Preplanned Studies

A Topographic Analysis of Malaria Transmission — Khyber Pakhtunkhwa, Pakistan, 2019–2022

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Summary

What is already known about this topic?

Malaria remains a recurrent public health problem and is among the leading contributors to morbidity and mortality in Pakistan. However, research specifically linking malaria transmission with topographic factors in Pakistan is limited.

What is added by this report?

This study supplements existing knowledge by examining malaria transmission across different topographic regions of Khyber Pakhtunkhwa Province, Pakistan. High-altitude regions experienced low transmission, whereas low-altitude regions showed high transmission rates.

What are the implications for public health practice?

Considering topography in malaria control strategies may help policymakers design more targeted and effective prevention measures to reduce the burden of recurrent malaria in the region.

ABSTRACT

Introduction: Malaria is a major public health concern in Pakistan. Data examining the relation between topography and malaria transmission in Pakistan are limited. This study aimed to analyze malaria transmission in relation to topography across Khyber Pakhtunkhwa from 2019 to 2022.

Methods: This retrospective study analyzed malaria case data collected from the provincial health department, the District Health Information System, and district health offices across Khyber Pakhtunkhwa. Time-series analysis was conducted to determine malaria trends over time.

Results: The results showed the highest cumulative case counts in Charsadda (303,900), Dera Ismail Khan (292,070), and Bannu (241,640), whereas high-altitude districts, such as Kolai Palas (2.56 km), reported far fewer cases (<1,000). These findings indicate an inverse relation between altitude and malaria incidence, highlighting high vector density in low-altitude regions.

Conclusion: Topography strongly influences malaria risk. Integrating elevation-based spatial data into provincial malaria control policies is recommended.

Malaria remains a major public health concern, with more than 282 million cases and over 610,000 deaths reported worldwide by 2024, despite decades of progress in control and prevention efforts. Millions of people in Pakistan are affected annually (*1*). The global disease burden of malaria is particularly high in sub-Saharan Africa and parts of Asia, where environmental and geographical conditions strongly influence the transmission dynamics of *Plasmodium* parasites (*2*). Malaria control strategies in Pakistan focus on optimal resource allocation to enhance surveillance and reduce disease burden, particularly in the context of population vulnerability, displacement, and climate change (*3*).

Despite intensive efforts to eliminate malaria since the 1960s, the disease resurged in the 1970s and has remained endemic in several regions because of multiple factors, including environmental and socioeconomic conditions that contribute to transmission (*4*). Topography is an important determinant of malaria transmission, as regions with high elevation and low temperatures generally exhibit low transmission risk (*5*). However, recent advances in spatial modeling, remote sensing, and Geographic Information Systems have enhanced malaria risk assessment by producing high-resolution risk maps (*6*).

Malaria is recurrent across all provinces of Pakistan; however, the country remains a low-resource setting and bears a high burden of malaria-related morbidity, mortality, and prevention costs. Topographic variations in Khyber Pakhtunkhwa (KP) have not been adequately considered in previous analyses. Therefore, this study analyzed malaria transmission patterns in KP from 2019 to 2022.

Secondary data on malaria incidence were obtained from the Provincial District Health Information System and District Health Offices across multiple districts. These data included the number of malaria cases reported in each district. Case records were initially verified by a district medical entomologist and subsequently approved by a provincial medical entomologist. Blood smear microscopy was used for malaria diagnosis (*1*). Data on latitude, longitude, and altitude were obtained from the Provincial Meteorological Department, Peshawar.

KP is located in northwestern Pakistan and is the third most populous province in the country. The study population included all districts of KP, while the target population comprised malaria-sensitive districts. The province was categorized into three zones to assess the impact of topography on malaria transmission:

Southern KP: Bannu, Tank, Karak, and Dera Ismail Khan.

Northern KP: Haripur, Abbottabad, Dir, Kohistan, Swat, and Chitral.

Central KP: Peshawar, Charsadda, Nowshera, and Mardan.

Districts were further classified as low-altitude (<0.46 km), mid-altitude (0.46–1.22 km), and high-altitude (>1.22 km; Supplementary Table S1, available at https://weekly.chinacdc.cn/).

The topographic distribution of KP highlighting high-altitude regions, such as Chitral and Swat, and low-altitude regions, such as Bannu and Dera Ismail Khan.

