ANALYSIS OF SPATIAL AND TEMPORAL PATTERNS OF COVID-19 INCIDENCE IN THAILAND

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Abstract. Knowing the variations in the incidence and locations of coronavirus disease 2019 (COVID-19) over time can enable us to better understand its epidemiology. In this study we aimed to determine COVID-19 incidence patterns over space and time and identify factors significantly associated with those patterns in Thailand in order to inform efforts to control this disease in Thailand. We obtained data regarding the COVID-19 cases reported daily to the Department of Disease Control, Ministry of Public Health (MoPH) for Thailand during January 2020-April 2022. We pooled the daily cases into monthly cases and separated them by gender, age group, province and year. The COVID-19 incidence rates per 1,000 population were calculated. A log-linear model was used to investigate COVID-19 incidence patterns over time and space in Thailand and identify factors significantly associated with these cases. Subjects were grouped by age into 8 groups. A total of 3,334,331 subjects were included in our study. The median COVID-19 incidence was 1.27 (average: 3.51; range: 0-105.33) cases per 1,000 population per month. The groups with significantly higher incidences of COVID-19 cases per 1,000 population in our study were males aged 20-29 years (incidence: 6.17, 95% confidence interval (CI): 5.88-6.48, p<0.001), males aged 30-39 years (incidence: 5.02, 95% CI: 4.96-5.46, p=0.003), males aged 40-49 years (incidence: 3.95, 95% CI: 3.77-4.15, p=0.050), females aged 20-29 years (incidence: 4.83, 95% CI: 4.60-5.07, p=0.010) and females aged 30-39 years (incidence: 4.18, 95% CI: 3.99-4.39, p=0.043). There were five temporal incidence wave peaks during the study period: April 2020 (incidence: 0.037, 95% CI: 0.033-0.041, p<0.001), January 2021 (incidence: 0.057, 95% CI: 0.052-0.063, p<0.001), June 2021 (incidence: 0.387, 95%CI: 0.367-0.407, p<0.001), August 2021 (incidence: 5.23, 95% CI: 4.99-5.48, p<0.001) and March 2022 (incidence: 12.19, 95% CI: 11.63-12.77, p<0.001), with the latter two being greater than the overall average.

Twenty-one provinces in central Thailand and 7 provinces in the southern Thailand had significantly higher COVID-19 incidence rates than the average. All provinces in northeastern Thailand and in northern Thailand, except Tak Province, had incidence rates lower than average. In summary, we found significantly higher than average incidence rates of COVID-19 among males aged 20-49 and females aged 20-39 years and significantly higher than average incidence rates during August 2021, February, March and April 2022 and significantly higher than average incidence rates in central and southern Thailand. We conclude, prevention efforts should focus on these age groups and genders in central and southern Thailand in order to have the greatest preventive benefit. Further studies are needed taking into account other factors, such as vaccinations and environmental factors to determine if other factors of COVID-19 incidence are relevant, especially since the advent of vaccinations to prevent COVID-19.

Keywords: COVID-19, incidence rate, spatial-temporal, log-linear model, patterns, Thailand

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INTRODUCTION

The coronavirus disease 2019 (COVID-19) was first reported publicly in December 2019 in Wuhan, Hubei Province, China (WHO, 2020a; Lu *et al*, 2020). COVID-19 is caused by the severe acute respiratory syndrome-coronavirus-2 (SARS-CoV-2) (Lu *et al*, 2020). The COVID-19 outbreak was declared to be a pandemic by the World Health Organization (WHO) in March 2020 (WHO, 2020b).

The first wave of COVID-19 in Thailand, which began in March 2020 and extended across 68 provinces, was triggered by spread among those attending boxing events and night clubs in Bangkok (Rajatanavin *et al*, 2021). The second wave began in mid-December 2020 and continued

until February 2021, when some Thai workers who had previously worked in a resort in northern Myanmar entered Thailand illegally and eluded the state quarantine (Rajatanavin *et al*, 2021; Wetchayont and Waiyasusri, 2021). The third wave of COVID-19, caused by the Alpha variant, began in mid-April 2021 (Uansri *et al*, 2021; Suphanchaimat *et al*, 2022). The fourth wave, caused by the Delta variant, began in June 2021, peaked in August 2021 and spread twice as fast as the original variant from China causing 5 times more cases than the previous wave (Uansri *et al*, 2021; Suphanchaimat *et al*, 2022). The fifth wave, caused by the Omicron variant, began in January 2022, peaked during March-April 2022 (Theparod *et al*, 2023) and was less severe but more easily transmitted than the previous variants (Daria and Islam, 2022; Suphanchaimat *et al*, 2022).

