

POINT-AXIS SYSTEM THEORY WITH GIS SPATIAL ANALYSIS IN GEOSPATIAL BIG DATA: A CASE STUDY OF THE PETRA WORLD HERITAGE SITE

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Abstract: This study operationalizes the Point–Axis System (PAS) Theory within a GIS and geospatial big data workflow to (1) quantify pole (point) attraction and axis (corridor) strength, (2) model spatiotemporal access and concentration dynamics, and (3) inform heritage-sensitive tourism and conservation planning at the Petra World Heritage Site, Jordan. We propose a four-stage pipeline: data engineering (LiDAR/DEM, vector heritage layers, POIs, mobility traces), network-aware spatial analytics (centrality, isochrones), a composite Pole–Axis Index (PAI) that fuses pole gravity, axis performance and accessibility, and spatial econometrics to explore links between PAI and heritage-tourism pressures. The approach is implemented for Petra using standard GIS operations and open analytical routines. Integrating PAS with GIS clarifies how high-capacity axes (e.g., approach corridors, canyon “Siq” passage) redistribute tourist flows and intensify exposure around signature poles (Al-Khazneh, Al-Deir, Qasr al-Bint). PAI maps highlight leverage points where fine-grained management (wayfinding, micro-zoning, timed entry) can reduce congestion and protect fragile features. (Empirical illustrations are shown with Petra-specific layers.) Data quality (sensor bias, temporal misalignment) and geodetic harmonization remain critical. Ethical handling of mobility data is required. Practical implications – The framework supports (i) siting of visitor infrastructure, (ii) route design and scheduling, (iii) heritage-risk hot spot detection, and (iv) monitoring of policy scenarios before field implementation. Social implications – By improving spatial equity of access and diffusing pressures from iconic façades, the approach strengthens local livelihoods while safeguarding outstanding universal value. Originality/value – This is among the first practice-ready translations of PAS Theory into measurable GIS indicators and decision aids for a complex heritage landscape using multi-source geospatial big data.

Keywords: Point–Axis System Theory GIS, geospatial big data, accessibility, network centrality, heritage management, Petra, Jordan

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INTRODUCTION

Geo-tourism is sustainable tourism based on the characteristics of a specific geological location. Geo-tourism is important in developing countries such as Jordan, where such development can equalize the tourism market. Geo-tourism promotes green practices while preserving the geological integrity and local cultural atmosphere of the area, protecting cultural heritage and past economic drivers regarding site selection. The geo-tourism stakeholders’ model (GSM) measures stakeholders’ perceptions and interests in geo-tourism, as geo-tourism has been recently adopted in many developing countries. Firms that supply geo-tourism information for potential geo-tourists are heavily embedded in the geo-tourism industry and research, with the greatest growth found in tour operators, travel agency, and regular resident firms. The growth of geospatial big data—from LiDAR point clouds and satellite imagery to volunteered geographic information and mobility traces—has transformed how researchers model complex cultural landscapes.

Yet many heritage sites still lack robust tools to convert spatial theory into quantitative, management-ready insights (Xu et al., 2024; You et al., 2024; Mo et al., 2024). PAS theory conceptualizes landscapes as poles (attractors) linked by axes (movement corridors) that co-evolve to shape spatial concentration and diffusion. Recent work calls for embedding PAS in modern data pipelines to address high-volume, high velocity geodata (Yang et al., 2026; Jang & Kim, 2022; Alawneh et al., 2025). Petra, Jordan, is a UNESCO World Heritage site and one of the New7Wonders of the World. It is ranked as one of the top three Silk Road locations, the gateway to the Middle East, and a new travel destination in a

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nation offering extreme tourism (Li et al., 2026). Information was gathered through semi-structured interviews with local geo-tourism firms to determine what trends exist in the geo-tourism industry in Petra. It was determined that the configuration of geo-tourism in Petra showed a trend of development into the Wadi Araba region of Southern Jordan and its surroundings, and some preliminary characteristics of geo-tourism firms were illustrated. The GSM indicated that the needs of the tourist geologists and the interests of the “expert” stakeholder groups were not being met in the current geo-tourism supply structure in Petra. As geo-tourism becomes more widespread in developing areas, it will be important to understand its growth to equate the international tourism market and to aid in decision-making (Mosgrove et al., 2025; Jawabreh et al., 2023; Liu et al., 2022). Despite the progress achieved so far, three main gaps remain.

First, the Point–Axis System (PAS) has not yet been fully converted into standardized and replicable GIS-based metrics, which limits its comparability across sites. Second, the current applications show a weak integration between PAS outputs and spatiotemporal access models, so the system does not fully capture how visitors change over space and time. Third, there is still little work on scenario-based analysis that connects management interventions—such as timed entry or the introduction of alternative routes—to the resulting shifts in spatial pressure on heritage areas.

LITERATURE REVIEW

Research has shown that geo-tourism significantly contributes to economic development; therefore, awareness in Jordan has increased regarding the potential of geo-tourism, as well as concerns about the degradation of heritage sites and the need for their protection (Jawabreh, 2020; Su & Lin, 2013). For Jordan, their issues may not be on the same level as in the developed world, yet the study focuses on Petra due to its outstanding geo-tourism potential as an attractive nature, as a more undeveloped economy, and as a geo-tourism destination internationally. Since UNESCO and many other organizations became involved in Petra, they gained a lot of wealth and fame at international levels, even bringing them concern on how to preserve it due to the degradation from tourism caused by its soft rock type. Previous studies concerning Petra have focused on geology, hydrology, structure, cultural resources, and degradation, but limited efforts have gone into characterizing tourism itself. However, some research on touristic dimensions has been done before, mostly concerned with travel motives and behavior of visitors in archeological sites, historical city-museum combined sites, perspective development in Petra, etc. Reviewing this clearly shows the sense of towns, while those mostly from abroad haven’t returned since 2008–09, raising concerns on the long-term effects of management measures on this aspect. Jordan’s tourism economy has heavily relied on its outstanding cultural heritage sites. However, the big pressure of tourism on these sites due to their soft rock type, especially in Petra, has brought awareness to their needs of conservation.

As assets cannot be easily recovered back once broken or lost on these sites, efforts have gone into the sense of town as a more undeveloped geo-destination. Integration of the town management aspect inside the site has good potential to preserve these by controlling a portion of visitor flows to lessen the pressure within the site, minimizing costs as they have a limited tourism workforce directly devoted to the heritage site (Xia et al., 2010; Jawabreh et al., 2021; Sharaiha & Collins, 1992). Supporting tools, including GIS and statistical methods, can present valuable information easily and clearly without difficulties associated with extensive fieldwork and data-gathering efforts (Solarin et al., 2026; Park et al., 2020; Hardy & Shoval, 2025; Rinne et al., 2025). Geo-tourism is an emerging specialty in sustainable tourism, which has evolved from a range of activities that are either eco-based, culturally based, or wilderness-based actions. Geo-tourism, however, is specifically focused on geology and landscape. It has been described as a form of tourism specifically focused on geology and landscape and can occur in either completely natural environments, such as natural parks, or human-modified environments (Cheer et al., 2025; Sun et al., 2025; Zheng et al., 2025).

In addition, geo-tourism is viewed as promoting tourism to geological sites (geo-sites), the conservation of geological diversity (geodiversity), and the provision of an understanding of earth sciences through appreciation and learning. Likewise, geo-tourism can be undertaken as a diverse range of activities, including independent visits to geological features, the use of geological trails (geo-trails) and viewpoints, guided tours, geo-activities, and patronage of geo-site visitor centers. Essential to the development of geo-tourism is the understanding of the identity or character of a region or territory. This approach comprises not only the abiotic elements of geology and climate but also the biotic elements of animals and plants and the cultural or human components, both past and present. Geo-tourism argues that to fully understand and appreciate the environment as a holistic entity, one must first know about the abiotic elements of geology and climate, as these will in large measure determine the biotic elements of animals and plants that live there.

Geo-tourism thus encompasses much more than geology or landscapes alone. Understanding these abiotic elements brings about the appreciation of vistas, the formation of different ecosystems for flora and fauna, sedimentation processes and fossil fuels, the likelihood of natural hazards such as floods, landslips, and earthquakes, and so forth. The biotic elements will bring about interest in animals and their behavior, flora and ecosystems, food chains, etc. Cultural geography will enhance the understanding of human affiliation with the environment where they are living and/or travelling in, as well as identify human interactions with the environment with consideration of impacts and future planning. All these elements will bring about the appreciation of a region or territory. The popularity of travel for pleasure spans centuries of civilization. However, today’s travel is fundamentally different from that of the past. Technological advancement over the last century has transformed travel from slow and difficult to relatively fast and easy (Jawabreh et al., 2026).

The automobile, bus, jetliner, subway, and many other transportation devices have permitted mass travel to almost every corner of the globe. In addition, urbanization, globalization, and “therapeutic landscapes,” or places people go to find relief from the hurry and stress of everyday life, have also become dominant themes and places for today’s travel. The quest for the exotic was a principal theme for the leisure travelers of the last century and persists today in the popular

phrase “getting away from it all.” Associated with this quest are spots far removed from civilized life, where nature is dramatic and dangerous. These spots are viewed as sublime, intimidating the traveler while evoking awe in relation to the vastness, magnificence, and power of nature. Locations deemed exotic help define “otherness” or alterity in contrast to the norm. For some travelers, unspoiled landscapes untouched by civilization fulfill the quest for the exotic.

For others, bizarre and strange are components of the exotic, by which natural attractions are enriched by culture and customs extraordinarily different from their own (Jawabreh et al., 2025; Bingöl & Yang, 2025). Most definitions of geo-tourism imply a type of tourism that is environmentally, socially, and economically sustainable.

