Bridging Gaps in Heritage Interpretation: Insights from Local Perception and Geospatial Analysis in the Dadanitic Inscriptions Landscape of AlUla

Huda Taher Alarfaj [1], Luigi Barazzetti [1], Mattia Previtali [1], Oriel Prizeman [2]

[1]Politecnico di Milano, Piazza Leonardo da Vinci, 32, 20133 Milano, Italy –
(hudatahira.alarfaj, luigi.barazzetti, mattia.previtali)@polimi.it
[2] Cardiff University, Bute Building, Room 1.39, King Edward VII Avenue, Cardiff, CF10 3NB, United Kingdom –
PrizemanO@cardiff.ac.uk

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Abstract

This study explores how the local perception and geospatial analysis can each contribute to building more comprehensive interpretations of the ancient kingdoms of Dadan and Lihyan in AlUla, Saudi Arabia. Drawing on a broader PhD project conducted in collaboration with the Royal Commission for AlUla (RCU), this paper presents findings from two distinct yet complementary approaches. The first part involves a national survey assessing public awareness, engagement, emotional connection, and attitudes toward pre-Islamic heritage. Results reveal limited familiarity with the Dadan and Lihyan kingdoms, yet highlight strong identity-based connections to heritage and a positive attitude towards digital tools for engagement, emphasising the need for interpretive strategies that bridge archaeological knowledge with community perspectives. The second part applies geospatial analysis to examine the environmental context of Dadanitic inscription placement, analysing elevation, orientation, and solar exposure. The results suggest that inscriptions were not randomly distributed but may have been deliberately placed in environmentally favourable locations. Together, these findings support the development of interpretation strategies that are historically informed, locally meaningful and attentive to the spatial context of the heritage landscape.

1. Introduction

1.1 Case Study Context: Dadan and Lihyan Kingdoms

Located in the Wadi Al-Qura valley of northwestern Saudi Arabia, the ancient site of Dadan served as the capital of two of the earliest known Arabian kingdoms: Dadan and Lihyan (Alsuhaibani, 2023). Strategically positioned along major incense and trade routes, these kingdoms flourished between the 8th/7th and 1st centuries BCE, becoming important centres of commerce, religion, and political organisation in pre-Islamic Arabia (Curry, 2021). The cultural legacy of these civilisations is preserved through a rich corpus of Dadanitic inscriptions, rock-cut tombs, and archaeological sites (Al-Said, 2010; Burt et al., 2018; Hussein Abu Al-Hassan, 2010; Norris, 2024; Said Al-Said et al., 2010). (Figure 1).

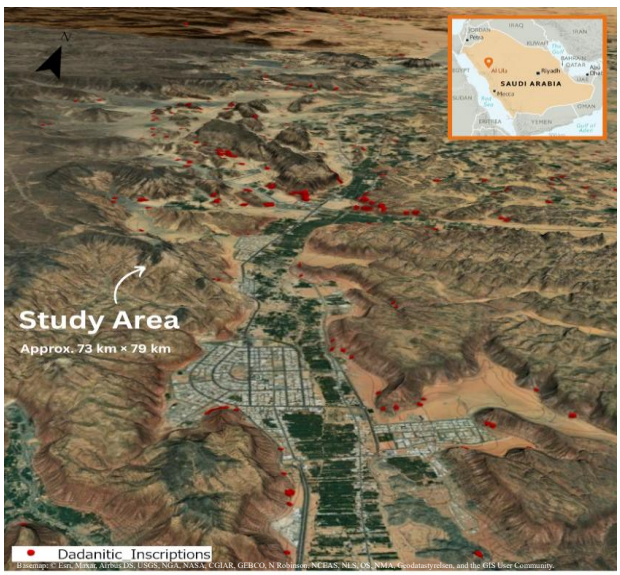

Figure 1. 3D spatial visualization of the study area with mapped Dadanitic inscriptions. © Huda Alarfaj (2025).