A COVID-19 vaccine was released toward the end of 2020 and began to be distributed in Thailand in February 2021 among health care workers first and then later to the general population (Pheerapanyawaranun *et al*, 2022). COVID-19 vaccination reduces COVID-19 disease severity, hospitalizations due to COVID-19 and mortality caused by COVID-19, but has a weaker effect on reducing COVID-19 incidence (WHO, 2021). By the end of 2022, 4.7 million people in Thailand had been infected with COVID-19, with 33,106 deaths (DDC, 2022).

COVID-19 distribution may vary over time and by place and be affected by other factors. Several studies have reported that males and females have similar infection rates (Lak *et al*, 2021; Nguyen *et al*, 2021). However, another study (Doerre and Doblhammer, 2022) reported among those of working age, infection risk was greater among women than men. They also reported infection rates varied by age group, with the highest incidence being among those aged 18-24 years (Doerre and Doblhammer, 2022).

Previous studies reporting COVID-19 incidences found incidences varied directly proportionally by distance from outbreak areas (Feng *et al*, 2020, Wu and Sha, 2021). Investigating the spatial and temporal patterns of COVID-19 incidence and their determinants is helpful for

understanding the epidemiology of the disease and can inform public health efforts to control the disease. These spatial and temporal patterns have not been well studied in Thailand. In this study we aimed to determine COVID-19 incidence patterns over space and time and identify factors significantly associated with those patterns in Thailand in order to inform efforts to control this disease in Thailand.

MATERIALS AND METHODS

Data source

We obtained data regarding the cases of COVID-19 reported daily to the Department of Disease Control, Ministry of Public Health (MoPH) for Thailand during January 2020-April 2022 from the following internet site: https://data.go.th/dataset/covid-19-daily. The data collected were: subject gender, age, province, month and year of infection and the numbers of new COVID-19 cases by month for each province. Gender was divided into either male or female. Subjects were divided into the following age groups: <20 years, 20-29 years, 30-39 years, 40-49 years, 50-59 years, 60-69 years, 70-79 years and ≥80 years. In order to eliminate interaction effects, gender and age groups were combined to form a 'gender-age' group and month and year were combined to form a 'month-year' group. Daily COVID-19 cases were combined to form monthly cases.

Statistical methods

Descriptive analyses were carried out: categorical variables, frequencies and percentages were calculated. For continuous variables, means and standard deviations (SD) were calculated. The monthly COVID-19 incidence rate was determined per 1,000 population. The incidence rate was calculated by dividing the number of infected cases by the total population in that province for each age group and year and then multiplied by 1,000. The determinants were gender-age, month-year and province. The incidence rate was transformed using the natural logarithm. A log-linear model was used to assess the spatial and temporal COVID-19 incidence rates for Thailand. The log-linear model used modeled the exponential increase or decrease in the incidence

of a disease over time by modeling the log of the number of infections as a linear function of time. The following is the log-linear equation used:

$$\ln\left(\frac{n_{ijk}}{P_{ijk}}\times 1{,}000\right)=y_{ijk}=\mu+\alpha_i+\beta_j+\delta_k$$

where P_i is the population in the gender-age group i for the year j and province k. n_{ijk} is the number of COVID-19 reported cases for the gender-age group i, during that month-year j for the province k. μ is the overall COVID-19 incidence rate. α_i is the effect of the gender-age group i. β_j is the effect of the month-year group j. δ_k is the effect of province k. The coefficients obtained from the log-linear model were converted to the incidence rate per 1,000 population and a plot of the 95% confidence interval for the incidence rate per 1,000 population by gender, age group, month, year, and province was constructed. The statistical calculations were performed using R program, version 4.2.0, (R Core Team, 2022).

RESULTS

A total of 3,334,331 subjects were included in the study; 1,844,567 (55.32%) females. The mean (±standard deviation) age of subjects was 36.66 (±19.47) years; 32.15% were males aged <40 years and 27.9% were females aged <40 years. 18.31%, 15.09% and 14.85% of cases occurred during March 2022, April 2022 and August 2021, respectively. The province with the greatest proportion of cases was Bangkok Metropolis (17.12% of cases), followed by Samut Prakan Province (6.11%) and Chonburi Province (6.10%). The average overall monthly COVID-19 incidence rate was 3.51 cases per 1,000 population and the median monthly incidence rate was 1.27 cases per 1,000 population. Males aged 20-29 had the highest monthly incidence rate (5.46 per 1,000 population), followed by males aged 30-39 and males aged 40-49 (4.96 and 3.85 cases per 1,000 population), females aged 20-29 years (4.07 cases per 1,000 population), females aged 30-39 years (3.70 cases per 1,000 population) and females aged <20 years 3.41 cases per 1,000 population). The highest incidence rate occurred in March 2022 (10.40 cases per 1,000 population), followed by April 2022 (8.37 cases per 1,000 population) and August 2021 (6.48 cases per 1,000

