



Original Article

## Dynamics of COVID-19 in the Gulf Cooperation Council (GCC) countries

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### المخلص

**أهداف البحث:** تُستخدم الأعداد التراكمية للحالات المؤكدة، على الرغم من تقديم القليل من التفاصيل المتعلقة بالديناميكية، على نطاق واسع لنمذجة جائحة كوفيد-19. كان الغرض من هذه الدراسة هو تحديد ديناميكيات كوفيد-19 في دول مجلس التعاون الخليجي باستخدام عدد الحالات الجديدة اليومية بدلاً من العدد التراكمي للحالات الجديدة.

**طرق البحث:** تم الحصول على بيانات عن الحالات اليومية الجديدة لكوفيد-19 في دول مجلس التعاون الخليجي من فبراير 2020 إلى سبتمبر 2021 من موقع وورلدوميتر. من خلال برنامج ماتلاب، تم استخدام مرشح سافيتزكي-غوليي للحصول على منحنيات ناعمة للملامح اليومية للوباء، وتم إجراء تحليل طيف الطاقة لتحديد الترددات السائدة.

**النتائج:** أشارت المنحنيات المنعومة إلى أن دول مجلس التعاون الخليجي شهدت موجتين رئيسيتين من الجائحة ذات فترات ذروة ومدد مختلفة. خلال الموجة الأولى، تراوحت معدلات النمو الأسّي من 9 حالات يومياً في البحرين إلى 53 حالة يومياً في المملكة العربية السعودية، في حين تراوحت معدلات الانخفاض من 6 حالات يومياً في الكويت إلى 72 حالة يومياً في المملكة العربية السعودية.

**الاستنتاجات:** على الرغم من أوجه التشابه في الظروف الاجتماعية والاقتصادية والبيئية بين دول مجلس التعاون الخليجي، أشارت النتائج إلى أن ديناميكيات كوفيد-19 كانت فريدة لكل دولة من دول مجلس التعاون الخليجي.

**الكلمات المفتاحية:** الأوبئة؛ كوفيد-19؛ الديناميكيات؛ تعميم المنحنى؛ التحليل الطيفي.

### Abstract

**Objectives:** The cumulative numbers of confirmed cases, despite providing few details regarding the dynamics, are widely used to model the COVID-19 pandemic. The purpose of this study was to determine the dynamics of COVID-19 in the Gulf Cooperation Council (GCC) countries by using the number of daily new cases rather than the cumulative number of new cases.

**Methods:** Data on daily new cases of COVID-19 in the GCC countries from February 2020 to September 2021 were obtained from the Worldometer website. In MATLAB, the Savitzky–Golay filter was used to obtain smoothed curves of the daily profiles of the pandemic, and power spectrum analysis was performed to identify the dominant frequencies.

**Results:** The smoothed curves indicated that the GCC countries have experienced two major waves of the pandemic with different peaks and durations. During the first wave, the exponential growth rates ranged from 9 cases/day in Bahrain to 53 cases/day in KSA, whereas the decline rates varied from 6 cases/day in Kuwait to 72 cases/day in KSA.

**Conclusions:** Despite the similarities in socio-economic and environmental conditions among GCC countries, the results indicated that the dynamics of COVID-19 are unique for each GCC country.

**Keywords:** COVID-19; Curve smoothing; Dynamics; Epidemics; Spectral analysis

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## Introduction

The rapid spread of the novel coronavirus (COVID-19) has negatively affected healthcare, economic and social systems worldwide.<sup>1,2</sup> To control the spread of the pandemic, countries have used various measures, e.g., hand washing, mask wearing, social distancing, quarantine, lockdown and vaccination.<sup>3–5</sup>

Mathematical models are commonly used by governments and health authorities to provide insights into the distribution patterns of diseases,<sup>6</sup> which can guide authorities' decision-making regarding control measures and the efficient use of available health care resources.<sup>7,8</sup> Because treatments for COVID-19 are scant, mathematical models are crucial for assessing the effectiveness of the implemented control measures.

