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The Epidemiology of COVID-19 in Malaysia

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ABSTRACT

Background: COVID-19 has rapidly spread across the globe. Critical to the control of COVID-19 is the characterisation of its epidemiology. Despite this, there has been a paucity of evidence from many parts of the world, including Malaysia. We aim to describe the epidemiology of COVID-19 in Malaysia to inform prevention and control policies better.

Methods: Malaysian COVID-19 data was extracted from 16 March 2020 up to 31 May 2021. We estimated the following epidemiological indicators: 7-day incidence rates, 7-day mortality rates, case fatality rates, test positive ratios, testing rates and the time-varying reproduction number (Rt).

Findings: Between 16 March 2020 and 31 May 2021, Malaysia has reported 571,901 cases and 2,796 deaths. Malaysia's average 7-day incidence rate was 26•6 reported infections per 100,000 population (95% CI: 17•8, 38•1). The average test positive ratio and testing rate were 4•3% (95% CI: 1•6, 10•2) and 0•8 tests per 1,000 population (95% CI: <0•1, 3•7), respectively. The case fatality rates (CFR) was 0•6% (95% CI: <0•1, 3•7). Among the 2,796 cases who died, 87•3% were ≥ 50 years.

Interpretation: The public health response was successful in the suppression of COVID-19 transmission or the first half of 2020. However, a state election and outbreaks in institutionalised populations have been the catalyst for more significant community propagation. This rising community transmission has continued in 2021, leading to increased incidence and strained healthcare systems. Calibrating NPI based on epidemiological indicators remain critical for us to live with the virus. (243 words)

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Research in Context

Evidence before this study

We reviewed literature from the WHO Global COVID-19 database, which crawls articles from multiple databases, focusing on the epidemiology of COVID-19 in Malaysia between 1 January 2020 and 31 March 2021. We found 304 research articles related to COVID-19 from Malaysia as of January 2021. 63% of these articles were linked to fields of Education, Business, Environment, Politics and others. The remaining were health related, with only 20% linked to the epidemiology of COVID-19. However, the majority of these centred around the national public health response to COVID-19 between February and April 2020. To the best of our knowledge, no articles have systematically analysed the epidemiology of COVID-19 in Malaysia beyond 2020. We concluded that there remains a paucity of published data on the progress of COVID-19 in Malaysia, which is critical in informing prevention and control measures.

Added value in this study

This study is the first comprehensive analysis of COVID-19 epidemiologic data in Malaysia to the best of our knowledge. The epidemiology of COVID-19 in Malaysia was found to be spatiotemporally diverse. The epidemiological indicators varied by region and calendar time with periodic large outbreaks. The incidence of COVID-19 is higher in the more populous urban central region of Peninsular Malaysia. Very high-

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intensity non-pharmaceutical interventions have been used for long periods to reduce transmission. Long term movement restrictions have not resulted in the containment of the disease, likely due to pandemic fatigue.

Implication of all the available evidence

The intensity of transmission varies by time, with a peak in outbreaks occurring every 4-6 months. The intensity of NPI should be dynamically calibrated based on the reported cases, incidence rates, time-varying reproduction number, case fatality rate, mortality rate, testing rate, and test positive ratio. Other potential indicators include healthcare utilisation (COVID-19 bed utilisation, COVID-19 ICU utilisation, ventilator use) and preventive public health service effectiveness (time from test to notification, time from test to contact tracing). Strong governance with evidence-based decision making remains critical for the long-term response towards COVID-19. The implementation of the national immunisation program must continue to gain momentum. There is also a need for greater transparency and collaboration in data-sharing.

1. Introduction

First reported in late December 2019, COVID-19 has rapidly proliferated into a global pandemic. [1] The World Health Organisation (WHO) currently estimates more than 170 million cases with an excess of 3.5 million deaths globally. [2]

The incidence and mortality statistics for COVID-19 have varied widely across regions and time. [3] Cumulative incidence rates as of 31 May 2021 have ranged from 0•3 to 17,700 per 100,000 population, whilst COVID-19 associated mortality rates in the same period have ranged from between 0•03 and 308 deaths per 100,000 population, across different countries. [4] Case fatality rates (CFR) have been estimated to range from between 0•8-15.2%. [5], [6] These variations are mediated by testing rates and transmissibility, which are further mediated by health systems capacity, the resilience of economies, and social dynamics.

The call for the global scientific community to systematically characterise the epidemiology of COVID-19 was made a year ago. [7] Epidemiologic indicators, estimated via a surveillance system, is critical in developing timely interventions. [8]. However, constraints in the surveillance process, especially in the developing world, has meant these epidemiological indicators are inadequately or not estimated. [9]. In Malaysia, there remains a paucity of published descriptive epidemiology of the outbreak. Despite the WHO Global COVID-19 literature database listing numerous research articles as of 31 March 2021, very few have focused on the epidemiology of COVID-19.

Understanding the evolving epidemiology of COVID-19 during this pandemic may better inform prevention and control policies. We aim to describe the incidence, transmission, testing, and mortality of COVID-19 in Malaysia from 16 March 2020 to 31 May 2021.

