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Impact of earthquakes on natural area-driven tourism: Case study of China's Jiuzhaigou National Scenic Spot

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ABSTRACT

Tourism is one of the most economically important industries worldwide, but is particularly vulnerable to natural disasters. Located in a remote and impoverished mountainous region, Sichuan's Aba Tibetan and Qiang Autonomous Prefecture (Aba) has become highly tourism-dependent, being home to China's highly visited Jiuzhaigou National Scenic Spot (Jiuzhaigou). Jiuzhaigou has experienced several recent turbulences following major earthquakes. To explore the implications of these types of events on resilient and sustainable tourism development, we examined the relationship between the tourism industry and the 2017 Jiuzhaigou Earthquake at multiple-scales (e.g., local, prefectural, and provincial) based on the tourism background trend line and (seasonal) autoregressive integrated moving average models. Following the 2017 Jiuzhaigou Earthquake, both Jiuzhaigou and Aba's tourism industries were devastated, but Sichuan's broader tourism industry experienced relatively little impact. Following the earthquake, subsequent visitation to Jiuzhaigou reduced by 56% (2017), 99% (2018) and 93% (2019), and Aba's international (54%, 68%, and 48%) and domestic (30%, 49%, and 40%) tourist volumes decreased over the same timespan. The impacts of the earthquake also varied significantly by month at the local and prefectural levels. Moreover, earthquakes considerably altered Jiuzhaigou's relative importance within Sichuan's broader tourism industry, with Aba's inbound tourism share decreasing from 35% (2004) to 8% (2008) and 2% (2017), following several major earthquakes. We highlight the importance of domestic tourism and economic diversity for achieving resilience and rejuvenating local economic activities following natural disasters.

1. Introduction

Tourism is one of the largest and fastest-growing economic sectors in the world, with international tourist arrivals increasing from 25 million in 1950 to 1.5 billion in 2019. This large travel volume yielded tourism revenues of US$8.9 trillion worldwide in 2019, or about 10.3% of the global gross domestic product (GDP) [1]. This rapid growth promoted economic development by increasing foreign exchange earnings, employment opportunities, infrastructure construction, and government tax revenues [2,3]. Thus, many countries have channeled great efforts into developing tourism industries to enhance regional economies and alleviate poverty [2,4]. This is particularly true in less developed regions, especially those dominated by mountainous topographies and coastal areas [2,3]. Nevertheless, tourism is particularly vulnerable to natural disasters, such as earthquakes, hurricanes, and tsunamis [5–7]. These disasters cause acute physical and economic damage, but also rapid declines in tourism demand and collapse of tourism-related industries [8–11]. These impacts tend to be more severe in mountainous and coastal regions, given their topographies and higher economic dependence on tourism [10,12–15]. Thus, understanding the tourism-natural disaster nexus is extremely important for tourism recovery and reconstruction, and critical for further sustainable development.

Tourist destinations in mountainous regions of China provide an intriguing context for researchers to study the relationship between tourism and spatial-temporal impacts of natural disasters. Southwest China's Sichuan Province is bestowed with abundant natural resources, a diverse topography, rich biodiversity, and diverse cultural traditions, so tourism became a primary vehicle for its economic development, especially for its sprawling under-developed mountainous regions [10,

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16,17]. Also, largely owing to its diverse and rugged topography, Sichuan is particularly prone to recurrent natural disasters [10,18,19]. Three deadly earthquakes occurred between 2008 and 2017, including the *M*s 8.0 Wenchuan Earthquake (May 2008), *M*s 7.0 Lushan Earthquake (April 2013), and *M*s 7.0 Jiuzhaigou Earthquake (August 2017). Following the Wenchuan Earthquake, thousands of research studies have investigated the mechanisms, spatial distribution, long-term evolution, and risk management and mitigation pertaining to the ensuing geohazards [19], but studies of the relationship between earthquakes and tourism have received comparatively little attention. Of the few that have, most exclusively studied the Wenchuan Earthquake, including its negative impact on Sichuan's tourism industry [10,16,20], the use of tourism for post-disaster economic recovery [21], and the unexpected rise in post-earthquake inbound tourism to Sichuan [22]. These studies were all carried out at one scale of analysis (e.g., usually province level), so further research is necessary to understand the spatial-temporal relationship between earthquakes and Sichuan's tourism industry at multiple scales of analysis.

Jiuzhaigou National Scenic Spot (Jiuzhaigou) typifies a disaster-prone destination with rapid tourism development in China. Located in Northwest Sichuan's Aba Tibetan and Qiang Autonomous Prefecture (Aba) (Fig. 1), Jiuzhaigou is distinguished by breathtaking lacustrine landscapes with turquoise lakes set against spectacular waterfalls (Fig. 2a–c). A World Heritage Site, Jiuzhaigou has garnered a respected worldwide reputation for its natural landscape management and tourism development [23]. Attracting tourists to Sichuan, it helped Aba become the province's second largest inbound tourism destination, after Sichuan's capital city, Chengdu. According to the Jiuzhaigou Administration Bureau (JAB), Jiuzhaigou's admission revenues grew 15.5% on average per annum (2000–2016), reaching 803 million yuan by 2016, accounting for significant portions of Jiuzhaigou County's (30.8%) and Aba's (2.8%) gross regional product (GRP). However, Jiuzhaigou has experienced several devastating earthquakes. In particular, the epicenter of the 2017 Jiuzhaigou Earthquake was located within Jiuzhaigou [24], so severely damaging the park that Jiuzhaigou closed for nearly three years.

As with Sichuan's tourism industry more broadly, Jiuzhaigou's tourism economy remains at risk from natural disasters [25], bringing new challenges to regional sustainable economic development. With most of Sichuan's tourist attractions clustered in remote, earthquake-prone mountainous regions with vulnerable environments [10], the negative impacts of natural disasters on Sichuan's sustainable development will likely continue. Therefore, this study broadly sought to analyze multiple-scales (e.g., provincial, prefectural, and local) of tourism development trends in Sichuan to better understand the relationship between earthquakes and sustainable tourism development. To achieve this, we had three specific goals: (1) examine the chronological relationship between the 2017 Jiuzhaigou Earthquake and changes in tourist arrivals to Sichuan at each scale; (2) understand the relative importance that Jiuzhaigou plays within Sichuan's broader tourism industry; (3) make recommendations for building greater resiliency and sustainable tourism development.