Table 1

Demographic characteristics, place and year of COVID-19 infected subjects (N = 3,334,331)

Factor	Frequency *n* (%)	Incidence per 1,000 population
Male: age in years		
<20	333,097 (9.99)	3.44
20-29	385,730 (11.57)	5.46
30-39	353,204 (10.59)	4.96
40-49	294,936 (8.85)	3.85
50-59	233,788 (7.01)	3.32
60-69	141,300 (4.24)	3.09
70-79	67,988 (2.04)	3.10
≥80	34,524 (1.04)	3.04
Female: age in years		
<20	347,331 (10.42)	3.41
20-29	306,550 (9.19)	4.07
30-39	276,504 (8.29)	3.70
40-49	223,829 (6.71)	2.89
50-59	164,105 (4.92)	2.48
60-69	99,767 (2.99)	2.58
70-79	49,550 (1.49)	2.96
≥80	22,128 (0.66)	3.28
Year 2020		
January	2 (0)	0.02
February	12 (0)	0.01
March	1,457 (0.04)	0.05
April	1,152 (0.03)	0.08
May	101 (0)	0.03

Table 1 (cont)

Factor	Frequency *n* (%)	Incidence per 1,000 population
June	90 (0)	0.02
July	137 (0)	0.03
August	89 (0)	0.03
September	105 (0)	0.02
October	141 (0)	0.03
November	125 (0)	0.02
December	1,012 (0.03)	0.07
Year 2021		
January	3,527 (0.11)	0.20
February	1,954 (0.06)	0.24
March	1,160 (0.03)	0.09
April	30,874 (0.93)	0.36
May	63,703 (1.91)	0.57
June	65,612 (1.97)	0.74
July	246,418 (7.39)	3.15
August	495,314 (14.85)	6.48
September	31,6142 (9.48)	4.20
October	235,811 (7.07)	3.57
November	145,728 (4.37)	2.27
December	76,389 (2.29)	1.24
Year 2022		
January	167,512 (5.02)	2.20
February	366,180 (10.98)	5.10
March	610,481 (18.31)	10.40
April	503,103 (15.09)	8.37

Table 1 (cont)

Factor	Frequency *n* (%)	Incidence per 1,000 population
Central region by provinces		
Bangkok Metropolis	570,929 (17.12)	4.11
Samut Prakan	203,894 (6.11)	7.02
Nonthaburi	112,938 (3.39)	4.54
Pathum Thani	72,163 (2.16)	3.38
Phra Nakhon Si Ayutthaya	64,465 (1.93)	4.73
Ang Thong	24,672 (0.74)	5.90
Lopburi	32,499 (0.97)	3.11
Sing Buri	10,264 (0.31)	3.69
Chai Nat	6,605 (0.20)	1.47
Saraburi	49,200 (1.48)	5.13
Chonburi	203,375 (6.10)	5.50
Rayong	77,052 (2.31)	6.18
Chanthaburi	37,090 (1.11)	4.40
Trat	13,441 (0.40)	4.43
Chachoengsao	70,428 (2.11)	6.28
Prachinburi	46,857 (1.41)	6.26
Nakhon Nayok	21,422 (0.64)	5.77
Sa Kaeo	31,356 (0.94)	4.10
Ratchaburi	67,426 (2.02)	5.09
Kanchanaburi	41,776 (1.25)	3.75
Suphan Buri	42,891 (1.29)	3.50
Nakhon Pathom	72,315 (2.17)	4.44
Samut Sakhon	123,236 (3.70)	11.96
Samut Songkhram	22,511 (0.68)	7.85

Table 1 (cont)

Factor	Frequency *n* (%)	Incidence per 1,000 population
Phetchaburi	34,162 (1.02)	4.51
Prachuap Khiri Khan	35,024 (1.05)	4.43
Northern region by provinces		
Chiang Mai	25,118 (0.75)	1.01
Lamphun	2,445 (0.07)	0.57
Lampang	5,328 (0.16)	0.56
Uttaradit	9,152 (0.27)	1.53
Phrae	5,650 (0.17)	1.17
Nan	12,596 (0.38)	2.07
Phayao	6,717 (0.20)	1.20
Chiang Rai	6,368 (0.19)	0.39
Mae Hong Son	4,439 (0.13)	1.68
Nakhon Sawan	34,557 (1.04)	2.23
Uthai Thani	11,035 (0.33)	2.77
Kamphaeng Phet	22,148 (0.66)	2.30
Tak	26,880 (0.81)	3.26
Sukhothai	17,464 (0.52)	2.39
Pitsanuloke	23,403 (0.70)	2.05
Phichit	10,379 (0.31)	1.51
Phetchabun	18,895 (0.57)	1.48
Northeastern region by provinces		
Nakhon Ratchasima	55,475 (1.66)	1.45
Buriram	12,292 (0.37)	0.52
Surin	37,044 (1.11)	1.97
Sisaket	43,576 (1.31)	2.25