2. Methods

2.1. Data

COVID-19 data, utilised here, was extracted from routine daily press releases by the Malaysian Director-General of Health between 16 March 2020 and 31 May 2021. This data included: i) national aggregates of cases, mortalities, and testing, ii) state aggregates of cases and mortalities, iii) cluster aggregates of cases and iv) mortality summaries. [66] Mid-year population data was acquired from the Department of Statistics (DOS) Malaysia. [67] Data on the number of partial and complete vaccinations from 24 February to 31 May 2021 were extracted from an open-source dataset maintained by the Ministry of Science, Technology and Innovation. Details on data collection case definition are available in the Supplementary appendix. (Appendix 1 &2)

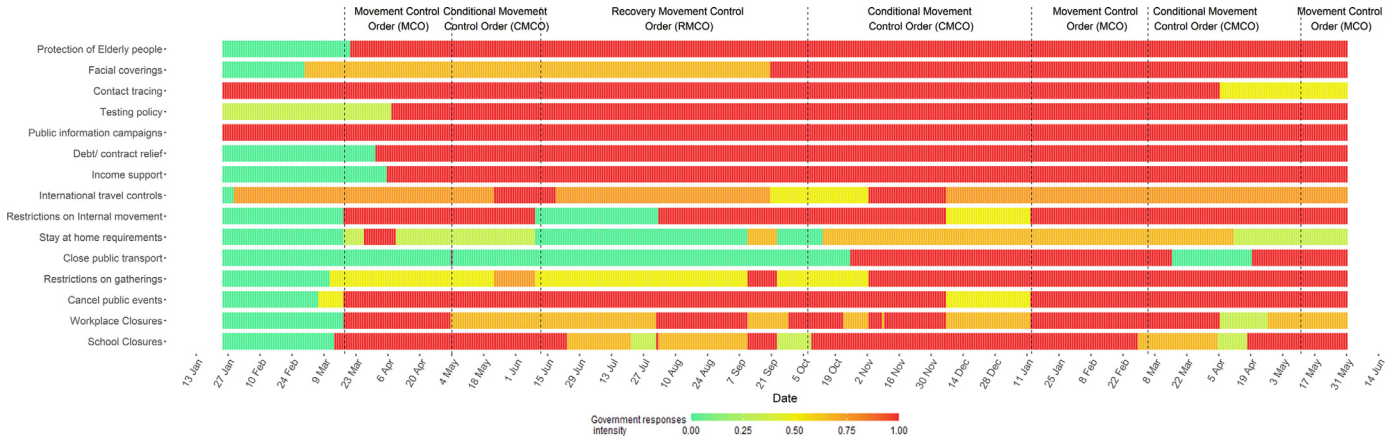
2.2. Operational definition

We define the phases of outbreak control as i) containment, ii) mitigation, and iii) suppression. Containment prioritises identifying and quarantining cases, testing and isolating their contacts, as well as other public health measures of infection control such as vaccinations. [12] As transmission intensifies, control measures transition to a mitigation phase that aims to delay propagation and mitigate its effects on health systems and societies using various community-based non-pharmaceutical interventions (NPI) such as personal protection, environmental disinfection, and low-intensity social distancing. [12–14][68] Suppression measures are defined here as measures aiming to reverse the effects of the pandemic using stricter NPI for high-intensity social distancing, such as the closure of educational institutions and movement restrictions. [[12,13,16]

Malaysia began containment in early 2020. A movement control order (MCO) utilising strong suppression measures was initiated on 18 March 2020. These measures were eased on 4 May 2020 and labelled a conditional movement control order (CMCO). On 9 June 2020, measures were further eased into a recovery movement control order (RMCO)- a transitional phase before suppression measures were lifted entirely. However, due to a rise in cases, intensification of measures to CMCO and MCO levels were carried out on 7 October 2020 and 13 January 2021, respectively. Restrictions were eased to CMCO on 5 March 2021 before another surge caused another intensification of measures to MCO on 11 May 2021. The intensity of these measures has varied at the state level after September 2020.

The Oxford COVID-19 Government Response Tracker (OxCGRT) was utilised to measure the intensity of NPI implementation. [17] The OxCGRT index is a multidimensional composite index tracking policies on an ordinal scale comprising domains of school closure, workplace closures, cancellation of public events, restriction on gatherings, stay at home orders, public transport closures, domestic travel, international travel, income support, debt relief, elderly care, public information campaigns, testing policy, contract tracing, and facial coverings.

The government response to the evolving outbreak had been adaptive and varied across time. The response to the pandemic in early February 2020 leveraged heavily on existing public health mechanisms such as contact tracing, testing, international travel controls, and public health awareness. The MCO was introduced on 18 March 2020, leveraging NPI, such as the cancellation of public events, workplace closures, school closures, partial stay-at-home requirements and restrictions of internal movement. These were further augmented by income support and debt relief schemes introduced by the government. Reduction in epidemic propagation led to the CMCO beginning on 4 May 2020, which opened workplaces. On 9 June, the introduction of the RMCO led to the easing of restrictions on internal movement, stay at home requirements and partial reopening of schools. Universal masking was implemented on 1 August 2020. The intensity of NPI (CMCO) was further calibrated at the state level on 7 October 2020 to adapt to the heterogenous state-specific incidence rates. CMCO activities included closures of schools, stay at home requirements and movement restrictions. De-escalation of restrictions was attempted from 7 December 2020 to 12 January, with the lifting of the interstate sanctions, reopening of workplaces, and social gatherings being allowed under strict infection prevention and control procedures. An



exponential increase in daily reported cases in December 2020 and January 2021 led to a nationwide MCO re-introduction on 13 January 2021 with strong restrictions in all sectors. Restrictions were eased on 5 March 2020 with the opening of several economic sectors and a reduction in the intensity of masking and public event policy in early April 2021. A resurgence in late April led to another nationwide MCO on 11 May 2021. (Figure 1)

Transmission was categorised as imported, cluster and unlinked. Imported cases acquired the infection from outside of Malaysia and were detected during the quarantine period following border entry. Cluster transmission are groups of cases that are epidemiologically linked. These epidemiologic links can include workplace-, community-, education-, religious-, prison-, and import- related transmission. Local cases that could not be linked to an existing cluster-linked were labelled as unlinked.

2.3. Data analysis

Data before 16 March was truncated as local transmission before 16 March 2020 was sporadic and not established. Additionally, consistent national-level tests-, and state-level case- reporting in the press only began after this point. Aggregate number of cases reported by clusters exceeded daily case counts at several time points between March-April 2020. These were smoothed by redistributing the difference in reported daily cases and cluster cases over a period of 7-days to ensure cluster cases were consistent with daily national aggregates.