Logistic models (e.g., Verhulst and Richards models) have been widely used to describe the cumulative number of COVID-19 cases. The curve of the cumulative case numbers (linear or logarithmic) is commonly used because its sigmoid shape resembles the response of a first order system.<sup>9</sup> However, models of the cumulative numbers of positive cases provide only a macro-level description of the pandemic but do not provide details regarding dynamics. Recognizing the changes and trends in the epidemic from models of cumulative number of cases is difficult. Moreover, the parameters of such models often have no physical meaning and cannot be accurately identified from data.<sup>10</sup> Therefore, these models cannot be relied upon for predictions.

To assess the effectiveness of the applied control measures, closer examination of an epidemic's course is necessary; however, profiles of cumulative cases cannot provide such insight. In contrast, the profiles of daily new cases generally contain important information regarding the dynamics of epidemics. Nonetheless, daily data also usually contain random noise and show periodic oscillatory patterns. To extract information on the dynamics (e.g., growth rate, decline rate and trends) from daily new data, noise must be removed, and the dominant periodical patterns must be identified. The objectives of this study were to assess and compare the dynamics of COVID-19 in the Gulf Cooperation Council (GCC) countries. Although several published studies have examined the spread of COVID-19 in the GCC countries,<sup>3,11–13</sup> no studies have addressed the dynamics of COVID-19. The present study is the first to analyze the dynamics of COVID-19 in the GCC states.

## Materials and Methods

COVID-19 daily new cases in the six GCC countries (Kuwait, KSA, Oman, UAE, Bahrain and Qatar), from February 2020 to September 2021 were obtained from the Worldometer website.<sup>14</sup>

MATLAB software was used to conduct power spectrum analysis of the daily data to identify the dominant

frequencies. Power spectrum analyses used Fourier transform to convert data from time series to frequency domain. Bergman et al. (2020) have also used spectral analysis to assess the periodicity of COVID-19 data in Los Angeles and New York.<sup>15</sup>

To reveal the trends in the daily number of positive cases, Savitzky–Golay filtering was performed in MATLAB to obtain smoothed curves of the daily new cases by removal of random noise. The Savitzky–Golay filter was chosen rather than the moving average filters because it preserves the features of data (peak height and width) and retains the trends. Removal of noise was performed with a three-degree polynomial Savitzky–Golay filter with different window lengths until a smoothed curve was obtained (Figure 1). Savitzky–Golay filtering, a classical signal smoothing technique based on the local least squares approximation of the analyzed signal,<sup>16,17</sup> has been widely used to reduce noise in data for many natural, social and engineered systems.<sup>16,18–21</sup> However, it has not been widely applied in epidemiology. One study<sup>22</sup> has used a Savitzky–Golay filter to obtain smooth curves of COVID-19 infected and death cases for Indonesia.

The exponential growth rates and decline rates were estimated for the first wave of the pandemic in the GCC countries. The approximately straight lines of the growth and decline phases were used to estimate these rates.

## Results

As shown in Figure 1, data on daily new cases of COVID-19 in GCC showed clear peaks at frequencies of 0.1424 (1/7 days) and 0.2864 (1/3.5 days), except those for Bahrain and Qatar, in which the peaks were less apparent. Moreover, the gap between the peaks in the power spectrum data indicated a periodic pattern rather than a random event. The weekly periodicity of COVID-19 daily new cases was expected and can be ascribed to differences in social activities, swab testing and/or reporting particularly, over weekends.<sup>15,23</sup>

As shown in Figure 2, the GCC countries experienced two major waves of the pandemic with varying degrees of intensity. The peaks and duration (days) of these two waves were estimated from the smoothed curves obtained with the Savitzky–Golay filter. As shown in Table 1, the first wave generally had a longer duration than the second wave, except in Bahrain and the UAE. The first wave ranged from 172 days in KSA to 301 days in the UAE, whereas the second wave (which is ongoing) varied from 181 days in Oman to 406 days in the UAE. In addition, the maximum number of daily positive cases (peak) during the second wave was generally higher than that during the first wave, except in KSA and Qatar.

