

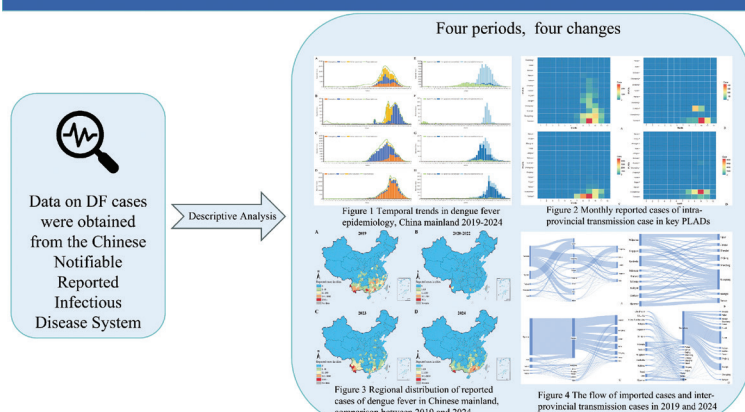


ORIGINAL ARTICLE

Changing Epidemiological Characteristics of Dengue Fever in Chinese Mainland Between 2019 and 2024

Graphical Abstract

Changing epidemiological characteristics of dengue fever in Chinese mainland between 2019 and 2024



From 2019 to 2024, the geographic distribution of reported cases has narrowed, primarily in Yunnan's border areas and the Pearl River Delta. The onset of indigenous transmission occurs progressively earlier and the duration of sustained local cases has been increasingly prolonged. The primary origin of reported cases has shifted from Cambodia to Myanmar, and then Indonesia and Laos.

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Brief Statement

In 2023, a local epidemic in Yunnan occurred approximately 1 month earlier. During other periods, Yunnan and Guangdong accounted for over 50% of indigenous cases, with subsequent triggered inter-provincial transmission. Moreover, the primary origin of reported cases has shifted from Cambodia to Myanmar.

Highlights

- Through a comparison of dengue fever trends across four distinct periods in Chinese mainland, dynamic shifts in the epidemiological characteristics have been observed.
- These are primarily reflected in an earlier onset and prolonged duration of indigenous transmission, a relatively concentrated geographical distribution of reported cases, and changes in origin countries of imported cases. Additionally, inter-provincial spread remains a noteworthy concern.
- These findings highlight the ongoing challenges in dengue prevention and control within the context of climate change and increasing international travel.

Changing Epidemiological Characteristics of Dengue Fever in Chinese Mainland Between 2019 and 2024

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Abstract

Background: Dengue fever is a mosquito-borne viral disease caused by the dengue virus, the prevalence of which has sharply increased in recent years worldwide. The indigenous dengue fever epidemic triggered by imported cases continues to pose a serious challenge to public health in China with a trend of expanding towards higher latitudes. The three largest local outbreaks of dengue fever in China since 2014 occurred in 2019, 2023, and 2024. A comparative analysis is needed to identify changes in the epidemiological characteristics of dengue fever during this period and to provide targeted prevention and control measures.

Methods: A descriptive epidemiologic analysis method was performed to compare the basic characteristics of dengue fever between four phases (2019, 2020-2022, 2023, and 2024) with respect to geographic distribution, seasonality, imported sources, and composition of cases. The data on dengue fever cases were obtained from the Chinese Notifiable Reported Infectious Disease System (CNRIDS). The clinical criteria for diagnosing dengue fever were based on the guidebook published by National Health Commission of the People's Republic of China.

Results: Between 2019 and 2024 a total of 67,389 cases of dengue fever were reported in mainland China, including 8189 imported and 59,200 indigenous cases. In 2024, the reported cases of dengue fever covered 28 provincial-level administrative divisions (PLADs), 217 cities, and 895 counties with more involved areas than 2023 (28 PLADs, 195 cities, and 739 counties) but less than 2019 (29 PLADs, 246 cities, and 1269 counties). Dengue fever cases were located primarily on border areas of Yunnan (21,309 [36.0%]) and the Pearl River Delta region (15,829 [26.7%]). Most imported dengue cases (92.1% [7546/8189]) of imported cases originated from the Southeast Asian region. The rapid growth of indigenous cases (weekly reported cases > 500) in 2023 started 3 weeks earlier than 2019. In 2024 the local outbreak of dengue fever exhibited the earliest onset and had the longest duration (238 days [3 May-27 December]) compared to 218 days (25 May-29 December) in 2023 and 202 days (24 May-11 December) in 2019. Inter-provincial transmission of dengue fever rose progressively between 2019 and 2024, as follows: 2.4% (2019); 6.2% (2023); and 6.5% (2024). Notably, Yunnan accounted for 90.1% of total inter-provincial transmission of dengue fever in 2023, whereas Guangdong became the primary source in 2024 (96.4%).

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Conclusions: From 2019–2024 the geographic distribution of reported dengue fever cases has narrowed, primarily within the border areas of Yunnan and the Pearl River Delta. The onset of indigenous dengue fever transmission has occurred progressively earlier and the duration of sustained local dengue fever cases has been increasingly prolonged. The primary origin of reported dengue fever cases has shifted from Cambodia to Myanmar, then Indonesia and Laos. Since 2023, provinces other than Guangdong and Yunnan have faced dual pressures from inter-provincial transmission and the imported cases originating primarily from Indonesia, Thailand, and Laos. Control of dengue fever relies on close monitoring of international disease dynamics with enhanced surveillance of incoming travelers and mosquito vectors.