In examining the spatial variation of the epidemiology of COVID-19, the country was divided into six regions: i) Northern region (Perlis, Kedah, Pulau Pinang, Perak), ii) Central region (Selangor, W.P. Kuala Lumpur, W.P. Putrajaya), iii) Southern region (Negeri Sembilan, Melaka, Johor), iv) Eastern region (Pahang, Kelantan, Terengganu), v) Sabah (Sabah, W.P. Labuan) and vi) Sarawak. The pooling of data into regions compared to individual states resulted in more precise estimates. Epidemic curves for new cases were plotted using the date of diagnosis at the national level with stratification by the type of transmission- either imported, cluster, or community (unlinked) transmission.

A Bayesian approach was used to estimate the time-varying (instantaneous) reproduction number (R_t) on 7-day sliding intervals, with 95% credible intervals(ci). This approach used a time-series of daily case data by reporting date, and a serial interval distribution assumed to follow a discretised gamma distribution. The time-varying reproduction number as such is defined as the fraction of the expected number of secondary infections at time *t* over the number of infected individuals weighted by their relative infectiousness at time *t*, which is given by the generation or serial interval distribution. [18] Serial intervals from a review of published and unpublished literature were assumed to fit the Malaysian profile of cases. [19–25] An R_t of more than 1 suggest that the epidemic will continue to grow, whilst an R_t of less than 1 suggest transmission is in decay. The R_t is given by:

$$R_t = \frac{I_t}{\sum_{s=1}^{t} I_{t-s} w_s}$$

Where I_t is the number of infections on day t, and w_s is the generation interval of s days separating an infector-infectee pair.

A 7-day moving incidence rate (IR), 7-day mortality rate (MR), case fatality rate (CFR), test positive ratio (TPR), and testing rate (TR) were then approximated and averaged cumulatively and quarterly across the study period beginning on 16 March 2020 to 31 May 2021. A simple exact method utilising Poisson distributions was used to estimate confidence intervals (CI) for each parameter with an alpha value of 0•05. [26,27] The duration from reporting to death was assumed to be 14-days [28,29]. Values below 0.1 were rounded to <0.1 to ease interpretation. The WHO utilises these epidemiological indicators in assessing transmission [30] . (Appendix 3).

Characteristics of all mortalities were also tabulated cumulatively and quarterly across the study period. A Fisher's exact test and Kruskal-Wallis test were utilised in testing the difference between periods and characteristics. Visualisations and analyses utilised the "tidyverse", "epitools"," caret", ""tableOne", and "EpiEstim" packages in R 4.0. [31]

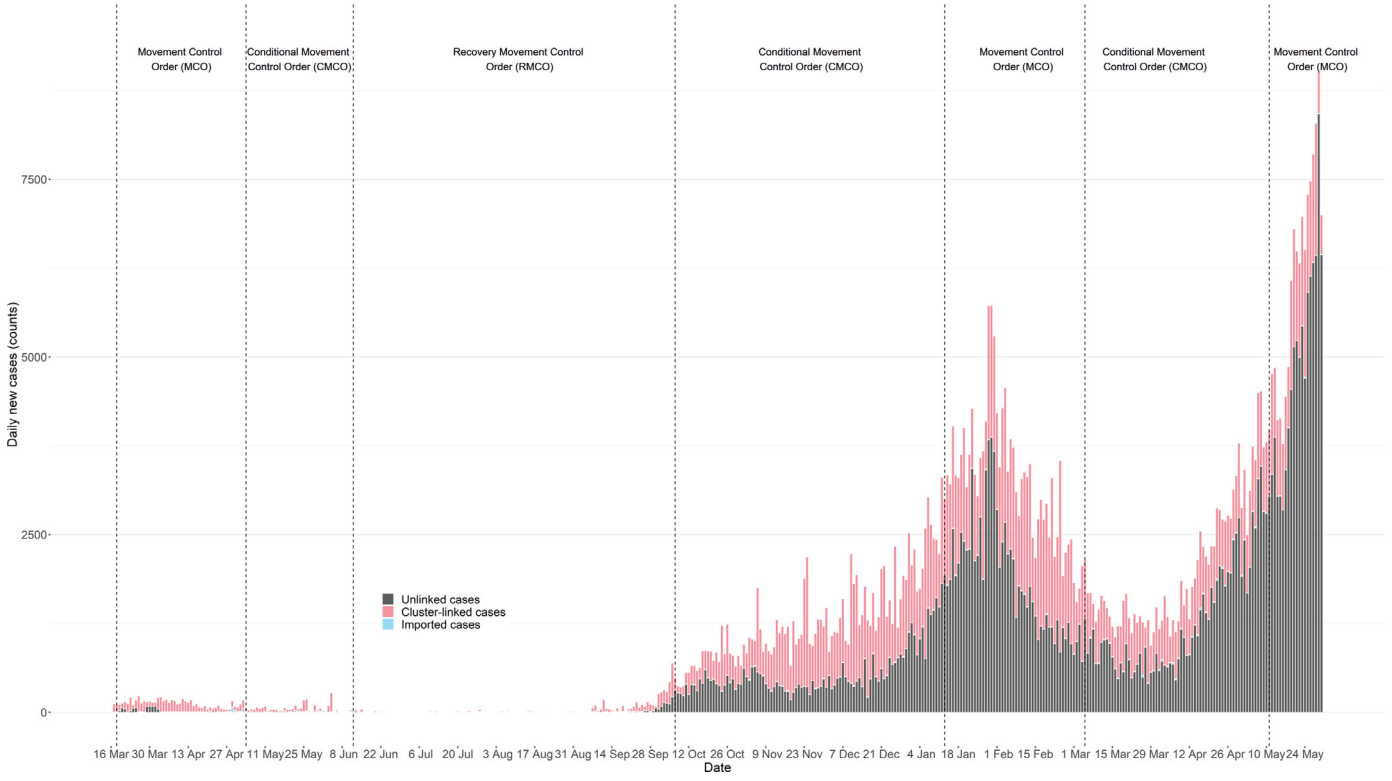
2.4. Role of Funding Source

The funder of the study had no role in the study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