Figure 3 shows that the shapes of the smoothed curves are similar to those of bacteria in a batch reactor (Figure 4), which typically have four distinct phases: a logarithmic (adaptation) phase, exponential (fast increase) phase, stationary (zero increase) phase and decline (death). However, in contrast to bacterial growth curves, the smoothed curves of the first wave (Figure 3) showed

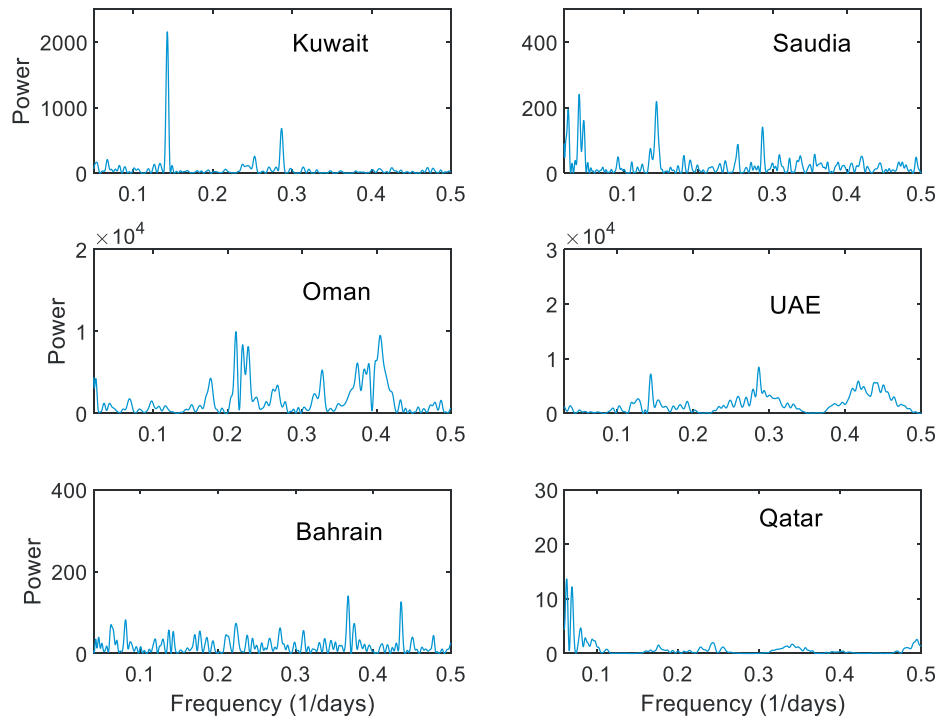


Figure 1: Oscillatory behavior of COVID-19 in GCC countries.