2. Literature review

2.1. Tourism and natural disasters

Analyses of the relationship of tourism and disaster events are

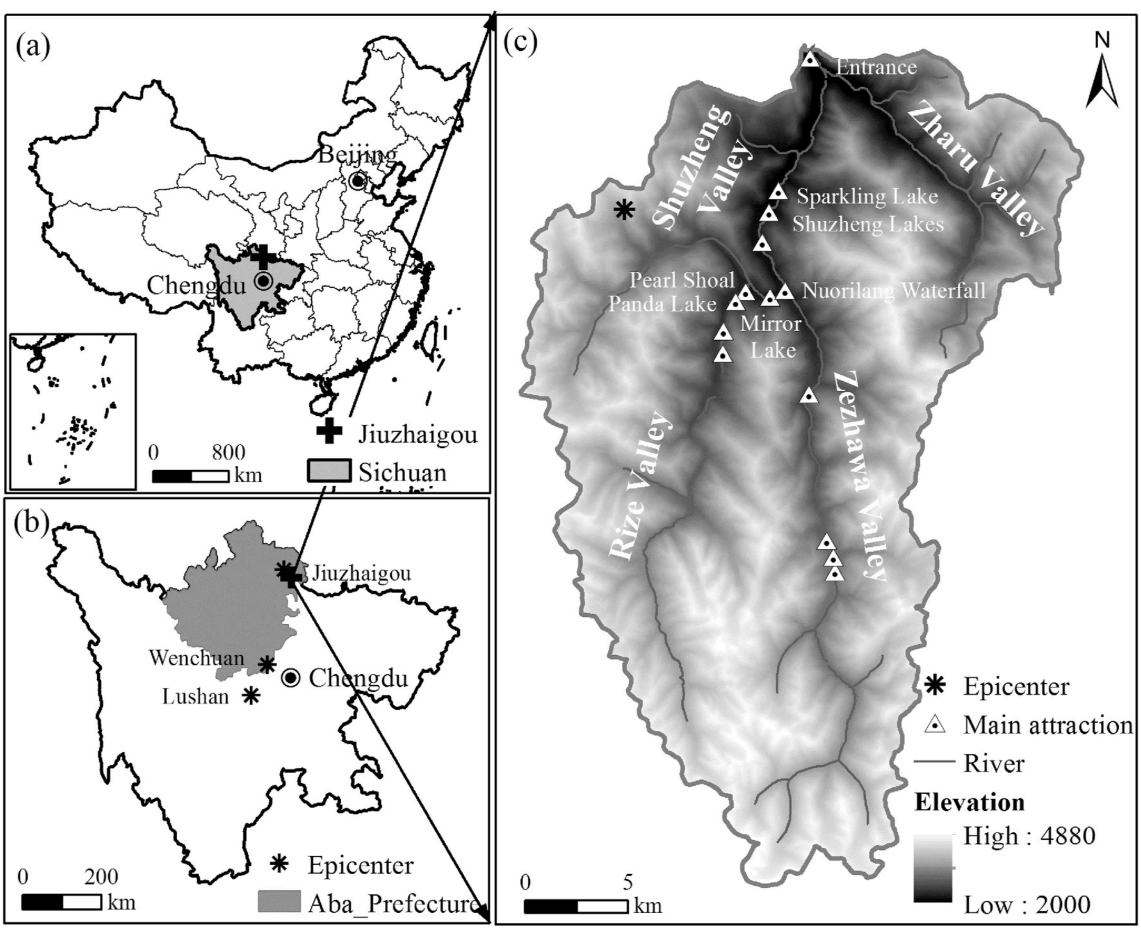


Fig. 1. Location of Jiuzhaigou National Scenic Spot within China (a), three earthquake epicenters within Sichuan (b), and Jiuzhaigou's main tourist attraction locations (c).

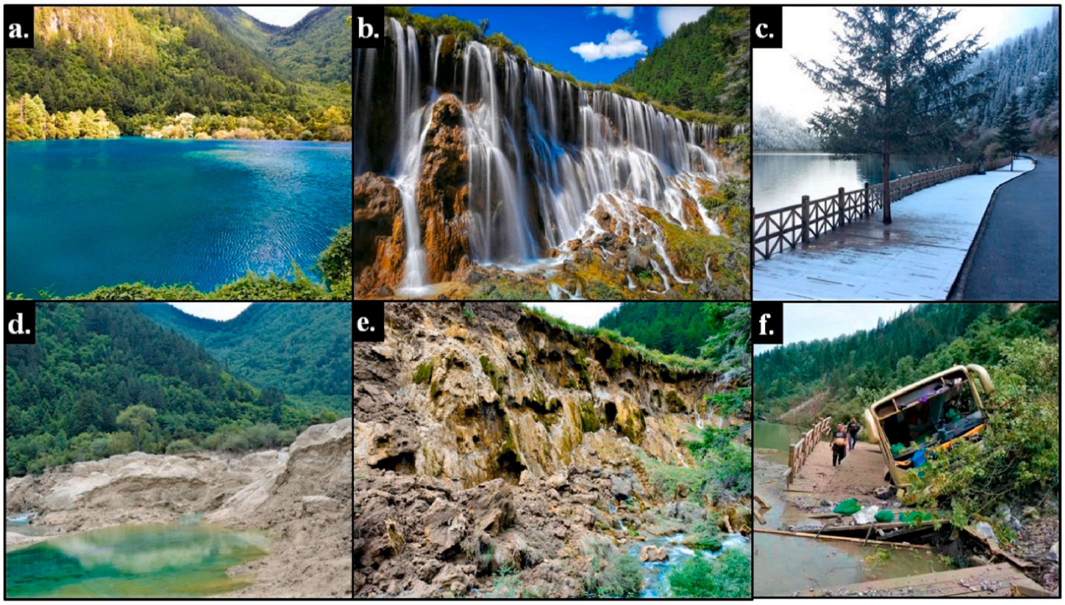


Fig. 2. Major scenic destinations before (a–c) and after (d–f) the 2017 Jiuzhaigou Earthquake. (a,d) Sparkling Lake, (b,e) Nuorilang Waterfall, (c,f) Pedestrian boardwalk and shuttle bus road bordering Arrow Bamboo Lake. Photo credits: YT (a,d), Jiuzhaigou Administration Bureau (b-c, e-f).

necessary for managing successful tourism recovery [26], but the research shows a lack of comprehensive knowledge in this area [22]. Although in some cases a positive effect is estimated [22,27], the impacts of natural disasters on tourism are commonly negative from a global analysis [28]. Studies researching the relationship between disasters and tourism are expanding, especially those linked to coastal (e.g., Malaysia, Thailand, and some island nations) [9,13,29] and mountainous dominated environments (e.g., Japan, New Zealand, and Nepal) [12,14,29,30], on a wide range of scales. At the regional scale, previous studies have mainly qualitatively examined the impacts of disasters on tourist attractions or their surrounding communities, covering the direct damage on tourist attractions and infrastructure [10], perceptions and responses from tourists, operators, and stakeholders [13,14], tourism recovery management and marketing [6,13,14,31], and tourism resilience [7]. For example, regions in Japan (Miyagi and Fukushima) and New Zealand (Christchurch) have been negatively affected by earthquakes, by which the importance of recovery marketing and tourism disaster management plans for disaster mitigation and tourism resilience have been highlighted [14,31,32]. But examining the impact of disasters on tourism economies on a broader regional scale is also of critical importance. Several examples, such as Nepal, Malaysia, Thailand, and some island nations, provide empirical evidence of reduction in visitation to the affected destinations following natural disasters, resulting in disruptions of their broader tourism economies [9,13,30,33]. Comparatively, empirical studies considering the relationship between disasters and tourism at local scales is still limited and few of them studied the economic impacts of disasters on tourist destinations and adjacent communities as well as tourism-related industries on a small-scale level with statistical models [5,12,26].

The impact of natural disasters may not only be local (e.g., physical damage), but can also spread to neighboring areas and those far beyond the directly impacted zones [28,29]. Usually, analysis of the impact of disasters on tourism at the regional and national scales is recommended from the management perspective [22]. Since the consequence and severity of disaster impacts can vary within regions because of their economic development and diversification, assessments of direct impacts of natural disasters on the local scale is also critically important [15,26]. Therefore, better understanding the relationship between disasters and the broader tourism industry at multiple scales of analysis can provide valuable insight for the purpose of building resilient tourism in areas at high-risk for regular natural disasters. Nevertheless, empirical research to confirm the nature and extent of natural disasters on tourism using statistical models across multiple scales is still lacking [5,26,28].

2.2. Measuring the impact of disasters on tourism

Tourism is vulnerable to various and recurrent types of natural disasters, which can have significant short- and long-term effects on sustainable tourism development [9,29]. However, most previous studies have focused on the impacts of a single natural disaster event over a short period using qualitative methods (mostly questionnaires and semi-structured interviews), providing descriptive statistics even if the impacts of the event may have changed over time by governmental recovery strategies [12–14,32]. To fill this knowledge gap, scholars applied tourism demand modelling and forecasting approaches to quantitatively examine the impacts of disasters on tourism economies, including time-series, econometric, and artificial intelligence-based models [8,34,35]. Tourism trends (e.g., tourism demand) can be predicted by reliable time-series models based on historical data before a disaster event, providing a baseline as if the event had not occurred [34]. The impacts of the disaster event can then be estimated by comparing the baseline with actual statistics after disasters occur, referred to as an event's impact analysis by Song and Li [34].

