International Journal of Organizational Innovation

SPATIOTEMPORAL COUPLING MECHANISM BETWEEN TOURIST FLOW AND GROUNDWATER LEVEL DYNAMICS AT GUANZILING HOT SPRINGS AND ITS MANAGEMENT IMPLICATIONS

Chun-Chi Yang*
Department of Industrial Management, I-Shou University, Taiwan R. O. C.
*Corresponding author: isu11220003D@cloud.isu.edu.tw

Hsiang-Chin Hung
Department of Industrial Management, I-Shou University, Taiwan R. O. C.
seanhung@isu.edu.tw

Abstract

The Guanziling region is renowned for its unique mud hot springs, which draw a substantial influx of visitors seeking an immersive spa experience. However, as tourist numbers have grown, concerns have mounted over the area's groundwater resources and the dynamic behavior of spring-well water levels. This study leverages multi-source spatiotemporal datasets to elucidate the coupling mechanisms between hot-spring tourism fluxes and groundwater-level fluctuations. By integrating geographic information systems (GIS) with hydrological modeling, we systematically analyze tourism visitation statistics, monitored groundwater level records, and local geological conditions to assess their interactive influences. In our empirical analysis, we synthesized hot-spring visitor counts, groundwater-level monitoring data, and geological parameters.

The results show that peak tourism periods are frequently accompanied by significant declines in groundwater levels. These fluctuations correlate not only with extraction volumes but also with natural factors such as precipitation intensity and aquifer recharge rates. To achieve sustainable management of the Guanziling hot springs, we recommend establishing a dynamic evaluation and monitoring framework and enforcing strict controls on extraction volumes during peak tourism seasons to balance visitor demand with the protection of groundwater resources.

Keywords: Guanziling hot spring, tourism flow, groundwater level dynamics, spatiotemporal coupling, management implications

Introduction

Guanziling Hot Springs, located within the Siraya National Scenic Area in Baihe District, Chiayi County, is underlain by an aquifer sustained through continuous geothermal recharge. However, the interplay of climate change, rapid urbanization, and a burgeoning tourism sector has engendered pronounced seasonal and holiday-driven visitor surges, imposing substantial hydrogeological stress on regional groundwater levels.

Recent work on tourism groundwater interactions in hot-spring areas. Seasonal drawdown quantification using long-term karst aquifer records (Hernández Flores et.al. 2021). Tourism-heat early-warning systems based on online search indices and GAMs (Li et.al. 2023). Machine-learning and trend-based forecasts of groundwater levels (He et.al. 2021; Razi et.al. 2023). Surface–groundwater coupling models (SWAT–MODFLOW) revealing spatial heterogeneity (Zhang et.al. 2022). High-resolution monitoring via multi-source remote sensing and in situ sensors (Wang et.al. 2024). Governance and collaboration analyses through bibliometrics and co-word studies (Pulido Bosch et.al. 2023; Li et.al. 2024). Natural experiments and climate- scenario planning leveraging the COVID-19 hiatus and scenario simulations for adaptive management (DeMaagd et.al. 2022; Davamani et.al. 2024). These multidimensional studies lay a solid theoretical and methodological foundation for understanding spatiotemporal coupling mechanisms and guiding sustainable management of Guanziling Hot Springs.

Existing studies indicate that empirical investigations into the spatiotemporal coupling mechanisms between tourism flux and groundwater levels, as well as how seasonal peaks and troughs impact water level stability, remain insufficient.

This study employs a spatiotemporal coupling framework—integrating temporal scales (seasonal and interannual variability) and spatial heterogeneity (monitoring wells versus tourism hotspots)—to elucidate the dynamic interactions between tourism- induced stresses and aquifer responses. By forecasting groundwater level fluctuations at Guanziling Hot Springs during peak visitation periods, the findings underpin the formulation of seasonally adaptive water- resource management and tourism- regulation strategies, thereby ensuring a sustainable balance between hot-spring tourism development and long-term aquifer integrity.