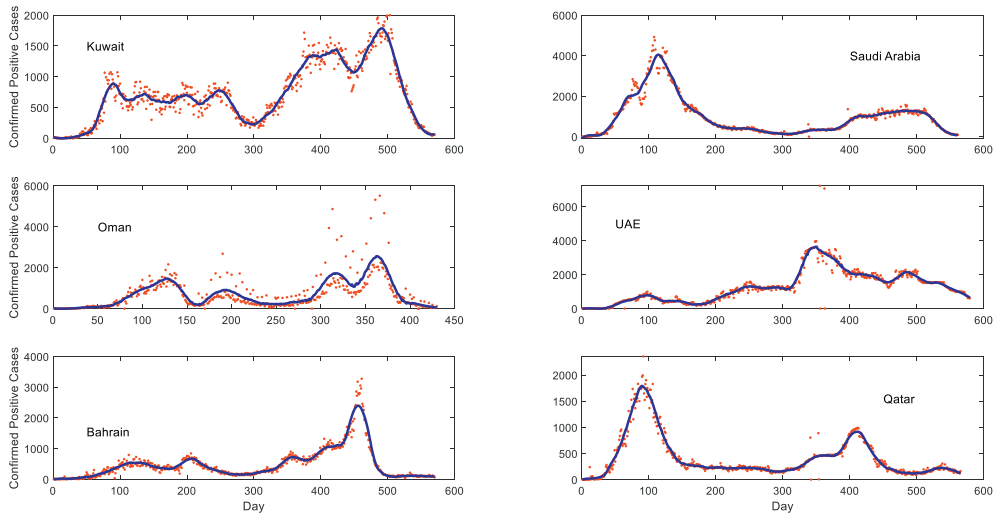


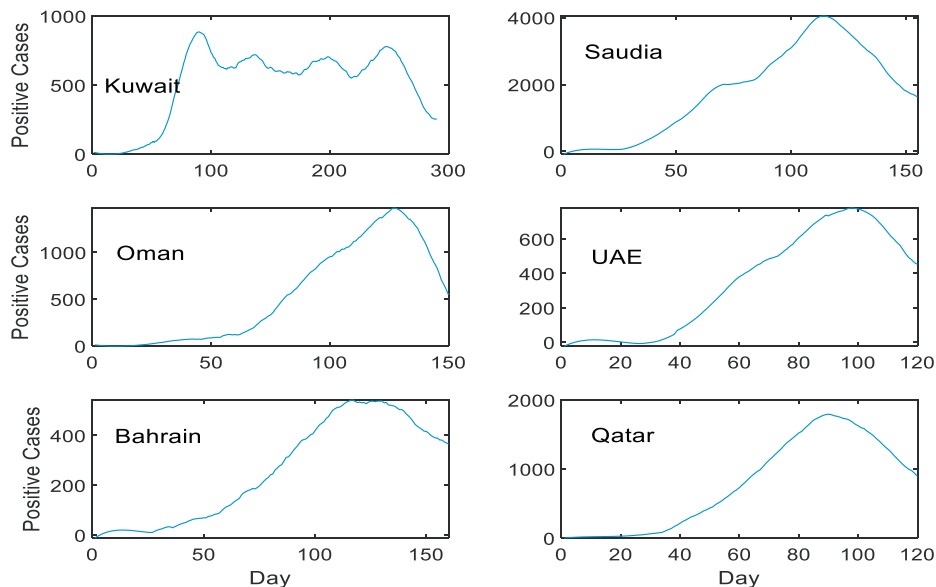
Figure 2: Savitzky–Golay smoothed curves of daily data for COVID-19 in GCC countries.

shorter stationary phases (1–10 days), except in Kuwait (162 days) and Bahrain (86 days). Apart from the weekly pattern identified through spectral analysis, the smoothed curve of Kuwait’s first wave showed an oscillatory stationary phase with a period of approximately 50 days. Weekly periodicity has also been observed in data for other countries, as explained above. However, no clear reasons explaining the 50-day cycles during the stationary phase in the Kuwait data were identified. Thus, the cause must be further investigated in future studies.

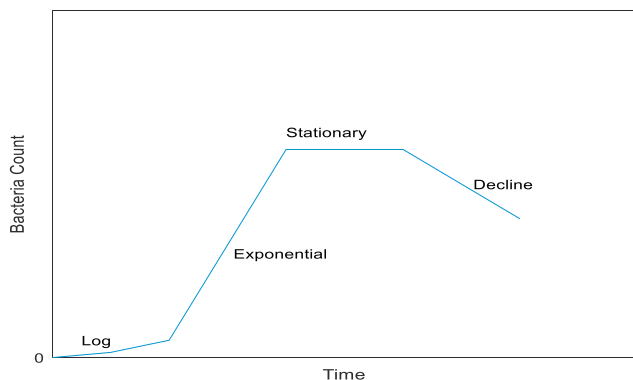
The estimated rates of the exponential growth and decline of COVID-19 (Table 2) illustrated the variability of COVID-19 dynamics in GCC countries. As shown in Table 2, the log

Table 1: Peaks and duration of COVID-19 pandemic waves in GCC countries.

Country	First wave		Second wave	
	Duration (days)	Peak value (cases/day)	Duration (days)	Peak value (cases/day)
Kuwait	297	870	270	1785
KSA	301	4848	260	1379
Oman	244	1468	181	2563
UAE	172	873	406	3571
Bahrain	277	705	293	2395
Qatar	286	1788	279	916



**Figure 3:** Smoothed curves of the first wave of the COVID-19 pandemic in the GCC countries.



**Figure 4:** Typical bacterial growth phases in a batch reactor.

(adaptation) phase varied from 26 in KSA to 62 days in Oman, whereas the stationary phase ranged from 1 to 10 days, except in Kuwait (162 days) and Bahrain (86 days). The exponential growth was estimated to range from 9 cases/day in Bahrain to 53 cases/day in KSA, whereas the decline rates varied from 6 cases/day in Kuwait to 72 cases/day in KSA.