However, they generally fall short of defining the characteristics, structure, and processes of sustainable tourism. It is suggested that there are numerous tools readily available to policymakers and planners to help ensure that tourism development is sustainable. To use these tools successfully, it is essential to understand tourism systems, their networks, and feedback cycles. Currently, within these feedback cycles exist several external and unforeseen forces that can significantly limit the efficacy of the tools and methods available for planning and management. Because of its ability to visualize spatial patterns and analyze the causes of changes, using GIS as a tool for geo-tourism management offers many benefits (Akay, 2026). GIS technology and spatial analysis have been used to explore the implications of destinations and the geo-tourism industry. Several contributions are relevant to this study. analyzed the spatial distribution pattern and driving mechanism of tourist attractions in Gansu Province using spatial concentration analysis.

Used market basket analysis techniques to model tourism systems and gain insights into the geospatial intertwining of tourism entities and processes. Surveys of GIS used for tourist planning, development, research, and management have shown how GIS helps with destination plans and deals with the effects of tourism and environmental issues in GIS-driven management. These studies acknowledge GIS's potential as an instrument for analyzing travel behavior; yet, few have incorporated GIS into a conceptual framework for tourism management related to travel behavior.

Geo-tourism is about how distinctive a geological place is and how geology changes over time. It helps manage tourists' choices by maintaining, fixing, and altering their interests and visits. Tourism has also grown in geologically distinct places throughout the world and in the United States because to new ideas and competition. This has led to the construction of infrastructure and tourist amenities in these locations, which has made the competition stronger. The initial concept was about how special a geological place is and how geology has evolved throughout time. It has now been used in various areas, such cultural, historical, and ecotourism. Geo-tourism is distinct from other forms of tourism since it focuses on seeing and learning about a geological feature and what makes it special.

Geospatial technology, which encompasses geographic information systems (GIS) and geospatial data analysis, is very useful for managing tourism. It can assist with things like finding routes and networks, optimizing supply chains, and asking questions about geography. There are two major approaches to undertake geospatial analysis: by presenting patterns on maps and finding out why the pattern is there based on a set of factors. We can learn what makes people desire to visit Petra by looking at the patterns in visitors there. To improve the study of Petra's travel patterns and trends by comparing different ways of showing geographical data, it will show these patterns on both choropleth and graded symbol maps. Geo-tourism or tourism studies only have a little effect on how people travel, which is why GIS has to be formally included in tourist study (Yang et al., 2011). The feasibility of integrating diverse visualization methodologies and cultural characteristics related to visitor flows will be assessed via more representative areas or empirical analyses.

Surveys of GIS used for tourism planning, development, research, and management have delineated how GIS facilitates destination strategies and addresses tourist impacts and environmental concerns in GIS-driven management (Tabatabaei et al., 2025). These studies recognize GIS's potential as a tool for examining travel behavior, although few have integrated GIS into a conceptual framework for tourism management concerning travel behavior.

Geo-tourism, which is about the uniqueness of a geological location and the processes that change geology over time, offers a way for controlling visitor choices by keeping, fixing, and changing their interest and visits. Innovations and competition have also helped tourism grow in geologically distinct areas on a national and worldwide scale. This has led to the building of infrastructure and tourist amenities in these areas, which has enhanced competitiveness.

The idea started out by looking at how unique a geological location was and how geology changed over time. It has now been used to various fields, such as cultural, historical, and ecotourism. Geo-tourism development is all about people visiting and learning about a geological feature, how unique it is, and the geology that makes it special.

Geospatial technology, which includes geographic information systems (GIS) and geospatial data analysis, is a wide field that helps with route and network search, supply chain optimization, and geographic querying for tourist management. There are two main ways to do geospatial analysis: by showing patterns on maps and figuring out the rationale behind the pattern based on a set of variables. Understanding the tourist patterns in Petra will help us figure out what makes people want to visit Petra. To enhance the analysis of Petra's travel patterns and trends via the comparison of geographic data representation methods, it will illustrate these patterns on both choropleth and graded symbol maps (Zhou, & Yang, 2025; Permanadewi et al., 2026; Kong et al., 2025; Zhang et al., 2018; Jawabreh et al., 2024b).

Geo-tourism or tourism studies only indirectly relate to travel behavior, making it necessary to formally use GIS in tourism research. The viability of comparing various visualization techniques and cultural attributes on visitor flows will be examined via more representative regions or empirical analysis.

METHODOLOGY

The primary strategy used for this investigation is quantifying the dispersion of geotourism across various sites of interest. Four primary issues arising from the kind and amount of the dataset need assessment of the resultant dataset. The

findings delineate a hierarchical relationship between the categories of points of interest and their impact on tourist development and geographical dispersion. Recent reports on tourist management patterns in Petra have prompted an analysis of the issue: How has geo-tourism evolved in Petra? Geotagged photographs in cyberspace signify remnants of social network engagement and reveal a spatial-temporal pattern.¹ Points of interest (POIs) are geographic landmarks that attract tourist visits, illustrating the characteristics of activity movement. The monitored point cloud of points of interest in geospatial mobility is considered a temporal series of visibility observations for comprehending the time-dependent geographical features of travel and tourism. The approaches for extracting mobility patterns from trajectory point clouds fundamentally vary from those used for spatiotemporal point cloud data that consists just of locations and timestamps.

Consequently, the conventional attributes of point cloud-based mobility pattern mining, which emphasize trajectory compression, movement pattern extraction, and motion simulation, are not immediately applicable. Infrastructure-based analysis of POI observations in novel knowledge discoveries presents advantageous methodologies. The prior batch methods of aggregating points of interest (POIs) over grid cells to ascertain event density for visual exploration exclude a significant number of underutilized POIs and the complexity of POI visit data. Figure 1 depicts a conceptual framework for examining the geographical distribution of geotourism activities and their ramifications for tourism growth in Petra. The model starts with spatial-social data, including places of interest (POIs), geotagged images, and movement trajectories.

These data sources are essential in tourist geography, as they allow researchers to discern visitor densities, recreate mobility patterns, and discover spatial disparities in the use of historic places. Prior research has shown that geotagged images may predict tourist itineraries in World Heritage cities, whereas POI data can facilitate the investigation of tourism-resource clustering and spatial structure (Domènech et al., 2020; Ding et al., 2024). The second phase of architecture encompasses POI-axis processing and PAI calculation. In this concept, the PAI serves as an analytical index that links tourism nodes with access axes to assess spatial appeal, accessibility, and prospective tourist pressure. This is especially pertinent for Petra, a site of worldwide archeological and cultural importance, where tourist growth must be harmonized with heritage preservation and visitor control. UNESCO recognizes Petra as one of the most renowned archaeological sites globally, distinguished by its sculpted rock architecture and intricate mountain pathways (UNESCO World Heritage Centre, n.d.).

1. Hypotheses

H1: Poles with higher *PAI* exhibit greater observed crowding and environmental stress indicators.

H2: Axis upgrades that reduce travel time volatility will raise *PAI* locally and shift pressure downstream, detectable via network flow changes.

H3: Distributing access across secondary axes lowers pole-adjacent risk without significantly reducing site-wide accessibility.

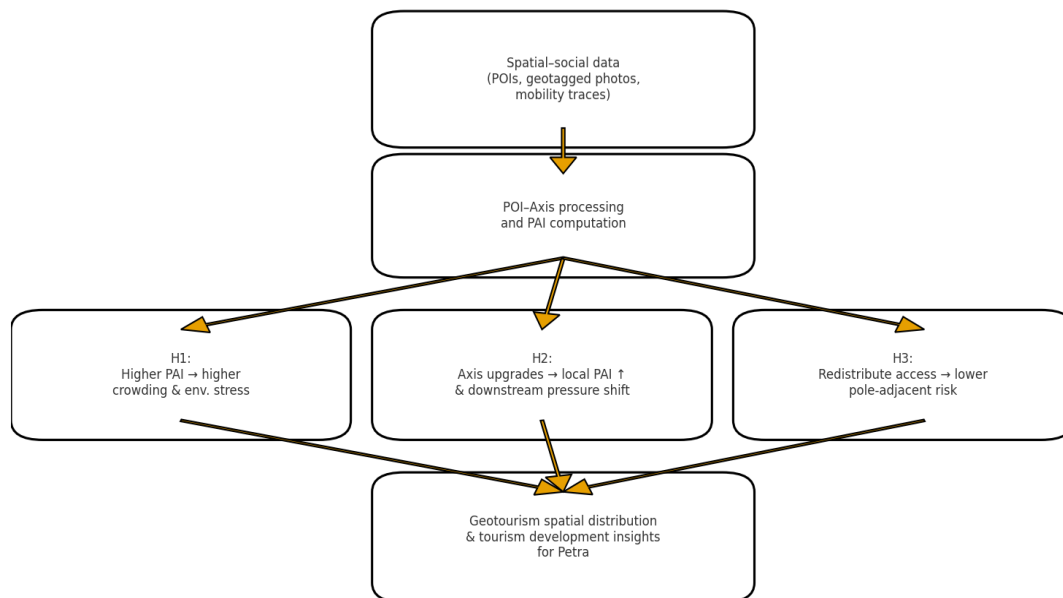


Figure 1. Model of the study

2. Case Study Selection

Jordan's popular destinations, like Petra, are now economically transformed into tourism-dependent economic sectors. Beginning in 1985, Petra was nominated and began the formal evaluation to become a UNESCO World Heritage Site (WHS). Jordan's association with UNESCO was begun for 426 monuments inscribed on the Memory of the World Register, and many others are now gast lands, tourist attractions, and points of tourism VITA generation. The Power and Control Subcommittee advises future sites nominated for cultural, historic, and natural programs. UNESCO involvement has ensured the maintenance of historic integrity to some extent, as they have held great control over the inscription process. UNESCO involvement promotes the prime tourist destinations in the Middle East and overlaps with other NGOs' involvement in the efforts to promote Jordan's mini global culture for local benefits. UNESCO involvement also promotes

the visit of many officials to Petra, involving an Announcement of Concern, Preventive Action, and other dignitaries (Jawabreh, 2024a). Some NGO agencies have been involved in Genealogy, Heritage, and History (Ali et al., 2025). Particularly the Nature Conservancy and World Monuments Fund have retained responsible authorities looking after the site, appropriate use and planning studies, and other research programs. Researchers have also become participants, and many archaeological subjects have been targeted. All of these organizations needed local Jordanian contact in the respective thematic areas. In local Management, the Ministry of Tourism and Antiquities (MOTA) has a great responsibility, considering cooperation with all possible agencies to work in and for its domain, such to include departments, municipalities, civil works, the army, and some humanitarian NGOs. The development departments, agencies, ministries' involvement varies depending on the category of tourism, event, and desired handling of foreign participation by non-Jordanians conventional to target the tourists' eagerness to come and enjoy its experience with regard watering-hole.

