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Historical Geographical Information System (HGIS): social trajectories of two Chinese historical figures Su Shi and Zuo Zongtang in spatial context

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Abstract

Historical figures have important significance worldwide. This paper introduces the concept of historical Geographical Information System (HGIS) using the lives of two personalities from Chinese history as case studies: Su Shi, a literary figure of the Northern Song Dynasty, and Zuo Zongtang, a military strategist from the late Qing era. By studying the geographical points marking their life activities, their migratory patterns were explored, along with the dynamics of their social networks within time and space, examining the distinctive phases and characteristics of their individual journeys. Kernel density estimation, standard deviation ellipse, location-based distance analysis, and social network graphs were employed in this work. Our findings reveal that Su Shi's migrations were largely dictated by official appointments, ultimately rooted in imperial successions and factional strife, with his intellectual pursuits significantly influenced by the humanistic milieu. Conversely, Zuo Zongtang's migrations were predominantly shaped by war, reflecting the challenges of the late Qing era in relation to governance, sovereignty, and diplomacy. The military encampments selected by Zuo Zongtang tended to be situated near water sources, illustrating how his migratory trajectory was influenced by natural geographic conditions. The social circles of these figures are tied to their social and political stature. Through the socio-historic context, the characteristics of these historical figures' behavioral trajectories relate to the unfolding process of societal and historical development. These insights offer a glimpse into the life journey behind historical figures, implicitly highlighting their perseverance and resilience in adversity, thereby describing innovative approaches to inheriting and disseminating the cultural legacy.

Keywords Historical Geographical Information System, Civil officials and military commanders, Spatial trajectories, Geographical locations, Social networks

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Introduction

Constrained by technological limitations, researching in humanities and social sciences has focused on the temporal dimension while marginalizing spatial considerations [1–3]. However, the advent and progression of GIS technology have sparked a "spatial turn" in these disciplines, emphasizing spatial thinking and the integrated application of GIS to articulate a multitude of humanistic information [4]. Historical Geographical Information System (HGIS), an interdisciplinary fusion of historical geography and geographic information science, centralizes its value proposition on the conjunction of temporal and spatial dimensions to examine the individuals, events, and geographic contexts underlying specific historical issues [5]. This concept facilitates the exploration of historical evolution patterns.

The notion of "historical figure" boasts a long-standing history. In the broadest sense, a historical figure refers to an recognizable and oft-legendary public figure [6, 7], encompassing heroes, politicians, scientists, artists, and intellectuals from different eras and regions worldwide [8]. More specifically, historical figures are individuals who, in one or more domains, had made extraordinary contributions to their people, ethnicity, or nation, casting a profound influence on posterity [9]. These historical personas embody cultural [7, 10], educational [11, 12], and potential socioeconomic values [9, 13]. As one of the four ancient civilizations, China is renowned for numerous such influential figures who are instrumental in preserving, advancing, and disseminating Chinese culture [14–16].

Historical figures are key cultural participants and creators in the social and historical development. A wealth of records from bygone eras [8, 17] has made invaluable contributions to the realm of big data on historical figures and events. These documents immortalize the words, ideologies, and behaviors of ancient individuals, laying the groundwork for historical research [7, 18, 19]. Nevertheless, the emergence of historical figures, in accordance with the demands of their respective era, was shaped by the prevailing social and historical milieu [20, 21]. The migratory trajectories of these individuals mirror the social framework and interpersonal relationships of a specific time and place, with timestamps, locations, personalities, and occurrences serving as evidentiary keystones of history. Considering the diverse backgrounds, upbringings, scholarly attainments, and societal contributions among historical figures, the revelation and tracing of their legacies, alongside the exploration of their spatial movements, not merely provides anecdotal value but also, to a certain degree, aids in deciphering societal transformations.

Trajectory data, constituting a sequence of spatial locations marked over time, typically arises from domains like transportation [22], communication [23], criminal tracking [24], and environmental monitoring [25]. The lives of historical figures generate volumes of such spatiotemporal data. Organized chronologically based on historical events tied to the individuals, this dataset charts a series of visited locales, unveiling activity patterns during specific historical periods [5, 9]. The mobility patterns of these historical actors are often intertwined with society dynamics [6, 26]. While every figure is constrained by their epoch, the profound and evolving impact evident in their movements is indisputable [18, 21]. Simultaneously, the didactic nature of history furnishes lessons for future generations to ponder and learn from.

In the study of historical figures, attention should be given to individuals potentially associated with their notable achievements or statuses [6, 13, 26]. In a narrow sense, social interaction denotes the formation of relatively stable relationships among people [27]. The exploration of social networks, utilizing methods like graphs, matrices, and statistical physics [28], fosters a link between individuals' micro-networks and society's macro-structure [27]. Moreover, social network analysis emphasizes structural perspectives, positing that the features of social relations emanate from the processes of structure and connectivity [29]. The trajectories of historical figures during specific epochs reflects their physical locations, thereby illuminating their social circles. Given the rudimentary state of ancient transportation, communication, and navigation, the social networks, to some degree, mirror genuine interpersonal relationships underpinning particular historical contexts. These connections can either foster or hinder the development of historical figures.

Given the passage of extensive time since the demise of ancient figures, reconstructing the historical events linked to them can prove challenging. Nonetheless, examining the lifetime trajectories of these individuals through archival records enriches our comprehension of their personal narratives, the culture prevalent in a specific era, and the socio-historical context. Presently, there exists a conspicuous void in research concerning the exploration of historical figures' phased life paths in relation to historical occurrences or realities. Also, temporally segmented investigations into these figures' authentic social relations, as shaped by changing geographic locations, remain scarce. Thus, by integrating GIS technology, geospatial data, and historical timelines within the theoretical framework

of HGIS, the main objectives of this study were to: (1) reveal the spatiotemporal patterns of social trajectories for historical figures; (2) analyze the migration characteristics across lifetimes of historical figures; and (3) explore the social circles of historical figures within dynamic spatiotemporal contexts.

Materials and methods

Profile of selected figures

This study centers on two historical figures from China: Su Shi, a literary figure, and Zuo Zongtang, a military strategist. By exploring their lives from a multifaceted perspective, the diverse trajectories and defining features of personal development, specific to different historical eras, are to be uncovered. An overview of their commemorations is depicted in Fig. 1, which includes sculptures, memorial structures, birthplaces, and trajectory points. Notably, Three Su Shrine commemorates the celebrated literati of the Northern Song Dynasty, Su Xun, Su Shi, and Su Zhe, collectively known as the "Three Su." In addition, the trajectory points encompass birthplaces, official postings, places of exile, and other transient locales, with the criterion for inclusion being that the individual resided at each location for over a year.

Data pertaining to historical figures' timelines, locales, associates, and events are primarily extracted from historical records, biographies, and documented sources (Table 1). Specifically, the "Notes" column outlines the identity of the "Associated Figure", while the "Engagement" column delineates the nature of the relationship