The Dadanitic inscriptions serve as an important written source for reconstructing aspects of life in the Dadanite and Lihyanite kingdoms. These texts, carved in the landscape, offer valuable information about the kingdoms' governance, trade, religious practices and relationships with neighbouring communities, and they offer historical context (Al-Thibi, 2023; Almushawh & AlAhmari, 2023; Alsuhaibani et al., 2023; Kootstra, 2022a, 2022b). Archaeological sites constitute another key source of knowledge, with site-by-site excavations conducted by both local and international teams contributing to our understanding of the Dadan and Lihyan kingdoms (Alahmari et al., 2022; Rohmer et al., 2024). However, both inscriptions and excavations also present limitations highlighting the need for complementary approaches. For example, although Dadanitic inscriptions offer a vital written record, their interpretation is hindered by their fragmentary condition and unresolved linguistic complexities regarding grammar and vocabulary (Kootstra, 2020, 2022a, 2022b). This highlights a critical gap in relying solely on epigraphy to understand these civilisations. Moreover, site-by-site excavations, while valuable, may overlook the broader distribution patterns critical for understanding the spatial logic of inscription placement. To contribute to a broader understanding, this paper presents findings from two distinct yet complementary phases of a broader PhD project on the Dadanitic inscriptions landscape (Figure 2).

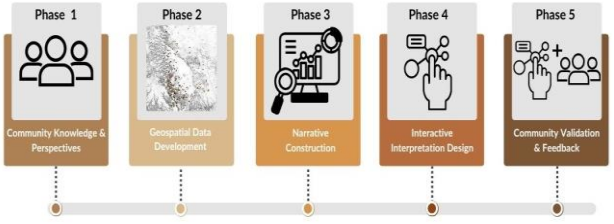

Figure 2. Five-phase structure of the PhD research project, aimed at developing more holistic and spatially informed heritage interpretation for the Dadanitic inscriptions landscape. © Huda Alarfaj (2025).

First phase, a national survey examines public perceptions of heritage, offering insights into how interpretation can reflect cultural identity and community relevance. Second phase, geospatial analysis offers a novel methodology for interpreting Dadanitic inscriptions in relation to their environmental context, highlighting how environmental factors may have influenced patterns in inscription placement.

2. Methodology

2.1 Phase One: Community Engagement Methods

Phase one of this research focuses on exploring how Saudi citizens perceive and engage with cultural heritage, with particular attention to the Dadan and Lihyan kingdoms in AlUla. This phase was designed to provide a baseline understanding of public attitudes, knowledge gaps, and engagement barriers, which would later inform the development of interpretation strategies and digital tools in the final phase of the PhD project.
The survey was developed after conducting semi-structured interviews with three local stakeholders in AlUla, including individuals engaged in cultural work and heritage interpretation. These conversations helped identify common narratives, gaps in public awareness, and sensitive topics, thus forming an understanding of community perceptions. From these insights, a draft survey was created and reviewed by two academic experts in Psychology for clarity and neutrality. A pilot version was tested with ten participants, and minor adjustments were made before full deployment.

The final version of the survey combined both closed- and open-ended questions to support a mixed-methods approach. It was structured around four key themes: (1) *Awareness and Knowledge of Pre-Islamic Heritage*, (2) *Cultural Identity and Belonging*, (3) *Engagement and Barriers to Engagement*, and (4) *Technology Acceptance*. A detailed description of each theme and its related findings is presented in the results section. The survey, designed using Google Forms, was distributed through WhatsApp, social media platforms, and in-person invitations at cultural events in Riyadh and Jeddah, Saudi Arabia. This multichannel approach enabled outreach to a wide demographic, including individuals who may not typically engage with heritage initiatives. A total of 531 complete responses were collected (Figure 3).

Quantitative data were analysed using descriptive statistics to identify general trends across different demographic groups, while open-ended responses were grouped thematically to highlight underlying cultural, emotional, or religious influences. The results of this phase contribute to the broader research aim by clarifying how the public currently engages with AlUla's heritage and what kinds of tools or narratives might resonate most in future interpretation efforts.

This research phase adhered to ethical standards and received approval from the Politecnico di Milano Ethics Committee (Ref: Parere n. 89/2024, issued 12/12/2024). All participants were informed of the purpose of the study, their right to voluntarily withdraw without penalty, and the anonymised handling of their data. Consent was obtained at the beginning of the survey, and no personally identifiable information was collected.