3. Results

Between 16 March 2020 and 31 May 2021, Malaysia reported 571,901 cases and 2,796 deaths. Incidence was relatively low between March-May 2020, with 84% of transmission attributed to clusters and the remaining 16% attributed to unlinked transmission. This trend is followed by a period of even lower transmission between June-August 2020. Unlinked transmission increased to 41%, 54% and 73% in the periods of September-November 2020, December 2020-February 2021 and March-May 2021, respectively. Across the study period, a daily maximum of 9,020 cases was reported on 29 May 2021. (Figure 2)

Rt peaks in early March at the national level before reductions in transmissibility are observed slightly before suppression measures are implemented. This trend is reflected in the Central re-



gion, Southern region and Sarawak. This trend is followed by a period of volatility in the R_t between June-August 2020 in all regions. A significant rise in the R_t is observed in early September 2020, reflecting the R_t in Sabah and the Northern region. R_t estimates begin reducing and stabilising at slightly above one after October 2020 in all of Malaysia. The R_t was consistently above one across all regions in Malaysia until strong restrictions were again implemented on the 13 January 2021 leading, to the R_t dropping below one in late January 2021 before again crossing unity in early April after easing of restrictions on 5 May. (Figure 3)

The average R_t across the study period for Malaysia was 1•2 (95% ci: 1•1, 1•3). Epidemic growth in Malaysia was most rapid between September-November 2020-with an R_t of 1.5 (95% ci: 1•4, 1.6). The average R_t was 1•2, 1, 1•5, 1•1 and 1•1 in the months of March-May 2020, June-August 2020, September-November 2020, December 2020-February 2021 and March-May 2021, respectively. The Eastern region reports the highest point estimate of transmissibility in Malaysia with a peak of 3 (95% ci: 0•4, 9•2) between September and November 2020. Temporal trends distinctly vary by region. (Table 1)

The average 7-day IR in Malaysia was 26•6 cases per 100,000 population (95% CI: 17•8, 38•1) between 16 March 2020 and 31 May 2021. The average 14-day incidence rate was 2, 0•4, 12•4, 55, and 59•6 cases per 100,000 population in March-May 2020, June-August 2020, September-November 2020, December 2020-February 2021 and March-May 2021, respectively. Incidence is consistently higher in the Central region and lowest in the Eastern region. Incidence trends were observed to peak in Sabah between September-November 2020, followed by a peak in incidence within the Central and Northern regions between December 2020-January 2021. Trend trajectories in Sarawak, Northern and Eastern regions peak in May-March 2021. (Table 1)

Average TPR and TR for COVID-19 infections in Malaysia over the study period were 4•3% (95% CI: 1•6, 10•2) and 0•8 tests per 1,000 population (95% CI: <0•1, 3•7), respectively. TPR was observed to be 6•5, 0•2, 3•5, 7, and 4.3 in March-May 2020, June-August 2020, September-November 2020, December 2020-February 2021 and March-May 2021, respectively. The TR was observed to be 0•2, 0•2, 0•5, 1•2 and 1.9 tests per 1,000 population in the months of March-May 2020, June-August 2020, September-November 2020, December 2020-February 2021 and March-May 2021, respectively. Temporal trends of the TPR are bimodal and coincide with periods of exponential increase in COVID-19 incidence with peaks in March-May 2020 and December 2020- February 2021. The TR approximately doubles quarterly from June 2020 onwards before slowing down in March-May 2021. (Table 2)

The average 7-day MR was observed to be 0•1 COVID-19 deaths per 100,000 population (95% CI: <0•1, 3•7). The 7-day MR was observed to be 0•1, <0•1, <0•1, 0•1, 0•2 and 0•3 in the months of March-May 2020, June-August 2020, September-November 2020, December 2020-February 2021 and March-May 2021, respectively. The MR is highest in the Central region and Sarawak, with a reported 0•5 COVID-19 deaths per 100,000 population (95% CI: <0•1, 3•7) in March-May 2021. Mortality rate trends are observed to peak between March-May 2021 in all regions except Sabah. (Table 2)

CFR for Malaysia across the study period is estimated to be 0•6% (95% CI: <0•1, 3•7). The CFR was observed to be 1•7,0•5, 0•6, 0•4, and 0•8 in the months of March-May 2020, June-August 2020, September-November 2020, December 2020-February 2021 and March-May 2021, respectively. The highest regional CFR of 3•3% (95% CI: 1•1, 8•8) and 2•3% (95% CI: 0•6, 7•2) was observed in Sabah, between June and August of 2020, followed by Sarawak, between March and May of 2020, respectively. Sabah and Sarawak report the highest CFR in comparison to all other regions in Malaysia. (Table 2)

Among the 2,796 cases who died, the median age was 67 years (IQR: 58, 76, p=0•05), 87•3% were aged 50 and above, and 62•8% were males. Cardiovascular disease (70•4%), Diabetes mellitus (50•6%) and kidney disease (21•4%, p<0•01) were the most frequently reported comorbidities. These mortalities were also mostly recorded amongst Malaysians (95•1%, p<0•01) and occurred in hospitals (89•6%, p<0•01). Brought-in-dead COVID-

Table 1
COVID-19 associated 14-days incidence density and time varying reproduction number (Rt) in Malaysia