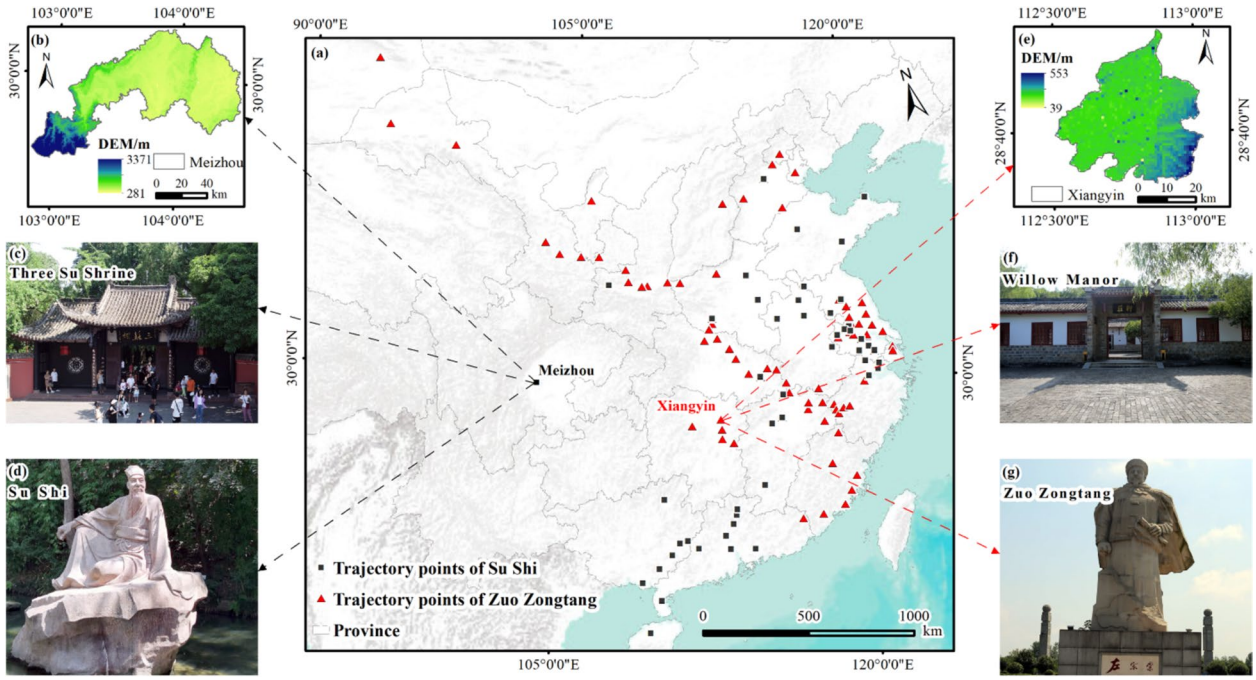

Fig. 1 Information on two Chinese historical figures. **a** Distribution of trajectory points; **b**-**d** birthplace, residence, and sculpture of Su Shi; and **e**–**g** birthplace, residence, and sculpture of Zuo Zongtang

Table 1 Statistical information on historical figures

Figure	Data	Data Items	Volume	Data Sources
Su Shi	Activity trajectory points from 1037 to 1101	Time, ancient place name, modern place name, event	50	*A New Biography of Su Dongpo*
	Social circle data from 1037 to 1101	Period, associated figure, relationship, notes, engagement	356	
Zuo Zongtang	Activity trajectory points from 1812 to 1885	Time, ancient place name, modern place name, event	86	*The Complete Biography of Zuo Zongtang, My Great-Grandfather Zuo Zongtang, Zuo Zongtang's Biography*
	Social circle data from 1812 to 1885	Period, associated figure, relationship, notes, engagement	205	

between the historical figure and the respective associate. Notably, ancient place names and administrative divisions have evolved over time. Thus, cross-referencing ancient place names with their contemporary equivalents ensures a degree of continuity and accuracy in the data. Given the millennium that separates us from the Northern Song Dynasty, data related to Su Shi employs ancient place names. Conversely, as the late Qing Dynasty is within the nineteenth century, modern place names are adopted for the analysis of Zuo Zongtang.

Su Shi

Su Shi (1037 – 1101 AD), or Su Dongpo, with the courtesy name Zizhan and the pseudonym Dongpo Jushi, was a native of Meizhou (present-day Meishan City), China. A preeminent figure in the literary sphere of mid-Northern Song Dynasty, he was not only a master calligrapher and painter but also an esteemed figure in hydraulic engineering, notably associated with the Su Causeway of Hangzhou's West Lake. His oeuvre, encompassing poetry, ci (a form of lyrical poetry), calligraphy, and paintings, continues to resonate globally, solidifying his status among history's most influential cultural luminaries. In this study, 50 trajectory points and records of 356 individuals associated with Su Shi were extracted from *A New Biography of Su Dongpo* (Table 1).

To scrutinize Su Shi's interpersonal dynamics, this research segments his life into seven epochs based on his official postings and personal vicissitudes: the Meizhou Period, the Imperial Examination Period, the Scrutiny Period (pertaining to the Tang and Song dynasties' promotion examination system [30]), the Huangzhou Period, the Yuanyou Period, and his Later Years. Categorizing Su Shi's social network reveals familial ties, friendships, mentor-disciple bonds, colleagues, and political adversaries. Typically, significant figures may reappear throughout one's life, exemplified by Zhang Dun, who began as a colleague of Su Shi during the Scrutiny Period but evolved into a political rival during the Huangzhou Period due to ideological discord.

Zuo Zongtang

Zuo Zongtang (1812 – 1885 AD), styled Jigao and known by the pseudonym Xiangshang Nongren, hailed from Xiangyin County, Hunan Province, China. He was a statesman, military strategist, poet of late Qing Dynasty, and counted among the modern national heroes of China. His life was punctuated by pivotal historical events, including the Taiping Rebellion, the Self-Strengthening Movement, and the reconquest of Xinjiang to safeguard China's territorial integrity. This study compiled 86 trajectory points and documented his associations with 205 individuals (Table 1) from *The Complete Biography of Zuo Zongtang, My Great-Grandfather Zuo Zongtang,* and *Zuo Zongtang's Biography*.

Zuo Zongtang's life is herein chronologically dissected into five epochs based on temporal milestones, historical incidents, and geographical locations: the Youth Period, the Aide-de-Camp Period, the Eastern Expedition Period, the Western Expedition Period, and his Later Years. Also, his social network is categorized under familial ties, friendships, mentor-disciple bonds, colleagues, and political adversaries.

Methodology

Kernel density estimation and standard deviation ellipse

In the context of historical figures' life trajectories, specifically the locations they inhabited each year, kernel density estimation and standard deviation ellipse were employed to scrutinize the clustering attributes and directional tendencies of their trajectory points. This dual approach serves to unfold the distinct migration patterns of historical figures and elucidate the geographical distribution governing their movements.

Kernel density estimation stands as a prominent non-parametric technique for assessing the density function of locations, offering both a visual representation and quantitative assessment of the spatial features and trends inherent in discrete trajectory points [31]. Fundamentally, this method overlays a smooth surface over each trajectory point, with the surface value peaking near the point and tapering off to zero as the distance from the point increases within a predefined search radius. Mathematically, it is encapsulated by the following formula [32]:

$$\hat{f}_h(x) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{x - x_i}{h}\right) \tag{1}$$

where K denotes the weighting function of the kernel; h denotes the search radius originating at point x, and governs the smoothness of the surface; n denotes the total count of trajectory points; i denotes the serial number of a given trajectory point; and $x - x_i$ denotes the distance between the density estimation point x and the trajectory point x_i.

The standard deviation ellipse is a sophisticated visualization technique employed in the analysis of multivariate datasets [33], serving to depict both the dispersion and correlation of the data. By leveraging parameters such as the centroid, azimuth, major/minor axes, and eccentricity, this method offers a comprehensive, spatially-oriented quantification of the central tendency, directional trends, extent of

distribution, and morphological characteristics of geographical elements in a global spatial context [34]. The formulas for the orientation, major-axis standard deviation, and minor-axis standard deviation of the ellipse are as follows:

$$\tan\theta = \frac{\left(\sum_{i=1}^{n}\tilde{x}_i^2 - \sum_{i=1}^{n}\tilde{y}_i^2\right) + \sqrt{\left(\sum_{i=1}^{n}\tilde{x}_i^2 - \sum_{i=1}^{n}\tilde{y}_i^2\right)^2 + 4\left(\sum_{i=1}^{n}\tilde{x}_i\tilde{y}_i\right)^2}}{2\sum_{i=1}^{n}\tilde{x}_i\tilde{y}_i} \tag{2}$$

$$\sigma_x = \sqrt{2}\sqrt{\frac{\sum_{i=1}^{n}\left(\tilde{x}_i\cos\theta - \tilde{y}_i\sin\theta\right)^2}{n}} \tag{3}$$

$$\sigma_y = \sqrt{2}\sqrt{\frac{\sum_{i=1}^{n}\left(\tilde{x}_i\sin\theta - \tilde{y}_i\cos\theta\right)^2}{n}} \tag{4}$$

where θ denotes the azimuth angle; (x_i, y_i) denotes the coordinates of a trajectory point in year i; and $\tilde{x}_i, \tilde{y}_i$ denotes the coordinate deviation of the trajectory point from the arithmetic mean center.

Visualization of Trajectories

The ArcGIS API offers a map service interface that encompasses functionalities like loading maps and map operations. On the other hand, Baidu's Echarts plug-in is an open-source visualization tool, crafted in JavaScript, enabling the creation of an engaging data visualization platform. This study blends the strengths of ArcGIS API and Echarts to visually represent historical figures' trajectories. Specifically, the trajectory point coordinates are sequenced temporally. By harnessing the online base map from the ArcGIS API and leveraging Echarts, aspects like the trajectory direction, speed, and details about stopping points are visualized. Furthermore, these tools can mimic the dynamic routes of historical figures, offering a clear depiction of the geographical positions of the trajectory points, their sequential appearance, and the trajectory's directional flow. Snapshots of this visualization are exhibited in Fig. 2.