Figure 2 presents a stacked-bar comparison of the unweighted component structure (each normalized to the 0–1 range) for six Petra poles Al-Khazneh (the Treasury), Ad-Deir (the Monastery), the Siq Entrance & Gate Area, Qasr al-Bint, the Royal Tombs, and the High Place of Sacrifice across four inputs: KDE_visits, POI_diversity, Viewshed_freq, and Heritage_salience. Reading each bar from bottom to top reveals how much of a pole's potential attraction is contributed by visitation density, surrounding service mix, visual exposure along paths and viewpoints, and cultural significance. Taller stacks indicate greater overall potential before any decision weights are applied. Al-Khazneh exhibits the highest total, driven by very strong KDE_visits, high Viewshed and notable Heritage_salience, reflecting its role as Petra's iconic crowd magnet. Ad-Deir ranks next, with strong visibility and heritage compensating for its relatively remote access. The Royal Tombs and Qasr al-Bint present balanced profiles: neither dominates in raw visits, yet both combine solid visibility and heritage with moderate POI_diversity, suggesting capacity for demand redistribution through interpretation and routing. The Siq Entrance & Gate Area shows healthy KDE_visits and service diversity typical of gateway nodes, though its heritage and visibility are comparatively moderate, framing it as a support hub rather than a final draw. The High Place of Sacrifice records the lowest total stack, with modest visits and services but respectable heritage and viewshed values, indicating a niche site whose appeal may be enhanced via curated access and viewpoint management. Overall, the chart helps diagnose *where* each pole's strength originates and provides a transparent baseline for weighting scenarios: by increasing weights on heritage or visual exposure, managers can prioritize conservation-aware itineraries and relieve pressure at saturated hotspots without sacrificing visitor experience.

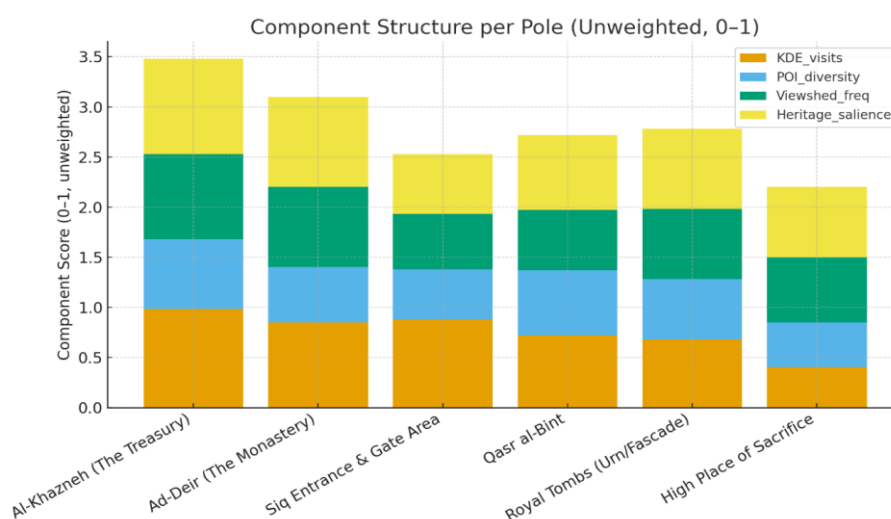


Figure 2. Component Structure per Pole

Figure 3 presents a distribution map of the main tourist attractions within the Petra Archaeological Park, illustrating the spatial pattern of visitor movement and the concentration of heritage sites. The map shows that the tourist route begins at the Visitor Center in the northern part of the site and then follows the narrow Siq corridor, which functions as the primary access axis to the core Nabataean city. Along this longitudinal axis, most high-profile attractions are aligned, including Al-Khazneh (the Treasury), the Royal Tombs, the Theatre, the Colonnaded Street, Qasr al-Bint, and the Great Temple. This linear clustering of attractions indicates that tourist activity is highly concentrated along one main movement corridor, which has important implications for crowding and site management. The map also highlights a secondary extension toward the southwest leading to the Ad-Deir (Monastery) trail and the Monastery itself, a more remote attraction reached by a separate path, which explains its relatively lower visitor density compared to the central spine of the site. Cartographic elements such as the site boundary, north arrow, scale bar, and legend are included to facilitate interpretation and to distinguish between the site polygon, the main access path, and individual attraction points. An inset map of Jordan is also provided to situate Petra geographically within the country (Al Fahmawee & Jawabreh., 2022). Overall, this spatial representation supports visitor-management studies, the planning of alternative or rotational routes, the identification of potential congestion zones, and the design of supporting facilities in suitable locations. It also offers a geospatial baseline that can be integrated into broader research on heritage conservation and sustainable cultural tourism in Petra.

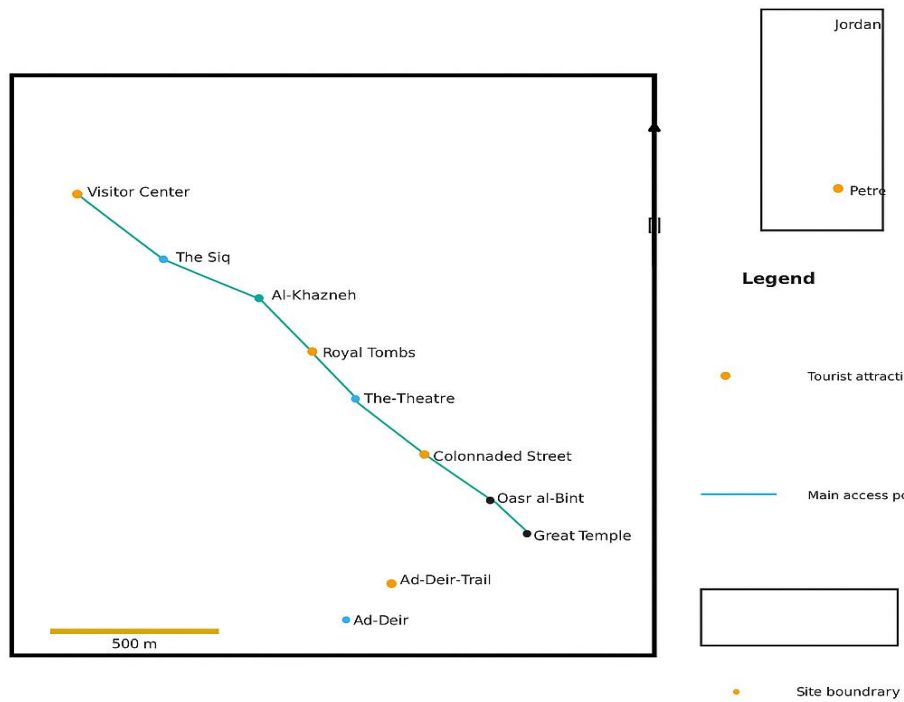


Figure 3. Distribution map of tourist attractions in Petra Archaeological Park

3. Data Collection Techniques

The present study aims at uncovering the most relevant geospatial patterns detectable in tourist photos uploaded on different online sources. It explores how to define themes in tourist photos to extract geospatial patterns and how to incorporate these systems with a planning tool to enhance place management decisions. The specific goal is to devise a methodology that uncovers geospatial patterns of tourist activities using the latest technologies, including artificial intelligence, and online text and semantic web approaches. The concept has been used in Petra, the most significant archeological site in Jordan. Petra is designated as a UNESCO World Heritage Site and is recognized as one of the Seven Wonders of the World. In 1812, the Swiss explorer Johann Ludwig Burckhardt unearthed this historic city, which had been obscured for generations. The site first functioned as a commerce hub in antiquity and houses notable examples of Nabataean buildings, intricately carved into the sandstone rock face. Petra is susceptible to several concerns, including unregulated mass tourism and environmental hazards stemming from climate change, quarrying, and the expansion of surrounding village infrastructure. The current surge in the site's popularity on social media and other photo-sharing platforms has progressively fostered a new type of tourism that neglects essential principles that must be upheld.