The integrated autoregressive moving-average (ARIMA) model and its family of variants, e.g., seasonal autoregressive moving-average (SARIMA), ARIMA with an exogenous variable, and multivariate ARIMA, are the most frequently used time-series models worldwide [34]. Many academics apply ARIMA-based models to evaluate the impacts of various crises and disasters, including earthquakes in Nepal [27] and Chile [15], hurricanes in the United States [5], epidemics [35], and global financial crises [35,36]. Min et al. [27] used ARIMA with twenty-one years of annual data to quantify the impact of earthquakes on Nepal's tourism and economy. Using the ARIMA model on quarterly data, Lim and McAleer [36] examined how financial crises affected Japanese visitors to Australia. Using the SARIMA model on monthly data, Huang and Min [8] found that inbound tourist arrivals were devastated more than 11 months after the 1999 Taiwan earthquake. Similarly, using SARIMA on monthly data, Mendoza et al. [15] investigated the inbound visitations to Chile following three earthquakes between 2007 and 2010, finding that the impacts of earthquakes varied by region due to their differing types of regional tourism. These studies highlight the advantages of using time-series models on event impact analyses, including the ability to 1) utilize tourism data with various frequencies (e.g., monthly, quarterly, or annual) for greater applicability, 2) provide reliable and accurate prediction capabilities, and 3) provide long-term tourism trends. Consequently, the models can be utilized to measure the impact of disasters on tourism at greater spatial-temporal scales and examine whether a tourism industry has recovered to pre-disaster levels.

Although globally the ARIMA models are the most frequently used [34], they are seldom applied in Chinese-language scholarship outside medicine, mathematics, and energy sector analyses [37,38]. Chinese-language studies mainly investigate the impacts of natural disasters on tourism with other time-series models (such as the tourism background trend line, TBTL), linear regression predictions with average growth rate, or comparisons to previous years [10,16,20]. For example, Ji et al. [16] and Ma et al. [20] applied the TBTL to evaluate the reduction of tourist visitation to Sichuan and its neighboring provinces following the Wenchuan Earthquake. However, few studies have utilized mixed methods approaches to analyze higher frequency tourism data, instead mostly analyzing annual data. Therefore, it is necessary to compare these models to understand their interchangeability for future meta-analyses and encourage greater integration of leading scholarship from around the world.

3. Material and methods

3.1. Study area

A network of shallow lakes, shoals, and waterfalls (Figs. 1, 2a-c) form the essence of Jiuzhaigou's (103°46′-104°05′ E and 32°55′-33°20′ N) spectacular natural beauty [39]. Formally opened to tourists in 1984, annual visitation at Jiuzhaigou increased dramatically from 28,000 (1984) to more than 5 million (2016). During the peak season (July–October), tens-of-thousands of tourists typically crowd into its valleys on any given day, being transported between the main scenic attractions by shuttle buses and boardwalks within a limited footprint area of only ~60 km^2 (9.3% of Jiuzhaigou's total) [40]. Yet, rapid tourism growth with its large visitation volume within a limited geographic area has raised strict requirements for tourism security, as tourism development and natural disasters must coexist in Jiuzhaigou.

Jiuzhaigou is a disaster-prone tourist destination, with significant hydrological, tectonic, and geological activity [18,41]. The region surrounding Jiuzhaigou experienced more than 50 earthquakes with magnitudes greater than 5.0 over the past century [18]. Although earthquakes and landslides are primarily responsible for the formation of Jiuzhaigou's beautiful natural landscape features [41], they also threaten the safety of local communities and visitors, as well as the beauty of its natural attractions.

The *Ms* 7.0 Jiuzhaigou Earthquake occurred on August 8, 2017 and resulted in 25 fatalities, 525 injured persons, and a total estimated economic loss of more than 114 million yuan (US$ 17 million) by August 13, 2017 [24]. The earthquake and subsequent geohazards severely damaged the infrastructure, roads, buildings, and natural landscapes of Jiuzhaigou (Fig. 2d–f). They damaged the dam of Nuorilang Waterfall, burst the Sparkling Lake dam (Fig. 2d–e), and blocked access from Mirror Lake to Pearl Shoal and other destination sites beyond [24,42]. The sightseeing routes were deemed unsafe due to landslides mainly occurring along valley floors [24], providing the source material and likelihood of additional geohazards (e.g., debris flows and landslides) [42,43]. For example, debris flows and floods occurred in Jiuzhaigou during storms on 25 June and July 10, 2018 [44]. Jiuzhaigou was closed immediately after the earthquake, before experiencing a process of re-opening (March 8, 2018), re-closing (July 1, 2018), and re-opening (September 27, 2019) due to ongoing geohazard fallout [44–46]. Despite the prefectural government and JAB proactively promoting Jiuzhaigou's revitalization with a three year reconstruction project, geohazard risks in Jiuzhaigou remain severe [42,43], posing an ongoing threat to tourism's sustainability.

3.2. Data sources

We analyzed tourism development and the Jiuzhaigou Earthquake's impact on tourism demand on three different spatial scales: local (Jiuzhaigou), prefectural (Aba), and provincial (Sichuan). The data used consisted of time-series statistics on domestic and international tourist arrivals. For Jiuzhaigou, the annual numbers of visitors (1984–2019) were collected from JAB. Those (both domestic and international) for Aba (2000–2019) and its major tourist attractions (2009–2019) were derived from the Culture, Sports, and Tourism Bureau of Aba Prefecture (http://wtlj.abazhou.gov.cn/). Aba's top four nature-based tourist attractions are Jiuzhaigou, Huanglong, Mount Siguniang, and Dagu Glacier (Fig. 3). The annual domestic and international tourist volumes and tourism revenues for Sichuan, including its prefectures and cities (2000–2019), were collected from the Sichuan Statistical Yearbooks (http://web.sctjj.cn/). China's annual tourist volumes and revenues (2000–2019) were collected from the China Statistical Yearbooks (http://www.stats.gov.cn). To accurately analyze the earthquake's impact duration, we also collected monthly tourist numbers for Jiuzhaigou and Aba between January 2009 and December 2019, from the same data sources as annual tourists, providing data balanced before and after the earthquake.

3.3. Methods

We performed time-series analyses based on the TBTL, ARIMA, and SARIMA models, examining impacts of the Jiuzhaigou Earthquake on tourism demand. Essentially, we took historical pre-earthquake tourist volumes to establish a reliable model predicting future tourist volumes, regarded as the level expected if the earthquake had not occurred. Thus, the earthquake's impacts can be measured by comparing the predicted tourist volumes with the actual ones [34]. We used annual tourist volumes to estimate the earthquake impact's geographic extent and monthly tourist volumes for the impact duration analysis. There are two reasons to conduct both annual and monthly analyses: 1) unlike yearly tourist volumes, the monthly ones are unavailable from some attractions and regions of China. Since many studies utilize quarterly and monthly data [34], we wanted to test the feasibility of using annual tourist volumes for examining the impact of natural disasters on tourism. 2) We also wanted to examine the earthquake's potential impact on seasonal tourism patterns.

3.3.1. Tourism background trend line model

The TBTL model is the most commonly used model in Chinese-language literature exploring dynamic trends in tourism development (baseline) [47]. From it, the background tourist volumes can be obtained, and an event's impact can be assessed by comparing the TBTL with actual volumes. We first drew time-series figures based on historical tourist volumes, searching for a starting point (n_a) and termination point (n_b) for each fluctuation. Second, we revised the actual tourist volumes of fluctuation periods based on the interpolation equation (Eq. (1)). Third, we drew time-series figures with the revised data based on general simulation equations and their compound forms (Table 1), including linear growth, exponential growth, logical growth, and sinusoidal growth. Finally, the optimal background trend line equation was chosen by comparing the correlation coefficients. Therefore, the tourism loss rate was calculated with Eq. (2). All time-series data were calculated using First Optimization software (7D-Soft High Technology Inc, http://www.7d-soft.com/). The fluctuation interpolation and background trend line optimized procedures are in the Appendix (Tables A1 and A2).