Key words: dengue fever, epidemiological characteristics, prevention

INTRODUCTION

Dengue fever (DF), a mosquito-borne viral illness caused by the dengue virus (DENV), is principally transmitted through the bites of infected *Aedes aegypti* and *A. albopictus* mosquitoes. DF is endemic to tropical and subtropical zones and exhibits pronounced seasonal patterns with transmission peaking during and shortly after monsoon seasons due to optimal breeding conditions for mosquito vectors. Notably, humans lack immunity to DENV, rendering all age groups susceptible to infection [1]. The global incidence of DF has surged 30-fold over the past 5 decades. Current estimates include 50–100 million annual infections and approximately 4 billion people residing in at-risk areas [2]. Emerging evidence underscores how accelerating urbanization, climate variability, and intensified globalized mobility patterns synergistically exacerbate viral dissemination and *Aedes* mosquito habitat expansion [3]. Most DF cases resolve spontaneously with supportive care. The case fatality rate is approximately 0.1% globally [4]. However, the mortality rates are 2%–5% in severe DF cases, such as dengue hemorrhagic fever (DHF) and dengue shock syndrome (DSS). Indeed, in resource-limited settings, where delays in medical care impair treatment outcomes, mortality rates may exceed 20% [5].

DF persists as a significant public health concern in China, where DF is primarily introduced through imported cases [6]. Since the 21st century two peaks in the number of DF cases have been reported (2014 and 2019), featuring notable growth in the number of cases and inter-provincial transmission chains [7,8]. Domestic transmission appears to display cyclical resurgence patterns with major epidemic waves recurring at approximately 5-year intervals across China [9]. In some high-risk border regions, such as Yunnan Province, this periodicity demonstrates accelerated recurrence cycles of approximately 2 years [10]. Surveillance data have revealed the main epidemic period of DF spans from June–December with the peak incidence between September and November [9]. The provincial-level administrative divisions (PLADs) report imported, inter-provincial transmitted, and intra-provincial transmitted DF cases, which have gradually expanded from the historical strongholds in southeastern and southwestern China to the central, northeastern, and northwestern regions [9]. The local DF outbreaks

exhibit a northward and high-latitude expansion trend in China [9]. This expansion of the epidemiologic footprint reflects changes in climate suitability, enhanced vector proliferation, and intensified human mobility networks, all of which pose new challenges for DF prevention and control.

The magnitude of DF epidemics hinges on multifactorial interactions, including imported case volume, climatic drivers (e.g., temperature and precipitation), efficacy of vector control programs, and population-level awareness [2,10]. The current study involved a comparative epidemiologic analysis of three consecutive large-scale outbreaks in 2019, 2023, and 2024 with two objectives: (1) to identify changes in epidemiological characteristics during this period, especially with respect to seasonality, geographic expanding trend, and transmission pattern; and (2) to provide evidence-based insights for a corollary study involving transmission dynamics, as well as refining targeted prevention strategies and containment measures in the evolving public health landscape in China.

METHODS

Data sources

DF case data were obtained from the Chinese Notifiable Reported Infectious Disease System (CNRIDS). The origins of DF case infections were derived from the epidemiologic investigation findings conducted by the local Centers for Disease Control and Prevention (CDC). DF cases were defined as clinically diagnosed and laboratory-confirmed cases reported in mainland China between 1 January 2019 and 31 December 2024. The clinical criteria for diagnosis were based on the guidebook published by the National Health Commission of the People's Republic of China.

Case classifications

1. An imported DF case was defined as a case in which the patient had traveled to countries or regions with a known prevalence of DF within a 14-d window before the onset of disease and ruled out the possibility of a domestic based on an epidemiologic investigation.
2. An indigenous DF case was defined as a case who had stayed in China during the 14-d period preceding disease onset and had no overseas travel history. Indigenous DF cases included intra- and inter-provincial transmission cases.

3. An intra-provincial transmission DF case was defined as a case who had stayed in the current PLADs of residence during the 14-d period preceding disease onset and the source of infection was clearly within the local PLADs.
4. An inter-provincial transmission DF case was defined as a case who had not travelled overseas but had travelled outside of the current PLADs of residence to other areas within 14-d prior to the manifestation of the disease where the DF case was reported, and the possibility of local infection within the current PLADs of residence was ruled out based on an epidemiologic investigation.

Statistical analysis

The study was divided into the following phases with a primary focus on the comparative analysis among the years 2019, 2023, and 2024: 2019; 2020–2022; 2023; and 2024. The annual incidence rate was defined as the annual number of new DF cases divided by the annual population. Microsoft Office Excel (version 2021; Microsoft Corporation, Redmond, WA, USA) was used for the establishment of a DF case database and data visualization. Temporal trends in the number of reported DF cases across key PLADs were visualized using a heatmap implemented in R software (version 4.5.1; R Core Team, Vienna, Austria). The directional flows of imported and inter-provincial transmission DF cases were visualized with the SankeyMATIC website (<https://sankeymatic.com>). Epidemiologic feature description and comparisons of differences between groups was performed using SPSS (version 21.0; SPSS, Inc., Chicago, IL, USA). The spatial distribution maps were implemented by ArcGis (version 10.8.2; ESRI, Inc., Redlands, CA, USA).