To further enhance the visualization of historical figures' trajectories, this study takes cues from the aforementioned dynamic routes. Utilizing ArcGIS software, static trajectory routes corresponding to different life phases of historical figures are traced, aiming to illustrate spatial activity patterns of these individuals. Simultaneously, multiple lines are employed to denote the frequency of visits at each trajectory point (Fig. 2).

Location-based migratory distance analysis

In this study, trajectory points of historical figures are sequentially arranged by age, employing migration index, distance from capital, distance from hometown, and distance from formative location to scrutinize their migration patterns. Specifically, the migration index denotes the spatial displacement of a historical figure from their previous year's location in any given year. The value of and frequency of changes in migration index reveal the intensity of migrations during different life stages [35], with higher values signifying more significant

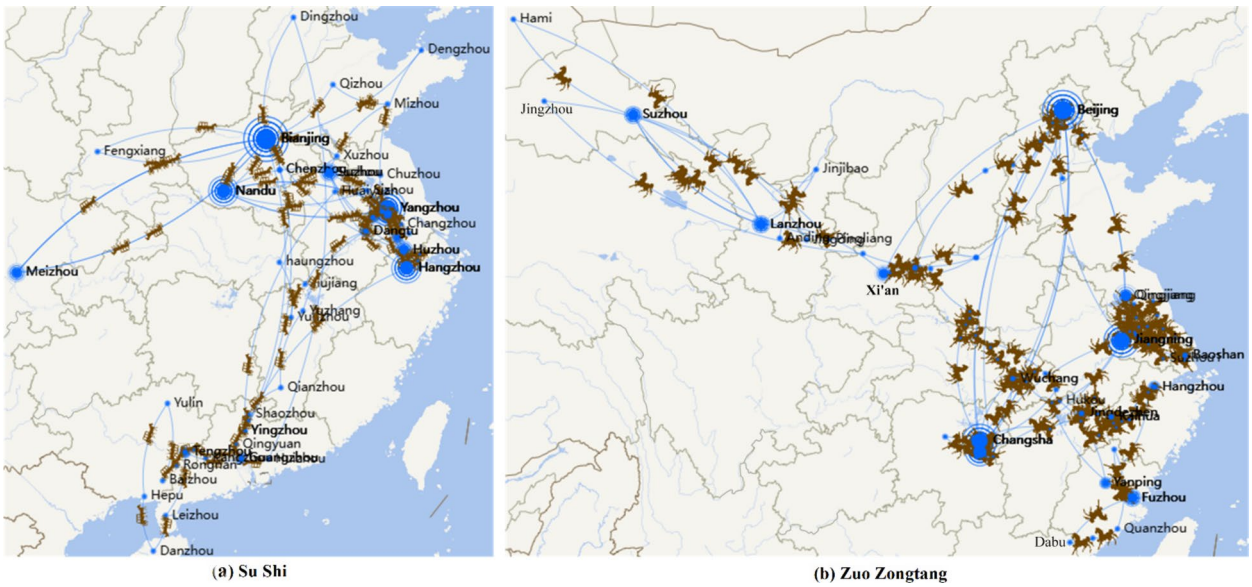

Fig. 2 Snapshots for dynamic trajectories of historical figures

location shifts and increased frequency indicating heightened migratory activity. Distance from capital, distance from hometown, and distance from formative location measure the spatial separation between one's location during a specific period and these respective places, thereby exploring their impact on migration patterns. The formula is as follows:

$$d(P_1, P_2) = Dis(L_i, L_j) \tag{5}$$

where $d(P_1, P_2)$ denotes the distance between any two trajectory points; L_i and L_j denotes the positions of the individual in year i and year j, respectively, corresponding to the geographical coordinates of the locations where the historical figure resided; *Dis* denotes the Euclidean distance.

Social network graphs

Social network analysis constitutes a structured methodology to examine interactions among social actors in social science research [36]. Open-source software Gephi, proven effective for its practicality and visual representation, enables the creation of social network graphs [26]. By quantifying the impact of social clusters on the careers, status, or accomplishments of historical figures throughout their lives, a social network is constructed. Additionally, by modeling "one-to-many" rather than "many-to-many" social relations of these figures, and examining the socio-historical context at the time and their life experiences, the dynamics between individual historical figures and societal transformations can be revealed to a certain degree.

Results

Spatial patterns of historical figures' trajectory points

Figure 3a illustrates that Su Shi's trajectory points exhibit a clustering characteristic, primary centered around present-day Anhui, Jiangsu, and northern Zhejiang Provinces. The kernel density center comprises 21 trajectory points including Hangzhou, Huzhou, and Changzhou, all clustering along the banks of the Yangtze River and the Beijing-Hangzhou Grand Canal south of it, with concentration diminishing concentrically outward. This pattern can be attributed to Su Shi's tenures as governor in cities such as Xuzhou, Huzhou, Hangzhou, Yangzhou, and Yingzhou (present-day Fuyang City). Peripheral points, more dispersed, include Bianjing (present-day Kaifeng City), Huangzhou (present-day Huanggang City), and Mizhou (present-day Zhucheng City). Furthermore, a secondary cluster emerges in central-western Guangdong and eastern Guangxi Provinces, where trajectory points align linearly, potentially linked to Su Shi's second exile to Lingnan. Lingnan, then a sparsely populated wilderness, saw Su Shi's movements greatly influenced by natural environment, particularly rivers. The standard deviation ellipse exhibits a notable elongation from northeast to southwest, reflecting Su Shi's official reassignments.

As shown in Fig. 3b, Zuo Zongtang's trajectory points demonstrate a clustered pattern, centered around a single kernel density center. The points are predominantly concentrated along both banks of the Yangtze River, specifically in Hubei, Jiangxi, and Zhejiang provinces, and also line the Huai River within Jiangsu Province. The dense clustering along the Yangtze River might be attributed to Zuo Zongtang's opposition against the Taiping rebels, whereas the points along the Huaihe River could be explained by the historical prevalence of flooding in the Huai River Basin. Notably, during his tenure as Viceroy of Liangjiang, Zuo Zongtang initiated water management projects to mitigate the impacts of such disasters. The trajectory points of moderate kernel density are scattered across Shaanxi, Henan, Zhili (present-day Hebei Province), and Beijing, primarily associated with Zuo Zongtang's western campaigns. The

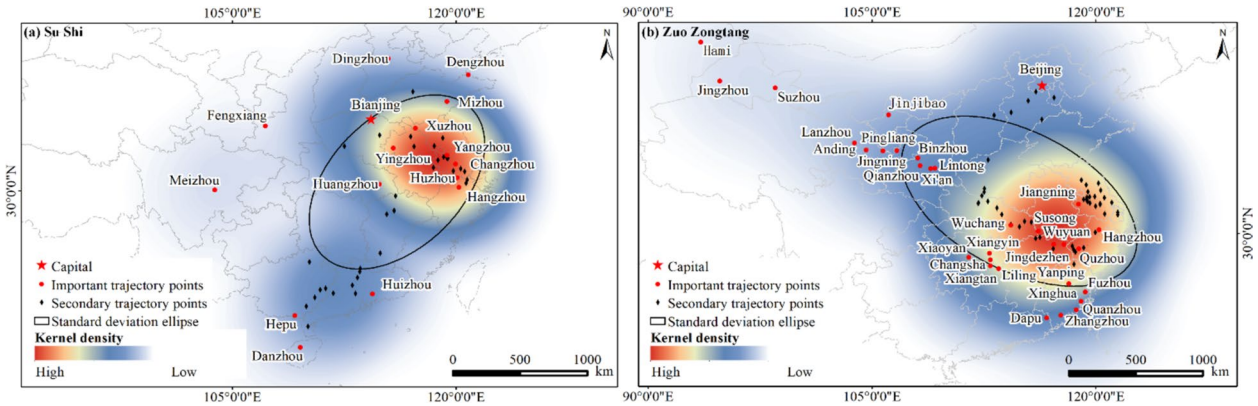

Fig. 3 Spatial distribution of the locales visited by **a** Su Shi from 1037 to 1101 and **b** Zuo Zongtang from 1812 to 1885

trajectory points of low kernel density are sporadically found in Gansu and Xinjiang, areas characterized by vast territories and sparse populations, exacerbated by population decline post the Hui Muslim uprisings in the late Qing era. This led to limited urban centers capable of sustaining military forces. The standard deviation ellipse reveals a distinct southeast-northwest distribution, aligns closely with his military deployments.