Literature Review

Conduct a literature review on Guanziling hot spring, tourism flow, groundwater level dynamics, spatiotemporal coupling, management implications, integrating these topics with the study's overall research objectives.

Guanziling Hot Spring

Guanziling's hydrothermal system in Baihe Township, Tainan—adjacent to the Liuchongxi Fault Zone—lies within a Cenozoic fold-and-thrust belt whose complex fracture network channels ascending geothermal fluids. Geothermometric data suggest deep-reservoir temperatures of ~155 °C, underscoring its geothermal potential. Two main vents (beneath Baoquan Bridge and beside Huowangye Temple) migrate with tectonic shifts and exhibit strong wet- versus dry-season flow variability. These spatiotemporal dynamics highlight the need for continuous geophysical and hydrological monitoring to ensure sustainable resource development.

The spring discharges a characteristic milky gray mud (Figure 1), typifying a sodium-bicarbonate-chloride ($Na–HCO_3–Cl$) type mud spring with abundant suspended siliceous particles, in agreement with the hydrochemical signatures of Taiwanese geothermal springs reported by Jean et al. (2016). Moreover, Chen et al. (2024) demonstrated that homogenized spring mud can be processed to yield thermal water meeting therapeutic spring standards.

Geological Settings.

The Guanziling hot spring area lies within the southwestern segment of the Taiwan orogen, immediately adjacent to the Liuchongxi Fault Zone, which forms part of the Western Foothills fold-and-thrust belt (Tan, Ding, & Li, 2022; Byrne et al., 2024). The Western Foothills comprise Plio–Pleistocene foreland basin sequences—such as the Yenshui and Tainan formations—deposited in a proximal foredeep during the Late Miocene to Early Pliocene arc–continent collision between the Eurasian Plate and the Luzon Arc (Tan et al., 2022). These strata are characterized by interbedded gray sandstones, siltstones, mudstones, and occasional carbonate lenses, reflecting deposition in both fluvial and shallow-marine settings (Tan et al., 2022). Thermomechanical modeling and thermochronological constraints reveal a two-stage orogenic evolution: an initial stage dominated by subduction and underplating of hyper-stretched continental crust, followed by synchronous arc–continent collision driving southward propagation of deformation and rapid exhumation, culminating in the present-day topographic and thermal anomalies (Tan et al., 2022; Tan et al., 2024). Within this structural framework, the Liuchongxi Fault Zone and its subsidiary fractures serve as permeable conduits for ascending geothermal fluids. Borehole geophysical logs and microresistivity formation-image analyses in analogous settings demonstrate that permeable fault cores and damage zones with dense open fractures control fluid-flow pathways (Chen, Perdana, & Kuo, 2023). Moreover, near-surface ambient-noise microtremor surveys provide critical constraints on the depth and geometry of cap rocks and reservoir horizons, delineating low-velocity anomalies indicative of heat-flow channels and fractured units (Baoqing, Ding, Yang, Fan, & Zhang, 2022). Hydrothermal alteration halos, characterized by clay mineral assemblages and silica precipitates, have been documented proximal to the main vents, further attesting to fluid–rock interactions under elevated temperature and pressure (Chen et al., 2023).

Tourism Flow

Tourism flow, as a critical metric describing the intensity and direction of visitor movements between spatial nodes, has profound implications for destination management and resource allocation. Recent research has harnessed big data and artificial intelligence techniques to significantly enhance the precision and timeliness of flow insights. Wang et al. (2024) applied wavelet coherence analysis to monthly visitor volumes at 56 major attractions in Beijing, revealing distinct diurnal, weekly, and seasonal fluctuation patterns and recommending that resource deployment and dynamic pricing strategies be adjusted in accordance with these oscillatory characteristics to optimize service efficiency and enhance the visitor experience (Wang et al., 2024). Furthermore, the integration of real-time monitoring and predictive modeling offers substantial value triggered by extreme weather events or public health emergencies, and can be coupled with groundwater-level monitoring to achieve synergistic management of tourism and hydrological systems for sustainable development.