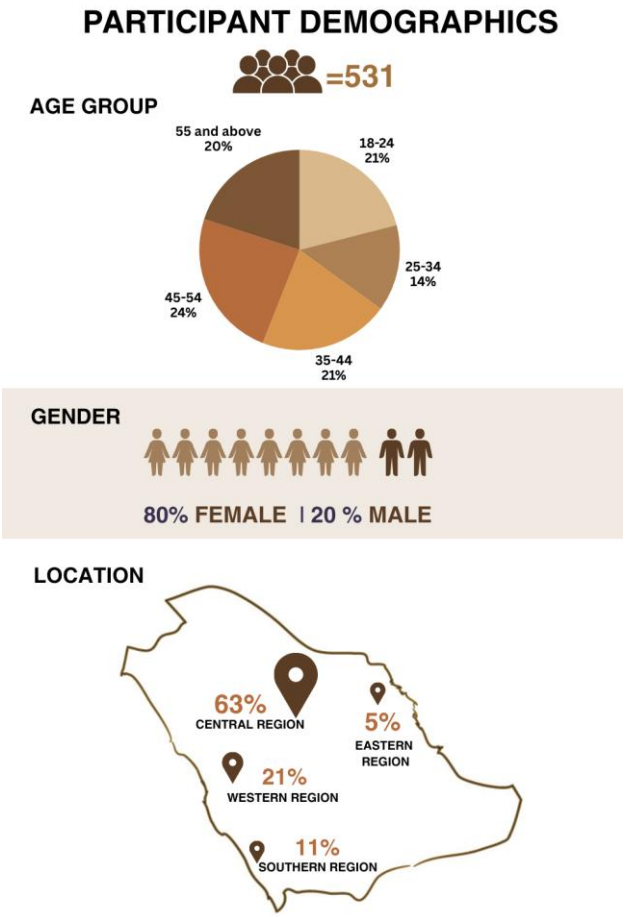

Figure 3. Survey participant demographics by age, gender, and region. © Huda Alarfaj (2025).

2.2 Phase Two: GIS-Based Spatial Analysis Methods

This section investigates whether Dadanitic inscriptions exhibit consistent spatial patterns in elevation and orientation, that may reflect environmental or intentional placement decisions. The geospatial analysis relied on two primary datasets the digital terrain model and the inscriptions location. The Digital Terrain Model (DTM) used in this study was provided by the Royal Commission for AlUla, captured using LiDAR technology in 2022 and processed at a 10-metre resolution for this analysis. The inscription point data was sourced from the Identification and Documentation of the Immovable Heritage Assets (IDIHA) project, conducted between 2018 and 2021 on behalf of the Royal Commission for AlUla (RCU), and is currently under study as part of the AlUla Inscriptions Corpus Analysis Project (AICAP). It is important to note that the IDIHA surveys were primarily conducted in wadi beds, and many high-altitude sites could not be explored. Additionally, several key elevated locations with Dadanitic inscriptions such as: Jabal Ithlib, Jabal al-Khuraybah, and Umm Daraj fell outside the original research area of the project.

2.2.1 Orientation Analysis

To analyse inscription orientation, aspect values representing slope direction (in degrees from 0° to 360°) were derived from the DTM. These values were then assigned to inscription points by intersecting the elevation surface with the inscription locations. Although the original aspect values were preserved as continuous data, they were subsequently grouped into generalised directional zones - North, East, South, West, and Flat to enable clearer spatial interpretation. This classification was based on conventional compass ranges:

- North: 0°–45° and 315°–360°
- East: 45°–135°
- South: 135°–225°
- West: 225°–315°
- Flat: areas with no slope.

The resulting directional categories allowed for comparison between orientation and elevation preferences. Inscriptions on flat terrain were treated separately, as these could reflect either true horizontal surfaces or georeferencing uncertainties. The results were visualised using classified symbology to support interpretation of spatial distribution patterns.

2.2.2 Elevation Preferences Analysis

To assess where Dadanitic inscriptions were typically placed in terms of elevation, each inscription point was assigned an elevation value derived from the DTM. These values were extracted from the DTM by intersecting point geometry with the continuous elevation surface. To identify broader patterns, the raw values were examined statistically and visualised in a histogram to inform the classification process. Based on this analysis, the elevation values were classified into three zones: Low, Mid, and High, to support clearer spatial interpretation. The classification thresholds were determined by combining visual interpretation of the elevation distribution with statistical references, including the mean (829 m), median (801 m), and standard deviation (89.4 m). The defined zones are as follows:

- Low: <750 metres
- Mid: 750–900 metres
- High: >900 metres.

This range-based classification was designed to differentiate between inscriptions located near valley floors, those on mid-slope or terraced terrain, and those on higher or more exposed surfaces. It also enabled comparison across other variables such as orientation and solar exposure in later analyses. To support visualisation and interpretation, the elevation zones were symbolised using graduated colour schemes and incorporated into spatial charts. These outputs facilitated the identification of spatial tendencies and supported subsequent correlation analysis between elevation and other environmental factors.

