, and chlorine in water samples from hot springs and surface waters in the Tengchong geothermal area. The data covered a range of sampling locations and time periods to ensure a comprehensive analysis of the region's geochemical characteristics.

Table 1. Characteristics of hot springs from Tengchong, Southwestern China (Guo & Wang, 2012).

No	Sample ID	Name of spring	Sampling location	T	B	Li	Cl/Li	Cl/B	Cl
1	RH02	Zhenzhu Spring	Rehai geothermal field	96	2.01	500	78.4	19.5	39.2
2	RH04	Dagunguo Spring	Rehai geothermal field	96.6	16.98	6133	87.9	31.7	539.1
3	RH05	Huaitaijing Spring	Rehai geothermal field	92	12.44	4289	97.8	33.7	419.6
4	RH06	Guming Spring	Rehai geothermal field	96	13.24	4378	91.6	30.3	401.2
5	RH07	Yanjing Spring	Rehai geothermal field	94	14.13	4667	88.6	29.3	413.6
6	RH08	Xiaogunguo Spring	Rehai geothermal field	82	5.61	1140	153.3	31.2	174.8
7	RH09	Dagunguo II Spring	Rehai geothermal field	70	6.63	1382	101.6	21.2	140.4
8	RH10	nameless	Rehai geothermal field	49.1	12.27	4200	82.1	28.1	344.7
9	RH11	nameless	Rehai geothermal field	65.8	7.93	2778	100.6	35.2	279.5
10	RH12	nameless	Rehai geothermal field	90	8.14	2867	97.5	34.3	279.5
11	RD01	Xianle Spring	Ruidian geothermal field	90	5.44	1509	86.7	24.1	130.9
12	RD02	Jinyazi Spring	Ruidian geothermal field	86	4.89	1400	84	24	117.6
13	RD03	Xianrendong Spring	Ruidian geothermal field	75	6.12	1242	84.5	17.2	105
14	RD04	Zhuyuan Spring	Ruidian geothermal field	85	5.1	1438	82.8	23.4	119.1
15	LH01	Laozaotang Spring	Lianghe	82	0.33	242.2	82.2	60.3	19.9
16	LH02	Longwo Spring	Lianghe	97	0.33	311.1	43.1	40.6	13.4
17	TCC01	Bapai Spring	Hehua	20.8	0.01	4.5	511.1	230	2.3
18	TCH01	Mayiwo Spring	Beihai	55	0.02	52	28.8	75	1.5
19	TCH02	Lingshan Spring	Guyong	40.4	0	69.1	10.1	0	0.7
20	TCH03	Tianbazaotang Spring	Danzha	50.6	0.06	68.2	51.3	58.3	3.5
21	TCH04	nameless	Danzha	37	0.05	69.8	47.3	66	3.3
22	TCH05	Jinquanzhuang Spring	Guyong	47.7	0.98	573.3	38.9	22.8	22.3
23	TCH06	Shiqiang I Spring	Jietou	66.7	5.59	1020	48.6	8.9	49.6
24	TCH07	Shiqiang II Spring	Jietou	31.1	0.11	15.5	58.1	8.2	0.9
25	TCH08	Zhongzhai Spring	Jietou	65.6	0.69	131.1	15.3	2.9	2
26	TCH09	Dongjiazhai Spring	Jietou	45.1	0.4	87.6	14.8	3.3	1.3
27	TCH10	Zhuanshan Spring	Jietou	43.8	0.28	89.3	15.7	5	1.4
28	TCH11	Xiaotangba Spring	Qushi	29.2	1.11	568.9	32.7	16.8	18.6
29	TCH12	Yanjiatang Spring	Chengguan	24	0	32.4	46.3	0	1.5
30	TCH13	Yongle Spring	Dongshan	38.3	0	26.9	44.6	0	1.2
31	TCH14	Hubang Spring	Puchuan	49.1	0.04	48.9	38.9	47.5	1.9
32	TCH15	Bazhu Spring	Puchuan	55	0.1	47.6	88.2	42	4.2
33	TCH16	Xiaotang Spring	Panzhihua	96.9	1.88	666.7	61.3	21.8	40.9
34	TCH17	Menglian Spring	Menglian	46	0.02	24.2	33.1	40	0.8

*Temperature (T) in ^{o}C; Cl and B concentration in mg/L; Li concentration in μg/L.

Tectonic setting and geology of Tengchong, Southwestern China

Tengchong, located in Southwestern China near the border with Myanmar, is a region of significant geological interest due to its unique tectonic setting and active geothermal features. The area is part of the Himalayan geothermal belt and is characterized by its intra-plate volcanic activity, which has been ongoing since the Holocene **(Figure 1)**. The geology of Tengchong is influenced by its position within the India-Eurasia collision zone. This tectonic setting has resulted in complex geological structures, including crustal rifting and subduction processes. The region is known for its volcanic activity, with the most recent eruption occurring in 1609. Despite the lack of recent eruptions, Tengchong remains volcanically and hydrothermally active (Yan et al., 2024). The Tengchong terrane is composed of various rock types, including granitoids that formed during the Early Cretaceous period. These granitoids are primarily monzogranites and granodiorites, which are derived from the partial melting of Mesoproterozoic metabasic rocks in the lower crust. The presence of these igneous rocks provides valuable insights into the tectonic evolution of the region and the formation of the Tibetan Plateau (Guo & Wang, 2012; Meju & Le, 2002).