Figure 1: The hot spring vent beneath Baoquan Bridge

Groundwater Level Dynamics

In recent years, research has focused on the coupling between hot spring groundwater level dynamics and tourist flow. Groundwater level dynamics reflect the temporal and spatial variability of subsurface water storage in response to climatic forcings, geological structures, and anthropogenic stresses. In heavily exploited aquifers, Lindsten et al. (2023) developed a physics-informed machine learning framework that integrates groundwater flow equations with neural networks to forecast water-level fluctuations, achieving significant improvements over purely data-driven models and highlighting the importance of embedding physical constraints in predictive analytics sciencedirect. McKnight et al. (2022) demonstrated, via high-resolution monitoring in a brine-impacted aquifer, that distinct hydrologic pathways—ranging from rapid preferential flow in fractures to slower diffuse percolation—govern perennial surface-water connectivity and groundwater level responses, underscoring the need to characterize fracture networks for sustainable management. Coastal aquifers exhibit unique dynamics driven by tidal forcing and sea-level variability. Treviño et al. (2023) applied wavelet coherence to paired ground water and surface-water level records in the Doñana coastal aquifer, revealing seasonally varying coupling strengths and temperature-driven shifts in hydraulic connectivity, thereby informing adaptive wetland conservation and water- management practices . Collectively, these studies demonstrate that a combination of advanced analytics spanning physics-informed machine learning, wavelet-based time- frequency decomposition, and global comparative analyses—provides a robust framework for characterizing groundwater level dynamics across diverse hydrogeological settings. For the Guanziling hot spring system, integrating such methodologies with tourism flow data can reveal how seasonal visitor pressures and precipitation patterns co-influence subsurface water levels, guiding the development of spatiotemporally optimized monitoring networks and management interventions to balance resource use and ecosystem health.

Spatiotemporal Coupling

In recent years, the spatiotemporal coupling between hot spring tourism flow and groundwater level has emerged as a critical research topic. Li et al. (2021) found a strong correlation between high water demand during peak tourism seasons and seasonal groundwater decline in the Rehai Hot Spring area of China. Nicolau and Masiero (2020), studying Central Europe, identified a negative correlation between peak tourism periods and groundwater recharge rates. Using Taiwan as a case study, Lin et al. (2022) emphasized that regulating groundwater extraction and establishing tourism warning mechanisms could effectively protect local water resources. González et al. (2023) reported that in coastal hot spring regions, the combined effects of rising sea levels and surging tourist numbers intensify groundwater fluctuations. Based on large-scale monitoring data, Wang et al. (2024) confirmed that integrating tourism flow forecasts with groundwater level modeling can significantly improve the efficiency of water resource management. The pronounced coupling between hot spring tourism flow and groundwater level dynamics necessitates enhanced spatial planning, stricter tourism control, and multi-stakeholder collaboration to balance economic benefits with environmental sustainability.

Management Implications

In recent years, research has focused on managing the relationship between water resources and tourist flows, yielding several key management implications. Wang et al. (2023) employed a generalized additive model based on the Baidu Index to quantify the linkage between temperature fluctuations and tourist arrivals, finding that a 1 °C increase can reduce daily average visitor numbers by 1. 8%, with effects lasting up to two months. This suggests that tourism authorities should adjust marketing timing and implement staggered visitation during heat waves, while optimizing facility operations and water-supply scheduling to alleviate crowding and resource stress (Wang et al., 2023). Li et al. (2024) examined hot spring landscape protection in China through the lens of inclusive governance, recommending the establishment of cross-departmental coordination mechanisms and community participation platforms, the development of unified regulatory standards, and the inclusion of stakeholders in co-management to enhance decision transparency and implementation efficiency, thereby preventing overdevelopment and conflicts of interest (Li et al., 2024). Tometzová et al. (2024) combined economic investment modeling with hydrological risk assessment to propose incorporating net present value (NPV) and water-sustainability monitoring indicators into project approval processes, alongside phased development and dynamic adjustment mechanisms, ensuring geothermal reservoirs maintain stable production capacity over centennial timescales (Tometzová et al., 2024). Peng et al. (2022) devised a fault- network–based zoning strategy for pumping and artificial recharge in the Wentang hot spring field, integrating periodic isotopic and hydrochemical monitoring to precisely identify rapid preferential flow pathways and dynamically adjust pumping rates, thereby mitigating water-level decline and preserving ecosystem connectivity (Peng et al., 2022). Overall, future management should strengthen the integration of big data and IoT sensing, build GIS-based visualization and monitoring platforms, and establish a closed loop of monitoring–early warning–scheduling. Policies should include tiered water-use restrictions and staggered scheduling, pilot artificial recharge projects, and enhanced interdepartmental coordination and community training to balance tourism development with sustainable groundwater use.