Statistical analyses were performed using SPSS (version 25.0, Armonk, NY, USA: IBM Corp.). Pearson's correlation analysis was used to assess the association between altitude and malaria incidence. QGIS software was used to generate maps and figures. A time-series analysis was conducted to examine malaria trends across KP districts. Space–time permutation scan statistics were applied to identify malaria hotspots in the region.

The incidence of malaria varies across the topography of KP from 2019 to 2022. Between 2019 and 2022, the confirmed malaria cases varied significantly across the KP districts (Table 1). Charsadda had the highest cumulative burden (303,900 cases), followed by Dera Ismail Khan (292,070 cases), Bannu (241,640 cases), and Mardan (233,749 cases). By contrast, districts, such as Kohistan Lower (423 cases), Kolai Palas (606 cases), and Kohistan Upper (1,637 cases), recorded the lowest number of cases. Districts with low altitudes, such as Dera Ismail Khan (0.18 km) and Lakki Marwat (0.17 km), reported high case numbers, whereas high-altitude regions, such as Kolai Palas (2.56 km) and Kohistan Upper (1.91 km), showed markedly fewer cases. Malaria incidence per 10,000 population is shown in Supplementary Table S1, which indicates that northern districts have a lower incidence than southern districts with low altitude.

Districts, such as Bannu, Dera Ismail Khan, and Lakki Marwat, are located at low altitude but accounted for more than 60% of cases; similarly, in central KP, Peshawar, Mardan, Charsadda, and Nowshera recorded higher confirmed malaria cases compared with those of other districts of KP (Figure 1). A negative correlation was observed between altitude and malaria incidence rates from 2019 to 2022 (Figure 2). Space–time permutation analysis was used to identify hotspot districts based on incidence (Supplementary Figure S1, available at https://weekly.chinacdc.cn/). Lakki Marwat and Tank, located at low altitudes, exhibited the highest incidence rates, indicating persistent spatial hotspots, whereas Shangla, Hangu, and Bannu demonstrated emerging and expanding temporal risks. Districts located at low altitudes (<1,500 ft) had a high malaria burden, whereas high-altitude districts (>4,000 ft) consistently reported low case counts.

DISCUSSION

This study investigated the spatial distribution of malaria incidence based on topographic features across several districts of KP, Pakistan. The findings demonstrate a strong association between malaria incidence and topographic factors.

Spatial heterogeneity in vector density and disease risk has emerged as a major concern. Kouame et al. showed that even within the same region, the relation between vector abundance and malaria incidence may differ because of local geographical and environmental factors (*7*). This insight is particularly important in the context of KP, where variable topography creates localized transmission patterns that cannot be addressed using uniform control approaches. In our study, malaria incidence hotspot districts were identified, showing that low-altitude areas had high malaria case counts. This pattern suggests that altitude plays a modifying role in malaria transmission within provinces. There is evidence that malaria transmission declines with increasing altitude, as highland areas

TABLE 1. District-wise confirmed malaria cases in Khyber Pakhtunkhwa.