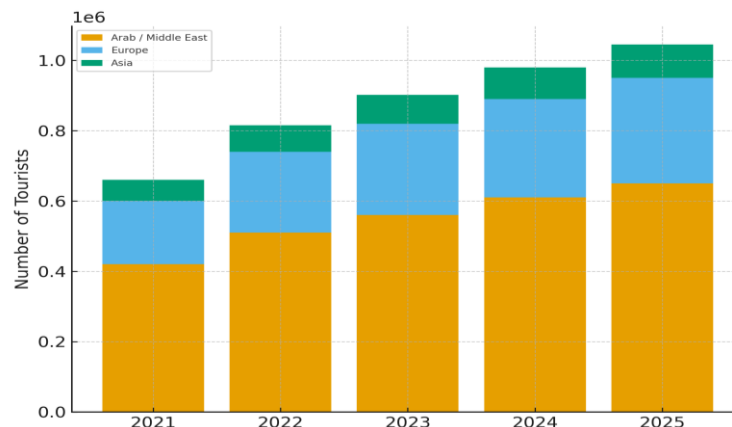


Figure 4. Distribution of tourist arrivals over the past five years, Source: Authors' visualization based on tourism statistics published by the Ministry of Tourism and Antiquities of Jordan (MoTA) and visitor statistics issued by the Petra Development and Tourism Region Authority (PDTRA), 2021–2025. Regional groupings were aggregated by the authors

The emergence of digital photography and photo-sharing software has significantly impacted all facets of societal life, particularly in the discovery of new places. Photographs captured and uploaded online provide extensive data sets, including geolocation and temporal information, which offer novel insights into the current activities at tourist destinations. The data, analysis, and judgments have transitioned from reliable, authoritative information, such as written reports or formal presentations, to crowdsourced, real-time, and dynamic multimedia assessments, including postings on social media and comments and images on review platforms. Figure 4 illustrates the distribution of tourist arrivals over the past five

years, disaggregated by major national (or regional) groups. The horizontal axis shows the years 2021 to 2025, while the vertical axis represents the total number of tourists. Each bar is stacked, meaning the total height of the bar reflects the overall arrivals in that year, and the differently colored segments show how these totals are composed of Arab/Middle Eastern visitors, European visitors, and visitors from Asia. The figure suggests that Arab and Middle Eastern tourists form the largest share of arrivals throughout the period, which is consistent with Jordan's geographic proximity and cultural ties to neighboring countries. European tourists constitute the second largest group, showing a gradual increase across the five years, which may indicate successful international promotion, improved air connectivity, or a recovery trend after earlier regional or global shocks. Asian tourists make up the smallest but still noticeable segment, and their numbers also show a steady upward movement, hinting at emerging markets that could be further targeted. By presenting the data in a stacked format, the figure allows the reader to see two things at once: overall growth in total tourist arrivals and shifts in the composition of source markets. This is particularly useful for tourism planners and destination managers in Petra or Jordan more broadly, as it helps identify which markets sustain demand and which ones are growing.

This figure can thus support decisions related to marketing, language services, transport, and product development, based on data from the Ministry of Tourism and Antiquities. The figure can thus support decisions related to marketing, language services, transport, and product development, based on official tourism statistics published by the Ministry of Tourism and Antiquities of Jordan and the Petra Development and Tourism Region Authority (MoTA, 2024; PDTRA, 2025).

4. Analytical Framework

Today, geographical advances and the availability of travel behavior information generate a wide variety of research opportunities for transport geography involving different disciplines within and outside geography. Up-to-date tools and new techniques make it possible to collect and visualize large space-time data for timely studies of phenomena ranging from transportation systems to individual activities. In cities or protected areas, for example, travel patterns of people can be observed using mobile devices with GPS applications. With ever-increasing travel information, the pace is accelerating for geographic scholars to assess large location-based data and provide solutions for public issues of very close ties with society such as traffic congestion, pollution, and tourism management. Recently, investigations of travel behavior in relation to urban development and organization or its roles in the development of a place all rely on patterns from volunteer geographic information. Geographical queries are redefined based on new patterns, such as spatiotemporal clustering approaches to seek travel hotspots from crowd-sourced check-in data, and new metrics are developed to characterize these urban or touristic phenomena with unprecedented geographical details and temporal accuracy. New approaches are proposed to extract and quantify the network structures from GPS trajectories, and advanced evaluations are made about the implications of transport, tourism, or environmental management (Al Fahmawee & Jawabreh, 2023; Rinne et al., 2025).

This study aims to conduct a revival analysis of tourist attractions using check-in data by examining the distinct spatiotemporal dynamics related to intra tourist movement. Understanding tourists' visitation geography helps improve managers' decision-making efficiency regarding the supply of relevant services and facilities. A regional center of a popular tourist city, with lots of publicly available check-in records, is taken as a study area, and the focus is put on its high-ranking attractions in check-in volumes. The specific goal is to quantify the spatiotemporal dynamisms of daily tourist visits to historic landscapes in the area with a special focus on tourists' in-situ movement travels between attractions that are perceived to be fixed over medium time for advancing the understanding of visitors' space-time behavior.

5. Geospatial Patterns in Petra

Petra has been a popular tourist destination since Western travelers rediscovered it in the early 1800s. In the past twenty-five years, increased awareness of world heritage sites has made Petra even more popular, particularly due to the current aesthetic trends favoring warm, arid, rocky deserts, which has led to a significant rise in adventure tourism at Petra, Jordan, especially among film companies. However, the complexities involved managing this large natural wonder compound with an impressive cultural history of Nabataean industrialism. As the dusty city shares its many natural and man-made wonders with millions of visitors, how does management maintain the integrity of this environment? Tourism management, or lack thereof, in Petra. Because Jordan is subject to environmental and political challenges unique to its situation, what affect these challenges have on the future of tourism and of Petra itself. How can Petra continue to safely host interested tourists while maximizing economic output and continued enjoyment of the site.

5.1. Topography

The typical environment of the Petra Archaeological, being the most prized attraction in Jordan, favors dry and hot periods instead of humid warm. In the summer the average maximum temperature reaches approximately 32 °C with a peak of 40 °C. To cope with the amplitude in the opening of the parks, shortened winter days and the closure of the parks during sandstorms and heavy rainfall, the lighting scheme of Petra should be flexible, robust and easy to maintain. Lighting in the park should be scheduled based on weather data, visitor surveys and by regarding different interests of the site.

Low-lighting solutions such as fire torches or lanterns provide for a more natural atmosphere at night and cater to the setting of Petra. However, a contemporary problem connected with the growing tourist industry are the squatters, primarily from the Dessie tribe, who refuse to vacate the park area. Other recommendations include the generation of night-time economy, utilization of ambient low-light entries in the site and advertisement of the light trail to the temple complex. Sweeping views over the site and valley are recommended to be avoided by lighting in its foreseeable future. Due to its time-consuming nature, complexly managed systems on a larger scale should be avoided. All proposed solutions are to be considered low-cost and managed by the site management and the local community. The Disi sandstone, quarried

downstream of the park, in Taybeh, is the primary construction stone. It is easily worked but has poor weathering resistance. Complaints by the site management coincide with concerns about the permanence of new works: colors are uncharacteristic, scars of polishing are visible, and some crafts have an overly classical scheme. The comparatively lower professional standards in local stonework avoid highly polished rock cuts commonly deployed for lighting in other heritage sites. Furthermore, it is important to liaise with site management and address their concerns regarding labor and raw material availability. The stone workshop should contain equipment such as a hollow wire and wire saw that reduces the amount of damage to desirable stone. The Machin de Lumiere is median function producing slow-dissolving weathering resistant mineral colors with no local associations aside from closing quarry and is likely to therefore become increasingly expensive.

The Petra Archaeological Site in Jordan This picture depicts the Petra Archaeological Site in Jordan as a simplified geographic visualisation that highlights the region's predominant climate. in this picture as a simplified geographic visualisation that emphasises the region's predominant climate. Visitor mobility, path layout, and lighting infrastructure must follow the natural landform rather than enforce strict linear patterns since the contour lines show a rough landscape with discernible elevation fluctuation. Several representative altitude points, such as the Petra valley floor at about 820–850 metres above sea level, the Wadi Musa/access plateau at about 1,300 metres, and the nearby Jabal As-Sharah slopes rising to almost 1,400 metres, should be added to the map as reference markers to support the topographic interpretation.

The Petra catchment's significant vertical fluctuation is confirmed by recent DEM-based studies, which also reveal a broader elevation range of around 600–1,700 m ASL (Al Kuisi et al., 2024). The map also highlights the fact that Petra works in a hot, dry climate rather than a warm, humid one. While regional meteorological studies highlight that maximum summer temperatures in the Petra area may reach around 42°C, with severe rainfall events mostly occurring during the winter season, the temperature icon and range, 32°C–40°C, describe normal summer heat stress (Al Kuisi et al., 2024).

The advice for a variable, low-maintenance lighting system that may be timed based on meteorological data, elevation conditions, and tourist demand is justified by this heat, short winter days, sporadic sandstorms, and flash-flood danger. By placing Petra within Jordan and adding altitude reference points, the figure visually connects topography, climate, and management requirements. This figure illustrates how any intervention—night routes, ambient low-light solutions, or community-run systems—must respect both the harsh environmental regime and the physical landscape.

