Transferability of ASTER-Derived Spectral Signatures for Lithium Mineral Exploration: From Clayton Valley (USA) to Qahavand Playa (Iran)

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Abstract

This paper presents a novel approach for identifying lithium bearing minerals in Qahavand Playa, Iran, using ASTER satellite imagery. The method utilizes reference spectra extracted from Clayton Valley Playas in the United States, a well-known lithium rich area, as input for mineral detection. Image processing was performed using Matched Filtering (MF) method to map potential lithium bearing regions in Qahavand Playa. Results from this remote sensing approach demonstrate strong correlation (R^2= 0.94) with field verification and geochemical analysis, confirming the effectiveness of using reference spectra from established lithium deposits for identifying similar mineralogical signatures in unexplored areas. This study highlights the importance of remote sensing techniques in exploration of strategic mineral resources such as lithium, which is essential for electric vehicle batteries and energy storage systems.

Overall, the results demonstrate the potential of cross regional spectral transfer as a powerful tool for guiding targeted mineral exploration in unexplored playa environments.

1. Introduction

With increasing global demand for "green" metals like lithium for electric vehicles and energy storage systems, exploration of new lithium resources has gained significant importance (Balaram et al., 2024; Vega-Muratalla et al., 2024). More than half of the world's lithium resources are contained in brine deposits, primarily found in playas and salt flats (Balaram et al., 2024; Rossi et al., 2022). Remote sensing has emerged as an efficient tool for identifying areas with high lithium potential, particularly in regions where physical access is challenging (Abrams & Yamaguchi, 2019; Othman & Gloaguen, 2014).

Among available remote sensing instruments, the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) has proven especially valuable due to its unique spectral capabilities in the Visible-Near Infrared (VNIR) and Short-Wave Infrared (SWIR) regions. These bands enable effective identification of lithium-bearing minerals and alteration zones (Abrams & Yamaguchi, 2019; Pour et al., 2017). ASTER's six SWIR bands allow discrimination among surface materials far beyond the capabilities of earlier instruments such as Landsat, revolutionizing lithological and mineral mapping since its launch (Abrams & Yamaguchi, 2019).

Building on these capabilities, recent studies have expanded the use of multi-source satellite data for lithium exploration particularly for large, arid playas where brine- and clay-hosted lithium accumulates. For instance, Feng et al. (2024) demonstrated the effectiveness of integrating multi-source remote sensing and structural interpretation for mapping clay-hosted lithium deposits in the Wenshan region of southeastern Yunnan, China. Their work highlights how remote sensing–based techniques can be adapted to different geological contexts. Several recent studies demonstrate robust methods for mapping lithium-related minerals from satellite and airborne data. Work on hyperspectral and multispectral estimation of Li content and mineral phases shows promising predictive capability when combined with field sampling and geochemical calibration (e.g., Cardoso-Fernandes et al., 2020; Cardoso-Fernandes et al., 2019).

In this context, evaporitic basins (playas) represent another major environment for lithium enrichment. Well-known examples include Silver Peak in the United States, where lithium-rich brines are actively extracted. In contrast, Qahavand Playa in western Iran has received limited attention, although its geomorphological and sedimentological characteristics suggest potential for lithium accumulation.

To address this gap, the present study investigates whether spectral information derived from the Clayton Valley playas can be used to identify lithium-bearing zones in Qahavand Playa using ASTER imagery. To our knowledge, this is the first study to apply cross-regional spectral transfer between two lithium-bearing playas located in distinct climatic and geological settings, demonstrating the feasibility of reference-based detection using ASTER data.

2. Study areas

Two playas located in distinct geological and climatic settings were selected for this study: The Clayton Valley system in Nevada, USA—which includes the Dijan, Silver Peak, and Ultra Lithium deposits— and the Qahavand Playa in western Iran. The Clayton Valley is well recognized for its lithium-rich brine deposits and served as the source for reference spectral signatures, while Qahavand Playa was the target area for lithium potential mapping. Recent studies have identified Qahavand Plain, situated in the center of the Hamadan region, as a

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prominent site for lithium exploration in Iran (Daneshvar et al., 2025).