Spatial patterns of historical figures' trajectories

The migratory trajectories of Su Shi and Zuo Zongtang throughout various life stages are visualized in Figs. 4 and 5. In these diagrams, the size of trajectory markers corresponds to the frequency of the individual's presence at specific locations, with larger symbols denoting higher recurrence.

Su Shi

As shown in Fig. 4a, the most frequently visited location is Bianjing, with nine instances, potentially linked to Su Shi's participation in the imperial examinations and subsequent official reassignments. Yangzhou, Nandu (present-day Nanyang City), and Hangzhou follow in terms of visit frequency, whereas locations like Kangzhou (present-day Deqing City,) and Leizhou recorded minimal visits, mostly singular occurrences.

Su Shi's lifetime travels spanned a significant portion of China (Fig. 4a), commencing in Meizhou (Fig. 4b). During the Imperial Examination Period, his movements, influenced by exam preparations and familial upheavals, were largely confined between Meizhou and Bianjing (Fig. 4c). The Scrutiny Period saw Su Shi hold official posts in Fengxiang, Hangzhou, Mizhou, Xuzhou, and Huzhou, with intermittent returns to Meizhou, resulting in a more intricate movement pattern (Fig. 4d). While exiled in Huangzhou following the "Wutai Poetry Case", his activities were notably confined to the exile place (Fig. 4e). The Yuanyou Period witnessed frequent relocations, including posts in Dengzhou (present-day Penglai City), Bianjing, Hangzhou, back to Bianjing, Yingzhou, Yangzhou, back to Bianjing again, and Dingzhou (present-day Baoding City), potentially amidst factional strife (Fig. 4f). His sojourn in Lingnan comprised successive exiles to Huizhou and Danzhou

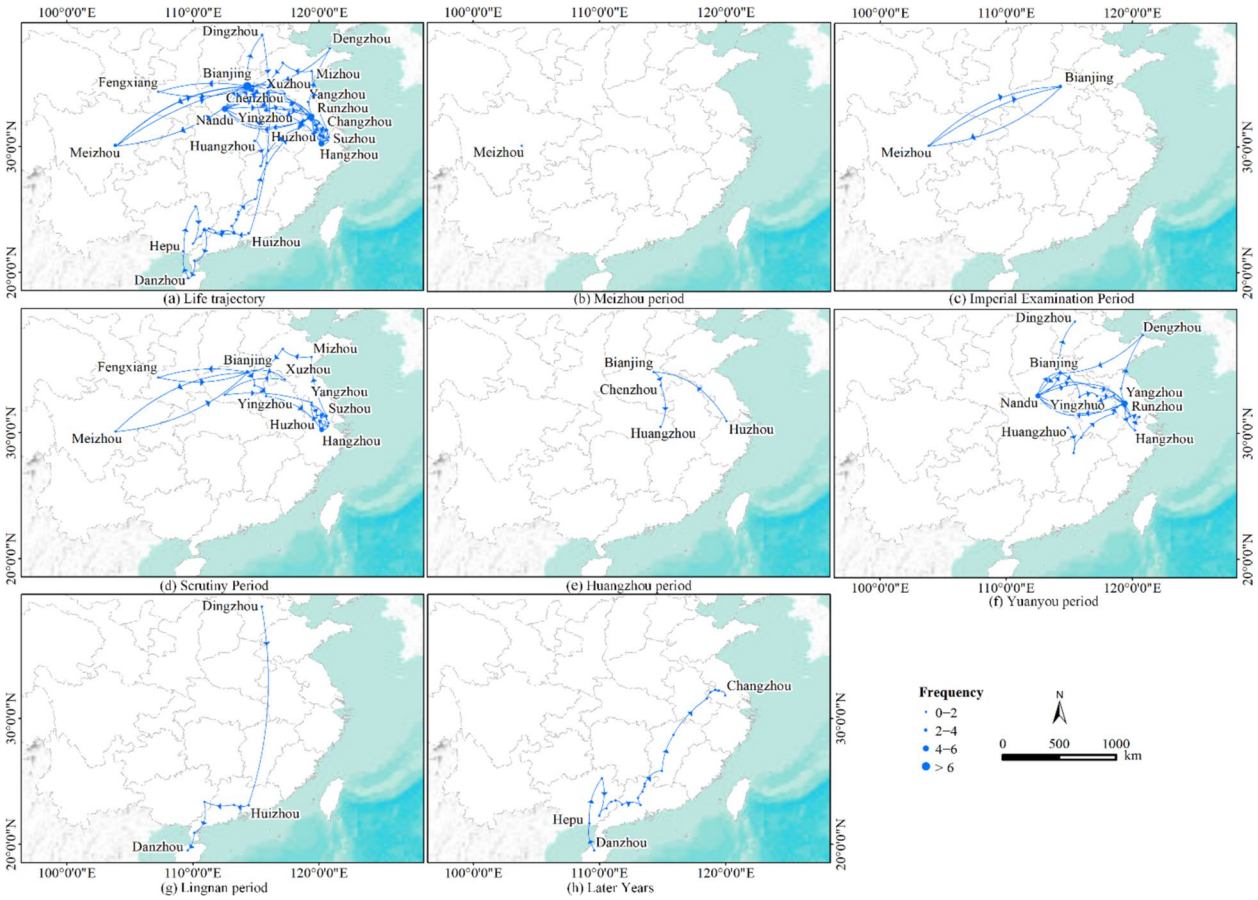

Fig. 4 Migratory trajectory of Su Shi

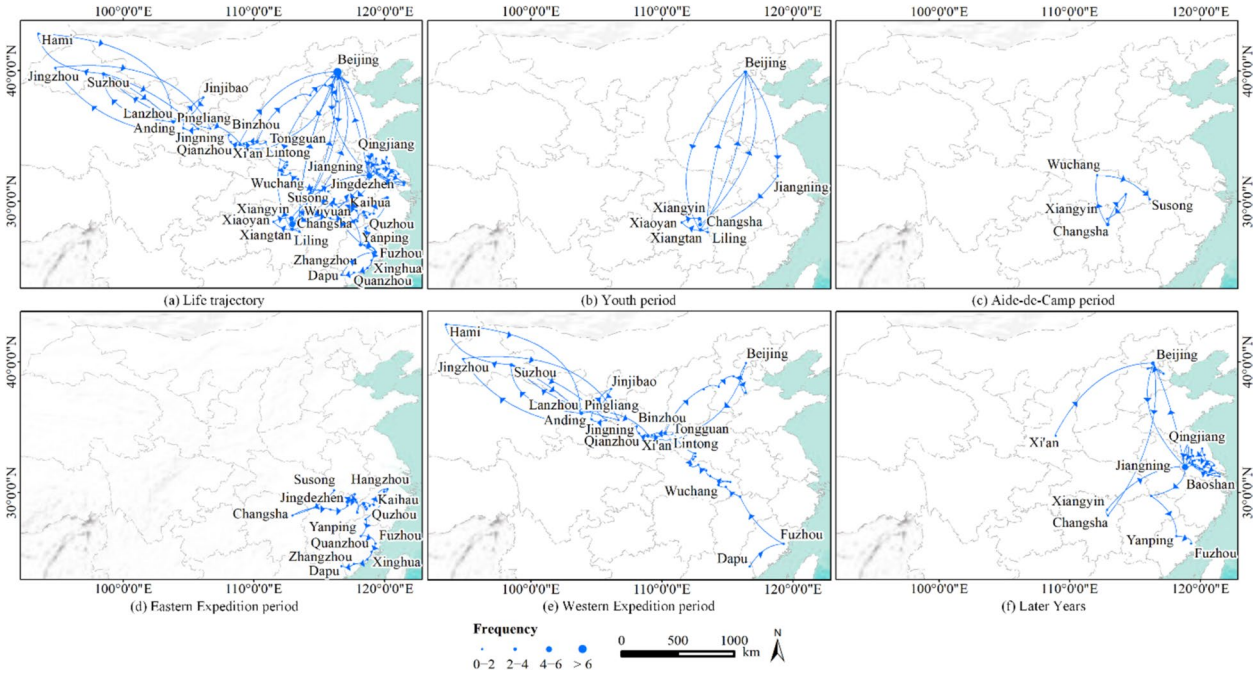

Fig. 5 Migratory trajectory of Zuo Zongtang

(Fig. 4g). Finally, towards the end of his life, Su Shi embarked on a northward journey but succumbed to illness in Changzhou (Fig. 4h).