Table 1 (cont)

Factor	Frequency *n* (%)	Incidence per 1,000 population
Ubon Ratchathani	55,304 (1.66)	2.17
Yasothon	15,938 (0.48)	2.34
Chaiyaphum	7,967 (0.24)	0.53
Amnat Charoen	7,908 (0.24)	1.70
Bueng Kan	8,227 (0.25)	1.81
Nong Bua Lamphu	10,130 (0.30)	1.62
Khon Kaen	46,959 (1.41)	1.80
Udon Thani	15,191 (0.46)	0.72
Loei	12,574 (0.38)	1.42
Nong Khai	18,613 (0.56)	2.96
Maha Sarakham	23,966 (0.72)	1.89
Roi Et	35,663 (1.07)	2.27
Kalasin	20,156 (0.60)	1.79
Sakon Nakhon	14,434 (0.43)	1.05
Nakhon Phanom	11,642 (0.35)	1.29
Mukdahan	8,151 (0.24)	1.88
Southern region by provinces		
Nakhon Si Thammarat	52,259 (1.57)	2.32
Krabi	20,299 (0.61)	2.95
Phang Nga	15,436 (0.46)	4.57
Phuket	53,441 (1.60)	8.96
Surat Thani	41,772 (1.25)	2.75
Ranong	16,178 (0.49)	6.74
Chumphon	26,060 (0.78)	3.66
Songkhla	95,290 (2.86)	3.99

Table 1 (cont)

Factor	Frequency *n* (%)	Incidence per 1,000 population
Satun	18,769 (0.56)	5.74
Trang	25,898 (0.78)	2.93
Phatthalung	35,845 (1.08)	4.89
Pattani	56,542 (1.70)	5.43
Yala	35,962 (1.08)	4.26
Narathiwat	48,805 (1.46)	4.06

COVID-19: Coronavirus disease 2019

population). However, the province with the highest province incidence was Samut Sakhon Province (11.96 cases per 1,000 population), followed by Phuket Province (8.96 cases per 1,000 population), Samut Songkhram Province (7.85 cases per 1,000 population), Samut Prakan Province (7.02 cases per 1,000 population) and Ranong Province (6.74 cases per 1,000 population).

The monthly COVID-19 incidence rates per 1,000 population for males aged 20-29 (p<0.001), 30-39 (p=0.003) and 40-49 (p=0.050) years were significantly higher than the mean monthly COVID-19 incidence rates. The monthly COVID-19 incidence rates per 1,000 population for females aged 20-29 (p=0.010) and 30-39 (p=0.043) years were also significantly higher rates than the mean monthly COVID-19 incidence rates. The monthly COVID-19 incidence rates per 1,000 population among males aged <20 (p=0.068) and 50-59 (p=0.052) years and among females aged <20 (p=0.066) years were not significantly different from the mean monthly COVID-19 incidence rates. Males aged 60-69 (p=0.006), 70-79 (p=0.001) and ≥80 (p=0.001) years and females aged 40-49 (p=0.047), 50-59 (p=0.011), 60-69 (p=0.002), 70-79 (p=0.001) and ≥80 (p=0.001) years had incidence rate significantly lower than the mean monthly COVID-19 incidence rates.

There were 5 waves of COVID-19 during the study period in Thailand. The first wave peaked in April 2020 (incidence: 0.037, 95% CI: 0.033-0.041, p<0.001), the second wave peaked in January 2021 (incidence: 0.057, 95% CI: 0.052-0.063 p<0.001), the third wave peaked in June 2021 (incidence: 0.387, 95%CI: 0.367-0.407 p<0.001), the fourth wave peaked in August 2021 (incidence: 5.23, 95% CI: 4.99-5.48, p<0.001) and the fifth wave peaked in March 2022 (incidence: 12.19, 95% CI: 11.63-12.77, p<0.001). During the study from January 2020 to April 2022, the monthly COVID-19 incidences during all 12 months of 2020 and during the first 7 months of 2021 were significantly lower (p<0.01) than the overall monthly average and during the remaining 5 months of 2021 and the first 4 months of 2022 (until the end of the study period) the monthly incidences were significantly higher (p<0.001) than the overall monthly average.