RESULTS

Profile of epidemiological characteristics of DF in mainland China from 2019–2024

Surveillance data documented 67,389 DF cases in mainland China from 2019–2024, of which 40,719 were laboratory-confirmed. The number of reported DF cases was 22,188 in 2019, 19,541 in 2023, and 24,278 in 2024, which represented 97.9% of all DF cases documented during the study period. The reported DF cases included 8189 imported and 59,200 indigenous cases. The average annual DF incidence rate was 1.06/100,000 on average and 4 deaths were reported, for a case fatality rate of 0.009%. Males accounted for most DF cases (38,035 [56.4%]), yielding a male-to-female ratio of approximately 1.30:1. DF cases encompassed individuals 1 month–102 years of age (median age, 44 years) with 82% concentrated in the 15–65 year age group. Farmers, homemakers, the unemployed, and commercial and service workers comprised the major occupational category (36,120 [53.6%]). Indigenous DF cases accounted for most reported cases. Specifically, Yunnan (22,041 [37.2%]), Guangdong (26,506 [44.8%]), and Guangxi (2,755 [4.6%]) were the PLADs with relatively high contributions. The imported DF cases were mainly from Southeast Asian, represented by Cambodia

(3330 [40.7%]), Myanmar (1855 [23.4%]), and Thailand (569 [6.9%]). Inter-provincial transmission DF cases originating from Guangdong and Yunnan Province accounted for 54.9% and 38.0%, respectively. The median interval between DF incidence and diagnosis in 2020–2022, 2023, and 2024 was 1.8 (0.8–4.9), 2.4 (1.4–4.5), and 3.6 (1.8–5.7) d, respectively, which was significantly less than occurred in 2019 (Table 1).

Changes in the seasonal distribution of reported DF cases

The DF epidemic in China exhibited a pronounced seasonal pattern. DF cases were concentrated between July and November (64,439 [95.6%]) and typically peaked between September and October (42,884 [63.6%]; Fig 1). Yunnan (5378 [33.2%]) recorded the highest number of intra-provincial transmission DF cases in 2019, followed by Guangdong (4801 [29.7%]), Guangxi (1598 [9.9%]), Chongqing (1243 [7.7%]), and Jiangxi (1099 [6.8%]). The DF epidemic began to rise gradually in August, peaked in Yunnan in September, and subsequently peaked in Guangdong in October. The intra-provincial transmission DF cases were mainly concentrated in Yunnan and Guangdong in 2023 with Yunnan serving as the representative hotspot. The reported DF cases demonstrated accelerated progression characteristics with intra-provincial transmission DF cases showing a rapid increase (weekly reported cases > 500) starting from mid-August (33rd week) and peaking on late September (1836 cases in the 37th week). The rapid growth of intra-provincial transmission DF cases in 2023 started from the 30th week (3 weeks earlier than 2019) and peaked in the 38th week (1528 cases). The intra-provincial transmission DF cases increased sharply from the 34th week and reached a peak in the 41st week (2443 cases), which was 3 weeks later than 2023. Guangdong (17,500 cases) had the most intense intra-provincial transmission DF cases in 2024, accounting for 80.5% of cases nationwide. Yunnan reported the second-highest number of DF cases (3538 [16.3%]). The reported DF case count remained consistently low from 2020–2022 yet retained the typical July–November seasonality (1223 [88.5%]; Fig 2).

Imported DF cases were detected year-round, whereas the onset of indigenous transmission DF cases occurred progressively earlier and the duration of sustained local DF cases was increasingly prolonged. Indigenous DF cases were reported in 2019, 2023, and 2024 with durations of 202 d (24 May–11 December), 218 d (25 May–29 December), and 238 d (3 May–27 December), respectively.

Variation in geographic distribution and composition of reported DF cases

In 2024 DF cases were reported for 28 PLADs, 217 cities, and 895 counties. These numbers represent an increase from 2023 (28 PLADs, 195 cities, and 739 counties) but remained below the number of DF cases reported in 2019 (29 PLADs, 246 cities, and 1269 counties). The

TABLE 1 | Comparison of dengue fever case characteristics between 2019 and 2024.

	2020–2022 n (%)	2019 n (%)	2023 n (%)	2024 n (%)	χ^2
Total (n)	1382	22188	19541	24278	
Incidence rate (/100,000)	0.03	1.2	1.28	1.72	
Gender					48.51 ($P < 0.001$)
Male	794 (57.45)	12824 (58.80)	10646 (54.48)	13771 (56.72)	
Female	588 (42.54)	9364 (41.20)	8895 (45.52)	10507 (43.28)	
Age					199.26 ($P < 0.001$)
<15	73 (5.28)	1353 (6.10)	1387 (7.10)	1579 (6.50)	
15–65	1214 (87.84)	18661 (84.10)	15782 (80.76)	19482 (80.25)	
≥65	95 (6.87)	2174 (9.80)	2372 (12.14)	3217 (13.25)	
Occupation					1189.10 ($P < 0.001$)
Retired individuals	41 (2.97)	1564 (7.05)	1484 (7.59)	2572 (10.59)	
Homemakers and unemployed	244 (17.66)	4466 (20.13)	3163 (16.19)	4006 (16.50)	
Farmers	179 (12.95)	4303 (19.39)	5609 (28.70)	5384 (22.18)	
Commercial, and service workers	296 (21.42)	3033 (13.67)	2045 (10.47)	3392 (13.97)	
Students	90 (6.51)	1551 (6.99)	1470 (7.52)	2066 (8.51)	
Others	532 (38.49)	7271 (32.77)	5770 (29.53)	6858 (28.25)	
Category of reported cases					5453.20 ($P < 0.001$)
Imported case	226 (16.43)	5474 (24.67)	1486 (7.60)	1003 (4.13)	
Intra-provincial transmission	1156 (83.57)	16190 (72.97)	16838 (86.17)	21735 (89.53)	
Inter-provincial transmission	0	524 (2.36)	1217 (6.23)	1540 (6.34)	
Provincial distribution					25085.00 ($P < 0.001$)
YunNan	789 (57.09)	6471 (29.16)	13420 (68.68)	3708 (15.27)	
GuangDong	88 (6.37)	6042 (27.23)	4202 (21.50)	17742 (73.08)	
Guangxi	379 (27.42)	1748 (7.88)	44 (0.23)	710 (2.92)	
Fujian	23 (1.66)	1617 (7.29)	194 (0.99)	155 (0.64)	
Chongqing	6 (0.43)	1411 (6.36)	137 (0.70)	36 (0.15)	
Others	97 (7.02)	4899 (22.08)	1544 (7.90)	1927 (7.94)	
Origin country of imported cases					3679.50 ($P < 0.001$)
Cambodia	44 (19.5)	3256 (59.48)	17 (1.14)	13 (1.30)	
Myanmar	18 (8.0)	821 (15.00)	1016 (68.37)	58 (5.78)	
Thailand	9 (4.0)	315 (5.75)	113 (7.60)	132 (13.16)	
Philippines	43 (19.0)	232 (4.24)	23 (1.55)	43 (4.29)	
Laos	6 (2.7)	181 (3.31)	127 (8.55)	154 (15.35)	
Others	97 (42.92)	526 (9.61)	147 (9.89)	366 (36.49)	
Interval between onset and diagnosis [Median (Q1, Q3)]	1.8 (0.7, 4.9)	4.5 (2.5, 6.7)	2.4 (1.4, 4.5)	3.6 (1.8, 5.7)	4209.20 ($P < 0.001$)