Zuo Zongtang

Figure 5a illustrates that the most frequented location for Zuo Zongtang was Beijing, with seven instances, followed by Changsha and Jiangning. His sphere of activity extended eastward to Shanghai, westward to Xinjiang, northward to Beijing, and southward to Guangdong, thereby encompassing a broader geographic range than Su Shi. During his youth, Zuo Zongtang's activities were largely concentrated within Hunan Province, a period which included three trips to Beijing for imperial examinations (Fig. 5b). As an aide-de-camp, his principal administrative bases were situated in Changsha, with his movements necessitated by military campaigns also encompassing Xiangyin, Susong, and Wuhan (Fig. 5c). During the Eastern Expedition Period, Zuo Zongtang systematically restored order in Jiangxi, Zhejiang, Fujian, and Guangdong provinces, aiming to quell the turmoil instigated by the Taiping Rebellion (Fig. 5d). Throughout the Western Expedition Period, his movements extended from southeast to northwest China, indicating an intricate mobility pattern probably linked to historical dynamics such as the suppression of the Western Rebels, the pacification of Hui Muslim insurgencies, and the reconquest of Xinjiang (Fig. 5e). During the later years, Zuo Zongtang primarily operated in Jiangning, concentrating his trajectory within Jiangsu Province, and ultimately breathed his last in Fuzhou (Fig. 5f).

Migration patterns for historical figures

Su Shi

As illustrated in Fig. 6a, during the Meizhou Period, the migration index for Su Shi stood at zero, indicating no geographical displacement over these years. Subsequently, the index began to fluctuate considerably. Throughout the Scrutiny Period, Su Shi held various posts across numerous prefectures and counties in China, with the oscillations in his migration index adhering closely to a three-year cyclical relocation pattern, evidencing a strong periodicity. During the Huangzhou Period, influenced by court factional strife, Su Shi was relegated to Huangzhou, resulting in a stable migration index for four years. In the early Yuanyou Period, the index generally trended upwards with fluctuations, potentially attributed to frequent official reassignments prompted by continuous political attacks. By 1094, the migration index reached its peak, correlating with his second demotion from Dingzhou to Huizhou. Later in his life, a general amnesty issued by the imperial court led to a second substantial increase in the index.

According to Fig. 6b, the two trend lines illustrating Su Shi's distances from capital and hometown between 1036 and 1070 exhibit a symmetrical pattern. This symmetry can be attributed to his travels between the

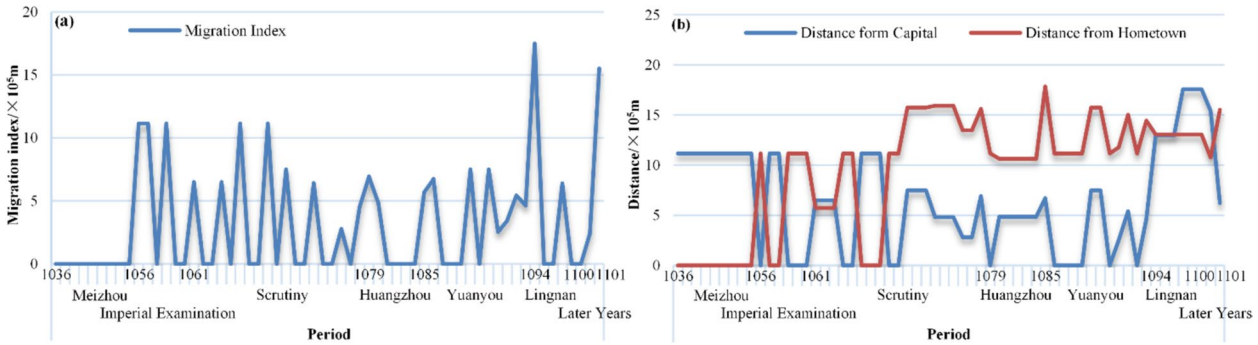

Fig. 6 Migration index, distance from capital, and distance from hometown for Su Shi (1037 – 1101)

capital Bianjing and his native Meizhou for imperial examinations and family upheavals. From 1071 to 1094, both the distances increase and decrease concurrently, with Su Shi's average distance from capital being less than from hometown, suggesting he predominantly resided closer to the capital while being farther from hometown. This geographical disposition aligns with his activities predominantly in Jiangsu and Zhejiang provinces. The maximum distance from hometown is observed in 1085 when he served in Dengzhou, marking the farthest point from Meizhou. During the Yuanyou Period, three instances of zero-distance from capital indicate Su Shi's repeated entries and exits from Bianjing, indirectly reflecting the turmoil within the imperial court. The apex of his distance from capital coincides with his exile to Lingnan, specifically Danzhou.

Zuo Zongtang

According to Fig. 7a, Zuo Zongtang's migration curve during his youth initially remains flat at a near-zero value, followed by a marked ascent before reverting to zero. This pattern likely reflects his activities predominantly within Hunan Province, and his journeys to Beijing for imperial examinations. During the Eastern Expedition Period and the initial phase of the Western Expedition Period, his migration index demonstrates an ascending then descending trend, with negligible instances of zero values, indicative of Zuo Zongtang's frequent relocations and, by extension, the intricate military landscape of the era. In his later years, Zuo Zongtang maintained a relatively high migration index, suggesting a tumultuous period for the Qing Dynasty and underscoring his pivotal role in its history.

In Fig. 7b, the absence of Zuo Zongtang's prolonged residencies in Beijing, as illustrated by his distance from capital, may be attributed to his extended military campaigns, involvement in suppressing uprisings, and his lengthy service in provincial posts. Regarding his distance from hometown, his early years and time as an aide-de-camp were characterized by shorter distances, suggesting that his primary activities were concentrated in Hunan Province. The Eastern and Western Expeditions saw this distance expand significantly without returning to zero, until his late life when it finally did. With respect to the distance from formative location, Zuo Zongtang was educated and

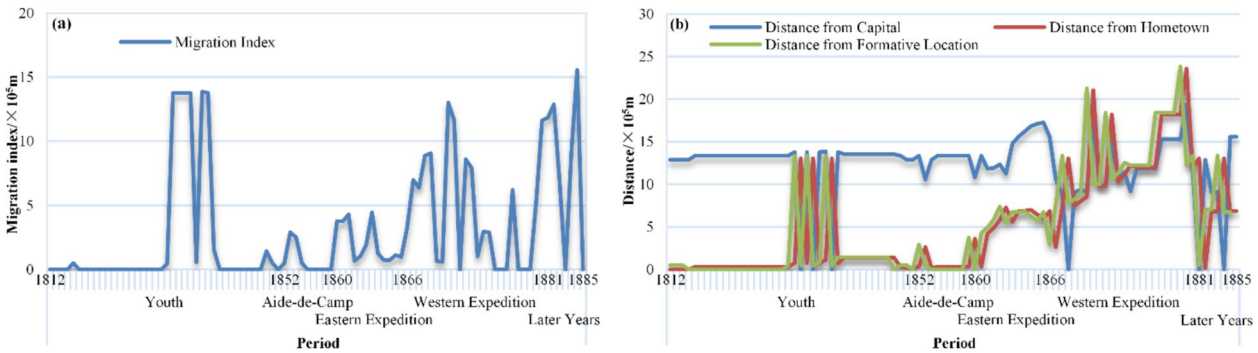

Fig. 7 Migration index, distance from capital, distance from hometown, and distance from formative location for Zuo Zongtang (1812 – 1885)

raised in Changsha. In his early youth, the trend lines illustrating the distances from hometown and formative location are symmetrically aligned, implying restricted movements between these two locales. Thereafter, similarities in the fluctuations and increases of these distances can be ascribed to the proximity between Changsha and Xiangyin.