All the provinces in northeastern and northern Thailand, except Tak Province, had significantly lower monthly COVID-19 incidences than the average (p-values are greater than 0.05 for all the provinces; Table 2) for Thailand while Tak Province had no significant difference from the average (incidence: 3.83, 95% CI: 3.43-4.28, p=0.052). In central, Chai Nat Province (incidence: 1.38, 95% CI: 1.22-1.55, p=0.005) and Suphan Buri Province (incidence: 2.70, 95% CI: 2.41-3.02, p=0.050) had significantly lower monthly COVID-19 incidences than the average for Thailand. Nakhon Si Thammarat Province in southern Thailand had significantly lower monthly COVID-19 incidences (incidence: 2.07, 95% CI: 1.85-2.31, p=0.036) than the average for Thailand. Twenty-one provinces in central Thailand and 9 provinces in southern Thailand had higher monthly COVID-19 incidences than the average for Thailand. Samut Sakhon Province had the highest monthly COVID-19 incidences for central Thailand, significantly higher (incidence: 16.47, 95% CI: 14.87-18.23, p<0.001) than the average for Thailand. Phuket Province had the highest monthly incidences for southern Thailand, significantly higher (incidence: 7.84, 95% CI: 7.03-8.75, p=0.001) than the average for Thailand.

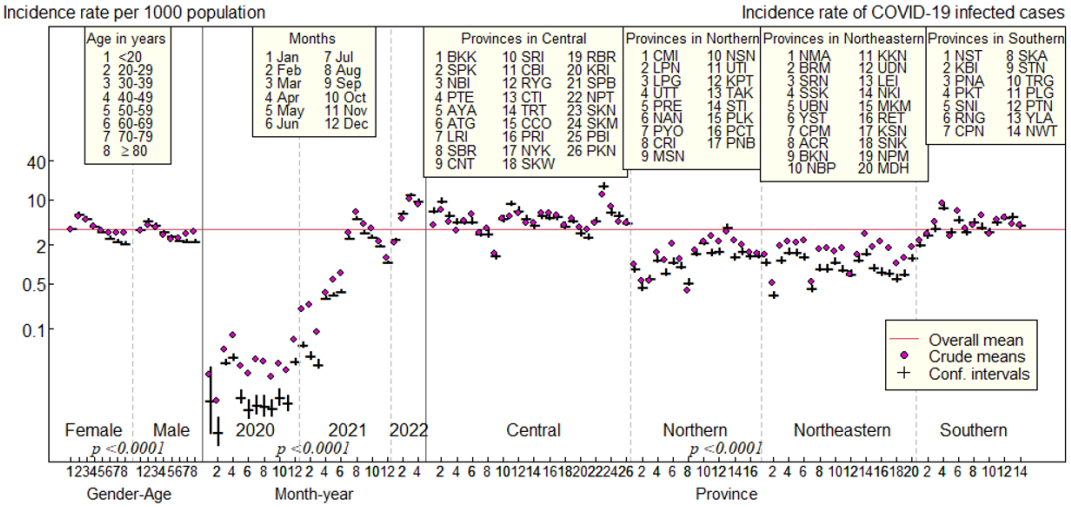

Fig 1 - 95% confidence interval plots of factors associated with the monthly COVID-19 incidence rates

COVID-19: Coronavirus disease 2019

ACR: Amnat Charoen; ATG: Ang Thong; AYA: Phra Nakhon Si Ayutthaya; BKK: Bangkok; BKN: Bueng Kan; BRM: Buriram; CBI: Chonburi; CCO: Chachoengsao; CMI: Chiang Mai; CNT: Chai Nat; CPM: Chaiyaphum; CPN: Chumphon; CRI: Chiang Rai; CTI: Chanthaburi; KBI: Krabi; KKN: Khon Kaen; KPT: Kamphaeng Phet; KRI: Kanchanaburi; KSN: Kalasin; LEI: Loei; LPG: Lampang; LPN: Lamphun; LRI: Lopburi; MDH: Mukdahan; MKM: Maha Sarakham; MSN: Mae Hong Son; NAN: Nan; NBI: Nonthaburi; NBP: Nong Bua Lam Phu; NKI: Nong Khai; NMA: Nakhon Ratchasima; NPM: Nakhon Phanom; NPT: Nakhon Pathom; NSN: Nakhon Sawan; NST: Nakhon Si Thammarat; NWT: Narathiwat; NYK: Nakhon Nayok; PBI: Phetchaburi; PCT: Phichit; PKN: Prachuap Khiri Khan; PKT: Phuket; PLG: Phatthalung; PLK: Pitsanuloke; PNA: Phang Nga; PNB: Phetchabun; PRE: Phrae; PRI: Prachinburi; PTE: Pathum Thani; PTN: Pattani; PYO: Phayao; RBR: Ratchaburi; RET: Roi Et; RNG: Ranong; RYG: Rayong; SBR: Sing Buri; SKA: Songkhla; SKM: Samut Songkhram; SKN: Samut Sakhon; SKW: Sa Kaeo; SNI: Surat Thani; SNK: Sakon Nakhon; SPB: Suphan Buri; SPK: Samut Prakan; SRI: Saraburi; SRN: Surin; SSK: Sisaket; STI: Sukhothai; STN: Satun; TAK: Tak; TRG: Trang; TRT: Trat; UBN: Ubon Ratchathani; UDN: Udon Thani; UTI: Uthai Thani; UTT: Uttaradit; YLA: Yala; YST: Yasothon