2.2.3 Solar Exposure Analysis

Following the preliminary analysis of orientation and elevation, which indicated that north-facing inscriptions were the most common across nearly all elevation zones, an additional analysis was conducted to examine whether sunlight exposure may have influenced the placement of north-facing inscriptions.To investigate this, solar radiation values were modelled across the landscape using the DTM as a base elevation surface. The model calculated the total annual solar energy (in Wh/m²/year) each location would receive under typical atmospheric and sky conditions over a full calendar year. Once the solar radiation surface was generated, the estimated solar exposure value at each north-facing inscription point was extracted by overlaying the inscription layer with the solar radiation raster.
Each north-facing inscription point was then assigned a solar exposure value, providing a quantitative measure of its exposure level. To facilitate interpretation, these values were classified into three categories: Low level of exposure, Moderate level of exposure, and High level of exposure. The classification thresholds were based on the mean solar radiation value of 1648.7 Wh/m²/year and a standard deviation of ±132.7 Wh/m²/year, which are also presented in the results section. Using this statistical framework:

- Low exposure = values <1516 Wh/m² (i.e., more than 1 standard deviation below the mean);
- Moderate exposure = values between 1516 and 1781 Wh/m² (i.e., within ±1 standard deviation); and
- High exposure = values >1781 Wh/m² (i.e., more than 1 standard deviation above the mean)

These categories were added as a new attribute field for each point, enabling comparison with other spatial variables such as orientation and elevation. The classified results were then visualised and analysed to assess the potential influence of sunlight exposure on inscription placement patterns.

3. Results

3.1 Phase One: Community Survey Results

The first theme, *Awareness and Knowledge*, examined participants' familiarity with heritage at three levels: national (Saudi Arabia), regional (AlUla), and heritage-specific (the Dadan and Lihyan kingdoms). The results reveal a consistent decline in awareness as the focus narrowed from general to local, highlighting key gaps in public knowledge of pre-Islamic heritage (Figure 4). At the national level, 44% of participants described their knowledge of Saudi Arabia's heritage sites as limited or non-existent, while only 2% considered themselves highly knowledgeable. A further 14.5% selected a neutral response, indicating uncertainty or disengagement. Regionally, when asked about their familiarity with heritage sites in AlUla, only 1% reported very good level of knowledge, and 20% indicated good knowledge together accounting for just 21% of respondents. In contrast, 67% described their knowledge as limited or non-existent. The most dramatic awareness gap appears at the heritage-specific level, focused on the Dadan and Lihyan kingdoms. Here, 73% of respondents reported having no knowledge at all, while only 1% rated their knowledge as very good and 8% as good. These figures highlight a steep decline in public familiarity with specific ancient civilisations, despite their recognised archaeological and historical significance.

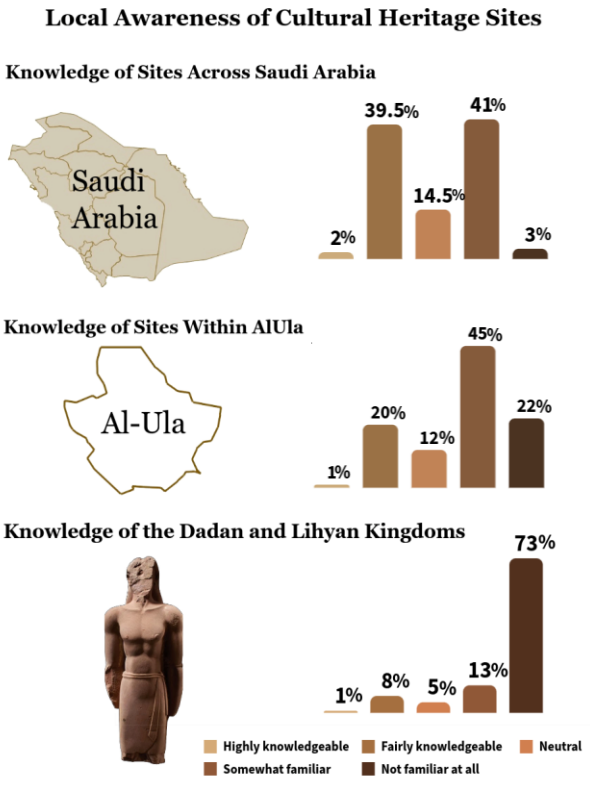

Figure 4. Local awareness of heritage sites in Saudi Arabia and AlUla, including the Dadan and Lihyan Kingdoms. © Huda Alarfaj (2025).