2.1 Geological Setting of Clayton Valley Playas, Nevada, USA

The Clayton Valley, located in Esmeralda County, Nevada, hosts one of North America's most productive lithium brine provinces (Fig. 1 and 2). The valley contains several well-known deposits, including Dijan, Silver Peak, and Ultra Lithium, occurring within a closed evaporitic basin. Its geological framework consists of Quaternary lacustrine deposits overlying Miocene-Pliocene volcanic and sedimentary rocks, with significant lithium enrichment in the Esmeralda Formation, particularly in smectite-rich clays (Lane et al., 2024).

The lithium-rich deposits in Clayton Valley are characterized by specific mineralogical assemblages, including clays (illite, montmorillonite), carbonates, and lithium-rich brines. Previous studies (e.g., Castor and Henry, 2020) have shown that lithium occurs primarily as illitic clay (similar to tainiolite - $KLiMg_2Si_4O_{10}F_2$) in the most lithium-rich deposits, while Li-smectite (hectorite - $Na_{0.3}(Mg,Li)_3Si_4O_{10}(OH)_2$) is present in rocks with lower lithium concentration. This mineralogical understanding provides context for interpreting the spectral signatures obtained from the ASTER imagery. Its spectral signature in the SWIR range (2.0–2.4 µm) serves as a robust reference for lithium-related surface materials.

Figure 1. The location of Clayton Valley, Nevada, in google earth image. Blue box shows the area of interest.

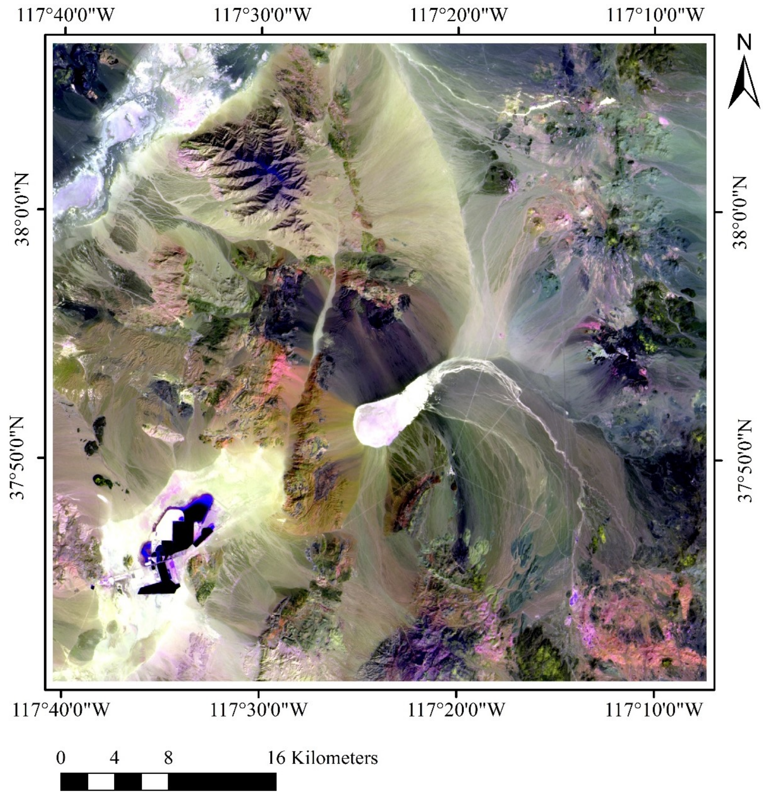

Figure 2. Color composite image of ASTER data from the Clayton Valley area, (RGB = 463).

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2.2 Geological Setting of Qahavand Playa, Hamedan, Iran

Qahavand Playa lies in the central-western Iranian Plateau (Fig. 3 and 4). It is a closed-basin evaporitic environment influenced by seasonal flooding and arid climate. The basin's hydrogeological setting, fine-grained sediments, and evaporitic crusts make it a promising candidate for lithium exploration.

Recent studies on the Qahavand Plain have revealed that sediments in this area contain lithium-bearing minerals, including zabuyelite (lithium carbonate (Li_2CO_3)) and pseudoeucrptite, which is a rare lithium aluminum silicate mineral typically associated with lithium-rich pegmatites (Daneshvar et al., 2025). The lithium concentration in this area has been found to vary from 30 to 102 ppm, with an average of 55.1 ppm. Analysis of strontium isotope ratios ($^{87}Sr/^{86}Sr$) in the Qahavand Plain, ranging from 0.7078 to 0.7103, suggests that the lithium sources are aligned with the Alvand granites, Eocene-Oligocene volcanic rocks, and Oligo-Miocene limestone in the surrounding area (Daneshvar et al., 2025).