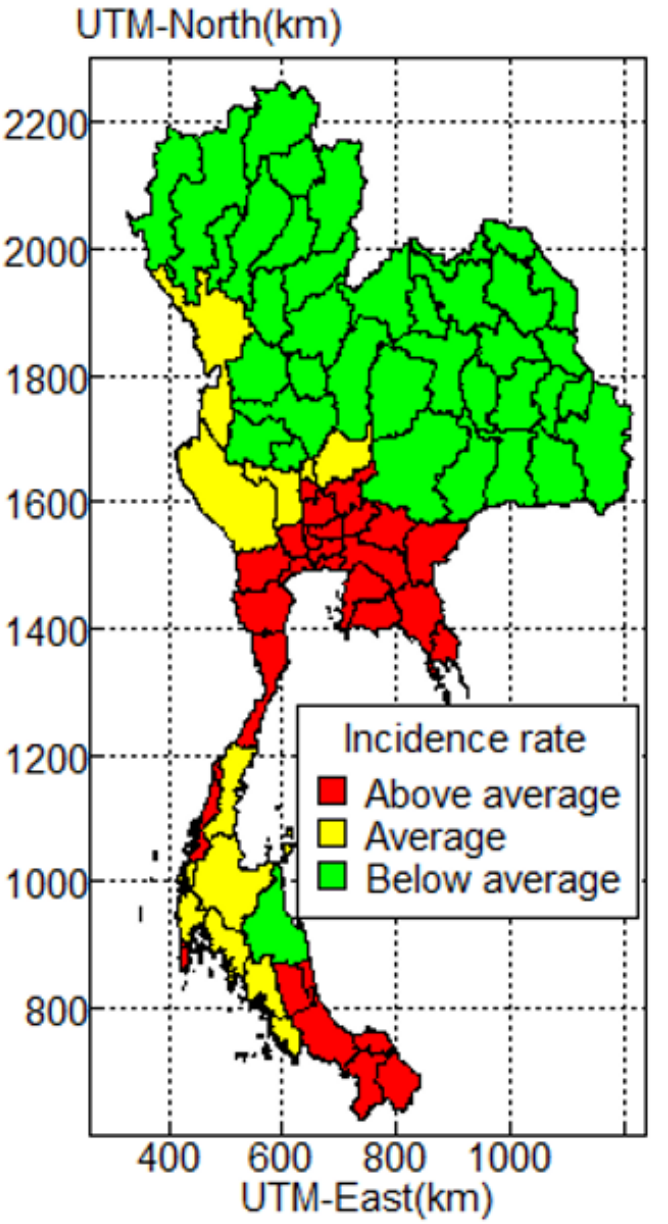

Fig 2 - COVID-19 incidence rate groups for each province in Thailand

COVID-19: Coronavirus disease 2019; km: kilometer; UTM: Universal Transverse Mercator

Table 2

Impact of demographic characteristics, time and province of residency on the COVID-19 incidence rate

Factor	Incidence per 1,000 population	95% CI		*p*-value
		Lower	Upper	
Male by age groups				
<20 years	3.618	3.443	3.801	0.068
20-29 years	6.174	5.884	6.478	<0.001
30-39 years	5.204	4.958	5.462	0.003
40-49 years	3.952	3.765	4.148	0.050
50-59 years	3.268	3.110	3.515	0.052
60-69 years	2.626	2.495	2.763	0.006
70-79 years	2.312	2.191	2.440	0.001
≥80 years	2.176	2.056	2.303	0.001
Female by age groups				
<20 years	3.514	3.344	3.693	0.066
20-29 years	4.832	4.604	5.072	0.010
30-39 years	4.183	3.985	4.391	0.043
40-49 years	3.216	3.063	3.376	0.047
50-59 years	2.760	2.627	2.900	0.011
60-69 years	2.418	2.298	2.544	0.002
70-79 years	2.279	2.159	2.405	0.001
≥80 years	2.277	2.147	2.413	0.001
Year 2020				
January	0.008	0.002	0.026	0.008
February	0.003	0.002	0.004	<0.001
March	0.030	0.028	0.034	<0.001
April	0.037	0.033	0.041	<0.001
May	0.009	0.007	0.011	<0.001

Table 2 (cont)