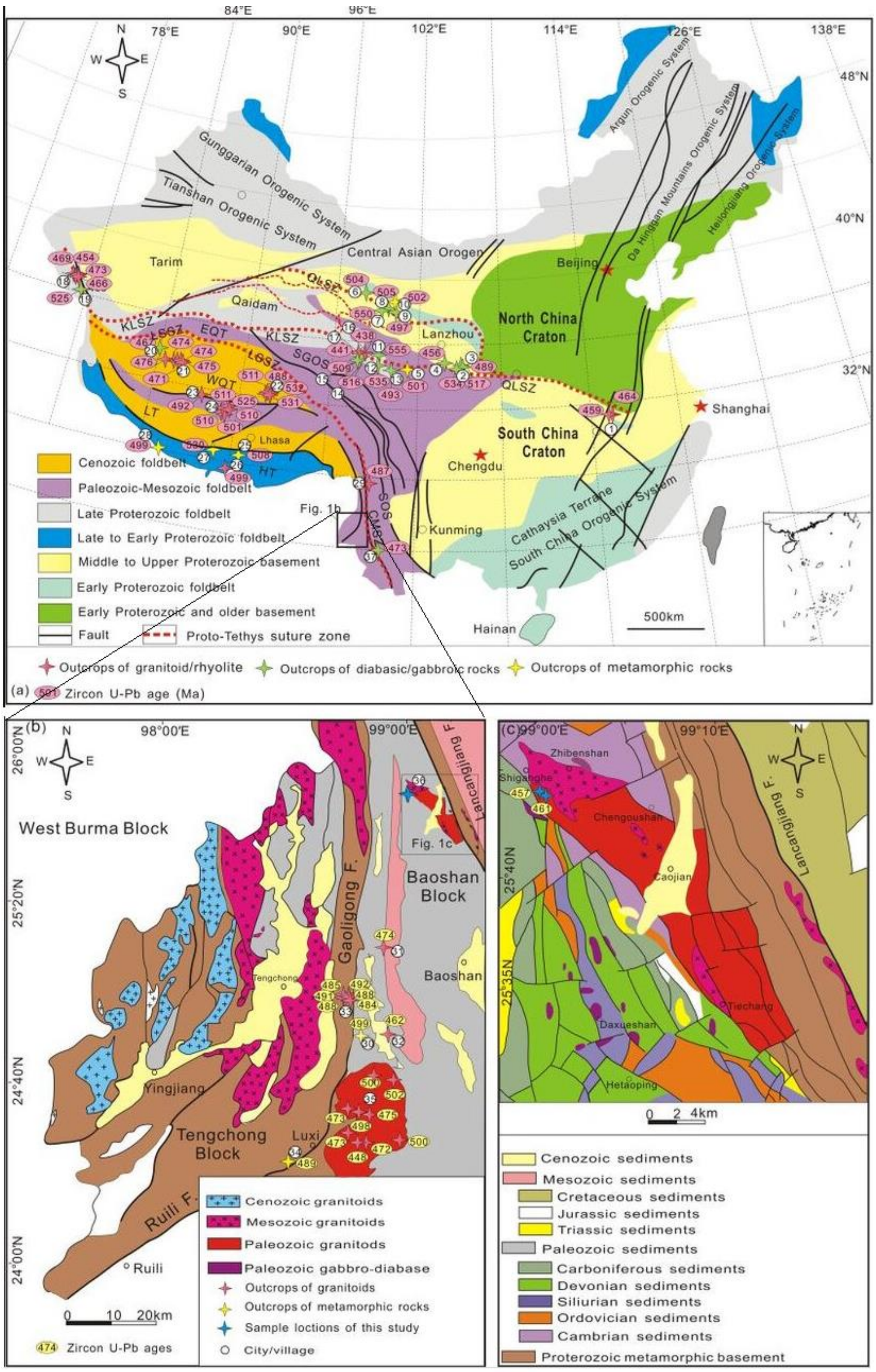

Figure 1. Geological maps and locations of Tengchong, Southwestern China (Yan et al., 2024)

In addition to its volcanic features, Tengchong is home to numerous hot springs and geothermal fields. The geothermal activity in the region is driven by the heat generated from the underlying magmatic systems. The hot springs in Tengchong are characterized by their high temperatures and unique geochemical compositions, making them an important area for geothermal research and exploration. Overall, the regional setting and geology of Tengchong make it a fascinating area for studying the interactions between tectonic processes, volcanic activity, and geothermal systems. The insights gained from studying this region contribute to our understanding of the broader geological and geothermal dynamics within the Himalayan geothermal belt and the India-Eurasia collision zone (Guo & Wang, 2012; Yan et al., 2024).

RESULTS AND DISCUSSION

The ability to distinguish between hydrothermal water and surface water is essential to understanding the dynamics of geothermal systems and to making informed decisions about the management of geothermal resources. In previous research conducted by Umam et al., (2024), **Figure 2** provides a very clear contrast of the differences between the three types of water: seawater, hydrothermal water, and meteoric water. These results provide initial clues that this contrast difference can be the basis for determining the contribution of hydrothermal waters to shallow groundwater or seawater (Umam et al., 2024).