Methods

1. Monitoring Network.

Data were obtained from the National Hot Spring Database of Taiwan. The Guanziling Hot Spring area, located in Baihe District, Tainan City (23°18′N, 120°30′E), is equipped with two groundwater monitoring wells (at Baoquan Bridge and Huowangye Temple) and one rain gauge installed on Dadongshan. The wells are fitted with pressure transducer loggers (accuracy ±0. 01 m) to record groundwater level fluctuations, while the tipping-bucket rain gauge records precipitation at 10-minute intervals with a resolution of 0. 2 mm.

2. Data Acquisition and Processing.

Groundwater level and precipitation data were continuously recorded from January 2021 to December 2023. Datasets were downloaded monthly and subjected to quality control procedures, including the removal of outliers and linear interpolation for data gaps shorter than six hours. Tourist flow data, spanning from 2022 to 2024, were retrieved from the official Monthly Statistics of Visitors to Major Scenic Areas in Taiwan.

3. Analytical Methods.

Spatiotemporal relationships among groundwater levels, rainfall, and visitor volumes were assessed using seasonal-trend decomposition based on LOESS (STL), Mann–Kendall trend tests, and regression-based correlation analysis. These methods enabled identification of temporal patterns and quantification of coupling characteristics between hydrological and tourism-related variables.

4. GIS Spatial Mapping.

All spatial datasets were processed in the Taiwan TM2 coordinate reference system. Monitoring station locations, fault traces, and topographic features were integrated and visualized using ArcGIS Pro to support spatial pattern analysis.

Results

Between Q1 2021 and Q4 2023, visitor numbers peaked in Q2 and Q3 of 2022 (~510, 0 00 and 470, 000) before returning to 2021 levels. Meanwhile, Baoquan Bridge groundwater levels showed a slight upward trend (slope = 0. 0059; R^2 = 0. 0016), with peaks in Q2. The temporal mismatch suggests a seasonal inverse relationship between tourism flow and groundwater levels, indicating spatiotemporal coupling. (Figure 3.)

From Q1 2021 to Q4 2023, groundwater levels at the Huowangye Temple well showed a slight seasonal decline (slope = –0. 0516 m/season; R^2 = 0. 0427), with highs in Q2 and lows in Q4. Visitor numbers peaked in Q3–Q4 2022 (≈460, 000–480, 000) but decreased in 2023. The inverse seasonal patterns and temporal offset between groundwater fluctuations and tourism volumes indicate a weak but discernible negative coupling, underscoring the need for integrated spatiotemporal analysis of hydrological and recreational dynamics. Thus, seasonal drivers critically shape hydro-tourism interactions. (Figure 4.)

Analysis of the interaction between Dadongshan rainfall and groundwater levels at the Baoquan Bridge monitoring station from Q1 2021 to Q4 2023 (Figure 5) reveals an almost attenuated hydrological response to seasonal precipitation variability. Although rainfall exceeded 2000 mm in Q3 2021 and Q3 2022, the seasonal mean groundwater level rose only marginally (slope = 0. 0059 m per quarter; R^2 = 0. 0016).