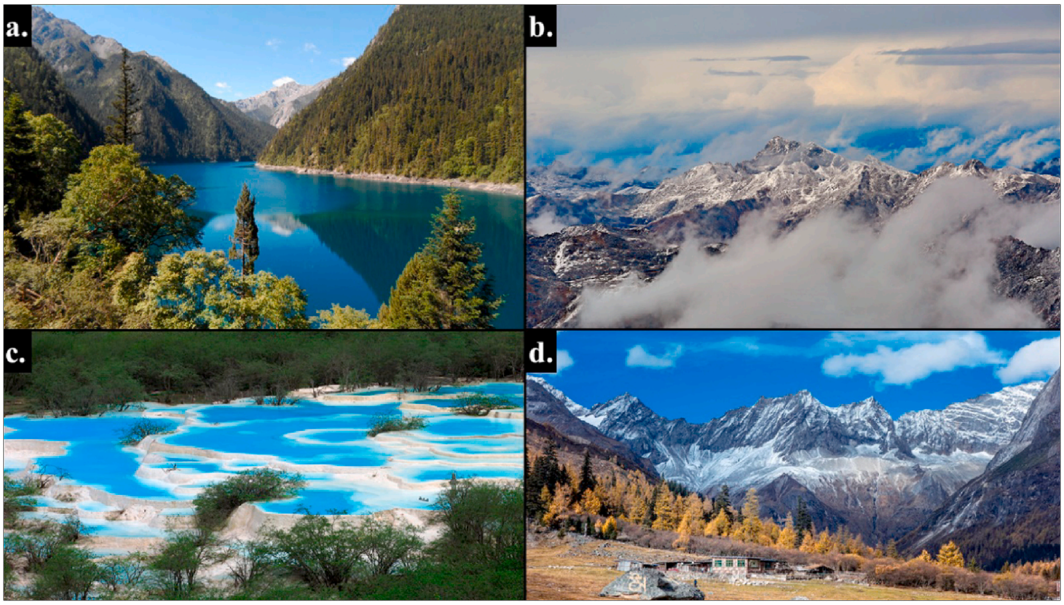


Fig. 3. Top four nature-based tourist attractions in Aba Prefecture. (a) Jiuzhaigou, (b) Dagu Glacier, (c) Huanglong, (d) Mount Siguniang. Photo credits: BCS (a), Wenjie Wong (b), Jie Du (c), Siyu Guo (d).

Table 1
The general simulation equations and their compound forms for the Tourism Background Trend Line model.

General equations	Compound equations
$y = a + bt$	$y = a + bt + q\sin(\omega t + \phi)$
$y = a + bt + ct^2$	$y = a + bt + ct^2 + q\sin(\omega t + \phi)$
$y = q\sin(\omega t + \phi)$	$y = q\sin(\omega t + \phi) + K/[1 + \exp(c - rt)]$
$y = K/[1 + \exp(c - rt)]$	$y = a + bt + K/[1 + \exp(c - rt)]$
$y = y_0 \times \exp(rt)$	$y = y_0 \times \exp(rt) + a + bt$
	$y = y_0 \times \exp(rt) + K/[1 + \exp(c - rt)]$
	$y = y_0 \times \exp(rt) + q\sin(\omega t + \phi)$

Note: y stands for the predicted tourist number at a certain time, t is an independent variable referring to the time series. Taking the equation of $y = a + bt + K/[1 + \exp(c\text{-}rt)]$ as example to explain other parameters, whereas *a, b, K, c and r* are parameters of the linear and log growth patterns.

$$Y_n = Y_a + (n - n_a) \times d = Y_a + (n - n_a) \times \frac{Y_b - Y_a}{n_b - n_a} \quad (1)$$

$$r = \frac{Y_{background} - Y_{actural}}{Y_{background}} \times 100\% \quad (2)$$

Where Y_a and Y_b stand for actual tourist volumes at the beginning and termination of a fluctuation, n stands for the year to be interpolated, d refers to the difference for linear interpolation. $Y_{background}$ and Y_{actual} are the number of tourists for background and actual tourist volume, respectively, and r represents the rate of loss ($r > 0$) and increase ($r < 0$).

3.3.2. ARIMA and SARIMA models

ARIMA models consist of three components: Auto-Regression (AR), Integration (I), and Moving Average (MA). An ARIMA model is usually represented as ARIMA (*p, d, q*), in which p and q represents the order of AR and MA processes, d is the order of differences. Moreover, for a time-series with seasonality, ARIMA requires supplementation with seasonal parameters, being denoted as SARIMA $(p, d, q)*(P, D, Q)_S$. The term (*P, D, Q*) represents the order of seasonal sections and (*p, d, q*) represents the order of non-seasonal sections. The detailed description and general process to forecast using ARIMA and SARIMA models are found in Hyndman and Athanasopoulos [48], including stationary and white noise testing, parameter estimation and model fitting, goodness-of-fit testing, and future outcomes forecasting. In our project, time-series data were processed and optimal ARIMA and SARIMA models were fitted in Python 3.8 (https://www.python.org/).

3.3.3. Model performance

We used mean absolute percentage error (MAPE) to evaluate forecasting accuracy, showing deviations in differences between predicted and actual values. The MAPE can be calculated using the following equation:

$$MAPE = \frac{\sum_{t=1}^{n}\left|\frac{F_t - A_t}{A_t}\right|}{n} \times 100\% \quad (3)$$

where A_t is the actual value and F_t is the forecasted value. When MAPE is close to 0, the forecasting model is highly accurate with good performance. The precision rate of the model can be classified into four levels: excellent (<10%), good (10%–20%), reasonable (20%–50%), and inaccurate (>50%).

4. Results

4.1. Multi-scale overview of tourism development

4.1.1. Sichuan

Sichuan's tourism is a significant component of China's overall tourism industry (Fig. 4), with the proportion of tourism revenues increasing from 5.7% (2000) to 17.5% (2019). On the provincial scale, tourism is Sichuan's pillar industry, with tourism revenues rising from 6.6% of GRP (2000) to 24.9% (2019) (Fig. 5a). Sichuan's domestic tourism has grown exponentially, while inbound tourism also showed an overall upward trend despite obvious slow-downs in 2003, 2008, and 2013 (Fig. 5b–c). In particular, inbound tourist volume dropped by 59% in 2008 (compared to 2007), primarily due to the impact of the Wenchuan Earthquake, not fully recovering until 2011.

4.1.2. Aba

Aba's tourism played an important role within Sichuan's overall tourism development, especially for inbound tourism. However, Aba's

Fig. 4. Sichuan's diversity of tourism destinations. (a) Mt. Emei's Golden Summit, (b–c) Chengdu Research Base of Giant Panda Breeding, (d) Leshan Giant Buddha, (e) Dujiangyan Ancient Irrigation System. Photo credits: BCS.

domestic and inbound tourism have shown different growth patterns from Sichuan's broader tourism industry (Fig. 5b–c). The attractiveness of Aba to domestic tourists remains relatively stable, but international tourist volumes have decreased. Aba was the second highest inbound tourism destination after Chengdu in 2000, with the ratio of international visitors increasing from 24% (2000) to 35% (2004, peak), then decreasing to 8% (2008) and 2% (2017). Despite inbound tourism resuming to some extent after the Wenchuan Earthquake, it never reached or exceeded former values, continuing an overall downward trend (Fig. 5c). Consequently, Aba's inbound tourism was in recession since the Wenchuan Earthquake, very different from the development paths of its domestic tourism sector and also Sichuan's inbound tourism.

Although lagging behind Sichuan's overall tourism, from the regional perspective, Aba still experienced rapid growth with tourist volumes reaching ~23.69 million in 2018 (12 times that of 2000), with an annual growth rate of 15%. The rapid growth of tourist arrivals to Aba has promoted the region's economy. Previously, tourism industry growth outpaced the overall GRP growth except for fluctuating years, and its collapse has led to a decline in economic growth (Fig. 5d).

4.1.3. Jiuzhaigou

Jiuzhaigou's tourism development showed an overall growth trend, on the destination scale. It comprises two periods: slow growth (1984–1997) and rapid but fluctuating growth (1998–2019) (Fig. 5e). The first period was characterized by low and slowly growing numbers of visitors, from 27,529 (1984) to 183,148 (1997), with an annual growth rate of 15.7%. The second period featured an overall upward trend, but it was not straightforward. The annual tourist numbers achieved a peak (>5.0 million) between 2015 and 2016 (13 times that of 1998), with an annual growth rate of 25%.