Factor	Incidence per 1,000 population	95% CI		*p*-value
		Lower	Upper	
June	0.006	0.004	0.008	<0.001
July	0.007	0.005	0.009	<0.001
August	0.007	0.005	0.009	<0.001
September	0.006	0.004	0.008	<0.001
October	0.009	0.007	0.012	<0.001
November	0.007	0.005	0.010	<0.001
December	0.032	0.028	0.036	<0.001
Year 2021				
January	0.057	0.052	0.063	<0.001
February	0.039	0.034	0.045	<0.001
March	0.029	0.025	0.033	<0.001
April	0.306	0.291	0.322	<0.001
May	0.347	0.330	0.365	<0.001
June	0.387	0.367	0.407	<0.001
July	2.613	2.492	2.740	<0.001
August	5.232	4.993	5.482	<0.001
September	3.158	3.012	3.310	<0.001
October	2.713	2.588	2.843	<0.001
November	1.958	1.868	2.052	0.029
December	1.089	1.038	1.143	0.001
Year 2022				
January	2.456	2.344	2.573	0.001
February	6.310	6.024	6.610	<0.001
March	12.185	11.631	12.765	<0.001
April	9.809	9.363	10.277	<0.001

Table 2 (cont)

Factor	Incidence per 1,000 population	95% CI		*p*-value
		Lower	Upper	
Central region by provinces				
Bangkok Metropoluis	6.923	6.329	7.574	<0.001
Samut Prakan	9.843	8.956	10.818	<0.001
Nonthaburi	5.894	5.336	6.510	0.005
Pathum Thani	4.668	4.217	5.168	0.022
Phra Nakhon Si Ayutthaya	4.653	4.174	5.187	0.027
Ang Thong	4.726	4.226	5.286	0.028
Lopburi	3.030	2.703	3.515	0.068
Sing Buri	2.976	2.649	3.518	0.068
Chai Nat	1.377	1.224	1.549	0.005
Saraburi	5.179	4.625	5.799	0.019
Chonburi	8.874	8.080	9.745	<0.001
Rayong	6.941	6.228	7.736	0.002
Chanthaburi	5.130	4.590	5.734	0.019
Trat	4.090	3.638	4.597	0.048
Chachoengsao	5.792	5.188	6.466	0.009
Prachinburi	5.448	4.871	6.092	0.014
Nakhon Nayok	5.615	5.008	6.296	0.014
Sa Kaeo	4.008	3.571	4.499	0.050
Ratchaburi	4.869	4.363	5.434	0.023
Kanchanaburi	3.144	2.806	3.524	0.068
Suphan Buri	2.700	2.414	3.018	0.050
Nakhon Pathom	4.851	4.380	5.373	0.019
Samut Sakhon	16.465	14.869	18.234	<0.001
Samut Songkhram	6.513	5.822	7.286	0.005

Table 2 (cont)

Factor	Incidence per 1,000 population	95% CI		*p*-value
		Lower	Upper	
Phetchaburi	5.871	5.269	6.541	0.008
Prachuap Khiri Khan	4.531	4.036	5.088	0.035
Northern region by provinces				
Chiang Mai	0.861	0.768	0.965	<0.001
Lamphun	0.458	0.401	0.522	<0.001
Lampang	0.609	0.539	0.687	<0.001
Uttaradit	1.208	1.072	1.360	0.002
Phrae	0.755	0.667	0.854	<0.001
Nan	1.112	0.984	1.256	0.001
Phayao	0.962	0.849	1.091	0.001
Chiang Rai	0.534	0.475	0.600	<0.001
Mae Hong Son	1.532	1.346	1.742	0.012
Nakhon Sawan	2.218	1.981	2.483	0.044
Uthai Thani	1.546	1.367	1.749	0.012
Kamphaeng Phet	1.619	1.438	1.823	0.013
Tak	3.829	3.430	4.275	0.052
Sukhothai	1.332	1.182	1.501	0.004
Phitsanulok	1.618	1.441	1.817	0.013
Phichit	1.371	1.218	1.543	0.005
Phetchabun	1.403	1.248	1.578	0.006
Northeastern region by provinces				
Nakhon Ratchasima	1.088	0.973	1.216	0.001
Buriram	0.338	0.300	0.380	<0.001
Surin	1.184	1.052	1.332	0.002
Sisaket	1.574	1.402	1.768	0.011

Table 2 (cont)