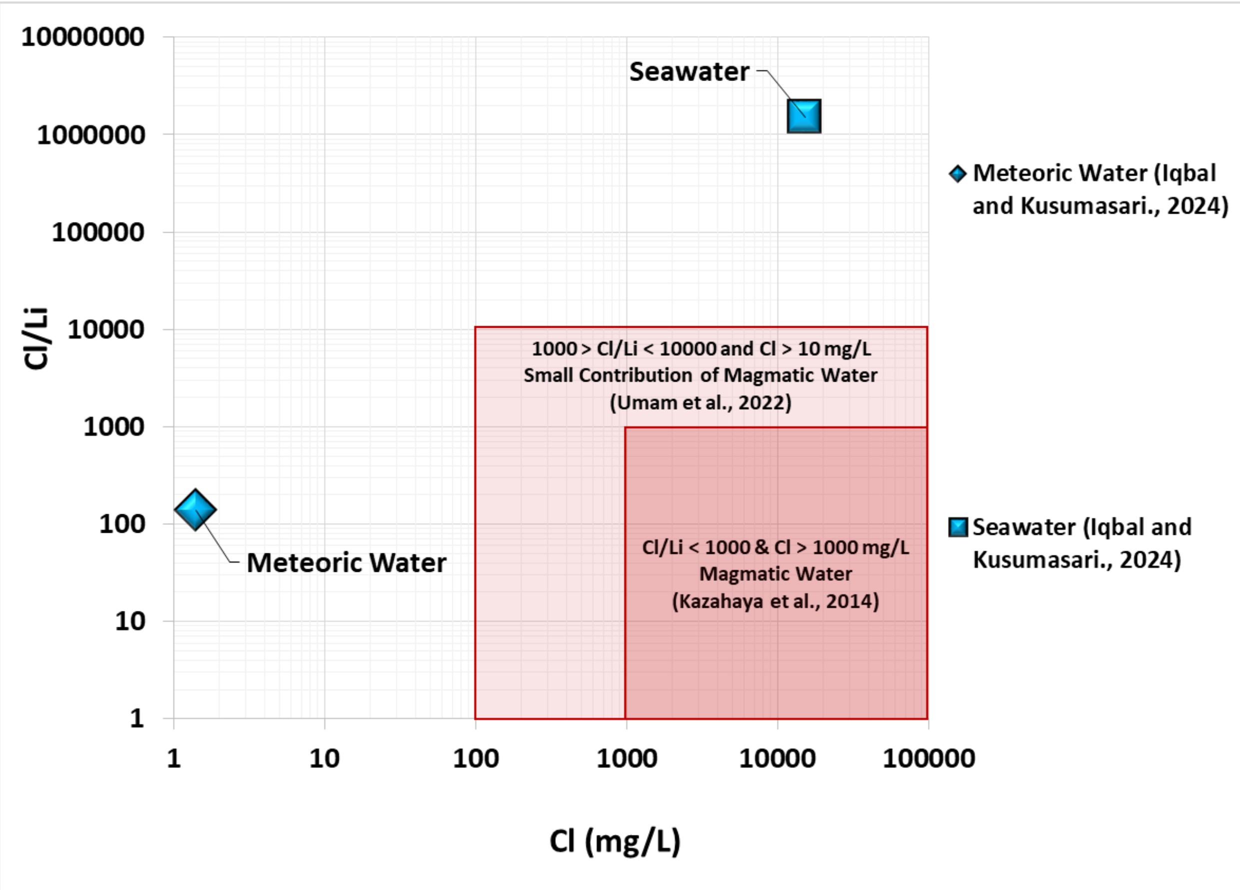

Figure 2. The range of Cl/Li ratio and Cl concentration for hydrothermal water, meteoric water, and seawater (Umam et al., 2024).

In addition, other supporting research is the variation of lithium isotopes **(Figure 3)** obtained from various types of water by Wan et al., (2017). They highlighted the significant relative mass difference between the two stable isotopes of lithium: and , which is the largest among metal elements. This mass difference allows for substantial isotopic fractionation in various geological processes. On the other hand, the authors discussed how lithium isotopes can be used as tracers for subduction-related processes, such as the release of slab-derived fluids, fluid/rock interactions, partial melting, and crust/mantle interactions. They emphasized that the distinct lithium isotopic compositions of surface materials and mantle rocks make lithium isotopes valuable for tracing the movement (Umam et al., 2022) and interactions of materials in subduction zones (Nakajima & Hasegawa, 2007; Stern, 2002; You et al., 1996, 1996; Zheng & Hermann, 2014).

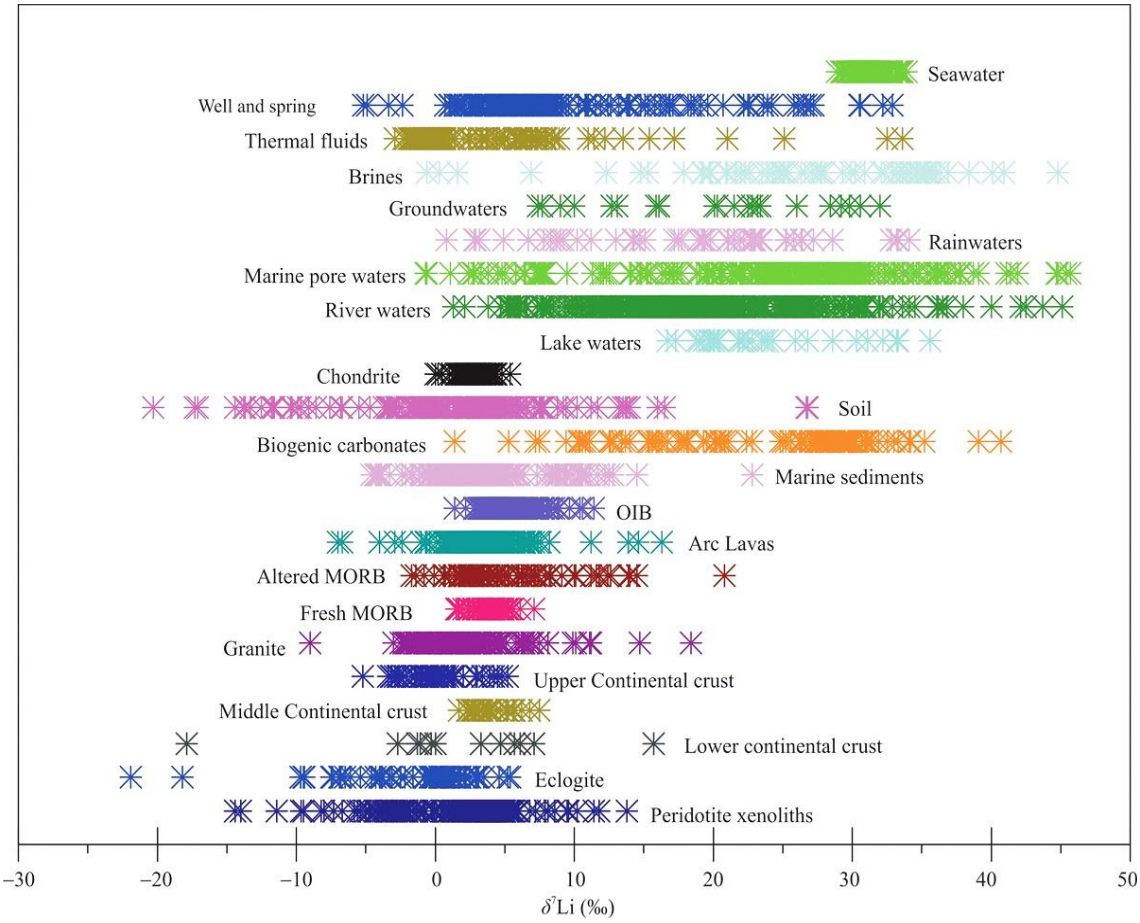

Figure 3. Isotopic variation of δ^7Li in various sources (Wan et al., 2017).