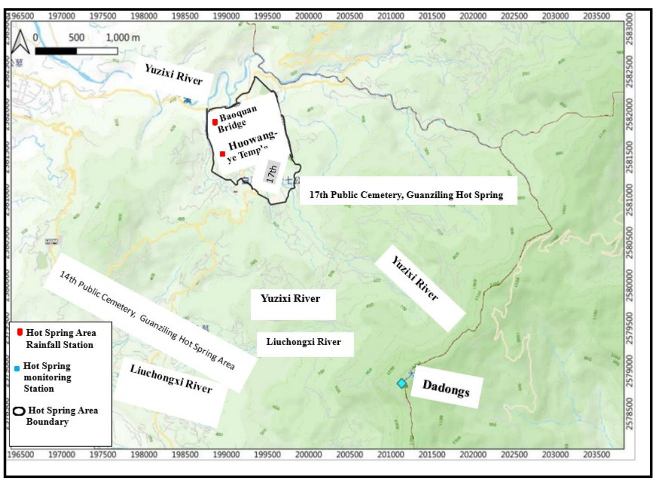

Figure 2: Study Area: Schematic Map of the Guanziling Hot Spring Tourism Area

Rainfall increased from nearly 0 to over 2, 000 mm, yet groundwater levels only oscillated slightly between 266. 5 and 269. 5 m and did not rise noticeably during peak precipitation. A trendline slope of –0. 163 m per season (R^2 = 0. 426) indicates a low degree of seasonal coupling between the two. This decoupling is primarily attributed to the aquifer's geological buffering capacity, evapotranspiration losses, and long-term drawdown from pumping, which together attenuate the short-term recharge response. (Figure 6)

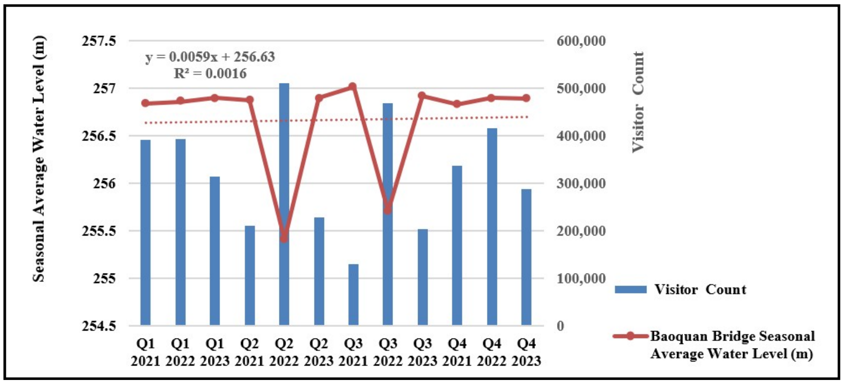

Figure 3: Seasonal visitor numbers and Baoquan Bridge seasonal average water level from Q1 2021 to Q4 2023.

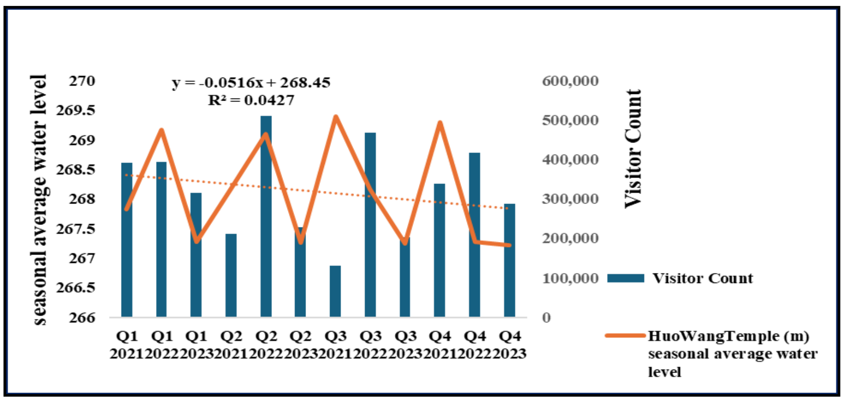

Figure 4: Seasonal visitor numbers and HuoWang Temple seasonal average water level from Q1 2021 to Q4 2023.