geographic distribution of reported cases at the county level narrowed from 2019–2024, focusing primarily on border areas of Yunnan (21,309 [36.0%]) and the Pearl River Delta region (15,829 [26.7%]), while DF cases in other areas were sporadic (Fig 3). The border regions

of Yunnan, represented by Xishuangbanna, Dehong, Lincang, and Pu'er, collectively accounted for 95.7%, 100%, 96.3%, and 99.7% of all indigenous DF cases reported within Yunnan during the 4 consecutive periods (2019, 2020–2022, 2023, and 2024), respectively,

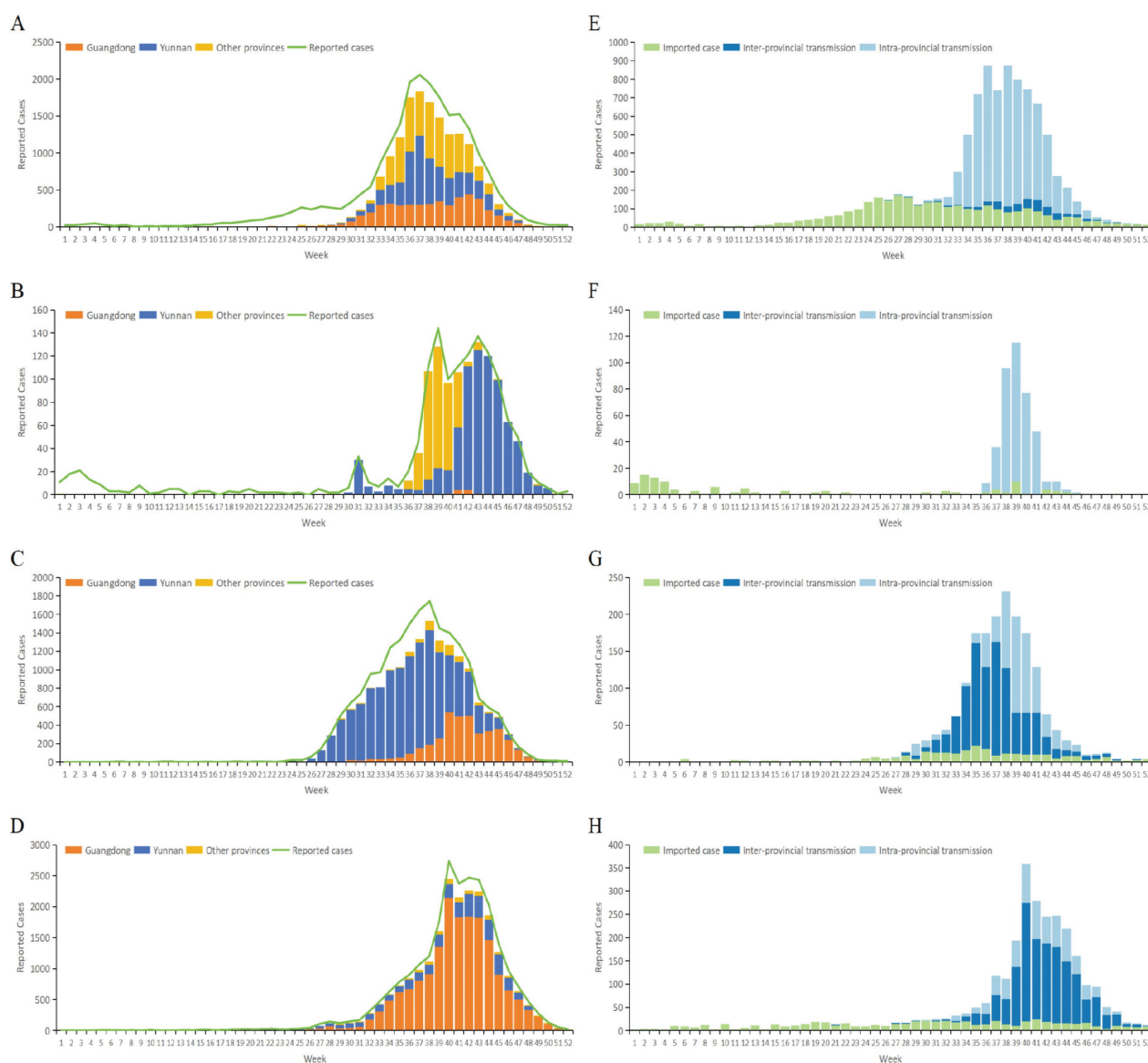


FIGURE 1 | Temporal trends in dengue fever epidemiology in mainland China (2019–2024). Note: The line graph (panels A–D) depicts the weekly nationwide dengue fever cases reported from 2019–2024. Stacked bar charts (panels A–D) illustrate the weekly distribution of intra-provincial transmission DF cases in Guangdong, Yunnan, and other provinces during the same period. A separate set of stacked bar charts (panels E–H) presents the weekly composition of imported, intra- and inter-provincial transmission DF cases in provinces, excluding Guangdong and Yunnan (2019–2024).