The ratio of Cl/Li and Cl/B to the concentration of Cl

The results of the interpretation of the geochemical characteristics of hot springs in the Tengchong geothermal area, specifically the ratio of Cl/Li and Cl/B to the concentration of Cl **(Figure 4** and **Figure 5)**, show that both form a downward trend up to a Cl concentration limit of 10 (mg/L). Previously, Kazahaya et al., (2014) explained that most hot springs or groundwater that contribute hydrothermal waters (magmatic waters) have a Cl/Li ratio of <1000, while the Cl/B ratio is not yet known. However, Cl/Li < 1000 has confirmed that all hot springs in the Tengchong geothermal area have hydrothermal water (magmatic waters) contributions. So that the interpretation of the geochemical characteristics of hot springs in the Tengchong geothermal area can be analysed in more depth.

The geographical location of the Tengchong geothermal hot springs supports the Cl/Li and Cl/B interpretation of Cl, that most of the hot water is mixed with meteoric water rather than seawater. The lower Cl/Li and Cl/B ratio values of meteoric water with a Cl concentration of <10 (mg/L) indicate that mixing does not only occur when migrating upwards, but also inwards. In this case, meteoric water that enters interacts with the rock and is heated by the reservoir, so that the ratio of Cl/Li and Cl/B will decrease due to the increase in the concentration of Li and B. As in the experiment conducted by You et al., (1996), meteoric water can be likened to a low-concentration liquid, while rock is a mineral source that, when heated at high pressure and temperature, causes the concentration of minerals in the rock to come out and mix into the water.

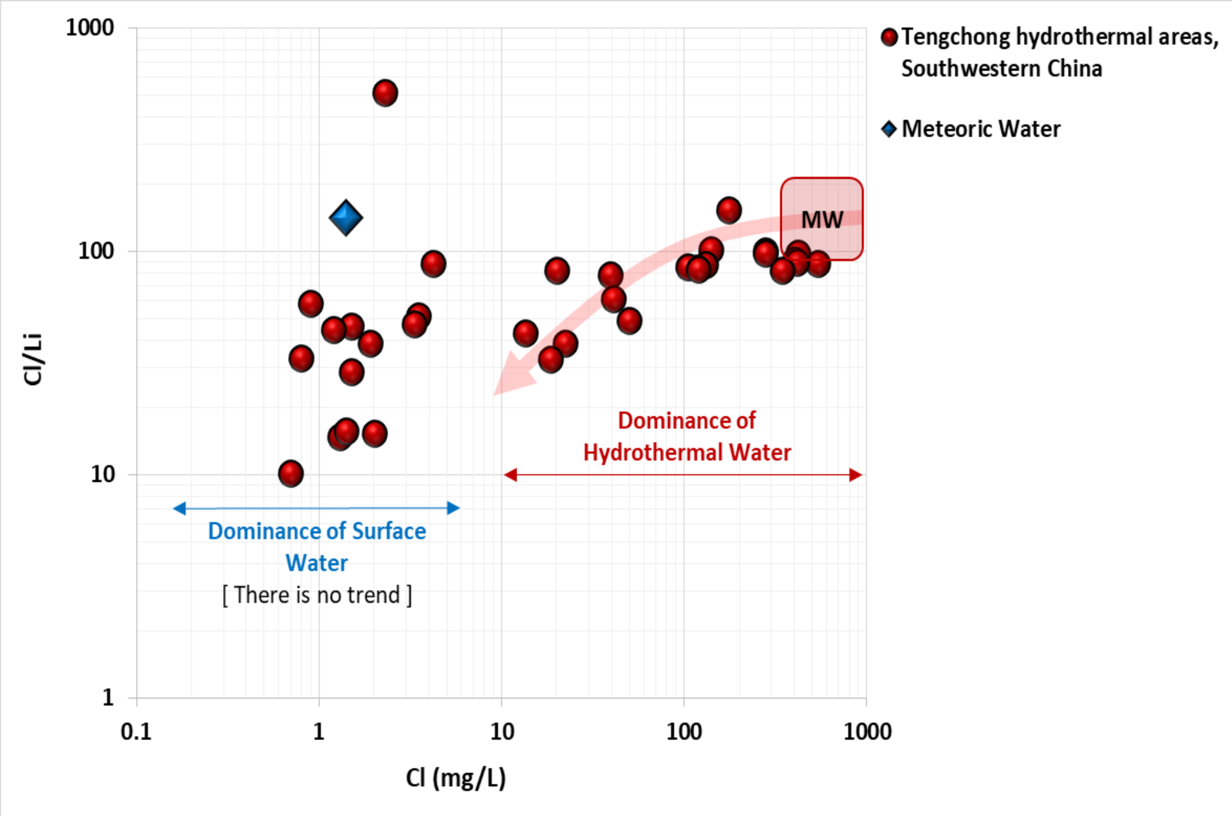

Figure 4. Interpretation of the Cl/Li ratio against Cl concentration in hot springs in the Tengchong area, Southwestern China