The Chemical Index of Alteration (CIA) for the Qahavand Plain, averaging 59.7, indicates an intermediate to felsic rock source for the sediments (Daneshvar et al., 2025). Additionally, low Ga/Rb ratios (0.18 to 0.27) and high Sr/Cu ratios (8.9 to 710) confirm that the sedimentation occurred under cool-arid climate conditions with low temperatures and minimal precipitation. The northern region of the Qahavand Plain shows elevated lithium concentrations, ranging from 71 to 102 ppm, which approaches the lower limit of economically viable lithium-bearing deposits worldwide (Daneshvar et al., 2025).

Figure 3. The location of Qahavand playa, Hamedan, in google earth image.

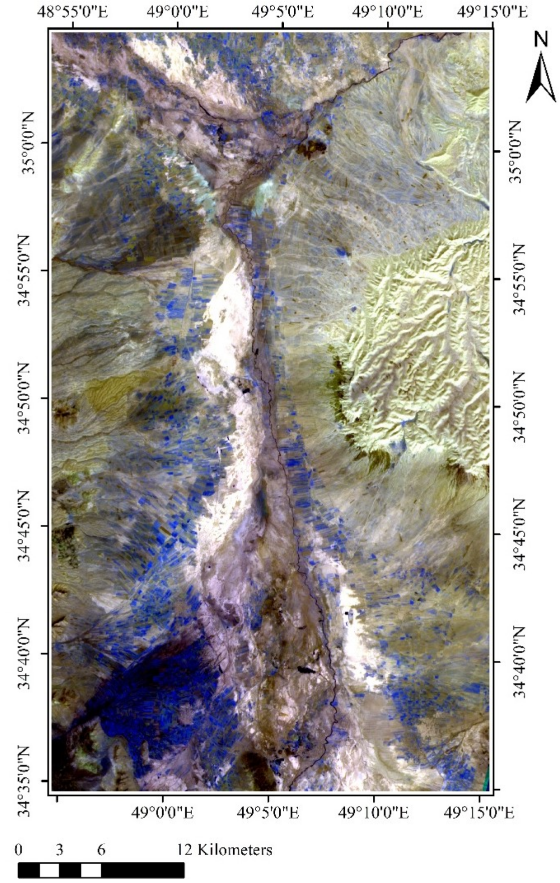

Figure 4. Color composite image of ASTER data from the Qahavand area, (RGB = 643).

3. Methodology

The procedures used for data acquisition and processing are as follows (Fig. 5):

1. ASTER Level 1T imagery was acquired for both Clayton Valley and Qahavand playas, and atmospheric correction was performed using FLAASH module.
2. Reference spectra of lithium-bearing minerals were extracted from ASTER imagery of Clayton Valley Playas, specifically from locations within the Silver Peak Mine, Ultra Lithium Mine, and Dijan Mine.
3. Multiple spectral signatures were collected from these known lithium-rich areas, and a mean spectrum was calculated to serve as the reference endmember.
4. The extracted reference spectra were applied as input for processing ASTER imagery of both Clayton Valley and Qahavand Playas within ENVI software.
5. Matched Filtering (MF) algorithm, was employed to identify areas containing lithium-bearing minerals (Othman & Gloaguen, 2014).