and were responsible for 31.8%, 66.2%, 70.5%, and 16.2% of the national total, respectively. Guangzhou, Foshan, Shantou, and Zhanjiang served as the major epicenters in the Pearl River Delta region. Guangzhou, Foshan, Shantou, and Zhanjiang were representative cities within the Pearl River Delta region. The cumulative number of indigenous DF cases represents 62.6%, 33.3%, 61.5%, and 58.8% of the provincial total, respectively, and 18.6%, 0.3%, 14.9%, and 47.3% of the national total, respectively.

The number of intra-provincial transmission DF cases increased from 16,190 cases in 2019 to 21,735 cases in 2024. Yunnan was the predominant hotspot in 2023,

contributing 12,324 cases (73.2%) with a 71.3% decrease compared to 2023 (12,324 cases). The focus shifted to Guangdong in 2024, during which 17,000 cases (80.3%) were reported. Most DF cases were caused by inter-provincial transmission in other PLADs (except for Yunnan and Guangdong) with Guangdong and Yunnan the main source. The composition of DF cases exhibited distinct patterns by 2019. Seven PLADs had a predominantly intra-provincial transmission ($\geq 50\%$ of all cases), represented by Yunnan (5385 [83.1%]), Guangdong (4801 [79.5%]), and Guangxi (1598 [91.4%]), whereas 21 PLADs had DF case profiles primarily comprised of imported infections originating from overseas (Fig 4).

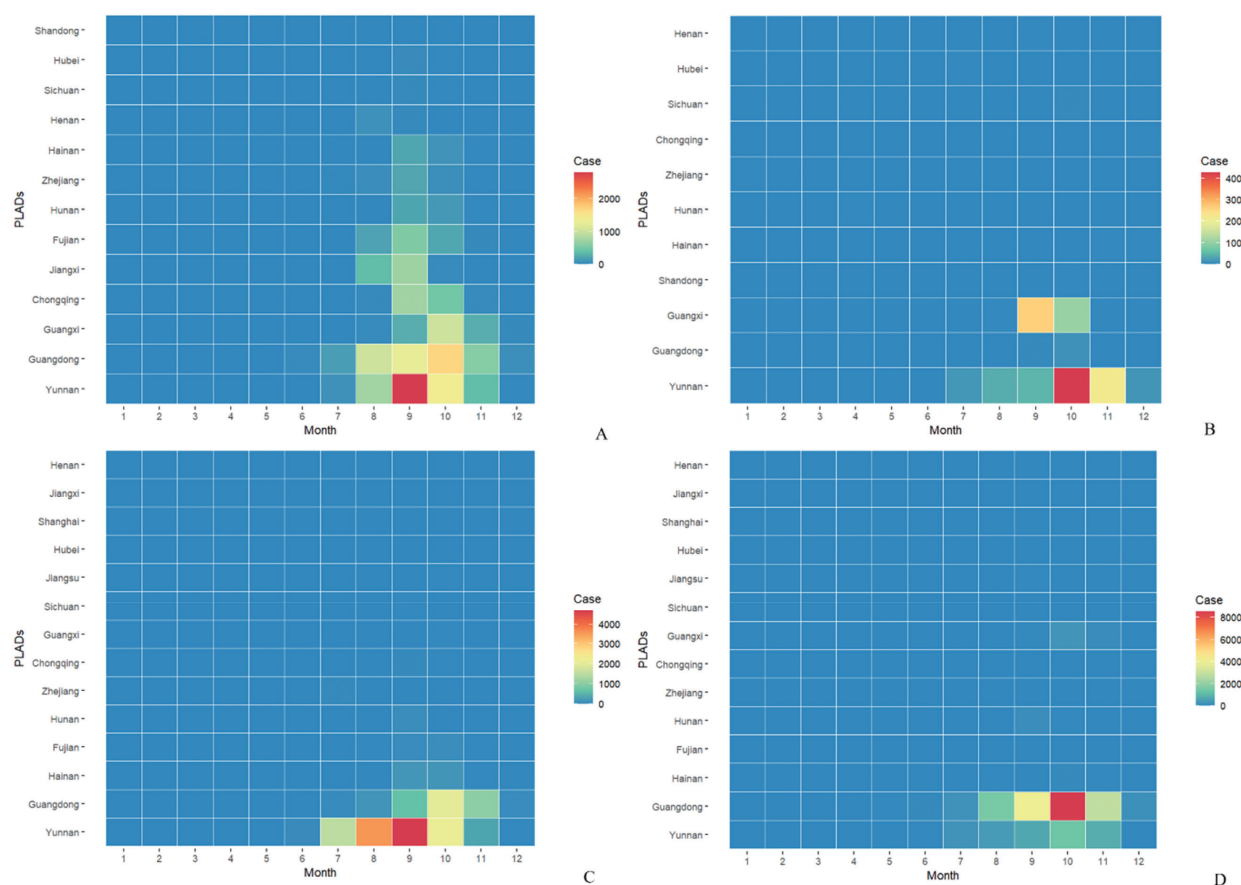


FIGURE 2 | Monthly reported DF cases of intra-provincial transmission in key PLADs. (A): Monthly reported DF cases of intra-provincial transmission in key PLADs in 2019. (B): Monthly reported DF cases of intra-provincial transmission key PLADs in 2020–2022. (C): Monthly reported DF cases of intra-provincial transmission in key PLADs in 2023. (D): Monthly reported DF cases of intra-provincial transmission in key PLADs in 2024.