	Overall	Period March-May 2020	June-August 2020	September-November 2020	December 2020-February 2021	March-May 2021
Incidence *7-day incidence rate (per 100,000 population)* *						
Malaysia	26•6 (17•8, 38•1)	2 (0•6, 7•2)	0•4 (0, 3•7)	12•4 (6•9, 21)	55 (42•3, 71•6)	59•6 (45•8, 76•1)
Central region	44•8 (32•8, 59•1)	4 (1•1, 8•8)	0•8 (0, 3•7)	12•9 (6•9, 21)	105•4 (86•8, 127•1)	95•4 (77•8, 116•1)
Sabah region	25•6 (17, 36•9)	0•7 (0, 3•7)	0•1 (<0•1, 3•7)	54•9 (41•4, 70•5)	50•1 (38, 65•9)	19•2 (12•2, 29•7)
Southern region	24•7 (16•2, 35•7)	2•4 (0•6, 7•2)	0•4 (<0•1, 3•7)	5•4 (2•2, 11•7)	65•4 (51, 82•8)	47 (34•5, 61•4)
Sarawak	25•5 (17, 36•9)	1•7 (0•2, 5•6)	0•4 (<0•1, 3•7)	1 (<0•1, 3•7)	21•6 (13•8, 32•1)	98•8 (80•5, 119•4)
Northern region	15•4 (9•1, 24•7)	0•6 (0, 3•7)	0•2 (<0•1, 3•7)	6•1 (2•8, 13•1)	26•8 (17•8, 38•1)	41•1 (30•3, 55•6)
Eastern region	14 (8•4, 23•5)	1•1 (0•2, 5•6)	<0•1 (<0•1, 3•7)	0•5 (<0•1, 3•7)	17•3 (10•7, 27•2)	49 (37•1, 64•8)
Transmissibility *Time-varying reproduction number (Rt)*						
Malaysia	1•2 (1•1, 1•3)	1•2 (1•1, 1•3)	1 (0•7, 1•3)	1•5 (1•4, 1•6)	1•1 (1, 1•1)	1•1 (1•1, 1•1)
Central region	1•1 (1, 1•3)	1•2 (1, 1•3)	0•9 (0•7, 1•3)	1•4 (1•2, 1•6)	1 (1, 1•1)	1•1 (1, 1•1)
Sabah region	1•3 (1, 1•7)	1•1 (0•7, 1•8)	1•2 (0•5, 2•3)	2•1 (1•7, 2•5)	0•9 (0•9, 1)	1•1 (1, 1•2)
Southern region	1•2 (1, 1•6)	1•2 (1, 1•4)	1•1 (0•6, 1•8)	1•7 (1•2, 2•4)	1•1 (1•1, 1•1)	1•1 (1, 1•1)
Sarawak	1•4 (0•9, 2•2)	1•6 (1, 2•4)	1•6 (0•7, 3)	1•4 (0•7, 2•6)	1•5 (1•2, 2)	1•1 (1, 1•1)
Northern region	1•5 (0•9, 2•5)	1•4 (0•6, 3)	2•2 (0•6, 5•3)	1•7 (1•4, 1•9)	1•1 (1•1, 1•2)	1•1 (1, 1•1)
Eastern region	1•9 (0•9, 4)	1•2 (0•9, 1•7)	3 (0•4, 9•2)	2•8 (1, 6•2)	1•3 (1•1, 1•4)	1•2 (1•1, 1•2)

*Values <0.1 ranged from 0.02-0.04 cases per 100,000 population

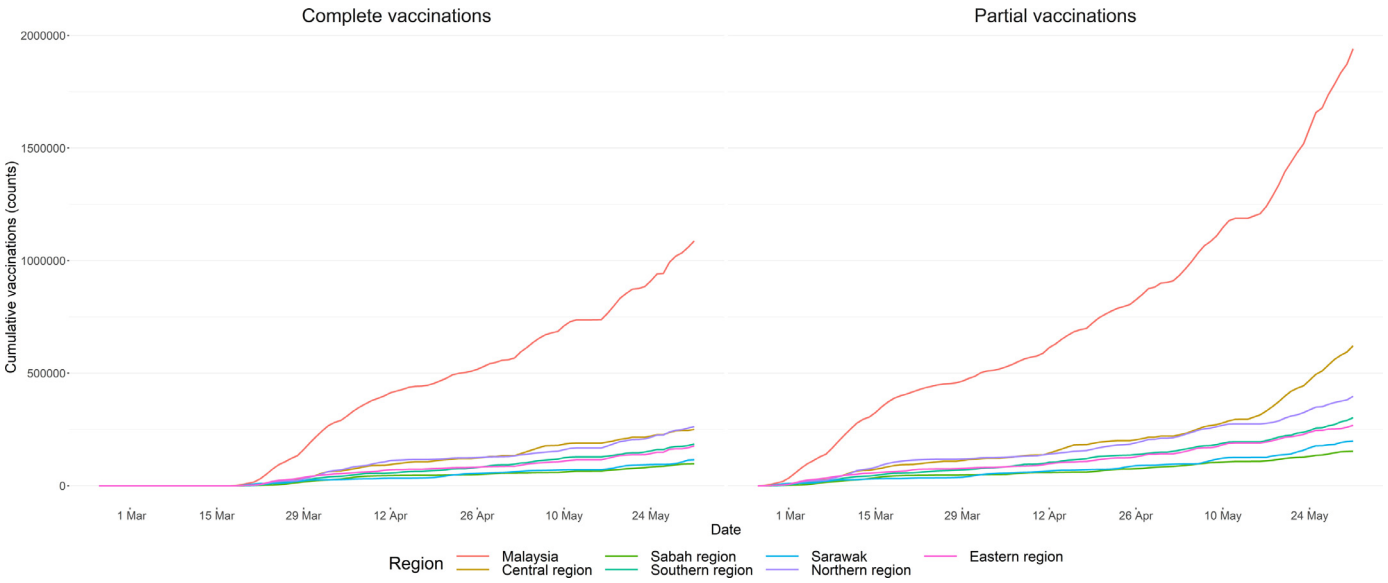
19 mortalities were significantly higher between December 2020 and February 2021 (14•7%) and March-May 2021 (10•1%) compared to March-May 2020 (3•6%; P<0•01). (Table 2) The median age of a Malaysian COVID-19 associated mortality was significantly higher compared to non-Malaysians (68 vs 54 years old; p<0•01). (Table 3)