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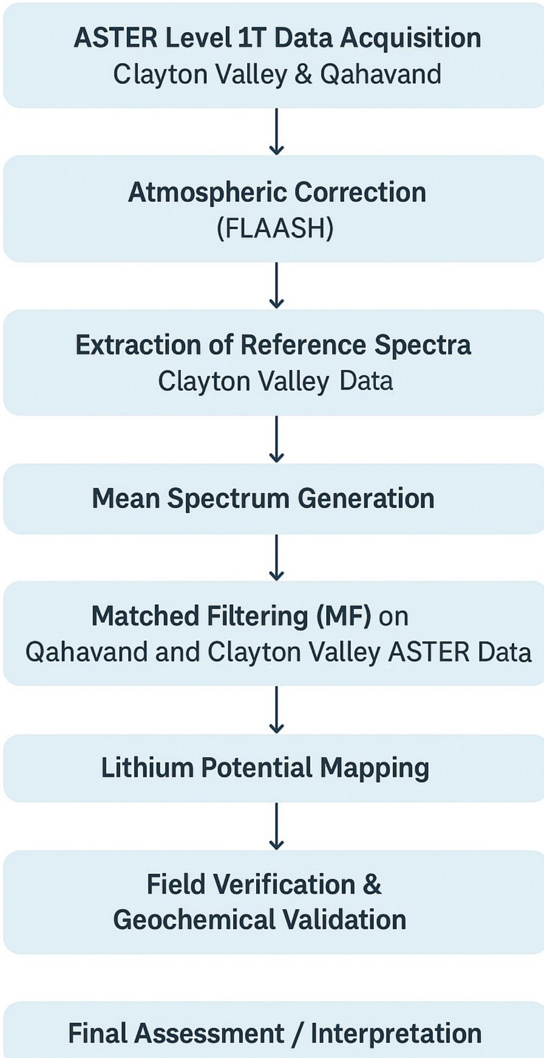

6. Field data and geochemical analyses reported by Daneshvar et al. (2025) were used to validate the remote sensing results.

Figure 5. Workflow for lithium-bearing mineral mapping using ASTER data and cross-regional spectral transfer.

4. Result

4.1 Endmember collected from ASTER imagery of Clayton Valley

Spectral reflectance signatures of lithium-bearing minerals were extracted from the Clayton Valley ASTER image using Regions of Interest (ROIs) derived from known lithium-rich zones (Fig. 6).
The first spectrum (x: 300, y: 2457) was obtained from the Silver Peak Mine, the second (x: 119, y: 741) from the Ultra Lithium Mine, and two additional spectra (x: 1525, y: 1903 and x: 1757, y: 1759) from the Dijan Mine. A mean reference spectrum (shown in black) was then generated by averaging the four extracted spectra, representing the characteristic spectral response of lithium-bearing clay minerals in the study area.

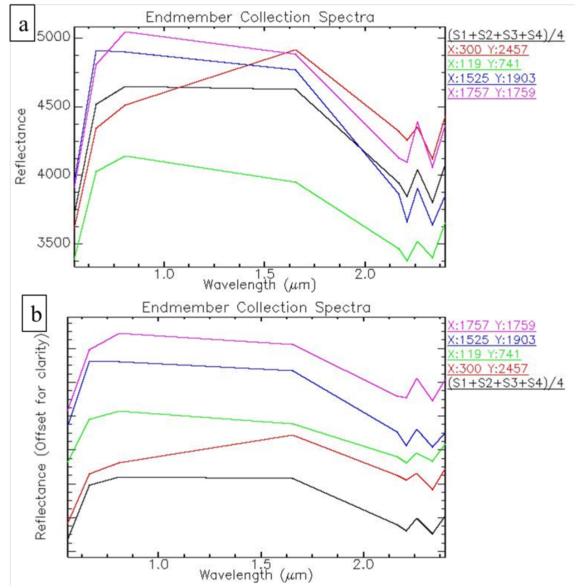

Figure 6. Extracted spectra from ASTER VNIR-SWIR dataset of the Clayton Valley area, in normal (a) and offset (b) form.

The reference spectra were analyzed using the Spectral Analyst tool in ENVI to infer potential mineral compositions. Although this tool is limited by ASTER's relatively low number of spectral bands, it provided useful indications of the dominant mineral phases associated with lithium-bearing zones.
The highest-ranked spectral matches included pigeonite, cookeite, rectorite, sodium bicarbonate, paragonite, illite, and lepidolite. While these minerals do not precisely correspond to the reported mineral assemblages of the Clayton Valley deposits, their chemical compositions suggest possible lithium substitution within their crystal structures, supporting their association with lithium-enriched environments.