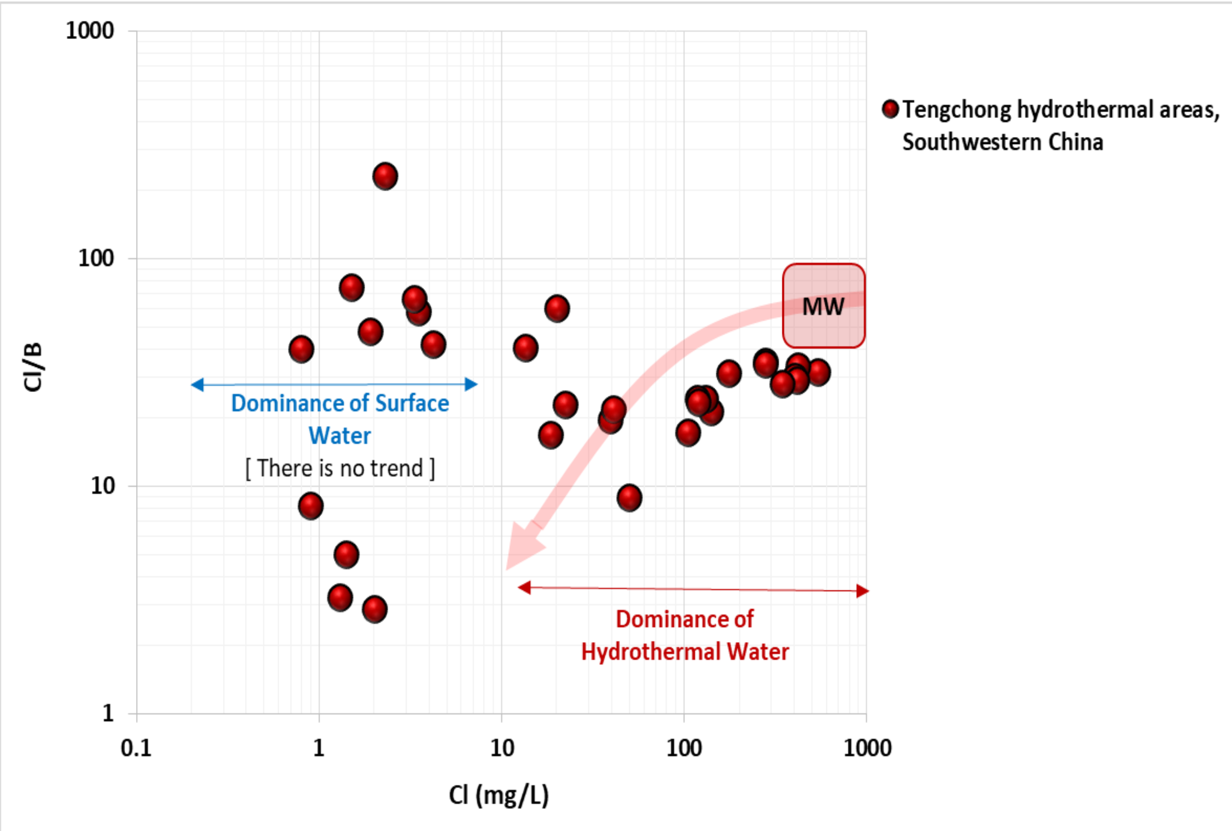

Figure 5. Interpretation of the Cl/B ratio against Cl concentration in hot springs in the Tengchong area, Southwestern China

The absence of a trend formed at a Cl concentration of <10 (mg/L) proves that the Cl concentration can be diluted by mixing with meteoric water. However, we can confirm that a Cl concentration >10 (mg/L) is groundwater (hot springs) originating from deep underground or reservoir water. These results are very similar to the hot springs in the Arima region of southwestern Japan (Kusuda et al., 2014).

Cl/Li ratio to Li concentration

In contrast to the interpretation results in **Figure 4** and **Figure 5** using Cl concentration, in **Figure 6** Li concentration < 100 (μg/L) forms a linear trend leading to meteoric water. Meanwhile, Li concentration > 100 (μg/L) forms a downward trend from magmatic water. This trend can explain and confirm that in general hydrothermal water has different characteristics from surface water (meteoric water). However, the high dominance of surface water (meteoric water) can eliminate traces of hydrothermal water contribution. However, this does not apply to Lithium. These results are similar to and confirm previous research by (Tanimizu et al., 2021; Umam et al., 2022, 2024) that a contribution of hydrothermal water of only 0.1% can be detected by the lithium isotope. The difference in lithium isotope contrast between hydrothermal water and surface water means that dilution by meteoric water does not eliminate traces of hydrothermal water contribution.

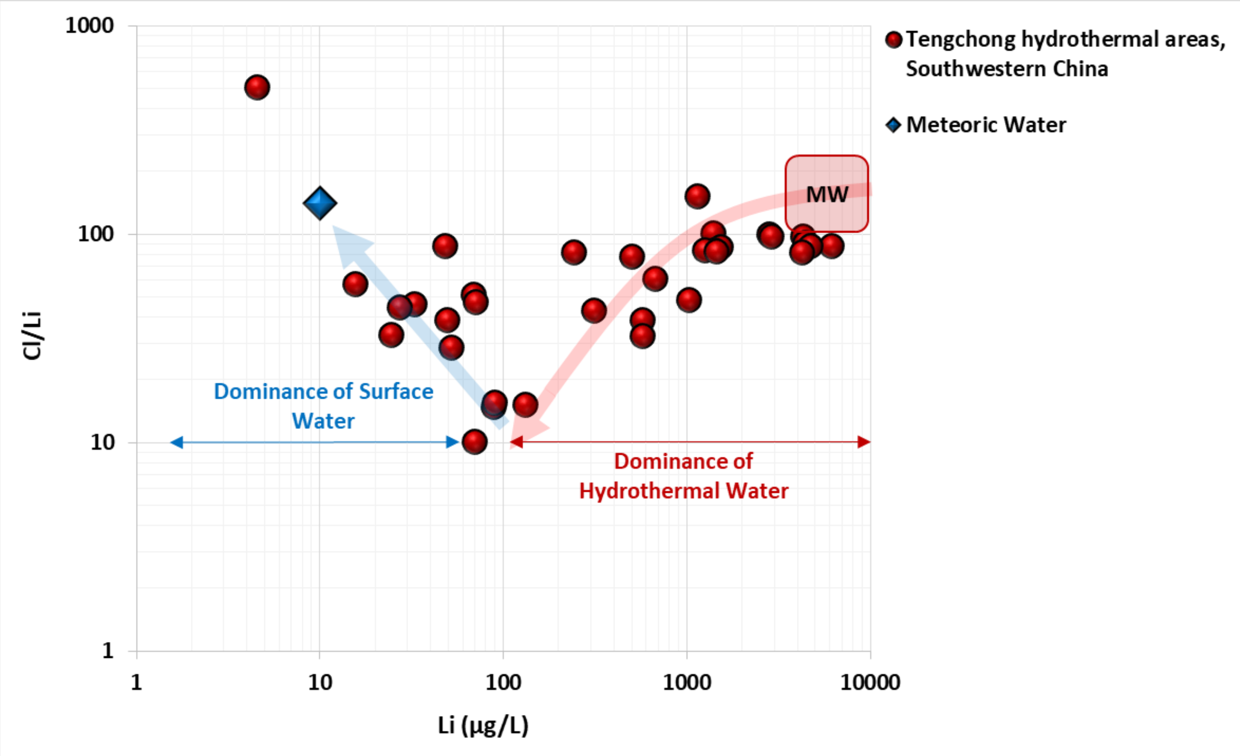

Figure 6. Interpretation of the Cl/Li ratio against Li concentration in hot springs in the Tengchong area, Southwestern China

Cl/B ratio to B concentration

The result of the interpretation of the Cl/B ratio against the B concentration in **Figure 7** has a similar trend to the interpretation of the Cl/Li ratio against the Li concentration in **Figure 6**. Almost all hot springs in the Tengchong area have a Cl/B ratio of <100, and this value is the basic assumption that a Cl/B ratio of <100 can also describe the characteristics of hydrothermal water. However, there is a need for more analysis of the distribution of the Cl/B ratio, as done by Kazahaya et al., (2014) in their study of the Cl/Li ratio in Japan. Boron (B) concentration < 1 (mg/L) also shows a linear trend that is most likely towards meteoric water, while B concentration > 1 (mg/L) has a decreasing trend from magmatic water. Both interpretations between Lithium and Boron confirm previous research conducted by You et al., (1996) on the behaviour of minerals in subduction zones. The behaviour of Lithium and Boron towards temperature changes has the same trend, which can illustrate the origin of hydrothermal water.