Vaccinations began on 24 February 2021. Up until 31 May 2021, 8•28% and 4•64% of the population have been inoculated with their 1st and 2nd dose of vaccines, respectively. Inoculation rates were observed to be highest in Sarawak and the Central region; with 9•65% and 10•08% of the adult population receiving at least one dose of a vaccine with a total of 5•59% and 4•06% of the total adult population completing their vaccination. " 'Sabah's vaccination rates remained the lowest, with only 5•37% and 3•41% of the total adult population here having been partially and completely vaccinated, respectively. (Figure 4)

Table 2
COVID-19 associated test positive ratio, testing rate, case fatality rate and mortality rate in Malaysia

	Overall	Period March-May 2020	June-August 2020	September-November 2020	December 2020-February 2021	March-May 2021
Testing						
test positive ratio	4•3 (1•6, 10•2)	6•5 (2•8, 13•1)	0•2 (<0•1, 3•7)	3•5 (1•1, 8•8)	7 (2•8, 13•1)	4•3 (1•6, 10•2)
Testing rate (per 1,000 population)	0•8 (<0•1, 3•7)	0•2 (<0•1, 3•7)	0•2 (<0•1, 3•7)	0•5 (<0•1, 3•7)	1•2 (0•2, 5•6)	1•9 (0•2, 5•6)
Mortalities						
7-day Mortality rate (per 100,000 population) *						
Malaysia	0.1 (<0•1, 3.7)	<0•1 (<0•1, 3•7)	<0•1 (<0•1, 3•7)	0•1 (<0•1, 3•7)	0•2 (<0•1, 3•7)	0•3 (<0•1, 3•7)
Central region	0.2 (<0•1, 3.7)	<0•1 (<0•1, 3•7)	<0•1 (<0•1, 3•7)	<0•1 (<0•1, 3•7)	0•3 (<0•1, 3•7)	0•5 (<0•1, 3•7)
Sabah region	0.2 (<0•1, 3.7)	<0•1 (<0•1, 3•7)	<0•1 (<0•1, 3•7)	0•4 (<0•1, 3•7)	0•3 (<0•1, 3•7)	0•2 (<0•1, 3•7)
Southern region	0.1 (<0•1, 3.7)	<0•1 (<0•1, 3•7)	<0•1 (<0•1, 3•7)	<0•1 (<0•1, 3•7)	0•1 (<0•1, 3•7)	0•3 (<0•1, 3•7)
Sarawak	0.2 (<0•1, 3.7)	0•1 (<0•1, 3•7)	<0•1 (<0•1, 3•7)	<0•1 (<0•1, 3•7)	0•2 (<0•1, 3•7)	0•5 (<0•1, 3•7)
Northern region	0.1 (<0•1, 3.7)	<0•1 (<0•1, 3•7)	<0•1 (<0•1, 3•7)	<0•1 (<0•1, 3•7)	0•1 (<0•1, 3•7)	0•2 (<0•1, 3•7)
Eastern region	0.1 (<0•1, 3.7)	<0•1 (<0•1, 3•7)	<0•1 (<0•1, 3•7)	<0•1 (<0•1, 3•7)	<0•1 (<0•1, 3•7)	0•2 (<0•1, 3•7)
Case fatality rate (%) †						
Malaysia	0•6 (<0.1, 3•7)	1•7 (0•2, 5•6)	0•5 (<0.1, 3•7)	0•6 (<0.1, 3•7)	0•4 (<0.1, 3•7)	0•8 (<0.1, 3•7)
Central region	0•5 (<0.1, 3•7)	1•2 (0•2, 5•6)	0•1 (<0.1, 3•7)	0•1 (<0.1, 3•7)	0•3 (<0.1, 3•7)	0•8 (<0.1, 3•7)
Sabah region	0•8 (<0.1, 3•7)	1•3 (0•2, 5•6)	3•3 (1•1, 8•8)	0•9 (<0.1, 3•7)	0•6 (<0.1, 3•7)	1•3 (0•2, 5•6)
Southern region	0•6 (<0.1, 3•7)	1•5 (0•2, 5•6)	0•5 (<0.1, 3•7)	0•1 (<0.1, 3•7)	0•3 (<0.1, 3•7)	1 (0•2, 5•6)
Sarawak	0•8 (<0.1, 3•7)	2•3 (0•6, 7•2)	1•4 (0•2, 5•6)	0 (<0.1, 3•7)	1•2 (0•2, 5•6)	0•7 (<0.1, 3•7)
Northern region	0•5 (<0.1, 3•7)	1•2 (0•2, 5•6)	1•6 (0•2, 5•6)	0•5 (<0.1, 3•7)	0•3 (<0.1, 3•7)	0•7 (<0.1, 3•7)
Eastern region	0•6 (<0.1, 3•7)	1•6 (0•2, 5•6)	0 (<0.1, 3•7)	0 (<0.1, 3•7)	0•3 (<0.1, 3•7)	0•7 (<0.1, 3•7)

*Values <0.1 ranged from 0-0.06 deaths per 100,000 population
†Values <0.1 ranged from 0-0.07%



4. Discussion

4.1. The Malaysian response from March 2020 to May 2021

An outbreak of cases in early March 2020 due to a large religious event triggered a wave of primarily cluster-based infections [32], leading to NPI prioritising the rapid suppression of transmission. The public health response between March and May 2020 was largely considered to be successful in reducing incidence within Malaysia. [33–36]

However, a total of 562,938 cases have been reported since 6 September 2020. This outbreak of infections was initially triggered by a series of outbreaks amongst institutionalised and incarcerated populations in Sabah. Overcrowding increases the vulnerability of these populations leading to higher disease transmission. [37,38] Moreover, prisons in Sabah have been estimated to be 25 to 30% over-capacity. [39] A state election in Sabah further accelerated eventual community spill over and propagation. During this election, the widespread campaigning and easing of border controls across state lines led to a re-introduction of infections into the Central region, followed by the South, North, East regions, and Sarawak. [39,40] Higher incidences in the Central, South and Sabah regions have been attributed to the underlying higher density and mobility of urban populations. [38] Additionally, higher proportions of migrant worker communities and the poorer living conditions associated with them have been suggested to have further exacerbated transmission in these regions. [41–43]