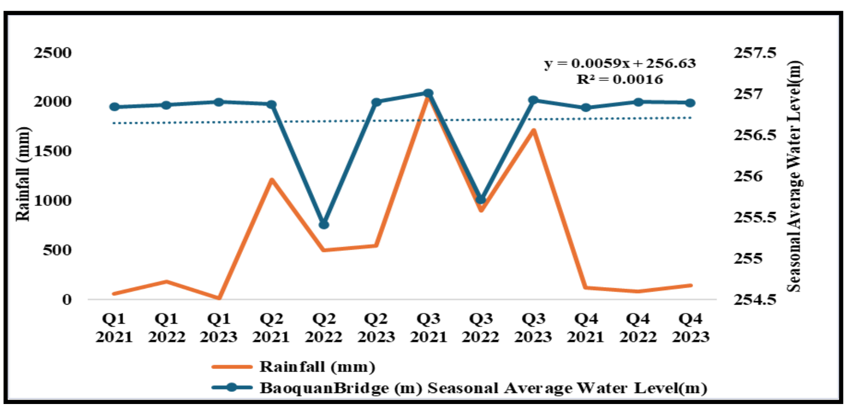

Figure 5: Seasonal rainfall (Q1–Q4) from 2021 to 2023 and the corresponding seasonal average groundwater level at Baoquan Bridge.

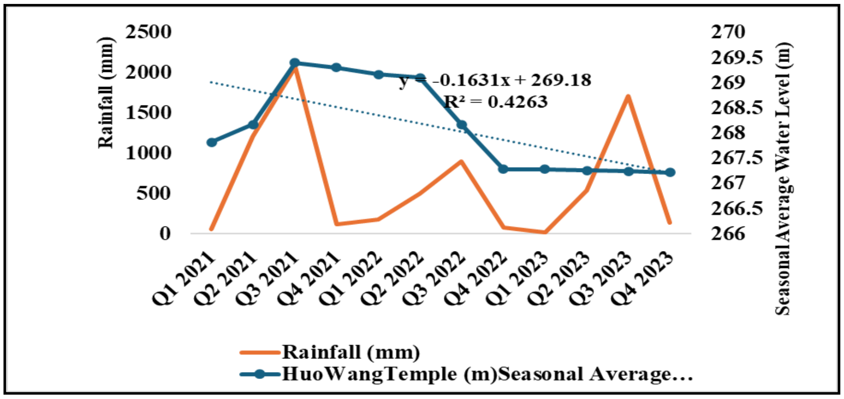

Figure 6: Seasonal rainfall (Q1–Q4) from 2021 to 2023 and the corresponding seasonal average groundwater level at HuoWang Temple

Conclusion

There is a seasonal mismatch in the coupling between tourism flows and groundwater level dynamics at Guanziling Hot Springs (Figures 3 and 4). During the wet season, groundwater levels peak while visitor numbers remain moderate to low; conversely, the dry-season tourism peak coincides with the lowest groundwater levels. To resolve this decoupling, we recommend reinforcing road maintenance and promoting dispersed tourism experiences during the wet season, and implementing visitor-control measures alongside artificial recharge in the dry season, thereby aligning tourism demand with groundwater availability and fostering sustainable hydro-tourism governance. Although precipitation is the primary source of groundwater recharge, its direct regulatory effect on seasonal water-level fluctuations in this study area is limited, indicating that geological buffering, evapotranspiration losses, and pumping processes collectively govern the groundwater recharge–discharge balance (Figures 5 and 6).

Acknowledgements

We thank Professor Hung for his assistance, and we also thank the anonymous reviewer and the assistant for their help.