The second theme, *Cultural Identity and Belonging*, examined how heritage contributes to personal and collective identity. The first question asked whether heritage sites and cultural traditions shape respondents' sense of identity within society. A clear majority (90%) agreed, suggesting that heritage engagement is most meaningful when it reflects and reinforces cultural identity.

The second question brought this connection to the local level, asking whether the history and heritage of one's city influence feelings of belonging. Here, 86% reported a strong or noticeable connection. For those who did not, follow-up responses pointed to barriers such as limited access to information, perceived irrelevance to daily life, and lack of participation opportunities. Participants were also asked which types of heritage they felt most connected to. Responses showed strong recognition of tangible features such as religious sites, historical buildings, and archaeological landmarks were frequently selected, while intangible elements like values, oral traditions, and festivals also received strong responses, at times surpassing physical components. This distribution reinforces the importance of addressing heritage holistically.

The third theme, *Engagement and Barriers*, explored the conditions that encouraged or hindered meaningful public engagement with heritage. The results offer insight into how historical interpretation, religious sensitivity, and presentation methods shape public willingness to interact with heritage sites. A key question asked whether it was important to understand the full historical context of heritage sites, including pre-Islamic practices and beliefs. At 54%, a majority agreed without reservation, while 29% supported historical awareness but preferred to exclude certain religious interpretations. In contrast, 15% expressed reluctance toward narratives that may conflict with cultural or religious values. These results reflect a general openness to historical inclusivity, but also highlight the need for sensitivity when addressing content rooted in pre-Islamic or non-Islamic contexts.

Another question focused specifically on religious reservations about visiting heritage sites in AlUla. While 76% of participants reported no concerns, 24% expressed religious hesitation. In follow-up responses, participants cited reasons such as prophetic warnings, associations with divine punishment, and references to specific sites like Madain Saleh. These answers show that, for some, engagement with heritage is shaped by personal beliefs as much as by historical or educational interest.

To better understand how engagement could be improved, participants were asked what factors would make heritage sites in Saudi Arabia feel more important and meaningful to them. The most frequently selected response (68%) was learning the historical stories behind the heritage sites. This was followed by linking the sites and past civilisations to the present and showing how history contributes to shaping today's identity and culture (61%). Respondents also supported using modern interactive technologies (49%) and increasing opportunities for community involvement through workshops and cultural activities (43%). Together, these results point to a desire for deeper, more connected forms of engagement where history is not only told but made relevant and accessible.

The final theme, *Technology Acceptance*, explored participants' views on the role of digital technology in enhancing engagement with cultural heritage. A strong majority representing 92% of respondents agreed that digital tools can help improve awareness and interest in heritage, indicating wide public openness to technology-enabled forms of interpretation. When asked which types of technologies would be most helpful, interactive platforms were the most frequently selected (67.4%), followed by virtual reality heritage exhibitions (62.7%), documentary films (59.1%), and digital games (36.5%). These preferences point to a demand for immersive, participatory, and narrative-rich experiences over static or passive content delivery.

3.2 Phase Two: GIS Analysis Results

This spatial dataset included 724 inscription locations, each representing a documented rock surface bearing one or more Dadanitic inscriptions. The following analysis interprets general spatial trends in orientation and elevation based on these points.

3.2.1 Orientation Analysis Results

Among the 724 documented points, the most frequent orientation is north-facing, with 198 points classified in this category (Figure 5). This is followed by east-facing surfaces (168 points), while west-facing and south-facing surfaces are less represented. Notably, 145 points are classified as 'flat', meaning they had no measurable slope based on the DTM. This distribution suggests a preference for north- and east-facing surfaces, while south and west facing surfaces were notably less common across the study area. However, conclusions about intentional orientation choices should be made with caution, as other factors may have influenced the observed distribution. This will be discussed further in the discussion section. The absence of strong representation in southern aspects may be due to environmental conditions such as increased solar exposure, though this cannot be confirmed without direct surface condition data. The high number of 'flat' classifications likely reflects a combination of true horizontal carving surfaces and limitations in the DTM-based orientation analysis, particularly where the rock face orientation was not accurately captured in the elevation raster.