District	2019 (*n*)	2020 (*n*)	2021 (*n*)	2022 (*n*)	Latitude (º N)	Longitude (º E)	Altitude (km)
Bannu	32,640	68,284	70,983	69,733	32.986	70.604	0.36*
Dera Ismail Khan	51,209	78,252	75,800	86,809	31.862	70.901	0.18*
Lakki Marwat	34,240	50,705	48,114	85,480	32.613	70.901	0.17*
Tank	25,734	22,807	25,132	33,576	32.216	70.389	0.26*
Abbottabad	1,861	190	923	474	34.168	73.221	1.26§
Haripur	7,263	3,530	3,996	5,019	33.994	72.910	0.52†
Kohistan Upper	402	133	412	690	34.250	73.500	1.91§
Mansehra	1,901	1,087	1,586	1,756	34.331	73.198	1.09†
Battagram	419	632	279	2,352	34.672	73.024	1.04†
Tor Ghar	1,821	525	266	1,907	34.449	70.199	2.44§
Kohistan Lower	20	62	169	172	35.250	73.500	1.68§
Kolai-Palas	20	24	100	462	35.100	73.000	2.56§
Karak	13,243	17,306	17,084	25,813	33.111	71.091	0.55†
Kohat	22,048	24,612	25,746	40,640	33.589	71.443	0.49†
Hangu	13,073	17,598	21,335	31,138	33.522	71.062	0.81†
Buner	21,096	18,184	32,177	48,014	34.394	72.615	0.80†
Chitral Lower	6,621	3,327	5,445	4,143	35.370	71.740	1.49§
Dir Lower	27,721	27,640	39,994	47,309	35.370	71.740	0.97†
Malakand	16,711	11,886	14,543	20,104	34.503	71.905	0.45*
Swat	21,085	23,280	17,684	14,066	35.223	72.426	0.98†
Dir Upper	12,883	11,434	12,011	7,234	35.208	71.875	1.84§
Shangla	14,419	20,157	26,066	41,316	34.802	72.757	1.52§
Chitral Upper	679	332	484	453	35.833	71.783	1.50§
Mardan	45,446	48,968	57,322	82,013	34.199	72.040	0.28*
Swabi	7,182	4,589	4,527	4,230	34.117	72.281	0.34*
Charsadda	53,718	74,692	87,219	88,271	34.149	71.743	0.30*
Nowshera	29,467	20,780	29,518	43,286	34.011	71.988	0.55†
Peshawar	8,852	7,274	10,713	37,370	34.026	71.560	0.37*

* means low altitude (<0.46 km);
† means mid-altitude (0.46–1.22 km);
§ means high altitude (>1.22 km).

report significantly fewer cases than those of low-altitude areas (*8*). Previous studies have developed high-resolution malaria models incorporating population density, climate, and surface hydrology (*9*). In our study, districts with seasonal flooding and irrigation infrastructure had high malaria incidence, which is consistent with these findings. Furthermore, our results align with those of studies from Africa that identified significant associations between malaria frequency and topographic variables, such as elevation and slope. Their spatial modeling approaches informed the analytical framework of our study, underscoring the need to incorporate topography into disease surveillance systems. High topographic features restrict malaria transmission from highland areas to lowlands, where malaria-related morbidity is high (*2*).

Geographical highlands influence vector density. Bannu District, a southern district, has a low altitude but high mosquito density, which leads to elevated malaria prevalence. Malaria transmission is higher in KP than in other provinces, such as Punjab and Sindh (*3*). Punjab may have more effective vector control strategies. In addition to altitude, increased temperature (≥22.4 °C) enhances vector density and, consequently, malaria transmission (*10*). Climatic factors, such as high rainfall, humidity, and flooding, promote habitat development, vector population growth, vector longevity, and breeding site availability,

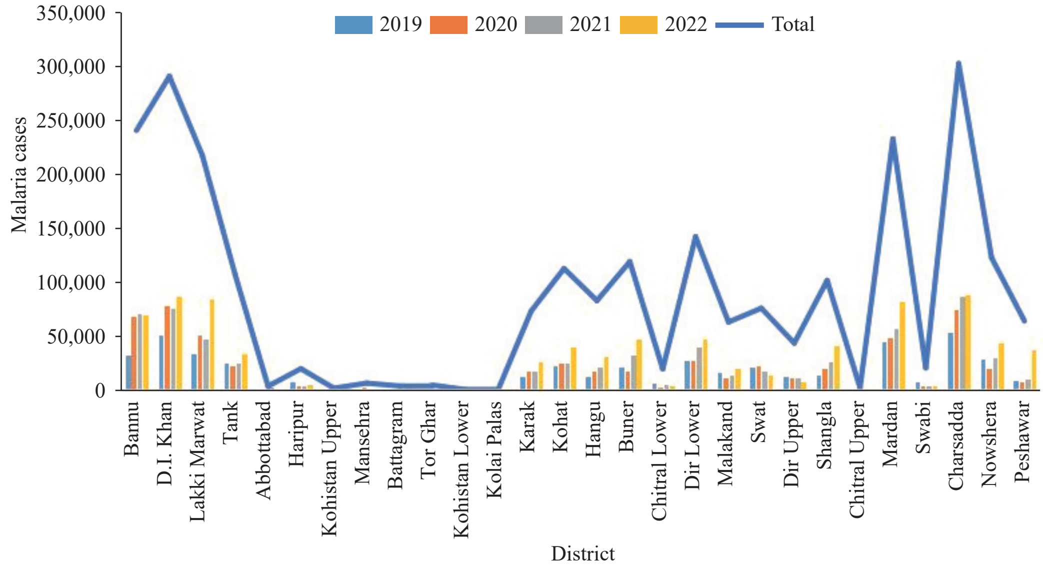

FIGURE 1. Confirmed malaria cases in various districts of Khyber Pakhtunkhwa, Pakistan.
Note: Low-altitude districts [including Bannu and Dera Ismail (D.I) Khan] accounted for more than 60% of total cases.