However, annual tourist volumes showed four major disruptions in several years (Fig. 5e). For instance, tourist arrivals fell by 11% in 2003 with a substantial rebound in 2004. Other sizeable declines in tourist volumes occurred in 2008 (74%), 2013 (20%), and 2017 (50%). Tourist arrivals dropped to 2.5 million in 2017, which was the same as ten years prior. The dates of these fluctuations were consistently associated with the dates of crises and natural disasters, for example, the Severe Acute Respiratory Syndrome in 2003, as well as the 2008 Wenchuan Earthquake [10], 2013 Lushan Earthquake and a landslide [39,49], and 2017 Jiuzhaigou Earthquake. Consequently, to evaluate the relationship between earthquakes and tourist arrivals at multiple scales, we mainly focused on the Wenchuan Earthquake and Jiuzhaigou Earthquake, finding large tourist volumes flowing away over long periods after both events.

4.2. Jiuzhaigou Earthquake's impact on yearly tourist volumes

4.2.1. Modelling description

At the Jiuzhaigou, Aba, and Sichuan scales, we calculated the TBTL functions based on Table 1 equations, obtaining 11 TBTL functions (Table A2), and compared R^2 to choose the optimal TBTL for tourist arrivals at each scale (Table 2). Using the ARIMA method, and based on available data, we selected appropriate models for tourist volumes of Jiuzhaigou (0, 2, 2), Aba inbound (0, 2, 1) and domestic (0, 2, 1) tourism, and Sichuan inbound (0, 2, 1) and domestic (0, 1, 1) tourism. The ARIMA models have a one year lag-time, which is consistent with previous findings [50,51]. The forecasting accuracy results of these models suggest that they provide accurate and reliable forecasting results with acceptable MAPE values, except for Aba's inbound tourism (Table A3). Therefore, tourist volumes between 2017 and 2019 were predicted, and declines in tourist volumes after the Jiuzhaigou Earthquake were estimated with both methods (Table 3).

4.2.2. Jiuzhaigou (local) scale

Following the Jiuzhaigou Earthquake, Jiuzhaigou's normal tourism activities experienced volume losses for the three subsequent years, revealed by both TBTL and ARIMA models (Fig. 6a; Table 3). The predicted visitor volumes to Jiuzhaigou between 2017 and 2019 were 5.94, 6.29, and 6.64 million with TBTL, and 5.68, 6.12, 6.57 million with ARIMA. Compared with the respective numbers of 2.50 million (2017), 63,600 (2018), and 468,100 (2019), the tourist numbers reduced by 57.9%, 99.0% and 93.0% with TBTL, and by 56.0%, 99.0%, and 92.9% with ARIMA, respectively.

4.2.3. Aba (prefectural) scale

After the Jiuzhaigou Earthquake, Aba's tourism also experienced declines in both domestic and inbound tourist volumes in 2017 and 2018 (Fig. 6e–f). Domestic tourists reduced by 30% (2017), 49% (2018), and

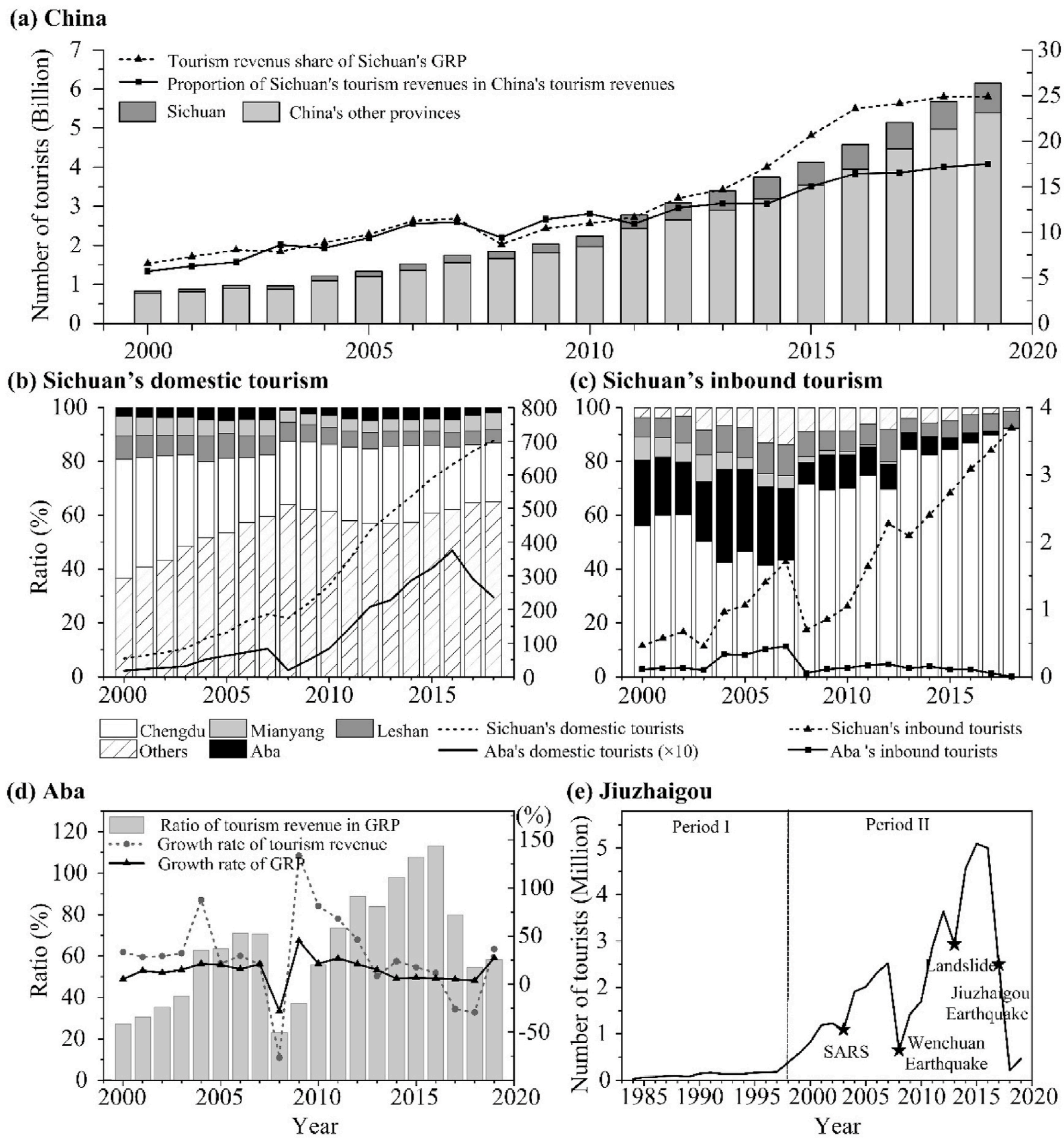


Fig. 5. Broader tourism development in China (a), Sichuan (b–c), Aba (d), and Jiuzhaigou (e). Note: in (b–c) "others" stand for Sichuan's other 17 prefectures and cities, including Deyang, Liangshan, Nanchong, Yibin, etc.

Table 2
The Tourism Background Trend Line models for Jiuzhaigou, Aba, and Sichuan.

Spatial Scales	Parameters	Functions	R^2
Jiuzhaigou	Tourist numbers	y = −20.42sin (0.41t-2.18) +18.53–7.98t+0.72t^2	0.9988
Huanglong		y = −7.9sin(8.44t+257.89)+246.98/(1 + exp(2.85–1.02t))	0.9985
Mount Siguniang		y = −38.2sin(-0.3t+8.17)+41.25/(1 + exp(-5.66 + 0.98t))	0.9991
Dagu Glacier		y = −0.26sin (2.72t-2.38) +13.93/(1 + exp (1.8–0.79t))	0.9999
Aba	Domestic Visitors	y = −17.9 + 111.84t+996.82/(1 + exp(31.162.44t))	0.9965
	Inbound Visitors	y = 141.6sin(-0.09t+0.03)+153.1/(1 + exp(2.39–0.56t))	0.9868
Sichuan	Domestic Visitors	y = 2.17 + 0.21t-2.0/(1 + exp(-15.96 + 1.30t))	0.9963
	Inbound Visitors	y = 77.46 + 11.66t-43.01/(1 + exp (-12.89 + 1.91t))	0.9993

40% (2019). Inbound tourist volumes declined in 2017 and 2018, but the two methods showed different results in 2019 with inaccurate forecasting (both MAPE>50%) (Table 3; Table A3). This may be due to fluctuating and unstable historical data, with few turning points. Few studies have analyzed the presence of changing trends in tourism time-series, which have serious implications for forecasting [36]. Nevertheless, not all tourist attractions in Aba experienced the same impact from the Jiuzhaigou Earthquake (Fig. 6b–d). For example, Huanglong visitations declined by 54% (2017), 87% (2018), and 74% (2019), but Mount Siguniang and Dagu Glacier attracted more tourists than expected during this timeframe.