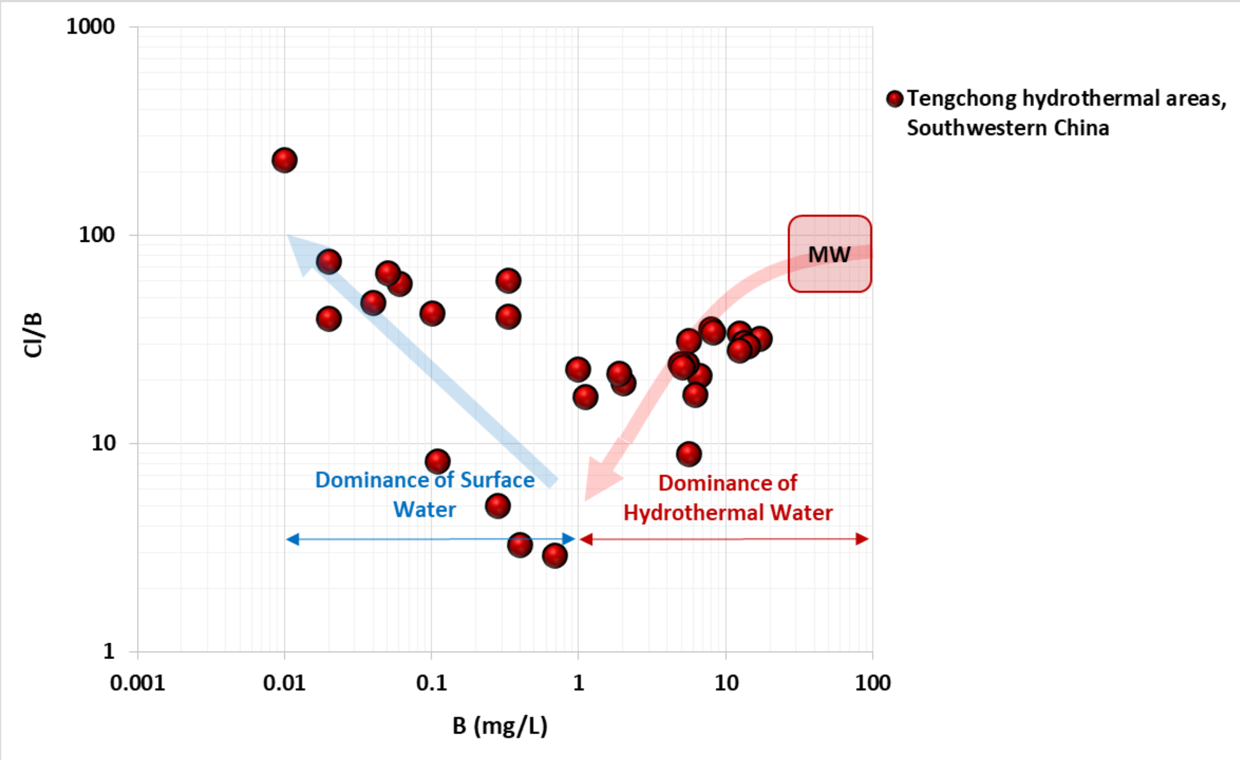

Figure 7. Interpretation of the Cl/Li ratio against B concentration in hot springs in the Tengchong area, Southwestern China

The ability to distinguish between hydrothermal water and surface water is essential to understanding the dynamics of geothermal systems and to making the right decisions about the management of geothermal resources. The B-Li-Cl trend line provides a reliable and effective method to achieve this goal, as our findings in the Tengchong geothermal area show. The results of this study contribute to a broader knowledge of geochemical processes in geothermal systems and highlight the importance of using advanced geochemical tools for geothermal exploration.

In addition, the insights gained from this research can be applied to other geothermal areas with similar geological and hydrothermal characteristics. The B-Li-Cl trend line has the potential to become a widely used tool in geothermal research, providing valuable information for the exploration and management of geothermal resources worldwide.

The findings of our analysis show different patterns in the B-Li-Cl trend line that can accurately distinguish between hydrothermal water and surface water. These patterns provide important insights into the geochemical processes occurring in the Tengchong geothermal system and contribute to a better understanding of the interaction between various water sources in the area. By using the B-Li-Cl trend line, we can identify certain areas in the Tengchong geothermal region that show high hydrothermal activity. This information is invaluable for geothermal exploration and resource management, as it helps to determine locations with significant geothermal potential. In addition, this study demonstrates the practical application and benefits of using the B-Li-Cl trend line as a geochemical tool in geothermal research.

CONCLUSION

The lower Cl/Li and Cl/B ratio values of meteoric water with a Cl concentration of <10 (mg/L) indicate that mixing does not only occur when migrating upwards, but also inwards. In this case, the incoming meteoric water interacts with the rock and is heated by the reservoir, so that the Cl/Li and Cl/B ratios will decrease due to the increase in Li and B concentrations. The absence of a trend formed at a Cl concentration of <10 (mg/L) proves that the Cl concentration can be diluted by mixing with meteoric water. However, we can confirm that a Cl concentration of >10 (mg/L) is groundwater (hot springs) originating from deep underground or reservoir water.

Meanwhile, a concentration of Li > 100 (μg/L) forms a downward trend from magmatic water. This trend can explain and confirm that in general hydrothermal water has different characteristics from surface water (meteoric water). However, the high dominance of surface water (meteoric water) can eliminate traces of hydrothermal water contribution. However, this does not apply to Lithium. The difference in lithium isotope contrast between hydrothermal water and surface water means that dilution by meteoric water does not eliminate traces of hydrothermal water contribution.