4.2 Mapping Results

Spectral analysis of ASTER imagery of Clayton Valley and Qahavand area using reference spectra from Clayton Valley Playas successfully identified areas with high probability of lithium-bearing mineral occurrence (Fig. 7 and 8). These areas were predominantly located along the playa margins and evaporative zones, consistent with the known pattern of lithium-rich deposits in playas (Balaram et al., 2024). Enhanced discrimination of lithium-associated minerals was achieved, especially for hydrated clays and evaporitic assemblages.
The MF analysis produced a detailed map of potential lithium-rich areas in Qahavand Playa, with specific geographic coordinates identified for follow-up field investigation. Field and geochemical verification (Daneshvar et al., 2025) confirmed that the remotely detected zones correspond to areas with measurable lithium concentrations, thereby validating the cross-regional spectral transfer approach. The successful detection can be attributed to ASTER's ability to capture distinctive spectral features associated with lithium minerals and their surrounding

alteration assemblages (Abrams & Yamaguchi, 2019; Pour et al., 2017).

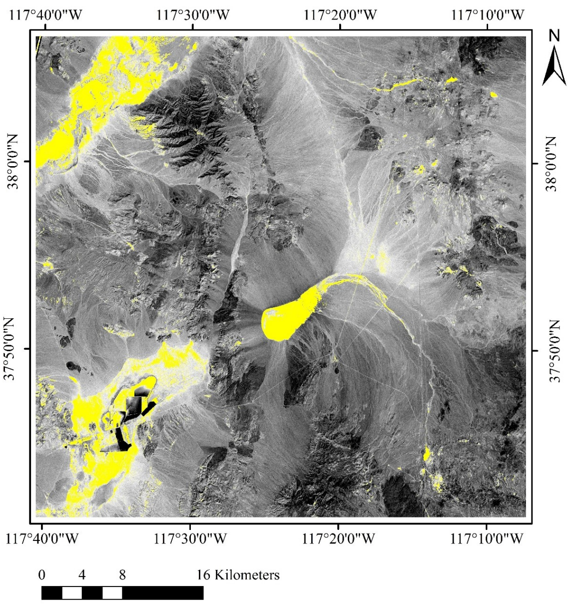

Figure 7. Lithium- rich area in the Clayton Valley area, Nevada, USA.

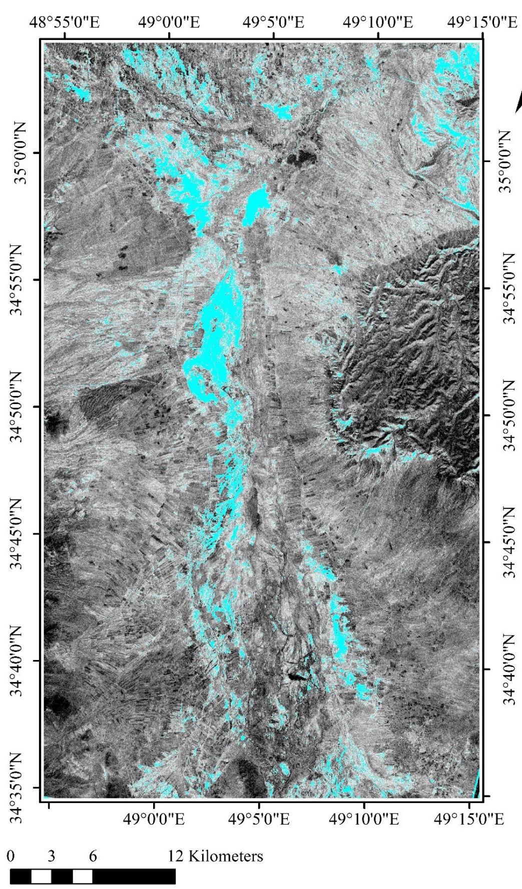

Figure 8. Lithium- rich area in the Qahavand area, Hamedan, Iran.

4.3 Verification

Field validation in Qahavand confirmed the spectral results, revealing that the identified zones correspond to clay-evaporite mixtures often enriched in lithium. The generated map shows strong agreement with field observations and geochemical analyses of lithium concentrations reported by Daneshvar et al. (2025) (Fig. 9), further supporting the reliability and robustness of the spectral approach. The correlation analysis between MF scores derived from ASTER imagery and field lithium concentrations yielded a coefficient of determination (R^2 = 0.94). This approach exemplifies a scalable methodology for knowledge-driven exploration where reference spectra from known deposits can guide remote sensing analyses in unexplored regions.