4.2.4. *Sichuan (provincial) scale*

Sichuan's tourism experienced no significant negative impacts following the Jiuzhaigou Earthquake. Domestic and international tourists were higher than predicted (Fig. 6g–h). There were 0.67 billion domestic visitors in 2017 (7.9% more than predicted), and the numbers grew in both 2018 (7.1%) and 2019 (9.3%). International tourists arrivals were 17% (2017), 24% (2018), and 34% (2019) greater than

Table 3
Three-year-ahead forecast of TBTL and ARIMA models as of 2016.

Scales		Year	Actual number of tourists	TBTL		ARIMA	
				Forecast	Loss rate %	Forecast	Loss rate %
Jiuzhaigou (Thousand)		2017	2500.2	5942.69	57.9	5680.78	56.0
		2018	63.6	6291.14	99.0	6115.06	99.0
		2019	468.1	6640.92	93.0	6565.01	92.9
Aba	Domestic (Million)	2017	29.10	29.62	1.8	41.28	29.5
		2018	23.65	30.73	23.0	46.76	49.4
		2019	31.50	31.68	1.1	52.57	40.1
	International (Thousand)	2017	53.1	114.50	53.6	89.13	40.4
		2018	40.3	124.25	67.6	60.95	33.9
		2019	75.2	145.25	48.2	24.65	−205.1
Sichuan	Domestic (Million)	2017	670	594.88	−12.6	621.06	−7.9
		2018	700	615.97	−13.6	653.77	−7.1
		2019	750	636.99	−17.7	686.48	−9.3
	International (Thousand)	2017	3362	2873.40	−17.0	3016.64	−11.4
		2018	3698	2990.0	−23.7	3280.43	−12.7
		2019	4148	3106.60	−33.5	3554.04	−16.7

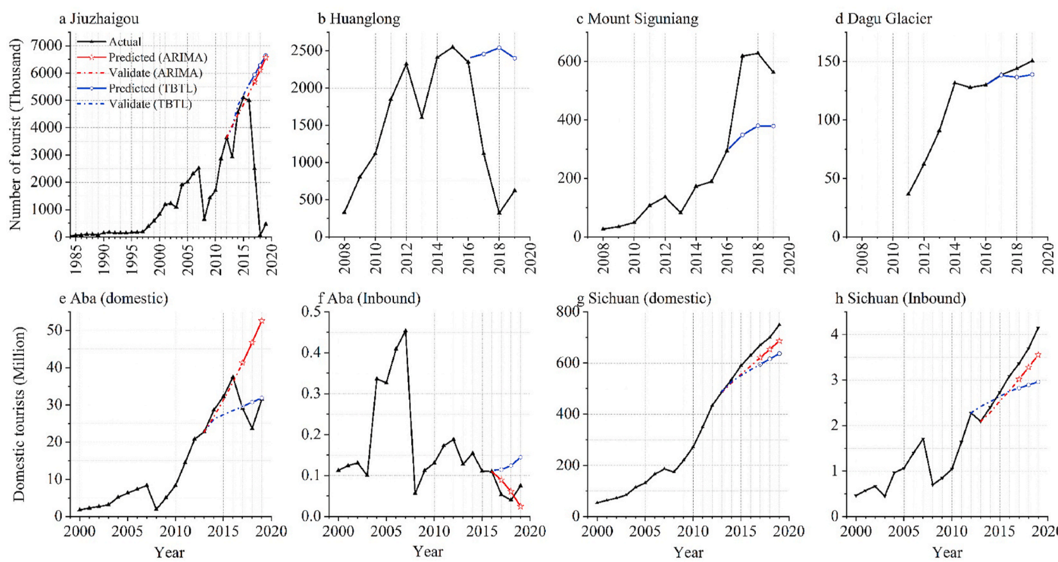


Fig. 6. Tourism background trend line of Jiuzhaigou (a), Aba (e–f) and its main tourism attractions (b–d), and Sichuan (g–h).

predicted. Overall, despite disturbances following the Wenchuan Earthquake and Jiuzhaigou Earthquake, Sichuan's domestic tourism experienced relatively steady growth.

4.3. Impact duration of the Jiuzhaigou Earthquake

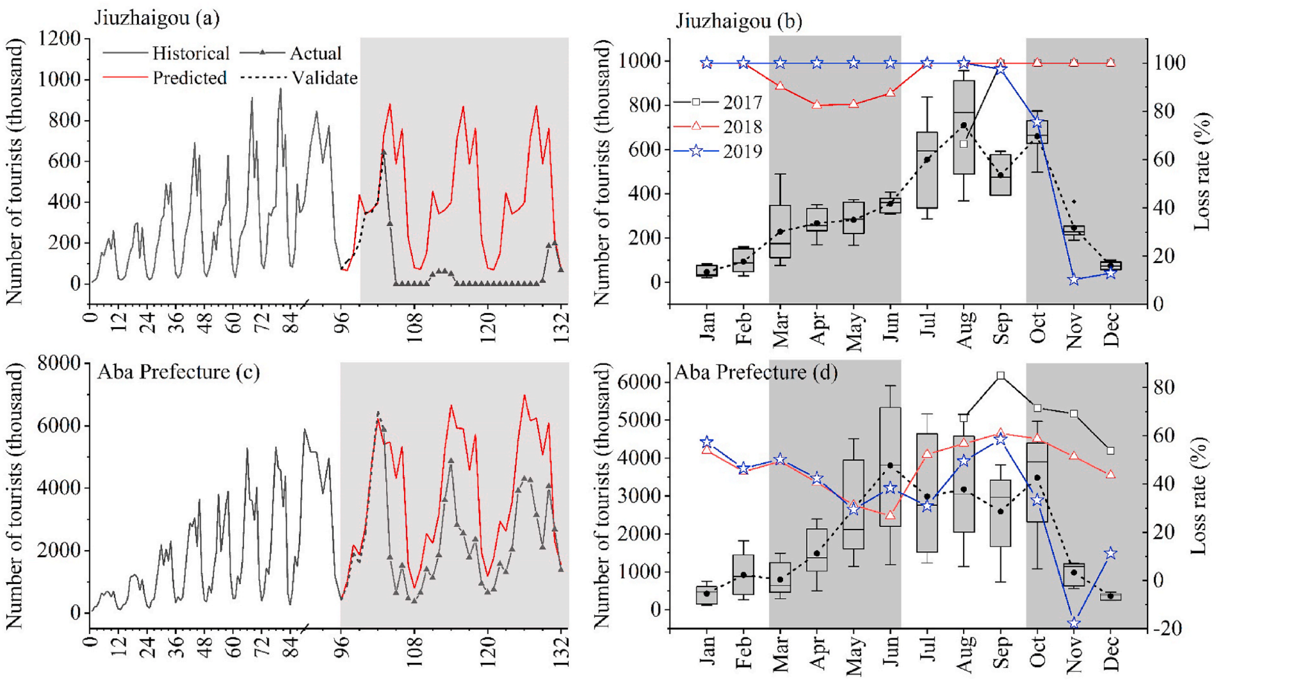
4.3.1. The optimal SARIMA model

The parameters for the SARIMA model were determined by grid research (Python 3.8) and the optimal model was selected based on smallest Akaike Information Criterion (AIC) [48]. The simulation method yielded the following SARIMA models for Aba (1, 1, 1) $(1, 1, 1)_{12}$ and Jiuzhaigou (1, 0, 0) $(1, 1, 0)_{12}$. We used the fitted SARIMA models to calculate 7-month-ahead forecasts from January to July 2017 with 95% confidence intervals. Taking the seven months' actual tourist volumes as testing samples, none fell outside the confidence intervals. The MAPE of Aba (1, 1, 1) $(1, 1, 1)_{12}$ and Jiuzhaigou (1, 0, 0) $(1, 1, 0)_{12}$ were calculated as 9.3% and 24.6%, indicating excellent and reasonable forecasts. Consequently, we used the Aba (1, 1, 1) $(1, 1, 1)_{12}$ and Jiuzhaigou (1, 0, 0) $(1, 1, 0)_{12}$ models to calculate 36-month forecasts as of January 2017 and subsequent loss rates (Table A.4).