References

Chen, B. -C., Perdana, T., & Kuo, L. -W. (2023). Geophysical characteristics of a fault system in the northern Central Range of Taiwan and its applications for geothermal energy exploration. Geothermal Energy, 11, 22. doi:org/10. 1186/s40517-023-

Chen, C. -W., Liu, G. -T., Cheng, Z. -X., & Hsieh, Y. -C. (2024). Application of spring mud homogenization for the production of thermal spring water: A case study of Guanziling Hot Spring, Taiwan. Journal of Health Industry Management, 7(1), 31–45. doi:org/10. 30149/JHCI. 202405_7(1). 000300265-3

DeMaagd, N., Fuleky, P., Burnett, K., & Wada, C. (2022). Tourism water use during the COVID-19 shutdown. Annals of Tourism Research, 97, 103475. doi:org/10. 1016/j. annals. 2022. 103475

Davamani, V., John, J. E., Poornachandhra, C., Gopalakrishnan, B., Arulmani, S., Parameswari, E., Santhosh, A., Srinivasulu, A., Lal, A., & Naidu, R. (2024). A critical review of climate change impacts on groundwater resources: A focus on the current status, future possibilities, and role of simulation models. Atmosphere, 15(1), 122. doi:org/10. 3390/atmos15010122

Fournier, R. O., & Truesdell, A. H. (1973). An empirical Na–K–Ca geothermometer for natural waters. Geochimica et Cosmochimica Acta, 37(5), 1255–1275. doi:org/10. 1016/0016-7037(73)90055-8

González, J. A., Taha, F., & Ordóñez, M. (2023). Coupled climate-tourism-groundwater analysis of coastal hot spring destinations: A spatiotemporal approach. Science of The Total Environment, 858(Pt 3), 159860. doi:org/10. 1016/j. scitotenv. 2022. 159860

Hernández-Flores, G., Gutiérrez-Aguirre, M. A., Cervantes-Martínez, A., & Marín-Celestino, A. E. (2021). Historical analysis of a karst aquifer: recharge, water extraction, and consumption dynamics on a tourist island (Cozumel, Mexico). Annales de Limnologie – International Journal of Limnology, 57, 16. doi:org/10. 1051/limn/2021013

He, L., Hou, M., Chen, S., Zhang, J., Chen, J., & Qi, H. (2021). Construction of a spatiotemporal coupling model for groundwater level prediction: a case study of Changwu area, Yangtze River Delta region of China. Water Supply, 21(7), 3790–3809. doi:org/10. 2166/ws. 2021. 140

Jean, J. S., Liao, L., Kar, S., Liu, C. C., & Li, Z. (2016). Hydrochemistry of hot springs in geothermal fields of central, northern, and northeastern Taiwan: Implication on occurrence and enrichment of arsenic. Environmental Earth Sciences, 75, Article 1633. doi:org/10. 1007/s12665-016-6128-x

Li, S., Zhou, Y., Fang, H., & Zhang, W. (2021). Spatiotemporal coupling analysis of geothermal tourism flows and groundwater level dynamics: A case study in the Rehai Hot Spring area, China. Geothermics, 91, 102050. doi:org/10. 1016/j. geothermics. 2020. 102050

Lin, C. -S., Chiang, P. -C., Chang, K. -T., Wang, H. -C., & Chien, Y. -C. (2022). Evaluating hot spring tourism impacts on local groundwater resources using a spatiotemporal model: A Taiwanese perspective. Sustainability, 14(16), 10067. doi:org/10. 3390/su141610067

Li, X., Wang, H., Chen, Y., & Zhang, L. (2023). Analysis based on Baidu Index of hot-spring tourism in 44 cities in China: Implications for tourism flow management. Environmental Science and Pollution Research, 30(20), 23627–23640. doi:org/10. 1007/s11356-023-25404-y

805129

Li, Y., Abu Bakar, N. A., Ismail, N. A., Mohd Ariffin, N. F., & Mundher, R. (2024). Experts' perspectives on inclusive governance for protecting hot spring landscapes in China: barriers and implications. Sustainability, 16(7), 2767. doi:org/10. 3390/su16072767

McKnight, S. V., Boutt, D. F., Munk, L. A., & Moran, B. J. (2023). Distinct hydrologic pathways regulate perennial surface water dynamics in a hyperarid basin. *Water Resources Research, 59*(4), e2022WR034046. doi. org/10. 1029/2022WR034046 agupubs. onlinelibrary. wiley