Shift in origin countries and recipient provinces of imported DF cases

A total of 8189 imported DF cases were documented during the study period. Specifically, 5474 DF cases were recorded in 2019, 226 between 2020 and 2022, 1486 in 2023, and 1003 in 2024, representing 24.7%, 16.4%, 7.6%, and 4.1% of the total reported DF cases during the same periods, respectively. In general, most DF cases (92.1% [7546/8189]) originated from Southeast Asian. A total of 1003 (4.1%) imported DF cases were reported in 2024. Indonesia (237 [23.6%]), Laos (154 [15.4%]), and Thailand (132 [13.2%]) were the three leading source countries, collectively accounting for the largest share. The distribution of these DF cases across provinces was similarly balanced with Guangdong (216 [24.8%]), Zhejiang (143 [14.4%]), and Yunnan (140 [14.1%]) ranked as the top 3 recipients. A total of 1486 imported DF cases were documented in 2023, constituting 7.6% of the reported cases, principally from Myanmar (1016 [68.3%]), Laos (127 [8.5%]), and Thailand (113 [7.6%]). Yunnan and Guangdong reported the highest number of DF cases with 1096 cases in Yunnan and 108 in Guangdong. In 2019, The countries of origin for imported DF cases in 2019 were also

primarily concentrated in Southeast Asia with Cambodia (3256 [59.5%]) ranked first, followed by Myanmar (821 [15.0%]) and Thailand (315 [5.8%]). Cambodia remained the primary source country for imported DF cases from 2020–2022.

Surge in inter-provincial transmission

Guangdong (1485 [96.4%]) emerged as the predominant exporter of inter-provincial transmission DF cases in 2024 with spreading infections to 24 provinces. Among the recipient provinces, Hunan reported the highest number of DF cases (538), representing 75.9% of the annual total. Nine PLADs reported imported DF cases originating from Guangdong that accounted for > 50% of the respective total case counts. In contrast, between 2019 and 2023 Yunnan served as the primary exporter of inter-provincial transmission DF cases (90.1%), which was up from 21.6%. DF cases originating from Yunnan affected 26 provinces with Zhejiang (232 cases), Guangdong (170 cases), Sichuan (157 cases), and Hunan (129 cases) the main recipient PLADs. Twenty-one PLADs reported that DF cases imported from Yunnan accounted for > 50% of the total cases with 3 PLADs indicating that all reported cases