4.3.2. Recovery duration of Jiuzhaigou and Aba

Tourist volumes to Jiuzhaigou and Aba underwent a long-term reduction period and their seasonal patterns were changed following the Jiuzhaigou Earthquake (Fig. 7). Monthly median arrivals in Jiuzhaigou started low in January and reached its first peak in August, followed by a jump in September, reached its second peak in October, and gradually dropped, reaching bottom in December for the next cycle (Fig. 7b). Monthly arrivals in Aba started low in January and first peaked in June, followed by a jump in September, reaching its second peak in October, before gradually reaching bottom in December for the next cycle (Fig. 7d). However, following the earthquake (August 8, 2017), Jiuzhaigou immediately closed and tourist volumes dropped by 67% in August, with declines continuing in subsequent months. Similarly, tourist volumes in Aba experienced declines of 67% in August and 85% in September, exceeding 50% through December 2017. In the following two years after the Jiuzhaigou Earthquake, Aba's tourism varied in different periods.

JAB proactively implemented policies to promote the recovery and reconstruction of Jiuzhaigou's tourism. Jiuzhaigou experienced two partial re-opening periods: Phase I (March 8-June 28, 2018) with tourist volumes limited to 2000 persons per day, and Phase II (September 27-October 18, 2019) with tourist volumes limited to 5,000, then raised to 8000 (October 19-November 27, 2019), and 20,000 persons per day (November 28, 2019-Janurary 28, 2020). The actual tourist arrivals in Aba was 168,900 (Phase I), a 34% loss compared to the forecast and 38%



Note: Light and dark grey backgrounds refer to post-earthquake period and two reopening periods, respectively.

Fig. 7. Forecast of monthly arrivals to Jiuzhaigou (a–b) and Aba (c–d). Note: Light and dark grey backgrounds refer to post-earthquake period and two reopening periods, respectively.

lower than the same period in 2019. Aba's loss rate in Phase II was 36%, which was 57% lower than the same period in 2018. Therefore, Jiuzhaigou's reopening alleviated Aba's tourist volume declines.

5. Discussion

5.1. Model comparison

Differences exist between how Chinese scholars and those from other countries formulate forecasting models to quantify the impacts of natural disasters on tourism. ARIMA and its variants are most frequently used outside China [34], while TBTL is one of the most frequently utilized methods in Chinese-language studies but infrequently used outside China [16,20,47]. In order to assess their interchangeability, we compared TBTL and ARIMA methods based on historic annual tourist volumes. Although exact figures differed, results were similar. This may be because the TBTLs are based on linear, sine wave, and exponential fitting methods, which are similar to the ARIMA-family models. Yet, TBTL has certain capabilities in forecasting tourism development trends, with easier procedures, no lag-time, and less data period requirements than ARIMA. Besides long-term trends, cyclical movements and seasonal patterns are also important features in sustainably managing tourism development [36], and the latter is of more concern to policy makers [34]. Although many English studies have used SARIMA models to forecast tourism demand, few linked them to event impact analysis. Chinese language studies rarely investigate the impact of disasters on tourism seasonality based on SARIMA models, probably because SARIMA requires at least 50 and preferably 100 or more observed units of seasonal data (e.g., months) to train the models [52]. But seasonal variables of high frequency (e.g., monthly or quarterly) are not easily obtained in China. In our study, we found fluctuations following the Jiuzhaigou Earthquake varied significantly by months using SARIMA.

5.2. The impact of Jiuzhaigou Earthquake on tourism

We found that the Jiuzhaigou Earthquake had a significant, negative impact on Jiuzhaigou's tourism economy. Not only did it negatively affect the integrity of natural attractions and tourism infrastructure, it also diverted tourist flows away to other regions, critically reduced visitation to Jiuzhaigou, and resulted in sustained economic losses. It is worth mentioning that Jiuzhaigou experienced two patial re-opening periods with limited tourist numbers [45,46], which contributed to the decrease in tourist visitations due to the scenic management policy. Nevertheless, this policy-driven decline was due to the fact that Jiuzhaigou's natural environment was severely damaged by the earthquake (Fig. 2) and could no longer carry the large number of tourists it had previously. Our findings are consistent with those from other natural disaster studies that documented negative impacts on tourism from earthquakes [6,8], tsunamis [9] and hurricanes [5], although the nature of disasters and tourist destinations were different.

Yet, the impact of the Jiuzhaigou Earthquake goes far beyond the destination itself, as Aba's tourism sector was also devastated. Despite Jiuzhaigou largely being closed, accessibility to Aba more broadly (including its other major tourist destinations) was not significantly affected. Nevertheless, due to its heavy reliance on Jiuzhaigou as a core component of its tourism industry, Aba not only experienced the initial emergency situation and short-term response, but its tourism sector remains today in the recovery period (>30 months).

Further, we initially anticipated that Jiuzhaigou had greater importance within Sichuan's broader tourism industry, believing that Jiuzhaigou's tourism collapse would also lead to a significant decline in Sichuan's tourism. However, contrary to expectations, we found the Jiuzhaigou Earthquake had negligible impact on Sichuan's broader tourism economy. This is likely due to Sichuan's highly varied tourism economy, with its robust seasonal tourist patterns, as well as geospatially and culturally-diverse tourism attractions and traditional products [10,17]. When tourists have diverse choices of travel destinations, especially to other safer regions in the immediate aftermath of a disaster, the overall tourism sector is more resilient. Thus, at the provincial-level analysis, Sichuan's diverse tourism economy was largely shielded from significant damage to its broader tourism sector following the Jiuzhaigou Earthquake.

Consequently, the recovery of Jiuzhaigou and Aba's economies must involve two aspects, reconstruction of the destination itself but also the tourism sector. As a nature-based tourism destination, the intangible nature of Jiuzhaigou's sightseeing and recreation-related services cannot be stored and sold to tourists following its damage. Therefore, the priority of Jiuzhaigou's post-earthquake reconstruction focused on the physical repair of damaged attractions, facilities, and infrastructure [25,53]. Then the two re-opening periods of Jiuzhaigou helped alleviate Jiuzhaigou and Aba's tourism decline (Fig. 7). However, this experience also revealed that the ongoing hazardous nature of Jiuzhaigou's tourism environment was also important. Research indicates that localized geohazards will frequently occur after a large magnitude earthquake [19]. The seismic events and decade of active debris flows in Jiuzhaigou during the 1970s highlight this reality [41]. Post-earthquake, most areas of Jiuzhaigou remain susceptible to geohazards [42,43], especially under intense or prolonged rainfall. For instance, debris flows and floods in 2018 hampered the re-opening process of Jiuzhaigou. Thus, sustainable tourism development must necessarily prioritize disaster management at all levels from the planning and management perspectives [7,13,54].

Second, it is important to implement measures to quickly reinvigorate the disaster-affected tourism industry [8,31]. In the Jiuzhaigou case, it was important to rebuild Jiuzhaigou's tourism sector to assist the recovery of Aba's entire economy. Yet, tourism recovery following disasters is complex [6,12]. Marketing strategies must be effective, with cohesive and positive messaging to re-brand the destination's image in the public's psyche, act to stabilize and restore businesses and consumer confidence, strengthen its relationships with loyal visitors, and encourage cooperation with neighboring and long-distance markets (e.g., economically-advanced cities) [6,12,14,53]. Furthermore, it is of great significance for Aba to focus on rebuilding a more resilient, diversified tourism sector, with the strong likelihood of encountering similar disasters in the future, it can learn from the relative immunity of Sichuan's broader tourism industry to the impacts of the Jiuzhaigou Earthquake.