Factor	Incidence per 1,000 population	95% CI		*p*-value
		Lower	Upper	
Ubon Ratchathani	1.539	1.372	1.727	0.010
Yasothon	1.322	1.170	1.492	0.005
Chaiyaphum	0.432	0.383	0.486	<0.001
Amnat Charoen	0.887	0.784	1.004	<0.001
Bueng Kan	0.871	0.766	0.989	<0.001
Nong Bua Lamphu	1.116	0.987	1.262	0.001
Khon Kaen	0.852	0.760	0.956	<0.001
Udon Thani	0.724	0.644	0.814	<0.001
Loei	1.204	1.072	1.353	0.002
Nong Khai	1.536	1.362	1.732	0.011
Maha Sarakham	0.901	0.802	1.013	<0.001
Roi Et	0.777	0.688	0.877	<0.001
Kalasin	0.743	0.658	0.839	<0.001
Sakon Nakhon	0.615	0.545	0.695	<0.001
Nakhon Phanom	0.732	0.646	0.829	<0.001
Mukdahan	1.272	1.124	1.440	0.004
Southern region by provinces				
Nakhon Si Thammarat	2.066	1.845	2.314	0.036
Krabi	2.866	2.554	3.521	0.067
Phang Nga	3.645	3.230	4.113	0.061
Phuket	7.840	7.029	8.745	0.001
Surat Thani	3.244	2.903	3.626	0.066
Ranong	4.996	4.441	5.621	0.026
Chumphon	3.274	2.913	3.681	0.067
Songkhla	4.613	4.142	5.139	0.028

Table 2 (cont)

Factor	Incidence per 1,000 population	95% CI		*p*-value
		Lower	Upper	
Satun	3.867	3.430	4.359	0.055
Trang	3.218	2.867	3.612	0.067
Phatthalung	4.563	4.067	5.119	0.034
Pattani	5.468	4.897	6.105	0.013
Yala	5.578	5.012	6.209	0.010
Narathiwat	4.106	3.684	4.577	0.043

CI: confidence interval

DISCUSSION

In our study, males aged 20-49 years and females aged 20-39 years had significantly higher COVID-19 incidence rates than the other gender-age groups. These findings are similar to study of the initial outbreak of COVID-19 in Thailand, which reported the risk of infection was higher among younger people, especially males (Jindahra *et al*, 2022). Our results contradict those of another study from Germany that reported infections were more common among females than males (Doerre and Doblhammer, 2022). This difference could be due to differences in lifestyles between women in Southeast Asia and Europe.

During our study period there were 5 waves of infection, where the first 3 waves had lower monthly incidences of COVID-19 than the average for the study period and during the final 2 waves the monthly incidences of COVID-19 were higher than the average. This change over time could be due to the fact that early in the outbreak Thailand implemented strict disease control measures that were complied with by most of the population (Suphanchaimat *et al*, 2022). However, during later waves compliance with control measures began to wane. Another factor that contributed to

the later higher incidences was the presence of viral mutations resulting in more contagious strains of the virus being present in the population (Suphanchaimat *et al*, 2022; Sandar *et al*, 2023). The emergence of the Delta and Omicron variants, in mid-2021 and at the beginning of 2022, respectively contributed to the rapid spread of the virus, especially in conjunction with a decrease in the strictness of infection control measures (Sandar *et al*, 2023).

In our study, COVID-19 incidence patterns varied by province. Higher incidences of COVID-19 were found in the majority of provinces in central Thailand, especially Samut Sakhon Province, which has a large number of foreign workers; and in southern Thailand, particularly Phuket, which has many tourist destinations. Infections were also more likely to spread in places where a large number of people congregate, increasing contagion risk (Wetchayont and Waiyasusri, 2021; Wang *et al*, 2021; Luo *et al*, 2022).

Our study had some limitations. We obtained the data for this study from the MoPH for Thailand. However, areas with limited resources or health services may not have reported all the cases, resulting in underreporting of cases in provinces with few resources and lower population densities. Household conditions and demographics have been reported to influence COVID-19 transmission (Wetchayont and Waiyasusri, 2021; Luo *et al*, 2022) but were not taken into account in our study. The incidence of COVID-19 has been shown to decrease due to vaccinations (Byambasuren *et al*, 2023) and environmental factors, such temperature, humidity (Kumar and Kumar, 2020; Pani *et al*, 2020; Sangkham *et al*, 2021), wind speed (Sangkham *et al*, 2021) and air pollution (Domingo *et al*, 2020; Zoran *et al*, 2022). These factors were not examined in this study and should be considered in future studies.

In summary, we found significantly higher than average incidence rates of COVID-19 among males aged 20-49 and females aged 20-39 years and significantly higher than average incidence rates during August 2021, February, March and April 2022 and significantly higher than average incidence rates in

central and southern Thailand. We conclude, prevention efforts should focus on these age groups and genders in central and southern Thailand in order to have the greatest preventive benefit. Further studies are needed taking into account other factors, such as vaccinations and environmental factors to determine if other factors of COVID-19 incidence are relevant, especially since the advent of vaccinations to prevent COVID-19.

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CONFLICT OF INTEREST DISCLOSURE

There are no potential conflicts of interest to declare.

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