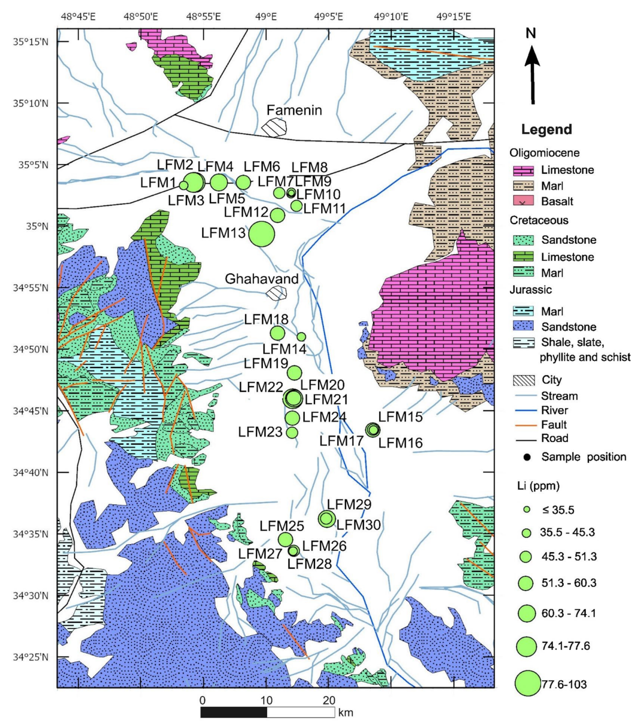

Figure 9. Seven populations of Li concentration based on the C-N fractal model on the geological Map, using ArcGIS (after Daneshvar et al., 2025). The main anomaly in Li concentration occurs mostly in the northern part of the study area.

5. Discussion

Lithium-brine deposits form through leaching of lithium from source rocks, transport via groundwater to playas, and evaporative concentration in closed basins (Rossi et al., 2022). Brines contain cations (Li^+, K^+, Ca^{2+}, Na^+, Mg^{2+}) and anions (SO_4^{2-}, Cl^-, HCO_3^-, CO_3^{2-}), with brine types classified as sulfate-, chloride-, or carbonate-dominated (Liu et al., 2023). These processes produce characteristic mineral assemblages detectable by ASTER spectral bands.

In Qahavand Playa, lithium-bearing minerals concentrate along marginal evaporitic zones, reflecting hydrogeological control over deposition. The strong spectral correspondence with Clayton Valley supports reference-based spectral transfer as an effective approach for lithium exploration in poorly studied regions, suggesting that lithium enrichment in

closed evaporitic systems may follow similar geochemical pathways.
Integrating ASTER imagery with reference spectra from both known and local deposits enables rapid, cost-effective screening of large areas, delineating targets for detailed geochemical and geophysical investigation. This knowledge-driven workflow is particularly valuable in arid, remote regions and demonstrates that structural depressions and playa-margin interfaces act as key traps for lithium-bearing fluids.

6. Conclusion

This study demonstrates that using reference spectra extracted from known lithium-rich areas (such as Silver Peak Playa) for processing ASTER imagery is an effective approach for identifying areas with high lithium potential in other playas (Qahavand Playa). The strong correlation between remote sensing results and field verification (R^2 = 0.94) confirms the high reliability and robustness of the proposed cross-regional spectral transfer method.

ASTER, with its unique spectral capabilities in the VNIR and SWIR regions, proves to be a valuable tool for mineral mapping and resource exploration, including lithium. The methodology presented in this study can be applied to explore new lithium resources in other playas and evaporative basins globally, contributing to the growing need for lithium resources in the green technology sector.

Our findings are particularly significant for lithium exploration in Iran, where the Qahavand Plain has been identified as a promising site. The lithium concentrations documented in the northern region of the Qahavand Plain (71-102 ppm) approach the lower limit of economically viable lithium deposits (Daneshvar et al., 2025), suggesting that further detailed exploration of this area could yield valuable results for Iran's emerging lithium industry.

Combining ASTER data with other remote sensing data and geophysical methods could enhance the accuracy of lithium potential mapping in future work. Furthermore, studying the hydrological system of the region is essential for better understanding the processes of lithium transport and concentration in playas.

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