The re-introduction of more stringent NPI during the CMCO from 7 October 2020 aimed to interrupt potential transmission while allowing for partial functioning of the economy. Whilst

Table 3
Characteristics of COVID-19 associated mortalities in Malaysia

	Overall	Period					
		March- May 2020	June- August 2020	September-November 2020	December 2020-February 2021	March- May 2021	p-value
n	2796	115	12	233	770	1666	
Age (median [IQR])	67 [58, 76]	65 [53•25, 72•75]	69•50 [62•75, 76]	63 [54, 73]	66 [57, 77]	68 [59, 77]	<0•01[b]
Gender (%)							0•04[a]
Male	1757 (62•8)	89 (77•4)	8 (66•7)	140 (60•1)	501 (65•1)	1019 (61•2)	
Regions (%)							0•03[a]
Central region	1049 (37•5)	40 (34•8)	3 (25•0)	4 (1•7)	344 (44•7)	658 (39•5)	
Sabah region	492 (17•6)	5 (4•3)	3 (25•0)	208 (89•3)	170 (22•1)	106 (6•4)	
Southern region	463 (16•6)	33 (28•7)	2 (16•7)	2 (0•9)	109 (14•2)	317 (19•0)	
Sarawak	292 (10•4)	17 (14•8)	2 (16•7)	0 (0)	64 (8•3)	209 (12•5)	
Northern region	296 (10•6)	9 (7•8)	2 (16•7)	19 (8•2)	50 (6•5)	216 (13•0)	
Eastern region	204 (7•3)	11 (9•6)	0 (0)	0 (0)	33 (4•3)	160 (9•6)	
Nationality (%)							<0•01[a]
Malaysian	2658 (95•1)	111 (96•5)	10 (83•3)	214 (91•8)	714 (92•7)	1609 (96•6)	
non-Malaysian	133 (4•8)	4 (3•5)	2 (16•7)	14 (6•0)	56 (7•3)	57 (3•4)	
Not available	5 (0•2)	0 (0)	0 (0)	5 (2•1)	0 (0)	0 (0)	
Place of death (%)							<0•01[a]
Hospital	2505 (89•6)	113 (98•3)	9 (75•0)	229 (98•3)	656 (85•2)	1498 (89•9)	
Comorbid status[1] (%)							
Cardiovascular disease	1968 (70•4)	62 (53•9)	8 (66•7)	137 (58•8)	534 (69•4)	1227 (73•6)	<0•01[a]
Respiratory disease	232 (8•3)	1 (0•9)	1 (8•3)	25 (10•7)	74 (9•6)	131 (7•9)	<0•01[a]
Kidney disease	599 (21•4)	17 (14•8)	2 (16•7)	22 (9•4)	206 (26•8)	352 (21•1)	<0•01[a]
Cancers	119 (4•3)	7 (6•1)	1 (8•3)	7 (3•0)	30 (3•9)	74 (4•4)	0•4[a]
Thyroid disease	31 (1•1)	2 (1•7)	0 (0)	1 (0•4)	10 (1•3)	18 (1•1)	0•6[a]
Diabetes mellitus	1415 (50•6)	43 (37•4)	7 (58•3)	70 (World Health Organization [30] 2021	408 (53•0)	887 (53•2)	<0•01[a]
Dyslipidaemia	511 (18•3)	0 (0)	1 (8•3)	31 (13•3)	135 (17•5)	344 (20•6)	<0•01[a]
Obesity	149 (5•3)	0 (0)	0 (0)	7 (3•0)	44 (5•7)	98 (5•9)	<0•01[a]
Others	355 (12•7)	8 (7•0)	0 (0)	34 (14•6)	134 (17•4)	179 (10•7)	<0•01[a]

Notes:
* There was no missingness in age, gender, region, place of death, and comorbid status. Nationality was available for 2,791 of the 2,796 deaths (%). Categories for place of death were either hospital or brought in dead
[a] A 'Fisher's Exact test was used
[b] A Kruskal-Wallis test was used

transmission ratios decreased from October 2020 onwards- the R_t consistently remained above 1. Reported infections continued to rise through October 2020 to January 2021. Very stringent NPI and strong movement restrictions were introduced on 13 January 2021 in response to the highly stressed healthcare system leading to R_t dropping below 1 in early March 2021. The magnitude of reduction during this period is not as large or rapid as observed after the previous NPI. As restrictions were lifted, a resurgence in transmission was observed, leading to a reintroduction of strong restrictions on 11 May 2021.

4.2. Transmission

Two distinct trends of COVID-19 transmission (R_t) can be observed in Malaysia from March 2020 to February 2021. The first trend can be observed between February and April 2020. Transmission exponentially increases in early March 2020 before a rapid decrease, which corresponds to strong NPI being implemented in early March. The second trend is observed between May 2020 and February 2021. R_t increase in this period is insidious as the transmission is constrained by low-intensity NPI. [44–46]. R_t in this period peaks in mid-September 2020 before it slowly declines to correspond to an intensification of NPI in October 2020. Despite this, R_t remains persistently over one until the implementation of stronger NPI in January 2021 drives it below one. Easing of restrictions in March 2021 led again to transmissibility increasing in May 2021.

The effect of NPI on transmissibility has been observed in multiple different settings within this pandemic. [47,48] The R_t has the potential to be used as an indicator for benchmarking the effectiveness of NPI. However, the variability of policy shifts and intensification of restrictions across time makes it difficult to isolate the signals of change in transmissibility due to individual NPI. Further research into the isolation of these signals may be instrumental towards more robust and effective epidemic management.