Boron (B) concentration < 1 (mg/L) also shows a linear trend that most likely leads to meteoric water, while B concentration > 1 (mg/L) has a decreasing trend from magmatic water. Both interpretations between Lithium and Boron confirm that the behaviour of Lithium and Boron towards temperature changes has the same tendency, which can illustrate the origin of hydrothermal water. Almost all hot springs in the Tengchong area have a Cl/B ratio of <100, and this value is the basic assumption that a Cl/B ratio of <100 can also illustrate the characteristics of hydrothermal water.

The B-Li-Cl trend line proves to be a valuable geochemical tool for distinguishing between hydrothermal water and surface water in geothermal environments. The application of this tool in the Tengchong geothermal area has provided important insights into the geochemical processes occurring in the region and has demonstrated its potential for broader use in geothermal research. The findings from this study will contribute to the effective exploration and management of geothermal resources, ensuring sustainable and efficient utilization of these valuable energy sources.

ACKNOWLEDGMENT

The author would like to thank the relevant parties who have provided support for this research.

CONFLICTS OF INTEREST

The authors declare no conflict of interest concerning the publication of this article. The authors also confirm that the data and the article are free of plagiarism.

REFERENCES

Amita, K., Ohsawa, S., Nishimura, K., Yamada, M., Mishima, T., Kazahaya, K., Morikawa, N., & Hirajima, T. (2014). Origin of saline waters distributed along the Median Tectonic Line in southwest Japan: Hydrogeochemical investigation on possibility of derivation of metamorphic dehydrated fluid from subducting oceanic plate. *Journal of Japanese Association of Hydrological Sciences*, *44*(1), 17–38. https://doi.org/10.4145/jahs.44.17

Arienzo, I., Liotta, M., Brusca, L., D'Antonio, M., Lupone, F., & Cucciniello, C. (2020). Analytical method for lithium isotopes determination by thermal ionization mass spectrometry: A useful tool for hydrogeochemical applications. *Water (Switzerland)*, *12*(8). https://doi.org/10.3390/W12082182

Guo, Q., & Wang, Y. (2012). Geochemistry of hot springs in the Tengchong hydrothermal areas, Southwestern China. *Journal of Volcanology and Geothermal Research*, *215–216*, 61–73. https://doi.org/10.1016/j.jvolgeores.2011.12.003

Han, J. L., Han, F. Q., Hussain, S. A., Liu, W. Y., Nian, X. Q., & Mao, Q. F. (2018). Erratum: Origin of boron and brine evolution in saline springs in the Nangqen Basin, Southern Tibetan Plateau (Geofluids (2018) 2018 (1985784) DOI: 10.1155/2018/1985784). *Geofluids*, *2018*. https://doi.org/10.1155/2018/6761910

Hendry, M. J., Wassenaar, L. I., & Kotzer, T. (2000). Chloride and chlorine isotopes (36Cl and δ37Cl) as tracers of solute migration in a thick, clay-rich aquitard system. *Water Resources Research*, *36*(1), 285–296. https://doi.org/10.1029/1999WR900278

Iqbal, M., Kusumasari, B. A., Atmapradhana, T., Trinugraha, A. C., Palupi, E. K., & Maulidi, I. (2023).

Characterization of Thermal Waters Origin from the Back Arc Lampung Province , Indonesia : An Evaluation of Stable Isotopes , Major Elements , and Li / Cl Ratios. *International Journal of Hydrological and Environmental for Sustainability*, *2*(1), 1–12.

Iwamori, H. (2007). Transportation of H2O beneath the Japan arcs and its implications for global water circulation. *Chemical Geology*, *239*(3–4), 182–198. https://doi.org/10.1016/j.chemgeo.2006.08.011

Jalili, M., Hosseini, M. S., Ehrampoush, M. H., Sarlak, M., Abbasi, F., & Fallahzadeh, R. A. (2019). Use of Water Quality Index and Spatial Analysis to Assess Groundwater Quality for Drinking Purpose in Ardakan, Iran. *Journal of Environmental Health and Sustainable Development*, *4*(3), 834–842. https://doi.org/10.18502/jehsd.v4i3.1500

Kazahaya, K., Takahashi, M., Yasuhara, M., Nishio, Y., Inamura, A., Morikawa, N., Sato, T., Takahashi, H. A., Kitaoka, K., Ohsawa, S., Oyama, Y., Ohwada, M., Tsukamoto, H., Horiguchi, K., Tosaki, Y., & Kirita, T. (2014). Spatial distribution and feature of slab-related deep-seated fluid in SW Japan. *The Japan Society of Hydrology and Water Resources*, *44*(1), 3–16.

Kusuda, C., Iwamori, H., Nakamura, H., Kazahaya, K., & Morikawa, N. (2014). Arima hot spring waters as a deep-seated brine from subducting slab. *Earth, Planets and Space*, *66*(1), 119. https://doi.org/10.1186/1880-5981-66-119

Meju, M. A., & Le, L. (2002). Geoelectromagneticexploration For Natural Resources:Models, Case Studies and Challenges. *Surveys in Geophysics*, *23*, 133–205.

Meredith, K., Moriguti, T., Tomascak, P., Hollins, S., & Nakamura, E. (2013a). The lithium, boron and strontium isotopic systematics of groundwaters from an arid aquifer system: Implications for recharge and weathering processes. *Geochimica et Cosmochimica Acta*, *112*(May 2020), 20–31. https://doi.org/10.1016/j.gca.2013.02.022

Meredith, K., Moriguti, T., Tomascak, P., Hollins, S., & Nakamura, E. (2013b). The lithium, boron and strontium isotopic systematics of groundwaters from an arid aquifer system: Implications for recharge and weathering processes. *Geochimica et Cosmochimica Acta*, *112*, 20–31. https://doi.org/10.1016/j.gca.2013.02.022

Millot, R., Hegan, A., & Négrel, P. (2012). Geothermal waters from the Taupo Volcanic Zone, New Zealand: Li, B and Sr isotopes characterization. *Applied Geochemistry*, *27*(3), 677–688. https://doi.org/10.1016/j.apgeochem.2011.12.015