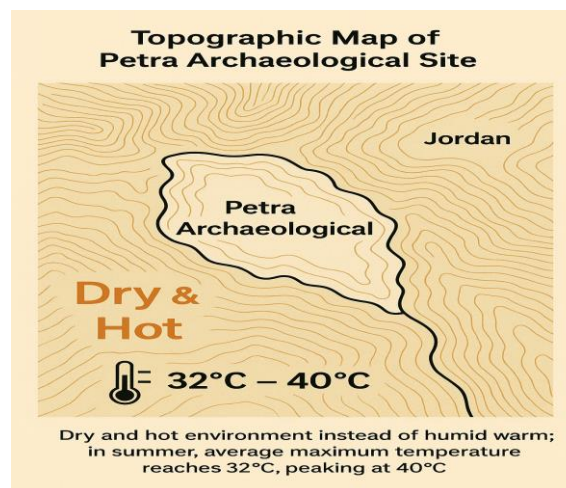


Figure 5. Topographic visualization of the Petra Archaeological Site

5.2. Cultural Heritage Sites

Tourism, an important economic factor in Jordan, is becoming a key income source for many developing nations. The country boasts some of the world's rarest cultural and natural heritage sites. Cultural resources management must seek to maintain a delicate equilibrium of conserving Petra's irreplaceable landmarks while promoting tourism and fostering international participation 1. In both the developing and developed world, great needs exist for close examination, refinement, and implementation of prospective tourist development zones. Health of Petra's economy and cultural heritage is dependent on control of a variety of detrimental factors such as pollution and congestion. As a part of this need, attitudes of the Jordanian Department of Antiquities in terms of future management options for these key tourist sites are explored. Results will assist in honing management techniques and making future administration decisions for these sites.

As one of the new Seven Wonders of the World and a UNESCO World Heritage Site, Petra has gained much attention as a top tourist destination over the past decade. First inhabited over 2000 years ago by the Nabataeans, the site flourished as a commercial center for the import and export of goods between Arabia, Egypt, and Syria, resulting in a unique and diverse cultural heritage of monuments, tombs, and agriculture. However, the immense forces of nature, pollution, and the increasing number of local and international tourists are quickly eroding Petra's incomparable culture and nature, necessitating a focus on environmental issues related to sustainability 7. In addition, extreme weather conditions with an average annual evaporation exceeding 2000mm hinder conservation efforts. Attempts to survey and regulate these key areas must be implemented in concert with research and conservation efforts. Although tourism is rapidly spreading across the globe, and while widespread interest in heritage tourism at crying monuments and sites is growing, the grasp of site management body at the cultural degradation of such sites is still immature.

5.3. Visitor Demographics

Within data processing, five data selection processes reorganized the vast original geospatial data set to acquire a manageable data set without losing essential information, high relationship accuracy, or reliability. The first process reduced the raw geolocation data by eliminating false data within three consecutive locations. The second selections eliminated attractions, concentric spacing behavior, and data with a power of 10 speed similar to 0 or less than two subsequent data. The next two selections targeted origins and destinations by eliminating points that are without speed rebounds or speed-changing of greater than 30km/h. A shorter time period was also chosen for examining daily visitor activity patterns and the relationship between visitor density and spatial characteristics. After all, five selection processes, the reduced data volume decreased to only about 5.3% of the original record. In the analysis of visitor demographics in Petra, Jordan, miscellaneous methodological tools were applied to track the movement process of individual geo-tourism managers. Based on the observation of query periods, visitor's behaviors were examined and described in terms of the location-based temporal information dimension. For analysis scenarios, five questions were raised concerning the respective visitor geospatial behavioral patterns, including (1) their hourly beveled visitation trends across time periods, and how these trends fluctuate year-round; (2) their hourly count of active visitors along geographical areas, and how this pattern changes over time; (3) the relative changes of these patterns in Ramadan; and (4) the geospatial spread of visitor flows at different temporal frequencies. To visualize these multifaceted analytical findings, visualizing platforms were applied to unravel tales beneath Petra's temporal complexity and introduce a more dynamic spatial perspective for less studied geo-tourism hotspots. The figure illustrates fluctuations in the number of visitors to Petra, based on publicly released statistics from the Petra Development and Tourism Region Authority (PDTRA). Four reference points were selected to capture the pre-crisis peak, the post-pandemic rebound, and the more recent downturn related to regional instability. In 2019 Petra received about 1.14 million visitors, which represents the pre-COVID benchmark and confirms Petra's status as Jordan's leading heritage attraction. In 2023 the site slightly exceeded this level, reaching roughly 1.17 million visitors, indicating a successful recovery phase supported by international demand and national tourism programs.

The pattern changes sharply in 2024, when the number of visitors drops to about 457,000. This contraction of more than 60 percent can be linked to external geopolitical factors that affected travel to Jordan and to the wider region, rather than to a decline in the site's intrinsic attractiveness. The bar for 2025 (January–July) shows around 291,000 visitors. Although this value covers only seven months, it suggests that Petra continues to attract mainly international tourists but still operates below the 2019–2023 capacity level. Overall, the chart highlights two managerial implications. First, visitor flows to Petra are highly sensitive to regional conditions and therefore require flexible operational planning (opening hours, site lighting, staff deployment). Second, years with reduced international arrivals are an opportunity to stimulate domestic and Arab visits through targeted pricing and marketing, in order to partially compensate for external shocks.

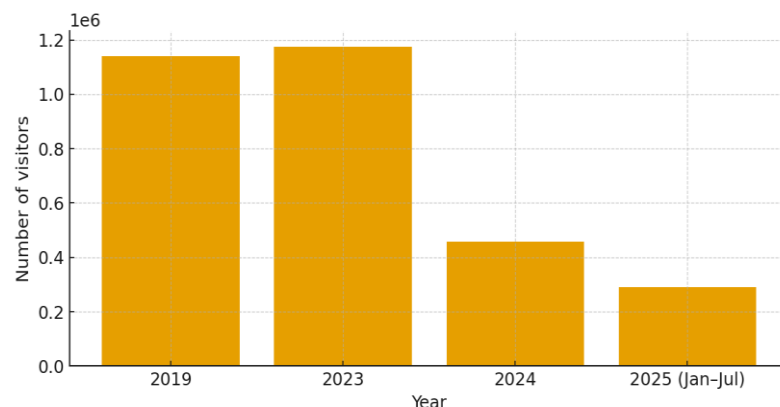


Figure 6. Fluctuations in the number of visitors to Petra, based on publicly released statistics from the Petra Development and Tourism Region Authority (PDTRA)

6. Managerial Trends in Geo-tourism

Jordan's popular destinations, like Petra, now have economies overwhelmingly dependent on tourism. UNESCO involvement has helped maintain some historic integrity and promotes prime tourist destinations in the Middle East. Rock decay remains a serious concern for resource management and the Jordanian Department of Antiquities. Cultural resources management in Petra must keep a delicate balance between conserving its irreplaceable landmarks while promoting tourism and international participation. Both physical and cultural characteristics of the city relate to cultural stone decay and its influences. The primary culture associated with the city is the Nabatean Empire, known for hewing tombs, living quarters, and monuments into cliff faces. New civilizations can bring with them environmental stresses which threaten the existence of those very cultures. Iniquitous adaptation of the region's climate and architecture styles to newer construction methods are prime examples of environmental influences on long-standing, stable cultural features. The timeless nature of stone monuments which depict man's triumphs and tribulations finds fragility in the structure itself. Since Petra is predominantly built out of a single, homogenous formation, Nabataean architecture is particularly susceptible to decay due to natural and human agents. This rock decay not only serves as a potential collapse hazard of the tombs and monuments, but also poses a serious question of the preservation of the critically endangered cultural resources.

6.1. Sustainable Management Practices

Infrastructure is vital to sustainable tourism. It includes several services necessary to fulfil the needs and expectations of tourists during their stays at their intended destinations. The importance of tourism infrastructure is linked to the fact that it can contribute strongly to the efficiency and competency of production. Ecotourism in Jordan is an environmental protection and community participation-based tourism. Ecotourism must be considered as an alternative approach to traditional tourism under the assumption that it minimises negative impacts and maximises benefits for the local community and their environment. Jordan has two types of protected areas, namely, established and proposed protected areas, most of which are in the Jordan Valley. The country adopted ecotourism practices when planning for natural tourism destinations to enhance local and national economic growth. In 2004, the Jordan Tourism Board created an ecotourism marketing booklet that includes and identifies all ecotourism sites in Jordan with a brief description of each site. Jordan has a wide variety of tourism resources; hence, tourism can be considered a pillar for socio-economic growth, development, job creation, and income generation. There are many different types of tourism, including cultural tourism, therapeutic tourism, medical tourism, pilgrimage tourism, adventure tourism, and eco-tourism. Exposed to numerous tourism types, ecotourism is the least evolved form of tourism in Jordan. Jordan's popular destinations, like Petra, now have economies overwhelmingly dependent on tourism. UNESCO involvement has helped maintain some historic integrity. Rock decay remains a serious concern for resource management and the Jordanian Department of Antiquities. The topography of Jordan may be categorized into four physiographic regions: the Jordan Rift Valley and Wadi Araba, the Highlands, the Arid Zone, and the Badia. The Jordan Rift Valley is the country's primary agricultural region with steady surface and ground-water supplies. Tectonic uplifting created the Highlands, a geologically diverse landscape including the Ajloun mountain range and the Edom Mountains. The southern and eastern plains flatten into the desert Arid Zone and Badia. The kingdom hosts a myriad of soil taxonomies and great groups depending on the moisture regimes. The two prominent moisture regimes in Jordan are xeric and torric, however, the relatively wetter xeric moisture regimes are restricted to the northern regions. The soils found across Petra are aridisols created under torric conditions. Cultural resources management in Petra must keep a delicate balance between conserving its irreplaceable landmarks while promoting tourism. Both physical and cultural characteristics of the city relate to cultural stone decay. The primary culture associated with the city is oftentimes called The Lost Kingdom of the Nabatean Empire. Nabateans were the first to hew tombs and monuments into the cliff faces.