Sociality analysis of historical figures

Given the consistent number of familial ties throughout historical figures' lifetimes and the minimal influence exerted by most relatives on these individuals, kinship relations have been excluded from our social group tallies. As Fig. 8a reveals, both the Scrutiny Period and Yuanyou Period of Su Shi's life witnessed a greater number of social affiliations compared to other periods. Specifically, Su Shi's formative years in Meizhou were marked by the smallest social circle which expanded significantly during the Yuanyou Period when his smoother official career progression facilitated a broader social outreach. Notably, friendships dominated Su Shi's social sphere, testifying to his extensive sociability that persisted even during periods of adversity and exile. The doubling of colleagues and political adversaries during the Yuanyou Period suggests that while Su Shi enjoyed imperial favor, he also attracted considerable enmity.

According to Fig. 8b, Zuo Zongtang's social connections were notably lower during his youth, tenure as an aide-de-camp, and later years, starkly contrasting with the substantial relationships formed during his Eastern and Western Expeditions. This disparity underscores the proliferation of social connections tied to his military campaigns. Within his official social dynamics, subordinates constituted the majority, with fewer peers, superiors, and political opponents, hinting at Zuo Zongtang's extensive time on campaigns and the consequent scarcity of opportunities for formal bureaucratic networking. A decline in the number of friends from his youth onward may relate to his martial temperament and less nuanced interpersonal skills. Starting from his role as an aide-de-camp, Zuo Zongtang's official duties and warfare simplified his social landscape, centering around hierarchical relationships. In summary, Zuo Zongtang's career was largely defined by external military campaigns, mirroring the turbulent state of affairs during the late Qing Dynasty.

Social networks of historical figures

Visualizing the social networks of Su Shi and Zuo Zongtang yields a series of graphs (Figs. 9, 10, 11, 12). In these diagrams, nodes of varying colors denote distinct types of social ties, while the thickness of connecting lines and the size of name labels reflect the significance of associated individuals – broader lines and larger labels signify a greater impact on the historical figure.

Su Shi

During the Meizhou Period (Fig. 9a), family education exerted the greatest influence on Su Shi, shaping both the creation of his literary works and the formation of his values. Moving into the Imperial Examination Period (Fig. 9b), Zhang Fangping mentored Su Shi and financially backed his examination endeavors; in Bianjing, Ouyang Xiu promoted and introduced Su Shi to elite circles. Amidst the "Wutai Poetry Case" in the Huangzhou Period (Fig. 9d), Su Shi's sentence was mitigated to exile rather than imprisonment, thanks largely to Empress Dowager Guangxian and Wang Anshi. The Yuanyou Period saw Su Shi highly favored by the imperial court (Fig. 9e). Post-exile in Lingnan and in his later years, Su Shi's social circle narrowed considerably (Fig. 9f and g).

Figure 10 encapsulates the expansive social network of Su Shi from 1037 to 1101. Corroborating Fig. 8a, as a literatus, Su Shi had the most friends, which constitutes 47.35% of his total social connections, followed by

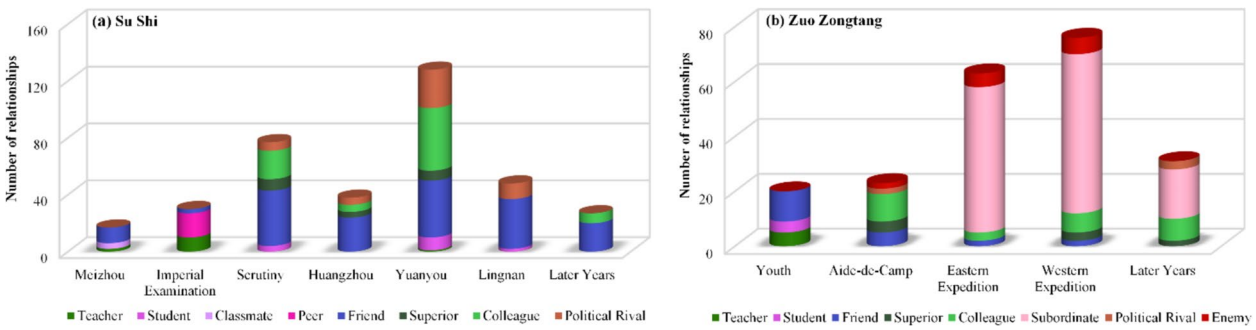

Fig. 8 Social connections for **a** Su Shi from 1037 to 1101 and **b** Zuo Zongtang from 1812 to 1885

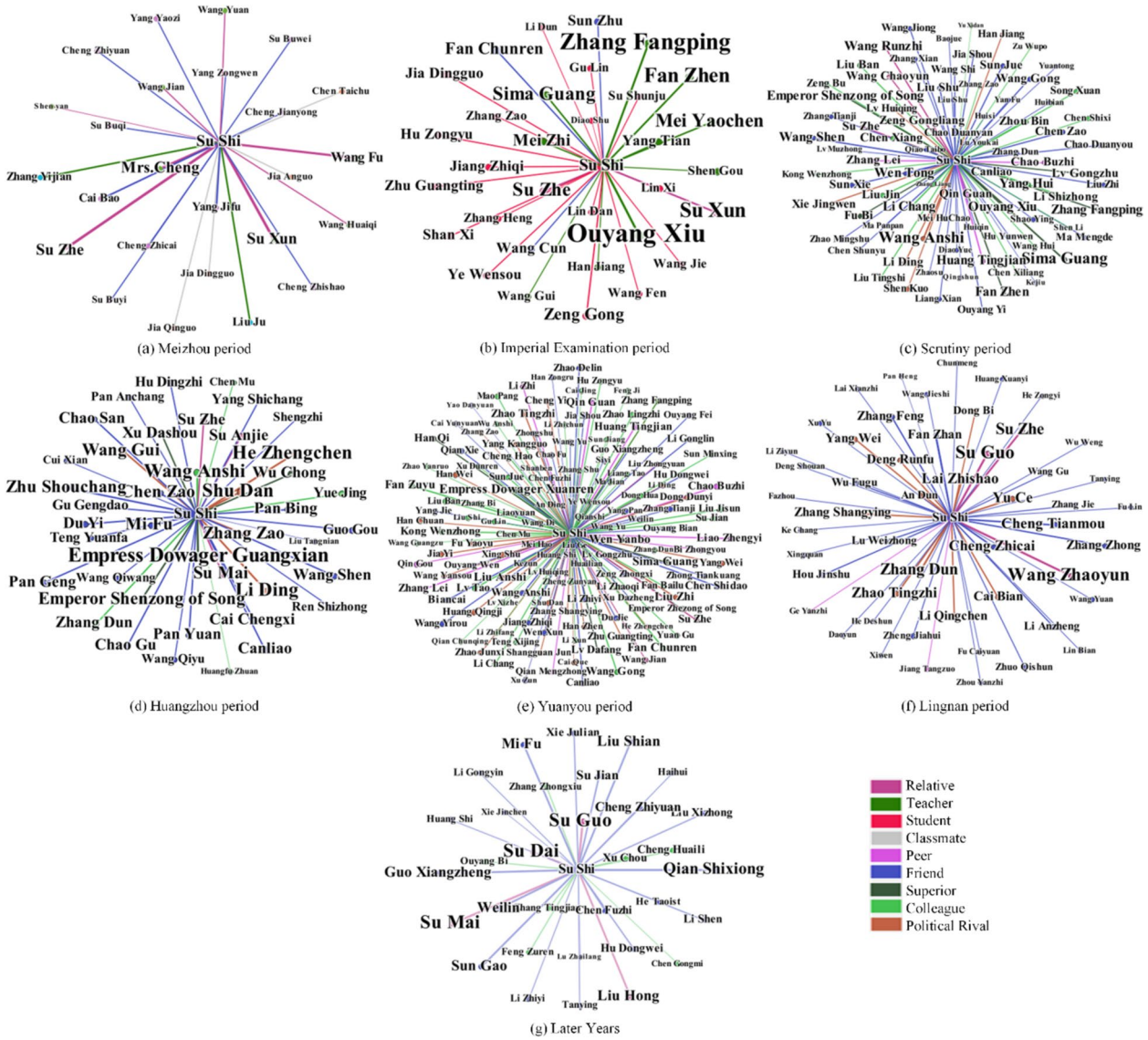

Fig. 9 Segmental social network of Su Shi's life phases (1037 – 1101)

colleagues at 20.56%. Political adversaries represented 12.15%, while classmates formed the smallest segment. Overall, Su Shi's social circle was vast, encompassing a multitude of individuals who predominantly exerted positive influences upon him.