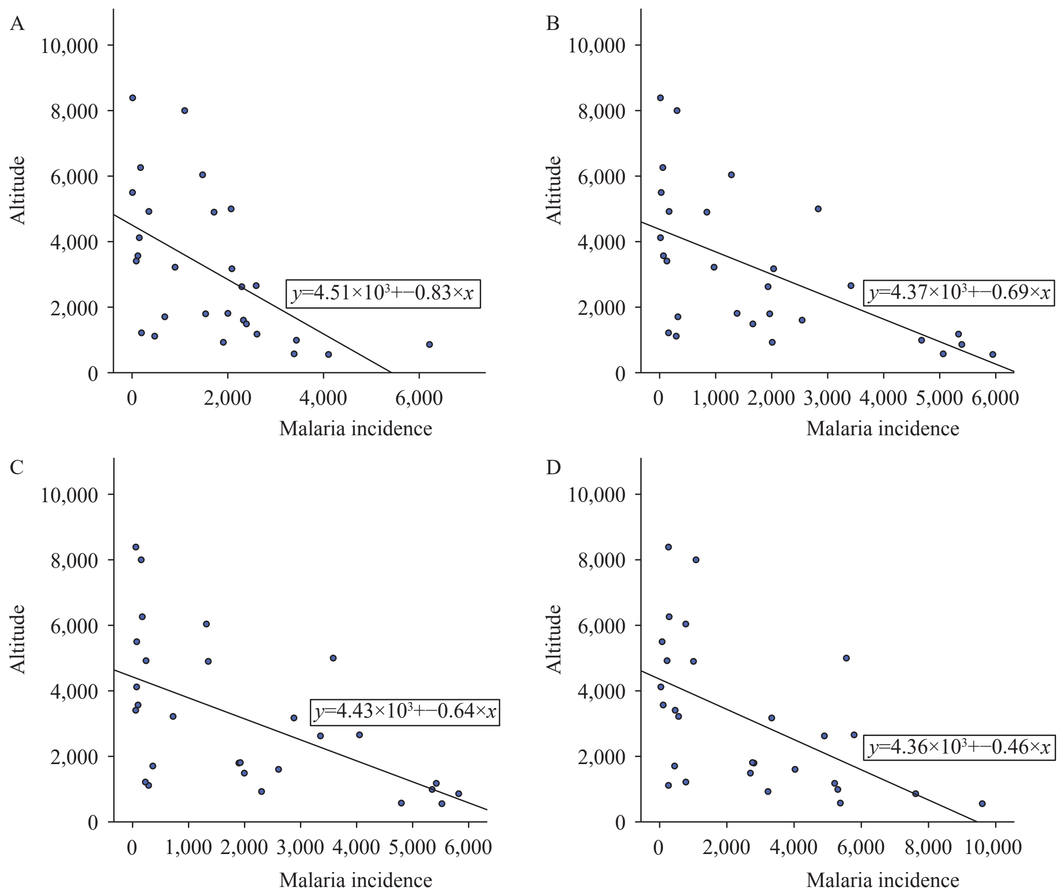

FIGURE 2. Scatter plot of altitude versus malaria incidence rates in Khyber Pakhtunkhwa. (A) 2019; (B) 2020; (C) 2021; (D) 2022.
Note: There was a negative correlation between altitude and malaria incidence across the study period; the altitude was measured in feet.

thereby facilitating malaria transmission. Several studies have examined malaria incidence in parts of KP; however, these efforts have largely been limited to district-level analyses or have focused primarily on environmental factors (*3*,*10*). These studies assessed the effects of temperature, humidity, and rainfall on malaria incidence in Pakistan. By contrast, there remains a lack of systematic topographic evaluations assessing how elevation, slope, and terrain influence malaria transmission across Pakistan, particularly in KP. Furthermore, no previous study has specifically examined spatial trends using province-wide data from KP.