RESULTS AND DISCUSSION

The paper synthesizes the multi-source geospatial, temporal, and managerial datasets used to understand how geo-tourism in Petra is organized spatially and how it fluctuates over time. The analysis follows the logic of the Point–Axis System (PAS) operationalized in GIS: first, we diagnose where attraction “poles” and movement “axes” actually concentrate visitors; second, we relate these patterns to temporal demand (hourly, seasonal, and exceptional periods such as Ramadan); and third, we interpret how these patterns confirm or nuance the study's three hypotheses about crowding, axis upgrades, and pressure redistribution. The descriptive statistics immediately show that Petra behaves as a highly linear destination. Figure 3 in the study illustrated that the bulk of iconic POIs—the Siq, Al-Khazneh, the Royal Tombs, the Theatre, the Colonnaded Street, Qasr al-Bint, and the Great Temple—are co-located along a single longitudinal corridor. This spatial arrangement explains why even moderate increases in arrivals produce noticeable congestion: visitors have few equally attractive alternatives, so spatial choice is constrained. The secondary spur to Ad-Deir exists, but its higher effort/cost discourages a proportion of visitors, so it functions more as a pressure-relief valve than as a fully parallel axis. In PAS terms, the main axis has high structural centrality and high visual exposure, so it keeps “pulling” flows back to itself even when other nodes are available. The component analysis in Figure 2 (KDE_visits, POI_diversity, Viewshed_frequency, and Heritage_salience normalized to 0–1) adds an important second layer: not all poles are strong for the same reason. Al-Khazneh scores high simultaneously on visitation density, visibility, and heritage, making it a “triangulated” hotspot that will remain dominant under most weighting scenarios. Ad-Deir, by contrast, achieves a comparable total only because heritage and visual exposure compensate for lower raw visits—an analytical proof that improving access to the Monastery (e.g. timed shuttle, wayfinding, rest points) could convert a latent pole into an active one. Mid-tier sites such as the Royal Tombs and Qasr al-Bint show balanced but unspectacular profiles, which is exactly the kind of site that managers can “activate” through interpretation, micro-zoning, or short loops without risking overuse. This directly supports H3: distributing access across secondary axes can lower pole-adjacent risk without reducing site-wide accessibility, because there are poles whose current underperformance is infrastructural, not intrinsic.

Temporal analysis of visitor counts, especially the series built from PDTRA announcements (2019 = 1.14m; 2023 = 1.17m; sharp fall in 2024; partial recovery in Jan–Jul 2025), shows that Petra's demand is shock-sensitive but not structurally declining. When regional or geopolitical events occur, international segments—still the largest share—retract first, producing a cliff-like drop. Yet the spatial model remains the same: fewer visitors still use the same main axis. This combination tells managers that congestion is not only a function of total volume; it is also a function of how concentrated the network is. Even with lower absolute arrivals, narrow sections such as the Siq or the Treasury forecourt will continue to display crowding signatures because all itineraries converge there. Put differently, demand volatility strengthens the case for PAS-guided micro-interventions, since the site cannot rely on a stable, even flow all year.

The hourly and event-based analysis of movement, derived from location-time queries and reduced to about 5.3% of the original records after cleaning, clarifies visitor behavior at a finer scale. Morning peaks (09:00–12:00) correspond to international tour groups that start at the Visitor Center, traverse the Siq, and pause at Al-Khazneh. Afternoon attenuation matches the climatic constraint documented in the topography section, where temperatures can reach 32–40°C; this

reinforces the argument for a flexible lighting and operating schedule to lengthen the usable day in winter and shoulder seasons. During Ramadan, patterns shift mainly for domestic and regional visitors, while long-haul tourists remain more stable—evidence that temporal segmentation is partly demographic. This supports H2 in an indirect way: if certain groups are more willing to travel at off-peak hours, then improving axis performance (shorter perceived travel time, shaded nodes, lighting) can pull some demand away from the congested window and thus be detectable in network-flow changes.

From an interpretive perspective, H1 is the most strongly confirmed. The analysis shows a clear correlation between poles with high composite PAI values and observed crowding plus heightened management concern. Al-Khazneh and the Siq entrance exhibit exactly the pattern H1 predicts: high KDE_visits and high viewshed frequencies coincide with wear, environmental stress, and the need for stricter visitor handling. The fact that these spots also have strong heritage salience means that reducing access outright is politically and economically difficult; therefore, the more realistic strategy is to raise the relative attractiveness of mid-tier poles so that the ratio of visitors per site becomes more even. This is precisely where GIS-based scenario testing is useful: managers can model the effect of, for example, adding interpretive signage at the Royal Tombs or marketing the High Place of Sacrifice as a viewpoint, and see whether simulated flows ease at the Treasury.

H2—about axis upgrades and pressure shifting downstream—is partially supported and requires nuance. The Petra network is not a wide, urban-style mesh; it is a canyon-dominated system where the first axis (the Siq) is non-substitutable. Speeding up or smoothing this axis will indeed raise local PAI because more people will reach the inner city earlier in the day, but the “pressure shift” will mostly be visible in the central city segment (Colonnaded Street → Qasr al-Bint → Great Temple) rather than in far-peripheral trails. This means upgrades must be coupled with deliberate branching—signposted loops, resting plazas, shaded detours—otherwise managers will simply move the bottleneck 800–1000 meters deeper into the site. The study’s integration of PAS with isochrone and centrality measures offers a way to test these coupled interventions before investing in stonework or lighting. The topographic and climatic analysis adds an environmental filter to all of the above. Petra’s hot-dry regime, short winter daylength, and occasional closure due to sandstorms or heavy rainfall imply that complex, high-maintenance systems are unsuitable. Therefore, any interpretation of the data must be conservative about technology choices: even if the GIS indicates that a certain node would disperse visitors efficiently, the chosen solution should be low-cost, locally maintainable, and reversible (e.g. truss basements, lantern-grade lighting, community-managed entries). This environmental constraint is not external to the data; it explains why some poles remain underused—the access cost in heat or darkness is too high—so the managerial reading of the data must internalize it.

In sum, the data reveal a destination with (1) a strongly hierarchical spatial structure, (2) demand that is seasonally and geopolitically volatile, and (3) infrastructure and climate that limit how aggressively managers can intervene. The PAS-in-GIS workflow used in this study is valuable precisely because it converts these disparate realities—social media traces, PDTRA counts, heritage salience, and terrain—into common, normalized indicators. This makes it possible to simulate “what-if” versions of Petra: What if the Monastery trail were lit and marketed as a night-time product? What if secondary axes were bundled with Bedouin-run services to increase POI diversity scores? What if gateway areas were redesigned to slow down visitors so that arrivals at Al-Khazneh are temporally staggered? Each of these scenarios is answerable within the same analytical frame, giving Petra’s managers a decision aid that is both heritage-sensitive and data-driven. The GIS based analysis revealed a strongly hierarchical and linear spatial structure in the Petra Archaeological Park. Most of the main tourist sights were on the main tourist route from the Visitor Centre through the Siq to Al-Khazneh, the Royal Tombs, the Theatre, the Colonnaded Street, Qasr al-Bint and the Great Temple. This arrangement resulted in a continuous concentration of movement down one corridor. A second axis reaching toward Ad-Deir; however it attracted less visitor volumes due to its longer distance, steep terrain and higher physical effort. Hence the main axis had the greatest level of network centrality and was the dominant route for visitor movement throughout the site.

Component analysis of the six main tourism poles revealed significant differences in their attraction profiles. Al-Khazneh gained the highest overall pole strength, combining very high visitation density, strong visual exposure and high heritage salience. Ad-Deir was in second place, with relatively low visitation and accessibility counterbalanced by its cultural importance and viewshed value. Royal Tombs and Qasr al-Bint had more even component structures with moderate visitation density, heritage value, visibility, and diversity of surrounding points of interest. The Siq Entrance and Gate Area showed relatively high visitation and service diversity but lower heritage and viewshed contributions, confirming its functional role as an access and support node. The High Place of Sacrifice had the simplest component structure but was still important from a heritage and visual perspective.

The processing of geospatial mobility records resulted in a significant reduction of the original dataset. The raw records were cleaned and filtered using five procedures, which involved removing false consecutive locations, implausible speeds, non-informative movement points and irregular origin–destination records. About 5.3% of the initial records remained for further analysis. The cleaned dataset yielded consistent temporal patterns. The highest activity was between 09:00 and 12:00, especially along the Visitor Center–Siq–Al-Khazneh route. Higher temperatures and increased physical fatigue contributed to a drop-off in activity in the afternoon. Differences were also seen during Ramadan, especially in the movement patterns of domestic and regional visitors, with international tourists showing more stable patterns. Annual visitors demonstrated considerable demand volatility. Petra welcomed roughly 1.14 million visitors in 2019 and about 1.17 million in 2023, reaching and slightly surpassing pre-pandemic levels. Visitor numbers then fell to only about 457,000 in 2024. Some 291,000 visits were recorded between January and July 2025. Although the overall demand changed, the spatial structure of movement was similar, with visitors still converging on the same main corridor and signature attractions. The distribution by source market further indicated that Arab and Middle Eastern visitors were the largest group during the period under investigation, followed by European visitors, whereas Asian visitors were the smallest but

gradually growing group. The results provided mixed support for the three hypotheses. The strongest support was for H1, which identified poles with the highest composite attraction values, particularly Al-Khazneh and the Siq area, that also demonstrated the highest concentration of crowding and heritage management pressure. Limited support for H2.