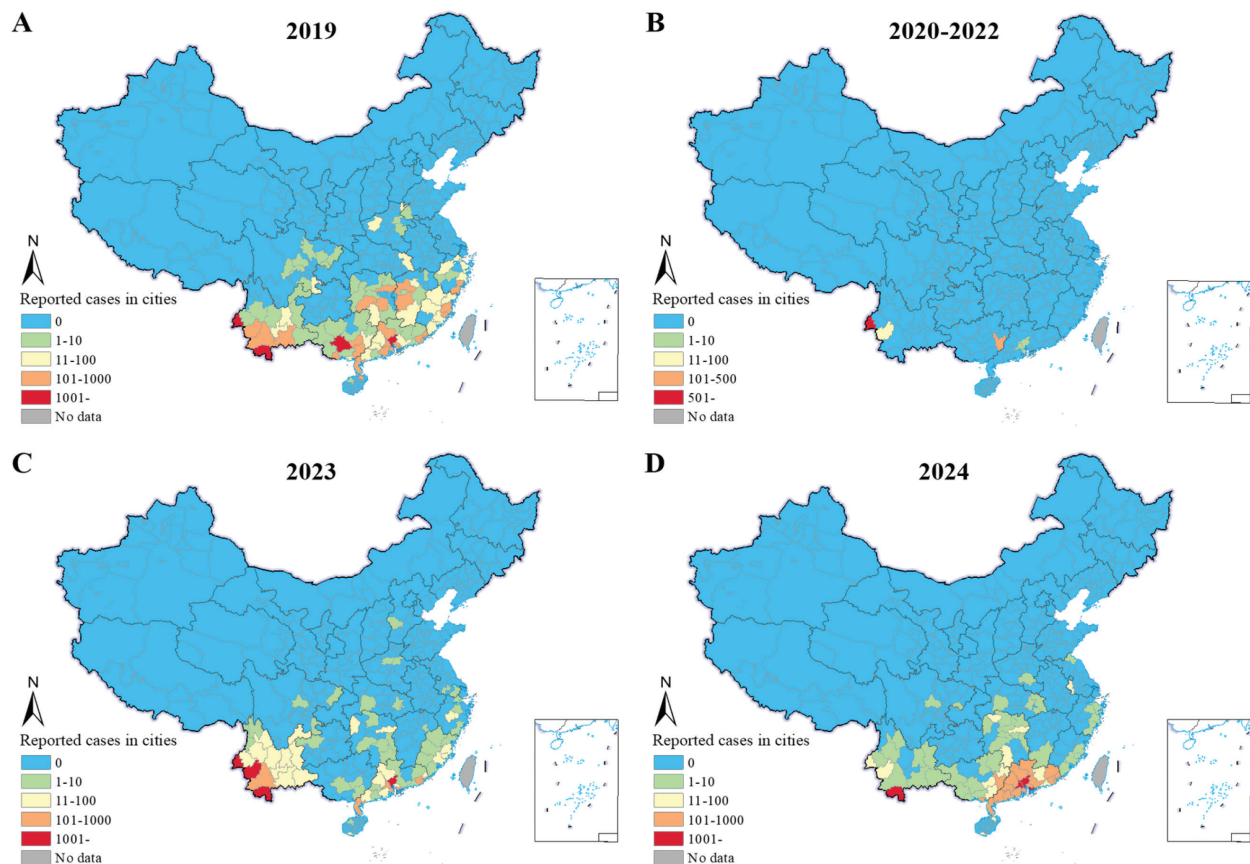


FIGURE 3 | Regional distribution of reported DF cases in mainland China between 2019 and 2024. (A): Geographic distribution of reported DF cases based on city level in mainland China in 2019. (B): Geographic distribution of reported DF cases based on city level in mainland China in 2020–2022. (C): Geographic distribution of reported DF cases based on city level in mainland China in 2023. (D): Geographic distribution of reported DF cases based on city level in mainland China in 2024.

transmitted from Yunnan. The increasing proportion of inter-provincial transmission of DF cases presented a dual challenge posed by imported and other PLADs transmitted infections. The contribution of Yunnan was significantly lower (113 cases) in 2019, with Zhejiang (23 cases), Sichuan (12 cases), Chongqing (11 cases), and Guangdong (10 cases) receiving most cases.

DISCUSSION

Over the past several decades, China has been grappling with the escalating risk of DF transmission, represented by an increase in the number of cases and an expansion in the geographic distribution. In recent years the epidemiological characteristics of DF have undergone notable changes. The current study indicated that the initial detection of a local epidemic in Yunnan occurred approximately 1 month earlier. Yunnan and Guangdong accounted for > 50% of indigenous DF cases with subsequent triggered inter-provincial transmission. Moreover, the primary origin of reported DF cases shifted from Cambodia to Myanmar. Overall, these findings highlight the dynamic changes in DF transmission characteristics in China.

The number of DF cases decreased significantly between 2020 and 2022 due to the impact of the COVID-19 pandemic. The number of DF cases reported in 2023 was slightly less than 2019, even though the seasonal pattern did not change. The peak number of reported DF cases during the season was reduced compared to 2019. Notably, a reduction in the number of DF cases has been observed in most hotspot PLADs, such as Guangdong and Hainan. Conversely, a significant surge has been recorded in Yunnan, which has also been reported in previous studies [11]. In 2023 an earlier onset was reported with a higher peak and longer duration of reported DF cases in Yunnan. This change may have resulted from the interactions of a range of factors. As a border PLADs adjacent to Southeast Asian countries where DF is endemic, Yunnan experienced a heightened prevalence of local DF outbreaks primarily driven by imported cases from neighboring nations [12]. The World Health Organization (WHO) documented a significant escalation in DF cases in several countries in 2023, including Myanmar, Laos and Thailand, compared to previous years [13]. Previous studies have shown that DF is non-endemic in Yunnan and the local DF outbreaks are closely related to imported cases from outside the country and the timeline of imported