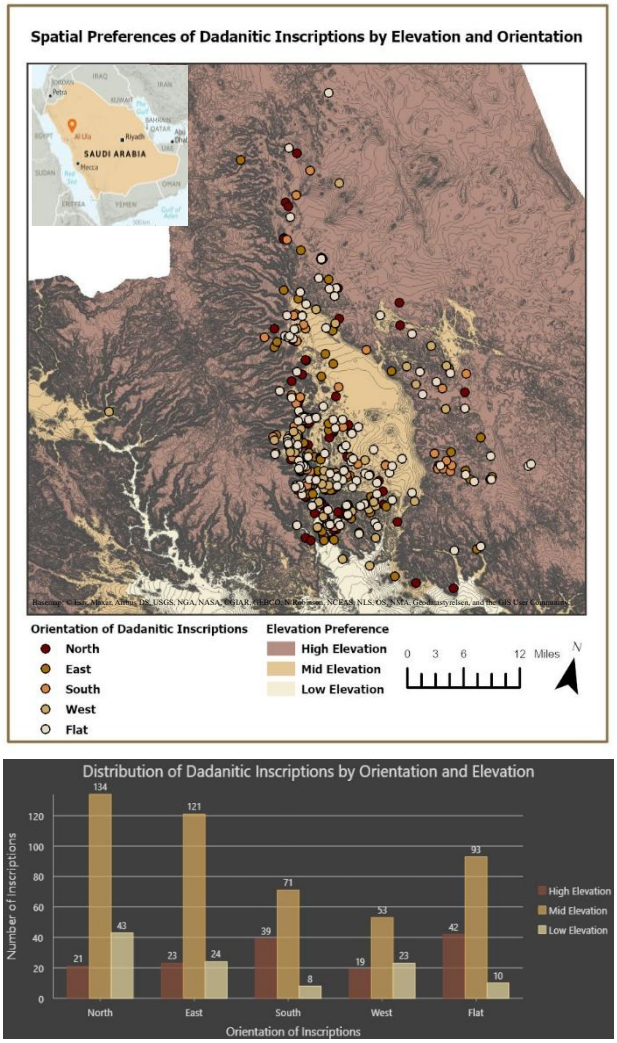

Figure 5. Map and chart showing the elevation and orientation patterns of Dadanitic inscriptions in AlUla. © Huda Alarfaj (2025)

3.2.2 Elevation Analysis Result

Elevation values at inscription points range from approximately 665 to 1193 meters above sea level, with a calculated mean of 829 meters and a median of 801 meters (Figure 6). Based on visual analysis of the elevation histogram and central tendency statistics, three elevation zones were established for classification:

- Low elevation: <750 metres
- Mid elevation: 750–900 metres
- High elevation: >900 metres

The mid-elevation zone contains the highest number of inscription points (472 out of 724), indicating a strong preference for moderately elevated terrain. In contrast, low-elevation surfaces account for only 108 points, and high-elevation sites for 144 points. When orientation and elevation data are considered together, consistent patterns emerge (Figure 5). North-facing surfaces are most frequently located within the mid-elevation

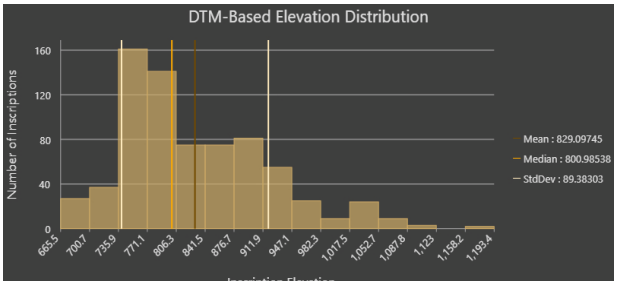

Figure 6. Elevation distribution of Dadanitic inscriptions based on Digital Terrain Model (DTM) values.© Huda Alarfaj (2025)

band (134 out of 198), followed by 43 at low elevation and 21 at high elevation. A similar mid-elevation concentration is seen for east- and west-facing inscriptions. While inscriptions occur across all elevation bands, the combination of north or east orientation and mid elevation is the most prevalent. However, this pattern cannot be firmly confirmed as intentional, since other factors such as: terrain accessibility, geological formations, or survey coverage may also influence the results. These considerations will be further discussed in the discussion section.