Nakajima, J., & Hasegawa, A. (2007). Subduction of the Philippine Sea plate beneath southwestern Japan: Slab geometry and its relationship to arc magmatism. *Journal of Geophysical Research: Solid Earth*, *112*(8), 1–18. https://doi.org/10.1029/2006JB004770

Oi, T., Ikeda, K., Nakano, M., Ossaka, T., & Ossaka, J. (1996). Boron isotope geochemistry of hot spring waters in Ibusuki and adjacent areas, Kagoshima, Japan. *Geochemical Journal*, *30*(5), 273–287. https://doi.org/10.2343/geochemj.30.273

Purnomo, B. J., Pichler, T., & You, C. F. (2016). Boron isotope variations in geothermal systems on Java, Indonesia. *Journal of Volcanology and Geothermal Research*, *311*, 1–8. https://doi.org/10.1016/j.jvolgeores.2015.12.014

Stern, R. J. (2002). Subduction zones. *Reviews of Geophysics*, *40*(4), 3-1-3–38. https://doi.org/10.1029/2001RG000108

Tang, Y. J., Zhang, H. F., & Ying, J. F. (2007). Review of the lithium isotope system as a geochemical tracer. *International Geology Review*, *49*(4), 374–388. https://doi.org/10.2747/0020-6814.49.4.374

Tanimizu, M., Sugimoto, N., Hosono, T., Kuribayashi, C., Morimoto, T., Ito, A., & Umam, R. (2021). *Application of B and Li isotope systematics for detecting chemical disturbance in groundwater associated with large shallow inland earthquakes in Kumamoto , Japan*. *55*, 241–250. https://doi.org/10.2343/geochemj.2.0633

Toki, T., HESHIKI, S., & Shinjo, R. (2016). Improved Method for Seawater Lithium Isotopic Ratio Determination Using MC-ICP-MS. *Bulletin of the Society of Sea Water Science, Japan*, 326–331.

Tsay, A., Zajacz, Z., Ulmer, P., & Sanchez-Valle, C. (2017). Mobility of major and trace elements in the eclogite-fluid system and element fluxes upon slab dehydration. *Geochimica et Cosmochimica Acta*, *198*, 70–91. https://doi.org/10.1016/j.gca.2016.10.038

Umam, R., Cengiz, K., & Said, A. (2024). Application of Major and Trace Elements for Detecting the Origin of Groundwater : Lithium Enrichment in Ain Al-Harrah Hot Spring Influenced by Red Sea , Saudi Arabia. *International Journal of Hydrological and Environmental for Sustainability*, *3*(3), 151–162.

Umam, R., Junaidi, R., Syazali, M., Farid, F., Saregar, A., & Andiyan, A. (2025). Optimization of Piper Trilinier Diagram Using Lithium Isotope Systematics : An Application for Detecting the Contribution of Geothermal Water from Aso Caldera after Earthquake 2016 in Kumamoto Aquifer , Japan. *Indonesian Journal of Science & Technology*, *10*(1), 159–170.

Umam, R., Tanimizu, M., Nakamura, H., Nishio, Y., Nakai, R., Sugimoto, N., Mori, Y., Kobayashi, Y., Ito, A., Wakaki, S., Nagaishi, K., & Ishikawa, T. (2022). Lithium isotope systematics of Arima hot spring waters and groundwaters in Kii Peninsula. *Geochemical Journal*, *56*(5), E8–E17. https://doi.org/10.2343/geochemj.GJ22015

Utama, H. W., Mulyasari, R., & Said, Y. M. (2021). Geothermal Potential on Sumatra Fault System To Sustainable Geotourism in West Sumatra. *JGE (Jurnal Geofisika Eksplorasi)*, *7*(2), 126–137. https://doi.org/10.23960/jge.v7i2.128

Vuataz, F. D. (1983). Hydrology, geochemistry and geothermal aspects of the thermal waters from Switzerland and adjacent alpine regions. *Journal of Volcanology and Geothermal Research*, *19*(1–2), 73–97. https://doi.org/10.1016/0377-0273(83)90125-7

Wan, H., Sun, H., Liu, H., & Xiao, Y. (2017). Lithium Isotopic Geochemistry in Subduction Zones: Retrospects and Prospects. *Acta Geologica Sinica (English Edition)*, *91*(2), 688–710. https://doi.org/10.1111/1755-6724.13126

Williams, L. B., & Hervig, R. L. (2004). Boron isotope composition of coals: A potential tracer of organic contaminated fluidsEditorial handling by R.S. Harmon. *Applied Geochemistry*, *19*(10), 1625–1636. https://doi.org/10.1016/j.apgeochem.2004.02.007

Wunder, B., Meixner, A., Romer, R. L., Wirth, R., & Heinrich, W. (2005). The geochemical cycle of boron: Constraints from boron isotope partitioning experiments between mica and fluid. *Lithos*, *84*(3–4), 206–216. https://doi.org/10.1016/j.lithos.2005.02.003

Yan, Y., Zhang, Z., Zhou, X., Wang, G., He, M., Tian, J., Dong, J., Li, J., Bai, Y., Zeng, Z., Wang, Y., Yao, B., Xing, G., Cui, S., & Shi, Z. (2024). Geochemical characteristics of hot springs in active fault zones within the northern Sichuan-Yunnan block: Geochemical evidence for tectonic activity. *Journal of Hydrology*, *635*(December 2023), 131179. https://doi.org/10.1016/j.jhydrol.2024.131179

You, C. F., Castillo, P. R., Gieskes, J. M., Chan, L. H., & Spivack, A. J. (1996). Trace element behavior in hydrothermal experiments: Implications for fluid processes at shallow depths in subduction zones. *Earth and Planetary Science Letters*, *140*(1–4), 41–52. https://doi.org/10.1016/0012-821X(96)00049-0

Zandvakili, Z., Nishio, Y., & Sano, Y. (2024). Geofluid behavior prior to the 2018 Hokkaido Eastern Iburi earthquake: insights from groundwater geochemistry. *Progress in Earth and Planetary Science*, *11*(1). https://doi.org/10.1186/s40645-024-00635-w

Zheng, Y.-F., & Hermann, J. (2014). Geochemistry of continental subduction-zone fluids. *Earth, Planets and Space*, *66*(1), 93. https://doi.org/10.1186/1880-5981-66-93