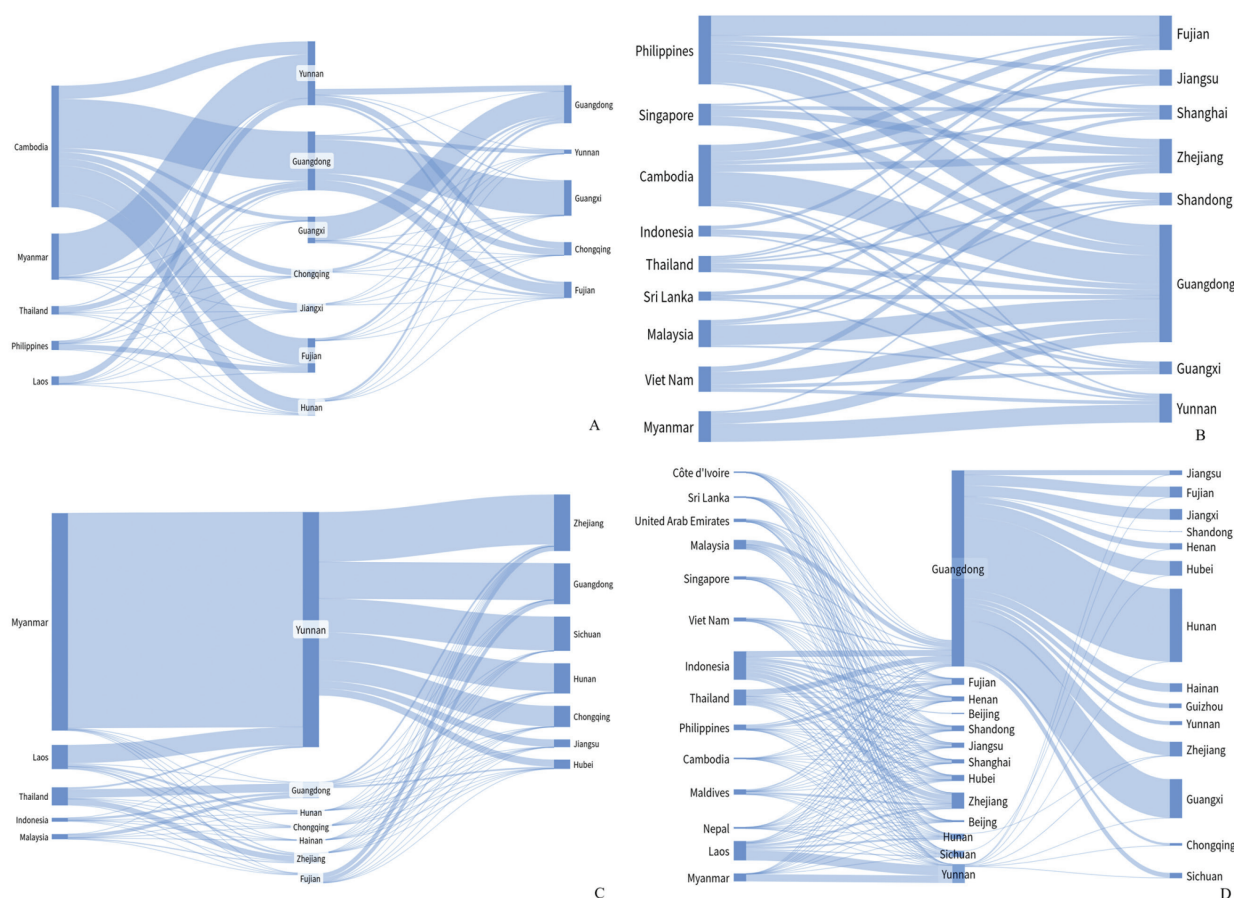


FIGURE 4 | Flow of imported and inter-provincial transmission DF cases in 2019 and 2024. (A): Flow of imported and inter-provincial transmission DF cases in 2019. (B): Flow of imported and inter-provincial transmission DF cases in 2020–2022. (C): Flow of imported and inter-provincial transmission DF cases in 2023. (D): Flow of imported and inter-provincial transmission DF cases in 2024.

cases will affect the timing of local outbreaks [14,15]. With downgrading of the control of the COVID-19 epidemic, the interactions between China and Southeast Asian nations have been reinforced. In 2023 the number of people entering and exiting ports in Yunnan reached 14.284 million, marking a year-on-year increase of 890% [16]. In 2023 the main source of importing countries changed from Cambodia-to-Myanmar with the second and third remaining unchanged for Laos and Thailand. All of the countries are adjacent to Yunnan. This significant surge underscores the heightened risk of local DF outbreaks.

As one of the most open PLADs in China, Guangdong annually received a substantial number of international travelers, which created a prerequisite for the indigenous transmission triggered by imported cases [17]. The annual average temperature in Guangdong ranged from 22–25°C with an annual precipitation exceeding 1800 mm [17]. These warm and humid conditions are optimal for breeding habitats of *A. aegypti* and *A. albopictus*. Furthermore, rapid urbanization, a continuous influx of floating populations, and persistently high urban population densities significantly increase the risk of DENV transmission [18]. Guangdong experienced significantly higher-than-normal precipitation in 2024. The rainy season commenced

earlier than usual, featured frequent and prolonged rainfall events, and recorded the highest pre-monsoon rainfall on record [19]. These hydrometeorologic anomalies substantially expanded mosquito breeding habitats, intensifying vector abundance and complicated control efforts, suggesting that prompt, effective vector control is crucial for containing outbreak spread.

As a common mosquito-borne viral disease, DF is characterized by the complex interactions between human hosts, the vector *Aedes* mosquitoes, the causative DENV, and environmental determinants [20,21]. Meteorologic variations, such as drought, precipitation, typhoons, and El Niño, may impact the mosquito vector breeding environment, thereby altering vector abundance. El Niño, the warm phase of the El Niño–Southern Oscillation (ENSO), is known to disrupt global atmospheric circulation, resulting in spectacle of seasonal temperature and precipitation [22]. This phenomenon is linked to elevated temperatures and aberrant rainfall in tropical regions. Studies have confirmed that ENSO events are potential risk factors contributing to the increased spread of vector-borne diseases [23]. In contrast with the cold phases of ENSO observed in 2021 and 2022, 2023 was marked by a swift transition into the ENSO-neutral region with a shift to El Niño

conditions by June [24]. In addition, the peak number of reported DF cases in Southeast Asian countries typically coincides with the rainy season from May-to-August [25,26]. The combined effects lead to variations in rainfall, temperature, and humidity, which in turn facilitates the proliferation of the *Aedes* mosquitoes. Correspondingly, this surge in *Aedes* mosquitoes significantly accelerates DF transmission globally, including China.

Currently, climate change and international travel pose significant challenges to the prevention and control of DF. By comparing the epidemiologic trends of DF across four periods, it was suggested that the control of DF should closely monitor international disease dynamics and enhance surveillance of incoming travelers and mosquito vectors. In indigenous DF control, mosquito prevention and elimination and the removal of breeding sites are of utmost importance. Therefore, enhanced community-based governance and resident health education are warranted. A comprehensive and participatory approach is essential to effectively curb the spread of DF.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the Chinese Center for Disease Control and Prevention but restrictions apply to the availability of these data, which were used under license for the current study. Data may be obtained from the authors upon reasonable request and with the explicit permission of the Chinese Center for Disease Control and Prevention.

ETHICS STATEMENT

The data on dengue fever were obtained from the Chinese Notifiable Infectious Disease Reporting System. Only aggregated, de-identified counts are presented; no individually identifiable or confidential information is disclosed and no clinical interventions were involved. Consequently, ethical approval was not required.

AUTHOR CONTRIBUTIONS

Hongrui Zhai, Huijie Qin, and Junyuan Chen jointly acquired and curated the data, performed the data analysis and interpretation, and drafted the manuscript. Qian Ren and Di Mu conceived and designed the study and established the overall research framework. Qiulan Chen critically revised and substantially improved the manuscript. Yanping Zhang oversaw all aspects of the work and is accountable for ensuring that any questions related to the accuracy or completeness of any part of the article are appropriately investigated and resolved.

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CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest.

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