3.2.3 Solar Exposure Result

In this analysis, the solar exposure calculation was limited to north-facing inscription points only, as the underlying hypothesis was that these surfaces may have been deliberately chosen due to their lower sun exposure. Given the scope of this research, other orientations were not investigated at this stage**.**

To investigate this, annual solar radiation values were calculated from the DTM using a raster-based solar modelling approach. The model estimated the total accumulated solar energy in watt-hours per square meter (Wh/m²) received at each surface location over the course of a full year, accounting for topography and sun angle variation. These values were then extracted for each north-facing inscription point to evaluate patterns of exposure. The extracted solar values were classified into three categories based on the dataset’s mean (1648.7 Wh/m²) and standard deviation (132.7 Wh/m²):

- Low exposure: <1516 Wh/m²
- Moderate exposure: 1516–1781 Wh/m²
- High exposure: >1781 Wh/m²

The results indicate that 74% of north-facing inscription points fall within low exposure zones, and the remaining 26% within moderate zones; no points were located in areas of high solar exposure (Figure 7). These results support the idea that north-facing inscriptions are preferentially located in shaded or less sun-exposed environments, possibly to limit weathering on soft sandstone surfaces. While definitive conclusions about intentional placement cannot be drawn from solar data alone, the strong correspondence between orientation and reduced solar load suggests that environmental protection may have been a contributing factor in site selection.

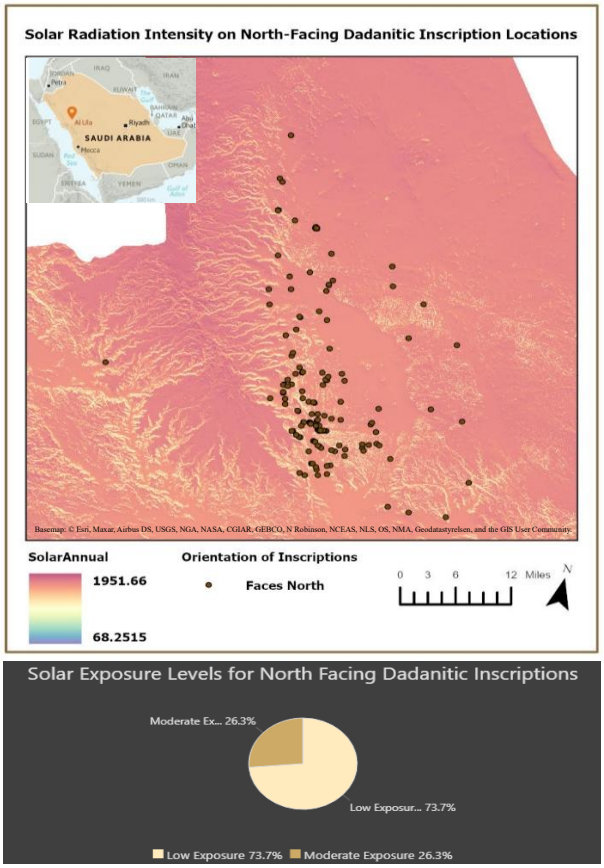

Figure 7. Map and chart illustrating solar radiation exposure at north-facing Dadanitic inscription sites in AlUla.
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4. Discussion

The survey findings from the Awareness and Knowledge of Pre-Islamic Heritage theme reveal more than just a lack of public familiarity with Dadan and Lihyan kingdoms. They reflect a structural gap in how heritage sites are represented and communicated in Saudi Arabia. While the Dadan and Lihyan kingdoms are central to understanding the cultural history of the region, the fact that 73% of respondents had no knowledge of these kingdoms points to their limited presence in educational, cultural events, and media discourse. This limited awareness is not merely a matter of historical obscurity but might signal a deeper disconnect between archaeological knowledge and public engagement. Even in AlUla, where growing efforts have been made to promote cultural tourism and heritage, only a small portion of respondents reported strong familiarity with ancient sites. This might suggest opportunities to further connect local communities with this deep historical legacy.

Beyond the gap in awareness, the survey results from the Cultural Identity and Belonging theme reveal that heritage, when made accessible and meaningful, remains a powerful source of personal and collective identity. An overwhelming majority of respondents (90%) affirmed that heritage shapes their sense of identity, and 86% reported that the history of their city influences their sense of belonging. These findings suggest that the issue is not a lack of public interest, but rather a lack of meaningful engagement that might be driven by limited exposure, minimal interpretive resources, and restricted opportunities for participation. Notably, respondents reported strong emotional connections to both tangible and intangible heritage. While physical landmarks, such as religious buildings, archaeological sites, and historic structures, were widely recognised, intangible elements such as values, oral histories, and traditions often resonated more deeply. This underscores the need for documentation strategies that go beyond material remains, but instead integrate cultural memory, lived experiences, and non-material forms of heritage expression.