**Table 2: Durations and rates during the first wave of COVID-19 in the GCC countries.**

Country	Duration of log phase (days)	Exponential growth rate (cases/day)	Duration of stationary phase (days)	Decline rate (cases/day)
Kuwait	53	40	162	6
KSA	26	53	1	72
Oman	62	23	10	54
UAE	32	14	1	8
Bahrain	37	9	86	8
Qatar	33	37	1	35

## Discussion

A thorough understanding of the dynamics of COVID-19 is crucial to enable comparison of the pandemic across countries. This study was aimed at demonstrating how to determine the different stages of a pandemic, and how to estimate the exponential growth rates and decline rates from smoothed profiles of daily confirmed new cases by using Savitzky–Golay filters. The rate of exponential growth of the pandemic in GCC countries was estimated to range from 9 to 53 cases/day. However, two articles published during early stage of the pandemic have reported very low growth rates.<sup>24,25</sup> Musa et al. have analyzed daily pandemic data from March 1 to April 13, 2020 for 12 African countries by using an exponential model, and have determined an average growth rate of 0.22 cases per day.<sup>24</sup> On the basis of pandemic data for Wuhan, China from December 10, 2019 to January 4, 2020, Li et al. have also estimated a very low value (0.11 cases/day) of the exponential growth rate.<sup>25</sup> Notably, the very low growth rates reported in these two studies reflect the growth rate during the adaptation phase rather than the exponential phase of the pandemic. The growth rate during the adaptation period is typically much lower than that during the exponential period (Figure 4). Therefore, the data analyzed did not contain information on the exponential phase. In contrast, Pinto et al. have found high growth rates in a study examining longer-term COVID-19 statistics for Germany, Russia and the United States.<sup>26</sup> Using MATLAB's polynomial interpretation tool, Pinto et al. have calculated the growth rates for Germany, Russia and the United States to be 6933, 11,656 and 34,517 cases/day, respectively, during the period from February 15 to May 18, 2020.

The oil-rich Gulf States have similar socio-economic, environmental conditions and health care capacities. Moreover, they have implemented nearly the same measures to control the spread of COVID-19 pandemic. However, the

dynamics of COVID-19 (duration of phases, growth rates and decline rates) were found to be unique for each GCC country. The observed difference reflected the sensitivity of the COVID-19 pandemic dynamics to differences in population mobility patterns, compliance with restrictions and changes in testing rates, rather than weather and socioeconomic conditions. Although weather was negatively associated with the exponential growth rate of COVID-19, it explained only 17% of the global variation in growth rates of COVID-19.<sup>27,28</sup> In contrast, city size, population mobility and changes in testing rates appear to explain individual differences in COVID-19 dynamics.<sup>29–33</sup> Therefore, further research is needed to gain a better understanding of the differences in the transmission dynamics of COVID-19 in the GCC countries.

The information obtained regarding the dynamics of COVID-19 should help the GCC countries retrospectively assess the effectiveness of the implemented control measures<sup>34</sup> and guide these countries' control measures and interventions in future waves of the pandemic. Moreover, the methods for extracting the dynamics from daily new cases could also be used to extract the COVID-19 dynamics in other countries.

The main limitation of the method used herein is that it is heavily dependent on the shape of the daily new case profile, particularly the inflection point. Because the data on new cases are influenced by numerous factors, the smoothed profiles of daily new cases may contain many uncertain factors that are difficult to identify. However, the method presented herein allows for the extraction of important information regarding outbreak dynamics, which can then be analyzed to improve understanding of the effectiveness of the control measures.

## Conclusions

The study indicated that the dynamics of COVID-19 varies considerably among the GCC countries. The information obtained is critical for assessing the COVID-19 control measures implemented in GCC countries. The method described in this study could also be used to extract COVID-19 dynamics in other countries. However, the dynamics of COVID-19 transmission in GCC countries requires further study.

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## Conflict of interest

There are no conflicts of interest.

## Ethical approval

Not relevant.

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