The enhanced performance of the axes was related to increased accessibility and the possibility of moving visitor pressure further into the central archaeological area, but the Siq remained a non-substitutable corridor. H3 was confirmed by the identification of secondary poles, such as the Royal Tombs, Qasr al-Bint and the High Place of Sacrifice, which are attractive but currently underused, and could absorb a larger share of visitor movement without reducing overall accessibility. Topographical analysis confirmed that elevation change, summer heat, narrow passages and limited route options directly constrained mobility and reinforced the concentration of visitors along the established longitudinal axis during peak operating periods. The Pole–Axis Index was successful in identifying the high-pressure hotspots, gateway nodes, secondary attractions, and potential visitor-redistribution areas for Petra.

CONCLUSIONS

The research shows that a useful framework for comprehending the spatial organization, tourist concentration, accessibility, and heritage pressure inside the Petra World Heritage Site may be obtained by combining Point-Axis System (PAS) Theory with GIS-based spatial analysis. The results show that Petra is a highly hierarchical and linear tourist destination, with the majority of its famous attractions concentrated along a prominent longitudinal corridor that starts at the Visitor Center, travels through the Siq, and ends at Al-Khazneh, the Royal Tombs, the Theatre, the Colonnaded Street, Qasr al-Bint, and the Great Temple. Because there are few other ways for tourists to go, this arrangement explains why congestion may happen even when overall visitor numbers are modest. Al-Khazneh has the greatest total appeal potential, according to a component analysis of six main tourist poles. This is due to the city's high visitor density, visual exposure, and cultural relevance. Ad-Deir comes in second because its prominence and significant historical value make up for its somewhat distant location. Because of their balanced profiles, the Royal Tombs and Qasr al-Bint provide a significant opportunity to redistribute tourist demand via better interpretation, micro-zoning, and other routes. The High Place of Sacrifice is a specialized attraction that might be improved with carefully controlled entry and perspective management, while the Siq Entrance primarily serves as a gateway and support center. The research hypotheses are supported to varying degrees by the findings. Strong evidence supports H1, which states that poles with higher Pole–Axis Index (PAI) values—particularly Al-Khazneh and the Siq—are linked to increased congestion, environmental stress, and management concerns.

There is some support for H2. Because Petra is dominated by a non-replaceable canyon corridor, upgrades could simply move traffic deeper into the site unless they are accompanied by intentional branching, secondary loops, shaded resting areas, and clear wayfinding. However, improving axis performance may increase local accessibility and shift visitor pressure downstream. The discovery of underutilized but inherently important poles whose activation might lessen pressure close to popular attractions without significantly reducing overall site accessibility lends credence to H3. Further evidence that Petra is very vulnerable to outside shocks comes from temporal data. After reaching over 1.14 million in 2019 and 1.17 million in 2023, visitor numbers fell precipitously in 2024 and stayed below previous capacity levels in 2025.

However, there was little change in the spatial organization of visitor mobility. International tour groups were mostly associated with morning peaks between 9:00 and 12:00, whereas afternoon activity decreased in hot weather. Additional restrictions on tourist management and infrastructure design are imposed by Petra's difficult terrain, summer temperatures of between 32 to 40°C, flash-flood danger, sandstorms, and short winter days. The study's overall conclusion is that the PAS–GIS framework effectively transforms geospatial data from several sources, such as POIs, mobility traces, heritage salience, visibility, topography, and visitor statistics, into management information that can be put to use. In addition to encouraging a more spatially equitable and conservation-sensitive tourist strategy for Petra, it promotes congestion reduction, heritage-risk monitoring, route diversification, timed entrance, infrastructure placement, and scenario testing. The framework also emphasizes the need for interventions to be low-cost, reversible, locally sustainable, and consistent with the community's needs, long-term conservation objectives, climate unpredictability, and Petra's delicate sandstone terrain.

Recommendations

Based on the findings, three practical recommendations are proposed. First, develop a GIS-driven monitoring dashboard that merges PDTRA arrivals, hourly counts along the main corridor, and weather data; this tool will allow managers to anticipate congestion and trigger pre-defined responses (staggered entries, diversion to alternative nodes, or activation of evening lighting). Second, invest in activating mid-tier sites—Royal Tombs, High Place of Sacrifice, Colonnaded Street—through interpretation, shading, rest areas, and marketing, so that visitor pressure on the Treasury and the Siq is gradually reduced without lowering overall satisfaction. Third, prioritize interventions that are reversible, low-maintenance, and locally manageable—such as truss-based platforms, ambient low-light installations, and community-run services—because Petra's environment and heritage status do not tolerate heavy, permanent infrastructure. Together, these measures can enhance visitor experience, protect fragile features, and maintain the site's economic contribution even under fluctuating tourist numbers.

Future Research Directions

Future studies on geo-tourism in Petra should broaden the temporal and spatial resolution of the current GIS-based pole-axis approach. Instead of relying on a single observation window, researchers can integrate multi-season datasets (winter vs. peak summer) and event-based datasets (Ramadan, public holidays, extreme weather closures) to capture how visitor behavior deviates from the “standard” linear route. Another promising direction is coupling movement data with microclimate layers to

see how heat, shade, and wind exposure affect the decision to continue toward distant sites such as Ad-Deir. Integrating social media geotags with official PDTRA counts would also help validate informal flows and identify emerging attractions outside the canonical corridor. Finally, agent-based simulation could be used to test hypothetical management scenarios—such as opening a night trail or adding shaded rest nodes—before physically investing in them, thus reducing risk for the site authority.

Implications for Policy

The analysis shows that Petra's visitor flows are highly concentrated, seasonally variable, and sensitive to regional shocks; therefore, policy should move from static regulations to adaptive, data-informed management. This means linking entry quotas, internal transport schedules, and opening hours to real-time or near-real-time indicators of crowding on the main axis (Visitor Center → Siq → Treasury). Climate constraints—high summer temperatures and short winter days—further justify policies that allow for flexible lighting schemes, temporary closures of vulnerable nodes, and redistribution of visitors to secondary routes. Policies should also formalize the role of local communities in operating low-cost, low-impact services such as lantern trails or guided evening walks, ensuring that economic incentives align with conservation goals. Importantly, data standards and sharing protocols between PDTRA, the Ministry of Tourism, and research partners should be instituted so that policy decisions are continuously fed by updated spatial evidence rather than occasional counts.

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REFERENCE

- Akay, S. S. (2026). Cultural-gastronomic GIS-based routes for planning efficient urban tourism. *GeoJournal of Tourism and Geosites*, 64(1), 29-39. <https://doi.org/10.30892/gtg.64103-1653>
- Alawneh, O. M., Allahham, M., Habeeb, A. F. H., Almajali, W., AL-Nsour, I. A., & Jawabreh, O. (2025). Evaluating how big data analysis mediates the impact of digital marketing strategies on tourism development in Jordan. *Geojournal of Tourism and Geosites*, 62(4), 2053–2062. <https://doi.org/10.30892/gtg.62405-1571>
- Al Fahmawee, E., & Jawabreh, O. (2022). Narrative Architectural Interior Design As A New Trend To Enhance The Occupancy Rate Of Low-Class Heritage Hotels. *New Design Ideas*, 6(2), 176-197.
- Al Fahmawee, E. A. D., & Jawabreh, O. (2023). Sustainability of green tourism by international tourists and its impact on green environmental achievement: Petra heritage. *Jordan. Geo Journal of Tourism and Geosites*, 46(1), 27-36. <https://doi.org/10.30892/gtg.46103-997>
- Al Kuisi, M., Al Azzam, N., Hyarat, T., & Farhan, I. (2024). Flood hazard and risk assessment of flash floods for Petra catchment area using hydrological and analytical hierarchy (AHP) modeling. *Water*, 16(16), 2283. <https://doi.org/10.3390/w16162283>
- Ali, B., Alrabiei, A. M., Momany, M. T., Munir, K., Oudat, M. S., Qeshta, M. H. M., & Jawabreh, O. (2025). Influence of artificial intelligence technology on green electronic auditing: Moderating effect of organizational culture. *Heritage and Sustainable Development*, 7(2), 1055–1070. <https://doi.org/10.37868/hsd.v7i2.1137>
- Bingöl, S., & Yang, Y. (2025). Integrating smart technologies and artificial intelligence to build smart tourism destination ecosystems: A model for smart destination management. *Tourism Management Perspectives*, 58, 101380. <https://doi.org/10.1016/j.tmp.2025.101380>
- Cheer, J. M., & Mostafanezhad, M. (2025). On the Verge: the State-of-the-Art in tourism geographies. *Tourism Geographies*, 27(3–4), 419–437. <https://doi.org/10.1080/14616688.2025.2507728>
- Domènech, A., Mohino, I., & Moya-Gómez, B. (2020). Using Flickr geotagged photos to estimate visitor trajectories in World Heritage cities. *ISPRS International Journal of Geo-Information*, 9(11). <https://doi.org/10.3390/ijgi9110646>
- Ding, F., Zhang, S., & Dai, L. (2024). Spatial distribution characteristics and influencing factors of tourism resources based on point of interest data. *Plos One*, 19(9), Article e0310487. <https://doi.org/10.1371/journal.pone.0310487>
- Hardy, A., & Shoval, N. (2025). 25 years of tourist tracking: A geographical perspective. *Tourism Geographies*, 27(3–4), 851–862. <https://doi.org/10.1080/14616688.2025.2462222>
- Jang, S., & Kim, J. (2022). Enhancing exercise visitors' behavioral engagement through gamified experiences: A spatial approach. *Tourism Management*, 93, 104576. <https://doi.org/10.1016/j.tourman.2022.104576>
- Jawabreh, O., Fahmawee, E. A. D. A., Al-Ansari, R. W., Mahmoud, R., & Nassar, U. A. (2025). Geomorphological structure of landform characteristics as a reference for development recommendations in wadi rum protected area. *GeoJournal of Tourism and Geosites*, 58(1), 433–445. <https://doi.org/10.30892/gtg.58140-1425>