The final two themes, Engagement and Barriers and Technology Acceptance, highlight both the constraints and opportunities shaping public interaction with heritage. While the majority of participants expressed a willingness to engage with the full historical context of heritage sites, including pre-Islamic narratives, a notable minority voiced religious concerns. These findings suggest that while historical inclusivity is broadly supported, interpretive strategies must be attentive to religious and cultural sensitivities. At the same time, the survey revealed a clear desire for deeper, more relatable engagement. Participants prioritised historical storytelling, relevance to present identity, and opportunities for active participation. The high level of support for digital tools, especially interactive platforms, virtual exhibitions, and documentary media, further underscores the public’s interest in accessible, immersive, and technology enhanced heritage experiences. Together, these findings advocate for a heritage strategy that is not only historically grounded, but also inclusive, participatory, and tailored to community expectations.

The GIS-based spatial analysis examined terrain characteristics, specifically elevation, orientation, and solar exposure, to explore whether environmental factors influenced the placement of Dadanitic inscriptions. The results indicate a strong concentration of inscriptions in mid-elevation zones (750–900 m) and a notable preference for north-facing surfaces. Among the north-facing inscriptions, 74% were located in areas of low solar radiation, suggesting a possible intentional preference for shaded environments. These patterns imply that factors such as protection from sun exposure and surface accessibility may have influenced site selection. However, interpretations must remain cautious, as they require corroboration from archaeological and epigraphic evidence.

In addition, several important considerations must be acknowledged when interpreting the results of this analysis. The inscription data used derives from the IDIHA project (2018–2021), which, while valuable, does not represent the full known corpus of Dadanitic inscriptions. Additional sites are still under study or remain unpublished, particularly as part of the ongoing AlUla Inscriptions Corpus Analysis Project (AICAP). Orientation and elevation data were extracted from georeferenced points, which may have been recorded at the base of rock faces rather than at the precise location of the carved inscriptions. This can lead to inaccuracies, especially in calculating elevation or orientation preferences.

Moreover, it remains unclear whether the observed orientation and elevation patterns reflect intentional choices by the engravers or are simply the result of where suitable rock panels naturally occurred due to erosion or geological formation. In addition, while the combination of mid elevation and north- or east-facing orientation appears most common, this pattern may partly reflect the fact that these are also the most represented categories individually. Therefore, their co-occurrence does not necessarily indicate a meaningful correlation but may result from the overall distribution of the dataset. These limitations underscore the need for caution when interpreting spatial patterns as evidence of intentional placement. Despite these constraints, this analysis

demonstrates the value of combining spatial data with cultural research to explore the environmental logic of inscription placement. Future work could refine this approach by incorporating higher-resolution 3D models, validating location data through fieldwork, and linking inscription content to spatial context to investigate potential ritual or symbolic meanings embedded in the landscape.

5. Conclusion

This paper explored how public perception and geospatial analysis, conducted as separate phases within a broader PhD project, each contribute to developing more comprehensive heritage interpretations. It addressed key gaps in heritage research, particularly the limitations of relying exclusively on epigraphy or site-by-site excavation to understand the Dadan and Lihyan civilisations. The national survey provided insight into how heritage is currently perceived by Saudi communities. While awareness of pre-Islamic kingdoms like Dadan and Lihyan was generally low, the findings revealed strong emotional connections to heritage when it aligns with cultural identity, along with a broad interest in digital tools for engagement. These results underscore the importance of heritage interpretation strategies that are accessible, context-rich, and rooted in community relevance.

The GIS-based spatial analysis examined terrain characteristics surrounding inscription sites. It revealed consistent placement patterns in mid-elevation, north-facing, and low solar exposure zones. While these environmental trends cannot yet confirm deliberate placement strategies, they suggest that landscape conditions may have influenced where inscriptions were carved.

Although these two research components were not fully analytically integrated at this stage, their joint presentation reflects the interdisciplinary structure of the wider PhD project. Together, they demonstrate how both public perception and spatial analysis can inform future interpretive strategies, ones that bridge historical evidence, community insight, and environmental context to deepen understanding of the Dadanitic inscriptions landscape. Future work will expand the analysis to include additional dimensions of the Dadanitic landscape and deepen community engagement to support a more holistic approach to heritage documentation and interpretation.

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