Zuo Zongtang

As illustrated in Fig. 11a, during his youth, several figures prominently influenced Zuo Zongtang. For instance, He Changling's pragmatic ideology left a significant impression on his thinking and writing style, Tao Shu lent crucial assistance to his official career, and Lin Zexu played a vital role in his efforts to reclaim and develop Xinjiang. In his capacity as an aide-de-camp (Fig. 11b), Zuo Zongtang garnered the trust and employment of Zhang Liangji and Luo Bingzhang, while Zeng Guofan was instrumental in facilitating his entry into government service. Throughout the Eastern and Western Expeditions, engrossed in military operations, Zuo Zongtang's social network demonstrated a relatively balanced distribution of influential figures (Fig. 11c). However, during the Western Expedition, his relationship with Zeng Guofan deteriorated, leading to the latter's eventual disappearance from his social circle (Fig. 11d). In his Later years, with wars mostly quelled, Zuo Zongtang experienced a substantial reduction in his social connections (Fig. 11e).

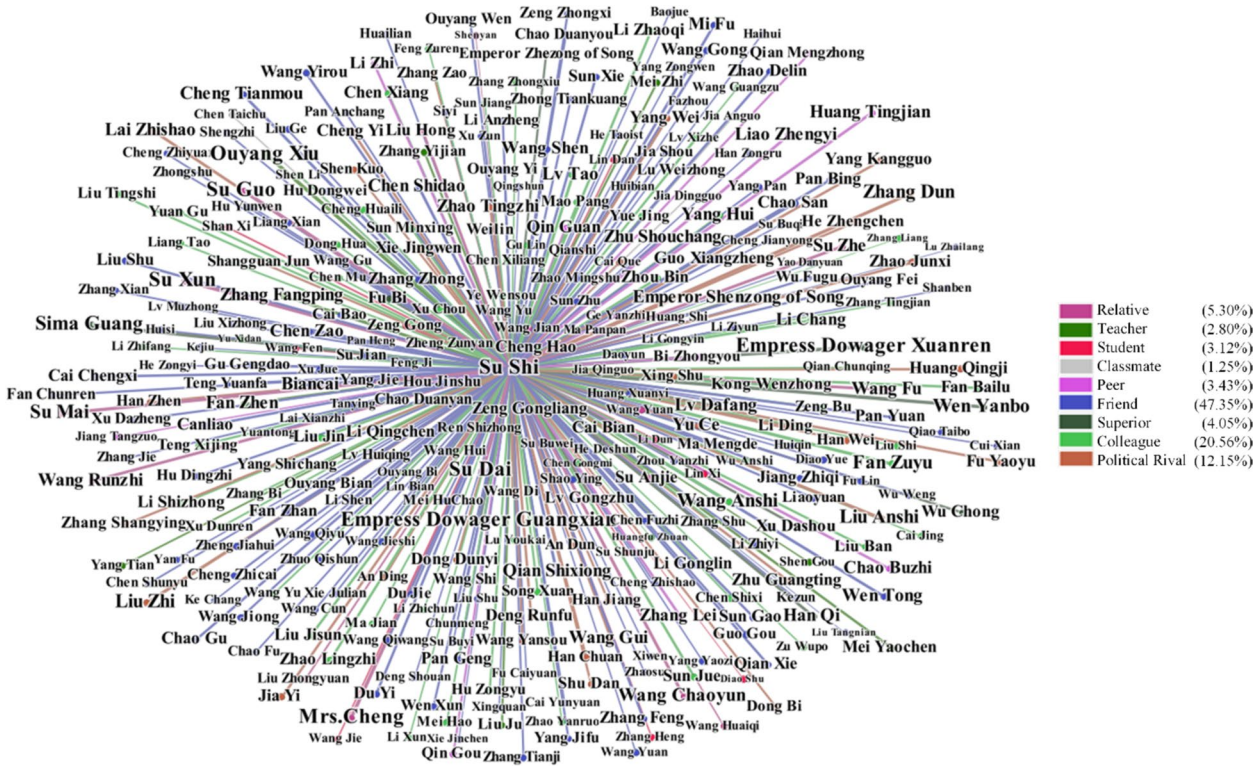

Fig. 10 Comprehensive social network of Su Shi (1037 – 1101)

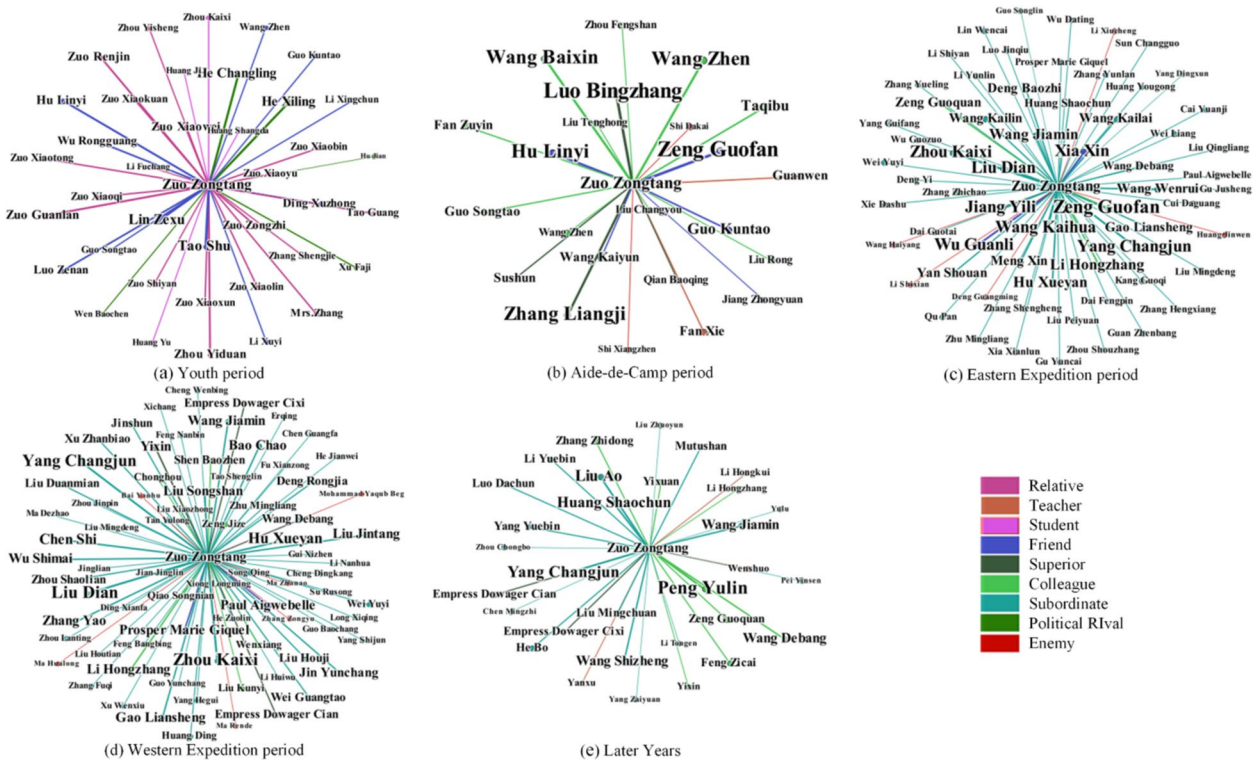

Fig. 11 Segmental social network of Zuo Zongtang's life phases (1812 – 1885)