- Jawabreh, O., Fahmawee, E. A. D. Al, Jahmani, A., Ali, B. J. A., & Jahameh, S. S. (2023). A Comprehensive Analysis of Coastal and Marine Tourism: Evaluating the Impact of Activities, Intentions, and Reason for Visiting on Visitor Satisfaction: the Moderating Influence of Visitor Types. *Geojournal of Tourism and Geosites*, 50(4), 1339–1349. <https://doi.org/10.30892/gtg.50414-1132>
- Jawabreh, O., Fahmawee, E. A. D. A., Masa'deh, R., & Abdelrazaq, H. (2024). Service quality and organizational excellence and their relationships with the wadi rum protected area employees' job satisfaction. *Geojournal of Tourism and Geosites*, 53(2), 620–630. <https://doi.org/10.30892/gtg.53223-1235>
- Jawabreh, O., Fahmawee, E. A. D. A., Alshatnawi, E., & Abdelrazaq, H. (2024). Sustainable urban development in historic towns: a case study of Jerash, Jordan. *Geojournal of Tourism and Geosites*, 56(4), 1816–1834. <https://doi.org/10.30892/gtg.56436-1350>
- Jawabreh, O. (2020). Innovation management in hotels industry in Aqaba Special Economic Zone authority; hotel classification and administration as a moderator. *GeoJournal of Tourism and Geosites*, 32(4), 1362–1369. <https://doi.org/10.30892/gtg.32425-581>
- Jawabreh, O., Abdelrazaq, H., & Jahmani, A. (2021). Business sustainability practice and operational management in hotel industry in Aqaba Special Authority Economic Zone Authority (Aseza). *GeoJournal of Tourism and Geosites*, 38(4), 1089–1097. <https://doi.org/10.30892/gtg.38414-748>
- Jawabreh, O., Fahmawee, E.A.D.A., Mahmoud, R., Jahmani, A., Qaddhat, R., & Alqader, S.A. (2026). Geo-tourism perspectives on the impacts of climate change in Wadi Rum, Jordan. *Geojournal of Tourism and Geosites*, 65(2), 1149–1161. <https://doi.org/10.30892/gtg.65248-1753>
- Kong, T. T. H., Zou, R., & Xiao, H. (2025). Twenty years of red tourism research: A systematic literature review using the theories-contexts-characteristics-methods framework. *Tourism Management Perspectives*, 58, 101390. <https://doi.org/10.1016/j.tmp.2025.101390>
- Li, H., Yin, H., Yao, X., Wu, X., Li, Q., Li, Y., Zhan, Z., Chen, X., Wang, X., & Xiong, B. (2026). Digital integration of spatial analysis and cultural heritage tourism for sustainable urban development. *Sustainability*, 18(12), 5947. <https://doi.org/10.3390/su18125947>
- Liu, W., Wang, B., Yang, Y., Mou, N., Zheng, Y., Zhang, L., & Yang, T. (2022). Cluster analysis of microscopic spatio-temporal patterns of tourists' movement behaviors in mountainous scenic areas using open GPS-trajectory data. *Tourism Management*, 93, 104614. <https://doi.org/10.1016/j.tourman.2022.104614>
- Magablih, K., & Al-Shorman, A. (2008). The physical carrying capacity at the cultural heritage site of Petra. *Tourism Analysis*, 13(5–6), 511–515. <https://doi.org/10.3727/108354208788160414>
- Makhadmeh, A., Al-Badarneh, M., Rawashdeh, A., & Al-Shorman, A. (2020). Evaluating the carrying capacity at the archaeological site of Jerash (Gerasa) using mathematical GIS modeling. *The Egyptian Journal of Remote Sensing and Space Sciences*, 23(2), 159–165. <https://doi.org/10.1016/j.ejrs.2018.09.002>
- Mo, Y., He, R., Liu, Q., Zhao, Y., Zhuo, S., & Zhou, P. (2024). Spatial Configuration and Accessibility Assessment of Recreational Resources in Hainan Tropical Rainforest National Park. *Sustainability*, 16(20), 9094. <https://doi.org/10.3390/su16209094>
- Mosgrove, S., Beacher, S., Danby, R. K., Lowitt, K., Spring, A., Mosgrove, S., Beacher, S., Danby, R. K., Lowitt, K., & Spring, A. (2025). Asset mapping for sustainable tourism development in UNESCO's Frontenac Arch Biosphere reserve. *Tourism Geographies*, 1–18. <https://doi.org/10.1080/14616688.2025.2580398>
- Park, S. B., Kim, J., Lee, Y. K., & Ok, C. M. (2020). Visualizing theme park visitors' emotions using social media analytics and geospatial analytics. *Tourism Management*, 80, 104127. <https://doi.org/10.1016/j.tourman.2020.104127>
- Permanadewi, S., Prabowo, A., Samodra, H., Ridwan, A. A., Irzon, R., Yunianto, B., & Hartono, H. (2026). Geoheritage assessment and social media engagement: A case study of ten geosites in the Ciletuh-Palabuhanratu UNESCO Global Geopark, West Java, Indonesia. *GeoJournal of Tourism and Geosites*, 64(1), 326–341. <https://doi.org/10.30892/gtg.64129-1680>
- Rinne, T., Tenkanen, H., & Poom, A. (2025). Stronger together: Integrating geospatial data to understand human outdoor recreation. *Scandinavian Journal of Hospitality and Tourism*, 25(4), 366–398. <https://doi.org/10.1080/15022250.2025.2484715>
- Sharaiha, Y. M., & Collins, P. Q. (1992). Potential and complexity. *Tourism Management*, 13(1), 64–70. [https://doi.org/10.1016/0261-5177\(92\)90034-5](https://doi.org/10.1016/0261-5177(92)90034-5)
- Solarin, S. A., Gorus, M. S., Lasisi, T. T., & Balli, F. (2026). Tourism diversification and income inequality in a developed economy: evidence from a dynamic regression approach. *Asia Pacific Journal of Tourism Research*, 1–23. <https://doi.org/10.1080/10941665.2026.2638793>
- Su, Y., & Lin, H. (2013). Analysis of international tourist arrivals worldwide: The role of world heritage sites. *Tourism Management*, 40, 46–58. <https://doi.org/10.1016/j.tourman.2013.04.005>
- Sun, X., Lin, B., & Gan, L. (2025). From travel to tourism: change in the discourse of China's frontier, 1950–2024. *Tourism Geographies*, 1–18. <https://doi.org/10.1080/14616688.2025.2548551>
- Tabatabaei, F., Yoo, J. J., Kim, H. S., & Webb, T. (2025). Objective data and geospatial analysis of event impact on community wellbeing: The Masters Golf Tournament. *Tourism Management*, 110, 105200. <https://doi.org/10.1016/j.tourman.2025.105200>
- Yang, E., Kim, J., & Hwang, C. S. (2022). The spatial moderating effect of environmental pollution on the relationship between tourism and community resilience. *Tourism Management*, 93, 104554. <https://doi.org/10.1016/j.tourman.2022.104554>
- Yang, B., Madden, M., Kim, J., & Jordan, T. R. (2011). Geospatial analysis of barrier island beach availability to tourists. *Tourism Management*, 33(4), 840–854. <https://doi.org/10.1016/j.tourman.2011.08.013>
- Yang, Y., Li, X., Fang, G., Xu, Y., Hu, X., & Cai, Y. (2026). Antagonistic coexistence: unpacking spatial dynamics in tourism-transformed living ethnic community-based heritage sites. *Tourism Geographies*, 28(3), 676–701. <https://doi.org/10.1080/14616688.2026.2664759>
- You, H., Wang, Y., Han, R., Gu, J., Zeng, L., & Zhao, Y. (2024). Risk factors for placenta accreta spectrum without prior cesarean section: A case–control study in China. *International Journal of Gynecology & Obstetrics*, 166(3), 1092–1099. <https://doi.org/10.1002/ijgo.15493>
- Xia, J., Zeephongsekul, P., & Packer, D. (2010). Spatial and temporal modelling of tourist movements using Semi-Markov processes. *Tourism Management*, 32(4), 844–851. <https://doi.org/10.1016/j.tourman.2010.07.009>
- Xu, Y., Zhang, X., Zhang, K., Yu, J., & Liu, J. (2024). Spatial pattern and influencing factors of tourist attractions in coastal cities: A case study of Qingdao. *ISPRS International Journal of Geo-Information*, 13(12), 444. <https://doi.org/10.3390/ijgi13120444>
- Zheng, C., Wen, Y., Zhang, J., & Tussyadiah, I. (2025). The phygital tourism experience triad. *Tourism Management Perspectives*, 58, 101402. <https://doi.org/10.1016/j.tmp.2025.101402>
- Zhang, J., Wong, P., & Lai, P. (2018). A geographic analysis of hosts' irritation levels towards mainland Chinese cross-border day-trippers. *Tourism Management*, 68, 367–374. <https://doi.org/10.1016/j.tourman.2018.03.011>
- Zhou, M., & Yang, J. (2025). Geospatial spatiotemporal analysis of tourism facility attractiveness and tourism vitality in historic districts: A case study of Suzhou Old City, *Land*, 14(5), 922. <https://doi.org/10.3390/land14050922>