5.3. Performance of Jiuzhaigou's tourism

Natural disasters can disrupt a tourism industry with long-lasting ripple effects that impact tourist destinations far away from the directly-impacted destination itself [7,13,28,29]. This study partially addresses a research gap about how recurring disasters affect the same destinations with relatively short-term effects [28], but our findings further reveal that disasters can have longer-term impacts by repositioning a destination's relative performance within a broader economy. Sichuan's broader tourism economy comprises many regions [17]. Although Jiuzhaigou's tourism development did greatly aid Aba's regional economy, we found that its contribution to Sichuan's tourism development was limited, featuring a relatively small share of Sichuan's overall domestic and inbound tourism (Fig. 5b–c). Further, by reviewing its historical development pattern, we found earthquakes adjusted Jiuzhaigou's and Aba's relative importance within Sichuan's broader tourism economy. For example, despite its previous significant contribution, Aba's inbound tourism decreased to a small proportion of Sichuan's tourism sector, to only about 1% over ten years after the Wenchuan Earthquake (2008–2019).

5.4. Resilient tourism economy: diversification and sustainability

The impacts of natural disasters on the growth pattern of Sichuan's overall tourism economy were temporary. This indicates the relatively resilient nature of Sichuan's tourism sector, in that its diversity helps the broader tourism industry overcome the cummulative effects of disasters. Despite being affected by the Wenchuan Earthquake, overall tourism in Sichuan endured and rapidly recovered due to its diversified tourism types, including red, historical, cultural, nature-based, and dark tourism[1] [10,21,55]. This diverse, broad-based tourism also helped Sichuan withstand and minimize the impacts of the Jiuzhaigou Earthquake. In addition, the diversity of Sichuan's broader (non-tourism) economy is also significant. An economy that is highly specialized in tourism and lacks diversity is vulnerable to external shocks [26,32,56]. Lacking economic diversity has been documented elsewhere, including the US cities of Honolulu [57] and Las Vegas [56], the petroleum-dependent economies of the Persian Gulf States [58], as well as China's Hainan Province [59]. Yet, in Sichuan, even if the tourism industry was damaged, other economic sectors (e.g., manufacturing, agriculture, energy) can facilitate a more rapid economic recovery, in order to avoid further economic recession [60].

Moreover, Sichuan's tourism industry is overwhelmingly dominated by domestic tourism, so economic fluctuations triggered by earthquakes are overcome rather quickly at the regional and provincial scales (Fig. 6e–g). This is because the impacts of natural disasters are more profound on inbound tourism [28,33] and domestic tourism is easily able to absorb shocks, which enhances resilience in the tourism industry and sustainable economic growth [13,61,62]. A robust domestic tourism sector requires a diversity of tourism products, markets, and geographical areas [56,61]. It can also contribute to the redevelopment of international tourism and thereby the overall tourism economy [61,63]. Yet, we also found that the spatial pattern of Sichuan's inbound tourism revolves now almost exclusively around Chengdu, while it was more equitably distributed in the past (Fig. 5c). This regional imbalance highlights a potential vulnerability of inbound tourism if a natural disaster occurred in Chengdu, since there are currently no other areas to "redirect" inbound tourism flows to within Sichuan.

Although the broader tourism industry in a large geographic region (like Sichuan) can maintain stable development, each consistuent jurisdiction (like Aba) may not be as resilient. Therefore, we recommend a diverse tourism economy like Sichuan to still focus efforts on rebuilding and rejuvenating its smaller constituent tourism areas after they are devastated by natural disasters, in order to maintain the strength of the overall diversified and geographically balanced economy of scale. This is especially important for the more immediate impact of regional and domestic tourism, to help promote more active rehabilitation of devasted tourism-dependent locales and maintain high-level resilience.

More broadly, many lower to middle-income countries (LMICs), such as Nepal, also experience high exposure to natural disasters, but have gradually shifted to heavily-tourism-based economies [30]. Moreover, these countries, largely due to their smaller-scale economies, have placed more emphasis on international tourism over domestic or regional tourism [4]. However, these strategies have unintentionally exacerbated their economic vulnerability to natural disasters [4,62,63]. This is similar to the early tourism development path taken by China [55]. In this sense, China's evolving experience and Sichuan's diverse model can be helpful examples to provide insight and also warn other LMICs about the benefits and risks associated with tourism development in natural-disaster-prone regions. Effective tourism development strategies require more attention to balance domestic/regional and inbound tourism, diversify the tourism economy itself, link natural disaster management to tourism development, and build rapid post-disaster rehabilitation efforts to maintain the broader tourism sector's resilience.

[1] In China, "red tourism" involves visitation to communist heritage sites, war or revolution sites, museums and monuments, and memorial halls for the sake of patriotic education. Whereas "dark tourism" includes travel to sites associated with death, suffering, or otherwise seemingly macabre (i.e., earthquake relics, mausoleums, and other memorials).

5.5. Limitations and suggestions for futher studies

Effective sustainable tourism management requires information about the relationship between tourism economics and impacts of natural disasters on various scales [26]. However, due to the lack of high frequency tourism data, we compared four top attractions in Aba based on annual tourist volumes but were unable to compare their seasonal responses to the earthquake. This may limit the generalizability of our findings. Therefore, we strongly recommend that government agencies and tourist destinations proactively collect and release higher frequency tourism data to allow for more robust analyses in the future. Rather than always using TBTL, Chinese researchers should increase the application of widely utilized and well-performing models (e.g., econometric and artificial intelligence models) [34], to allow greater comparison with scholarship worldwide. Moreover, combining various models in tourism crises and disasters studies will enable more rigorous conclusions to be drawn, especially in light of the heavy influence on tourism of COVID-19 and recent flooding events in China.

Finally, tourism is a social-ecological system, involving environmental and landscape features, varied destinations, tourists, tourism-based communities and supporting businesses, etc. [12], resulting in multifaceted impacts from natural disasters [5,10]. Our study only focused on one aspect of tourism demand (e.g, tourist numbers) to investigate the response of the tourism industry to earthquakes. In addition we only studied the relative importance of Jiuzhaigou's tourism at different scales following earthquakes in only two conditions, completely closed or partially reopened, but this study was not a long-enough duration to include the fully-opened period in the future when tourism numbers return to their pre-earthquake behaviors. Thus, further studies should seek to investigate at least two additional areas: (1) Plan for longer-term or followup analyses at all three scales to compare the relative resilience of Jiuzhaigou's tourism within Aba and Sichuan after full reopening occurs (e.g., was the damage caused permanent?); and (2) systemically evaluate the impact of natural disasters on all aspects of tourism (e.g., the entire social-ecological system).

6. Conclusion

The rapid development capacity of tourism and its economic contributions are indisputable, leading to the development of many tourism-focused economies worldwide. Yet, many tourist destinations affected by or exposed to natural disasters face significant challenges to sustainable development. Earthquakes and their associated geohazards precipitated significant negative impacts on Jiuzhaigou's tourism industry, in the local and regional scales over short and long-term periods. In response, Sichuan's historic tourism pattern has changed to favor domestic-tourism. However, Sichuan's highly diverse broader tourism economy proved resilient to and relatively immune to the cummulative effects of natural disasters on the local and regional scales. Consequently, learning from the example of the three scales of analysis in our study of Sichuan, to maintain sustainability and long-term economic resilience, tourism-dependent economies should strive to diversify away from relying solely on inbound tourism (e.g., Aba) and seek to rapidly rejuvenate local tourist destinations following natural disasters. Sichuan's tourism economy serves as a helpful case to provide understanding of the relationship between natural disasters and tourism development, insights on tourism reconstruction, and guidance for tourism disaster management protocols.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijdrr.2021.102216.

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