4.3. Testing

The TPR between February and April 2020 in Malaysia were consistently above the 5% TPR recommended by WHO. Nonetheless, this trend is observed in many countries worldwide, including parts of Europe and Asia. [38,49,62] There was a surge in lab capacity between March and October 2020. The resulting TPR between May and October 2020 of 0•02 to 2% was on par with New Zealand, South Korea, Denmark, Finland, Norway and Singapore. [3,62] The TPR again exceeded the 5% mark from late October 2020 onwards, as testing became increasingly targeted due to a strained health system, creating an overall 'U' shaped trend over the one

year. An important caveat here is that the TPR has a dynamic denominator and numerator, making it a temporally unstable estimate. As such, the TPR should be interpreted in conjunction with testing rates or using alternative indicators such as the adjusted TPR that overcome this limitation. [51]

Testing rates in Malaysia are observed to have exceeded 0.6 tests per 1000 population by October 2020, which is reported to be 11, 6, 4 and 1.5 times higher than neighbours Myanmar, Indonesia, Thailand and the Philippines. However, the Malaysia testing rate is nearly ten times smaller than neighbouring Singapore [38]. Similarly, testing rates reported up to July 2020 in Sweden, Norway, Denmark, and Finland are 13, 11, 40 and 10 times the testing rates observed in Malaysia. However, transmission in these countries were much higher at similar periods. [62][62]

4.4. Incidence and Mortalities

In Malaysia, a peak CFR of 1.5 is observed between March and May 2020. This estimate is relatively lower than CFRs of 1.86, 2.09, 2.57, 2.84, 3.31, 3.41 and 5.34 reported in Hong Kong, South Korea, Vietnam, Cuba, India, Australia and China in the same period, respectively. Taiwan and Singapore reported lower CFRs of 1.3 and 0.05, respectively. [61] These comparisons suggest a reasonably efficient response of the Malaysian public health system to COVID-19 early in the pandemic.

Nonetheless, heterogeneity in incidence and deaths is observed within Malaysia. Sarawak reports half the incidence but 1.5 times the CFR of the Central region. Sabah reports approximately 60% of the incidence but 1.75 times the CFR of the Central region and a similar mortality rate. CFR in Sabah and Sarawak is consistently higher than CFR in all other regions within Malaysia. A plausible explanation for this discrepancy could be a greater degree of undetected cases in Sabah and Sarawak as compared to west Malaysia. This finding is supported by media reports suggesting that Sabah had a smaller testing capacity than the other regions. [63] Mortality trends amongst sub-populations are also concerning. Non-Malaysians in Malaysia with COVID-19 died on average 14 years earlier than the average Malaysian with COVID-19. Almost 45% of these non-Malaysian deaths were brought in dead compared to only 9% of Malaysians. The majority of these non-national and brought in dead mortalities are from Sabah- where there have been issues with statelessness and undocumented migrants for many years now. [53,54] This trend is not specific to Malaysia, as the pandemic continues to disproportionately affect marginalised subpopulations across the globe. [42,48] Key to a comprehensive pandemic response is to identify inequities that exist within populations and target them, all the more urgent as inequities within a pandemic affect all of society.

4.5. Vaccinations

The Malaysian vaccination programme began on 24 February 2020 to inoculate all eligible individuals by the end of 2021 [65]. Vaccinations have grown but have not been as rapidly implemented compared to more affluent countries such as the United Kingdom, the United States and Israel. The global inequity in the vaccine supply chain has slowed progress in Malaysia, as observed in many lower- and middle-income countries [56,64].

4.6. Strengths and Limitations

This study tracked important epidemiologic indicators of COVID-19 across a period of more than one year. A dynamic and systematic data collection and analysis framework is utilised in monitoring the disease across Malaysia. These indicators can be utilised in driving mitigation, containment and localised suppression policies. The $R_{t,}$ for instance, provides a 1-to-7-day lead window on potential transmission, whilst incidence rates are a valuable indicator of disease burden.

There are several limitations to this research. Firstly, data limitations meant several important epidemiological parameters could not be ascertained. Underreporting is a potential issue with the data as it is heavily leveraged consistent testing and contact tracing policy. [58] This likely led to a degree of measurement bias within the data that was not adjusted for. Parameters were also estimated based on the reporting date of the case. Data quality of the collated aggregated data is also likely to be affected by some missingness. Secondly, there are limitations to the indicators utilised. The R_t estimates have a high degree of variability- in both trend and uncertainty. This variability is associated with periods and regions of low incidence. [59] Mortalities are of limited utility as real-time estimators of disease burden for decision making due to the time lag between case detection and death. [60] Input of dynamic surveillance could further be enhanced by including data on social networks, mobility, density, travelling waves, health system capacity and others to increase the sensitivity of the surveillance network. Finally, the publication of epidemiological indicators across the world remains scarce and reported in different formats. Consistently reporting indicators as prescribed by global institutions such as the WHO can overcome this challenge and ease comparative analysis and benchmarking.

5. Conclusion

The ever-evolving landscape of COVID-19 and its epidemiology exhibits no signs of slowing down. Continuous tracking and interpretation of critical epidemiological indicators of the disease such as the incidence, mortality rate, case fatality rate, R_t and testing will assist in assessing disease control locally whilst facilitating benchmarking efforts against other countries. Much remains unrecognised within the COVID-19 landscape, especially in lower- and middle-income countries.

As the developing world continues to grapple with COVID-19, there is an urgent need for more research into the epidemiology of the disease if the pandemic is to be effectively mitigated. As the vaccine rollout begins within the developed world, the tracking of the epidemiology of COVID-19 remains critical as we continue to learn to live with this virus.

Contributors

All authors contributed equally to this paper.

Declaration of Competing Interest

The authors have nothing to disclose

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Data sharing statement

All data used within the study can be sourced from the GitHub repository of the COVID-19 Epidemiology for Malaysia project at https://github.com/spm-um/c19-epi4msia-data.

Ethical statement

This study was registered under the National Medical Research Register with a registration ID (NMRR-20-1208-55087) and obtained ethical approval from the Medical Research and Ethics Committee (MREC), Ministry of Health Malaysia.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.lanwpc.2021.100295.

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