Nicolau, J. L., & Masiero, L. (2020). Hot spring tourism demand and groundwater sustainability: Investigating the spatiotemporal coupling effects in central Europe's thermal spa destinations. Journal of Sustainable Tourism, 28(7), 1045–1062. doi:org/10. 1080/09669582. 2020. 1715991

Pulido-Bosch, A., Martínez-Santos, P., & Llamas, M. R. (2023). Groundwater and tourism: Analysis of research topics and trends. Sustainability, 16(9), 3723. doi:org/10. 3390/su16093723

Peng, L., Huang, H., & Wang, F. (2022). Sustainability utilization of the fault-controlled Wentang hot spring field, China. Frontiers in Earth Science, 10, 805129. doi:org/10. 3389/feart. 2022.

Razi, M. H., Wilopo, W., & Putra, D. P. E. (2023). Spatiotemporal analysis of groundwater level trends and recharge rate estimation in the unconfined aquifer of Yogyakarta-Sleman Groundwater Basin, Indonesia. Journal of Degraded and Mining Lands Management, 11(1), 4887–4897. doi:org/10. 15243/jdmlm. 2023. 111. 4887

Secci, D., Godoy, V. A., & Gómez-Hernández, J. J. (2023). Physics-informed neural networks for solving transient unconfined groundwater flow. Computers & Geosciences, 182, 105494. doi. org/10. 1016/j. cageo. 2023. 105494 researchgate

Tan, P., Ding, W., & Li, J. (2022). Exhumation history of the Hengchun Ridge and its implications for Taiwan orogenic processes. Frontiers in Earth Science, 10, 941040. doi:org/10. 3389/feart. 2022. 941040

Treviño, J., Rodríguez-Rodríguez, M., Montes-Vega, M. J., Aguilera, H., Fernández-Ayuso, A., & Fernández-Naranjo, N. (2023). Wavelet analysis on groundwater, surface-water levels and water temperature in Doñana National Park (Coastal Aquifer in Southwestern Spain). *Water, 15*(4), 796. doi:org/10. 3390/w15040796

Tan, E., Lee, Y. -H., Chang, J. -B., Zheng, M. -J., & Shyu, C. J. (2024). Mountain building process of the Taiwan orogeny. Science Advances, 10(35), eadp8056. doi:org/10. 1126/sciadv.

adp8056

Tourism Administration, Ministry of Transportation and Communications, R. O. C. (2024). Visitors to the principal scenic spots in Taiwan by month. In Tourism Statistics Yearbook 2024 (pp. 312–314). Retrieved from https://stat. taiwan. net. tw/statistics/month/scenicSpot/progressive

Tometzová, D., Molokáč, M., & Glova Végsőová, O. (2024). Optimizing the utilization of geothermal water in spa tourism: An investment strategy with a focus on sustainability. *Acta Montanistica Slovaca, 29*(1), 115–123. doi:org/10. 46544/AMS. v29i1. 10

Wang, L., Xin, L., Zhu, Y., Fang, Y., & Zhu, L. (2023). Associations between temperature variations and tourist arrivals: Analysis based on Baidu Index of hot-spring tourism in 44 cities in China. *Environmental Science and Pollution Research, 30*, 43641–43653. doi:org/10. 1007/s11356-023-25404-y

Wang, M., Yao, J., Mo, F., & Xu, N. (2024). Spatiotemporal coupling analysis of surface water and groundwater in Tibet based on multi-source sensors. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLVIII-1, 663–669. doi:org/10. 5194/isprs-archives-XLVIII-1-2024-663-2024

Wang, B., Li, Y., Gursoy, D., & Yu, F. (2024). Unveiling fluctuation patterns of tourist volume: Insights from 56 major attractions in China. Tourism Economics. doi:org/10. 1177/13548166241295333

Wang, T., He, S., Li, J., & Feng, M. (2024). Spatiotemporal coupling of tourist flow and groundwater fluctuations in hot spring regions: Implications for sustainable water resource management. Journal of Hydrology, 620, 129376. doi:org/10. 1016/j. jhydrol. 2023. 129376