This study has some limitations. First, data were obtained from the District Health Information System and district health offices. Malaria cases are often underreported because of poor communication or because hospital and facility staff are engaged in competing responsibilities. Second, at the district level, there is typically only one medical epidemiologist responsible for multiple facilities, which further contributes to data limitations.

In conclusion, this study highlighted the importance of topography in malaria transmission. High altitudes were associated with few cases, whereas low altitudes were associated with high malaria transmission in KP. Altitude was negatively correlated with malaria incidence throughout the study period. Low-altitude districts with a high malaria burden require weekly surveillance, including hotspot mapping and the allocation of up to 150,000 rapid diagnostic tests (RDTs) per year. Mid-altitude districts require biweekly monitoring, hotspot mapping, and the allocation of up to 70,000 RDTs per year. High-altitude districts with a low malaria burden require monthly surveillance, hotspot monitoring, and the allocation of up to 10,000 RDTs per year. Policymakers should consider altitude-related risks in hotspot areas when designing malaria prevention strategies in the region.

Conflicts of interest: No conflict of interest.

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SUPPLEMENTARY MATERIAL

SUPPLEMENTARY TABLE S1. Estimated district-wise population and malaria incidence per 100,000 population with 95% *CI* (2019–2022).

District	Pop.				Cases				Incidence/100,000*			
	2019	2020	2021	2022	2019	2020	2021	2022	2019	2020	2021	2022
Bannu	1,250,886	1,279,657	1,309,089	1,339,198	32,640	68,284	70,983	69,733	2,609.35 (2,575.28, 2,643.42)	5,336.12 (5,281.09, 5,391.16)	5,422.32 (5,365.58, 5,479.06)	5,207.07 (5,152.03, 5,262.11)
Dera Ismail Khan	1,512,447	1,545,721	1,579,727	1,614,481	51,209	78,252	75,800	86,809	3,385.84 (3,348.83, 3,422.85)	5,062.49 (5,011.44, 5,113.54)	4,798.30 (4,746.14, 4,850.46)	5,376.90 (5,323.48, 5,430.31)
Lakki Marwat	834,137	852,488	871,243	890,410	34,240	50,705	48,114	85,480	4,104.84 (4,044.34, 4,165.34)	5,947.88 (5,871.53, 6,024.23)	5,522.45 (5,448.25, 5,596.65)	9,600.07 (9,507.64, 9,692.50)
Tank	414,104	422,800	431,679	440,744	25,734	22,807	25,132	33,576	6,214.38 (6134.55, 6294.21)	5,394.28 (5325.83, 5462.73)	5,821.92 (5746.74, 5897.10)	7,618.03 (7528.20, 7707.86)