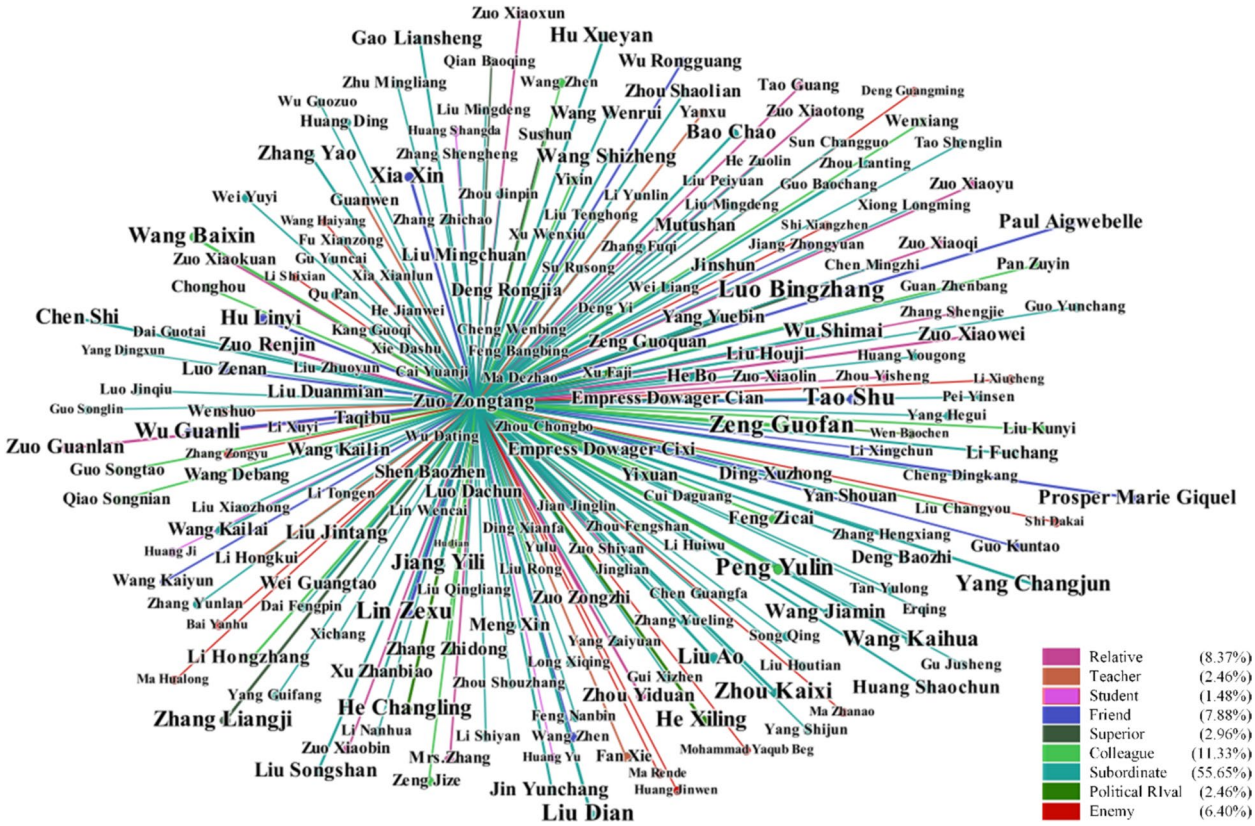

Fig. 12 Comprehensive social network of Zuo Zongtang (1812 – 1885)

Figure 12 depicts Zuo Zongtang's extensive social network from 1812 to 1885. Aligning with Fig. 8b, as one of the Qing Dynasty's foremost generals, Zuo Zongtang made remarkable contributions to quelling internal unrest and reclaiming territories, resulting in a preponderance of subordinate relationships, which constitute 56.65% of his total connections. Colleague relationships follow, accounting for 11.33%, with all other categories representing less than 10% each. Collectively, Zuo Zongtang's social network is primarily dominated by military-related ties.

Discussion

While a substantial body of scholarly work has centered on historical figures, examining aspects such as their ideologies [12, 37, 38], literary works [39], and writing styles [40, 41], there exists a scarcity of research addressing the geographical trajectories of these individuals. A study attempted to qualitatively trace the migratory trajectory of Su Shi using rudimentary point-and-line representations; however, it falls short in interpreting the correlation between his life journey and societal transformations [42]. Typically, the migrations of historical figures are conditioned by social transformations, productivity levels, and geographical contexts. By utilizing dynamic geographical locations, this study reveals the spatiotemporal patterns of migration trajectories of historical figures, further exploring how their life journeys evolved within specific societal epochs.

GIS-based technologies has witnessed an expanding role in the preservation and transmission of cultural heritage [43–45]. By spatially visualizing trajectory points with geographic coordinates, the movements of historical figures are employed as a lens to examine epochal cultural dynamics. Specifically, through visualizing migratory trajectories of historical figures, in conjunction with analyses of their social networks and socio-historical backgrounds, their life courses are inversely reconstructs, highlighting the pathways of cultural dissemination by these individuals. In terms of our findings, the migratory patterns reveals that Zuo Zongtang's migration index consistently surpasses that of Su Shi. This finding resonates with existing research suggesting that military figures exhibit higher migration indices compared to those belonging to the intellectual elite [35]. Additionally, our investigation underscores how the migratory regularities of historical figures are

influenced by their respective careers. For instance, the migrations of military leaders like Zuo Zongtang are intimately tied to warfare, a domain characterized by fluidity and unpredictability [46]. Consequently, Zuo Zongtang's migrations mirror this volatility.

The social networks of prominent figures emerge from the intricate interplay of myriad factors. One study, leveraging a photo library as its dataset and adopting a spatial perspective on social networks, examined the societal webs of modern luminaries, concluding that these networks' emergence is intertwined with mutual influences among prominent figures, industry dynamics, and specific events [47]. Generally, social relationships are both complex and mutable, with research indicating that fluctuations in historical figures' social connections are primarily linked to political events and individual personality traits [26]. Moreover, a study has affirmed a strong correlation between shifts in historical figures' social ties and their occupational categories as well as the progression of socio-historical contexts [35]. Notably, luminaries tend to possess broader social circles during the ascendancy of their careers, which constrict during periods of decline. In this study, the evolving social relationships of historical figures Su Shi and Zuo Zongtang across different epochs reveals that their social circles were related to their political status, personal accomplishments, and character traits. However, quantitative metrics for constructing social network relationships remain nascent. Assigning values to social affiliates to gauge their influence on historical figures introduces a degree of subjectivity into the quantification process. Nevertheless, the social relations elucidated in this study are grounded in historical evidence, and overall, such value assignments minimally affect the findings.

The data employed herein are chiefly sourced from biographies and historical documents, focusing on data curation and management. Consequently, unrecorded personal details may be omitted, limiting comprehensive coverage. Despite this, the compiled dataset still adequately illuminates the activity trails, mobility patterns, and social ties of historical figures. Our future endeavors aim to gather and organize a more diverse array of trajectory data and social relationship materials for historical figures, thereby scientifically examining the genesis and diffusion of culture along their migratory paths and exploring their impact on local cultures. Moreover, the development of an online visualization platform is envisaged to facilitate the sharing of migratory trajectories and social networks of diverse historical figures, thereby enhancing the means for preserving and disseminating the cultural legacies of these individuals.

Conclusions

In this study, GIS-based technologies were employed to visualize and explore migratory trajectories of historical figures, taking into account their geographical locations and time frames. Dynamic and static maps were utilized to reveal the migration patterns of these individuals throughout their lifetimes, and to elucidate their social relationships at different life stages.

Our findings reveal that the trajectories of historical figures were highly individualized, directly shaped by the geographical contexts and subtly impacted by social transformations. Meanwhile, their social networks were intricately linked to their social status, personal accomplishments, personality traits, and career progression. Specifically, Su Shi, a scholar and a litterateur, demonstrated frequent migrations, exhibiting a distinct periodic pattern. His distance from capital indicates an initial increase followed by a decline, while the distance from hometown first escalated and then stabilized. Su Shi's social network was intricate, with a preponderance of friendships. Conversely, Zuo Zongtang, a military strategist, experienced migrations greatly influenced by national security and warfare. His migrations extended over vast areas from southeast to northwest China, albeit with an irregular migration index. His distance from capital remained relatively constant, whereas the distances from hometown and formative location initially grew only to decrease later. Zuo Zongtang's early social relationships were predominantly friend-based; however, upon entering politics, his interactions were primarily military-oriented. These findings highlight the significance of HGIS, concurrently furnishing data and theoretical foundations for local governments to develop Geographic Information System for cultural heritage resources of historical figures.

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Author contributions

Conceptualization, J.F and J.Q; methodology, J.F, K.C, P.L and L.Y; validation, K.C, J.Q and W.Z,; formal analysis, J.F and L.Y; resources, P.L, L.Y and W.Z; data curation, K.C; writing original draft preparation, J.F and K.C; writing review and editing, J.F and J.Q; visualization, J.F and W.Z; supervision, J.Q and L.Y; funding acquisition, J.F, J.Q and L.Y. All authors have read and agreed to the submitted version of the manuscript.

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Availability of data and materials

No datasets were generated or analysed during the current study.

Declarations

Competing interests
The authors declare no competing interests.

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