Abbottabad	1,228,714	1,253,288	1,278,354	1,303,921	1,861	190	923	474	151.46 (144.61, 158.31)	15.16 (8.67, 21.64)	72.20 (67.21, 77.19)	36.35 (33.09, 39.61)
Haripur	1,062,422	1,083,670	1,105,344	1,127,450	7,263	3,530	3,996	5,019	683.63 (668.84, 698.42)	325.74 (314.61, 336.87)	361.52 (349.72, 373.32)	445.16 (431.92, 458.40)
Kohistan Upper	226,487	232,149	237,953	243,902	402	133	412	690	177.49 (160.41, 194.57)	57.29 (48.00, 66.58)	173.14 (156.06, 190.22)	282.90 (262.52, 303.28)
Mansehra	1,564,393	1,597,245	1,630,787	1,665,034	1,901	1,087	1,586	1,756	121.52 (115.95, 127.09)	68.05 (63.81, 72.29)	97.25 (91.61, 102.89)	105.46 (99.82, 111.10)
Battagram	478,520	488,569	498,829	509,304	419	632	279	2,352	87.56 (79.44, 95.68)	129.36 (118.84, 139.88)	55.93 (49.36, 62.50)	461.81 (443.58, 480.04)
Tor Ghar	165,641	169,120	172,671	176,297	1,821	525	266	1,907	1,099.37 (1,047.35, 1,151.39)	310.43 (284.34, 336.52)	154.05 (137.86, 170.24)	1,081.70 (1,030.66, 1,132.74)
Kohistan Lower	217,428	222,863	228,435	234,146	20	62	169	172	9.20 (5.35, 13.05)	27.82 (21.04, 34.60)	73.98 (62.76, 85.20)	73.46 (62.23, 84.69)
Kolai-Palas	163,071	167,147	171,326	175,609	20	24	100	462	12.26 (7.09, 17.43)	14.36 (8.56, 20.16)	58.37 (47.60, 69.14)	263.08 (239.68, 286.48)
Karak	861,636	880,592	899,965	919,765	13,243	17,306	17,084	25,813	1,536.96 (1,509.83, 1,564.09)	1,965.27 (1,931.57, 1,998.97)	1,898.30 (1,865.07, 1,931.53)	2,806.48 (2,764.51, 2,848.45)
Kohat	947,838	967,742	988,065	100,8814	22,048	24,612	25,746	40,640	2,326.14 (2,291.65, 2,360.63)	2,543.24 (2,505.27, 2,581.21)	2,605.70 (2,567.05, 2,644.35)	4,028.49 (3,977.21, 4,079.77)
Hangu	504,149	515,240	526,575	538,160	13,073	17,598	21,335	31,138	2,593.08 (2,552.10, 2,634.06)	3,415.50 (3,360.11, 3,470.89)	4,051.65 (3,987.36, 4,115.94)	5,786.01 (5,712.45, 5,859.57)
Buner	920,231	939,556	959,286	979,431	2,1096	18,184	32,177	48,014	2,292.47 (2,248.01, 2,336.93)	1,935.38 (1,891.49, 1,979.27)	3,354.27 (3,297.77, 3,410.77)	4,902.23 (4,832.93, 4,971.53)
Chitral Lower	386,497	394,613	402,900	411,361	6,621	3,327	5,445	4,143	1,713.08 (1,669.04, 1,757.12)	843.10 (816.18, 870.02)	1,351.45 (1,307.02, 1,395.88)	1,007.14 (970.85, 1,043.43)
Dir Lower	1,329,120	1,358,361	1,388,245	1,418,786	27,721	27,640	39,994	47,309	2,085.67 (2,044.16, 2,127.18)	2,034.81 (1,993.22, 2,076.40)	2,880.90 (2,825.12, 2,936.68)	3,334.47 (3,274.19, 3,394.75)
Malakand	699,375	714,062	729,058	744,368	16,711	11,886	14,543	20,104	2,389.42 (2,343.19, 2,435.65)	1,664.56 (1,619.48, 1,709.64)	1,994.77 (1,943.16, 2,046.38)	2,700.81 (2,643.05, 2,758.57)

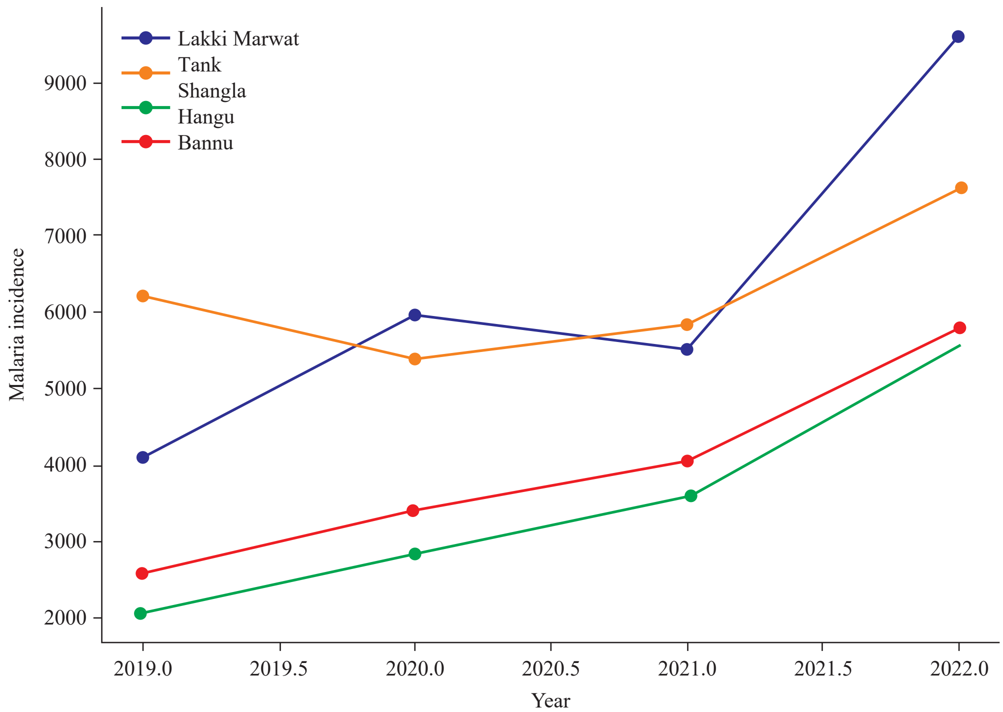
Continued

District	Pop.				Cases				Incidence/100,000*			
	2019	2020	2021	2022	2019	2020	2021	2022	2019	2020	2021	2022
Swat	2,346,589	2,395,868	2,446,181	2,49,7551	21,085	23,280	17,684	14,066	898.54 (873.53, 923.55)	971.67 (944.92, 998.42)	722.92 (692.53, 753.31)	563.19 (533.81, 592.57)
Dir Upper	874,219	892,578	911,322	930,460	12,883	11,434	12,011	7,234	1,473.66 (1,434.42, 1,512.90)	1,281.01 (1,243.91, 1,318.11)	1,317.98 (1,280.63, 1,355.33)	777.46 (740.58, 814.34)
Shangla	696,642	711,968	727,632	743,639	14,419	20,157	26,066	41,316	2,069.79 (2,023.69, 2,115.89)	2,831.17 (2,774.85, 2,887.49)	3,582.31 (3,515.63, 3,649.00)	5,555.92 (5,478.41, 5,633.43)
Chitral Upper	193,248	197,306	201,450	205,680	679	332	484	453	351.36 (323.58, 379.14)	168.27 (147.50, 189.04)	240.26 (216.15, 264.37)	220.25 (196.82, 243.68)
Mardan	2,383,250	2,435,682	2,489,267	2,544,031	45,446	48,968	57,322	82,013	1,906.89 (1,869.21, 1,944.57)	2,010.44 (1,971.21, 2,049.67)	2,302.77 (2,259.63, 2,345.91)	3,223.74 (3,171.82, 3,275.66)
Swabi	1,518,381	1,550,267	1,582,823	1,616,062	7,182	4,589	4,527	4,230	473.00 (456.88, 489.12)	296.01 (282.54, 309.48)	286.01 (272.90, 299.12)	261.75 (248.44, 275.06)
Charsadda	1,564,393	1,597,245	1,630,787	1,665,034	53,718	74,692	87,219	88,271	3,433.79 (3,389.57, 3,478.01)	4,676.30 (4,620.33, 4,732.27)	5,348.28 (5,287.39, 5,409.17)	5,301.45 (5,239.84, 5,363.06)
Nowshera	1,472,370	1,503,289	1,534,859	1,567,091	29,467	20,780	29,518	43,286	2,001.33 (1,958.33, 2,044.33)	1,382.30 (1,343.47, 1,421.13)	1,923.17 (1,880.45, 1,965.89)	2,762.19 (2,711.65, 2,812.73)
Peshawar	4,491,511	4,590,324	4,691,311	4,794,520	8,852	7,274	10,713	37,370	197.08 (183.52, 210.64)	158.46 (146.36, 170.56)	228.36 (213.77, 242.95)	779.43 (754.63, 804.23)

Note: Between 2019 and 2022, malaria incidence across districts showed substantial spatial and temporal variation. Southern districts, including Lakki Marwat, Tank, Bannu, Dera Ismail Khan, and Hangu, recorded the highest malaria incidence, consistently exceeding 2,000 cases per 100,000 population, with Lakki Marwat peaking at 9,600 cases per 100,000 population in 2022. By contrast, northern districts, including Abbottabad, Haripur, Mansehra, and Swat, exhibited markedly low incidence, often below 500 cases per 100,000 population, indicating low transmission potential or more effective control.

Abbreviation: Pop=population; *CI*=confidence interval.

* shown as incidence (95% *CI*).



SUPPLEMENTARY FIGURE S1. Space–time clustering characterized by a progressive increase in malaria incidence from 2019 to 2022.

Note: ".0" in years means the start of the year.