**Result**

More than 165.7 million cumulative confirmed cases and 3.43 million deaths had been documented globally and the global rCFR of COVID-19 is reported as 2.2% as of December 31st, 2020. The weekly global cumulative rCFR of COVID-19 reached a peak at 7.23% during the 17th Epidemiological week (April 22-28, 2020). The top five countries with COVID-19 rCFR are Yemen (28.9%), Italy (13.2%), United Kingdom (12.4%), Belgium (11.6%), and France (11.0%) (**Fig. 2 and S1**). The peak of the global COVID-19 rCFR was dominated by different WHO regions particularly at PAHO (especially the USA), EURO (especially the UK), and EMRO (especially Iran) (**Fig. 1**). After the 17th week, the weekly cumulative rCFR declines gradually in most WHO regions. The weekly mean cumulative rCFR was 3.6% (95% CI: 2.5-4.6) for the pre-peak period and 3.8% (95% CI: 3.3-4.3) for the post-peak period.

In the SES model, we found a constant trend between observed and predictive global rCFR of COVID-19 with a R2, RMSE and MAE being 95.29%, 0.02 and 0.01 respectively (**Table 1 and Fig. 3**). In the ARIMA and Prophet model, we found a strong increasing trend between observed and predictive global rCFR of COVID-19 with a R2, RMSE and MAE value of 99.20% and 97.46%, 0.91 and 0.02, and 0.44 and 0.01, respectively (**Table 1**). Again in the ARIMAX and BSTS model, we found a moderate increasing trend between observed and predictive global rCFR of COVID-19 with a R2, RMSE and MAE value of 98.13% and 84.78%, 0.16 and 0.15 and 0.02 and 0.02, respectively (**Table 1**). In terms of accuracy, ARIMA model performed better over Prophet, SES, BSTS and ARIMAX model (with better R2, RMSE and MAE value). The coefficient of determination of the ARIMA model was the larger and errors are lower than Prophet and benchmark SES model. According to the forecast in both models, the ratio of COVID-19 rCFR is expected to decrease considerably in the coming 10 days. The forecasting of global cumulative rCFR of COVID-19 for each model are shown in **Fig. 3.**

In M-K trend analysis, we identified an increasing trend of cumulative rCFR for the week 1-17th (p < 0.001 and tau = 0.54). Using Sen’s slope test, we found that over the 17-weeks, the slope was 0.008 (95% CI: 0.007 to 0.009). (**Table 1**).

In the beta regression model the percentage of precipitation over the country (IRR: 1.01, 95% CI: 1.01-1.02) and dew (IRR 1.03 [1.02-1.05]) were significantly positively associated with COVID-19 rCFR (**Table 2**). The relative humidity was slightly negatively associated with the COVID-19 rCFR in the experimented periods (0.99 [0.98-0.99] (**Table 2**). Other variables significant in this period were the prevalence of temperature max, temperature min, wind speed.

**Discussion**

We performed five time-series models taking real-time data into consideration to detect global trends of daily or weekly reported COVID-19 CFR and identified a declining trend since May, 2020. Using the M-K trend test, we found an increasing trend for global daily rCFR values of COVID-19 until the 17th week (pre-peak period, which ends on April 28th, 2020) at 7.23% and subsequently a significant declining trend up until the 53rd week (post-peak period) to 2.2% (December 29-31, 2020). Using a more robust time series model, (ARIMA, Prophet, ARIMAX, BSTS and SES), we detected a strong increasing trend of COVID-19 rCFR. Amongst five time-series models, the ARIMA and BSTS model outperformed the benchmark SES, Prophet and other models, which is probably because of the fact that the SES and Prophet methods were originally developed to handle the business-related problems.19,32

The rCFR of COVID-19 was associated with different factors, of which the precipitation, relative humidity and dew were strong predictors. This is a narrow variable set and other environmental factors such as pollutants, population density, innate population immunity and water pollution index could also be possible drivers but were not included here. Our findings of declining rCFR trends is consistent with findings from hospital-based studies using data of the early and later phase pandemic data.45,46 In New York, the mortality rate among hospitalized patients decreased by 18-20% in 3-4 months period accounting for 25.6% in March and 7.6% in June 2020.45 In England, the mortality rate at Intensive Care Unit and High Intensive Unit decreased substantially among the patients admitted in May compared to those admitted in March (9% and 11.2%, respectively).46

The rCFR is decreasing gradually over time and the exact reason for this is beyond the remit of this study. However, the decreased rCFR could be attributed to several reasons such as: increased numbers of asymptomatic or mild cases being detected by widespread rollout of testing, introduction of dexamethasone and other improvements in medical management of severely ill patients, experience gained by health professionals, increased public awareness, shielding from infection, possible effects of repurposed drugs like ivermectin which are increasingly used empirically, or increased rates of infection in younger people who have favourbale outcomes and shielding of peoples with co-morbidities.10,47,48

Globally, the COVID-19 cases are increasing with more than 200,000 daily cases from July 21st 2020 to up until the writing of this manuscript (December 31st, 2020). However, rCFR is decreasing after April 28th, 2020. The decreasing of COVID-19 rCFR could be partly anomalous with the increasing number of COVID-19 tests,3 which allows detection of more mild and asymptomatic cases which prior to this were excluded. For example, in Germany, the mean number of daily tests was 22,829 in the months of April 2020 and the figure is 117,423 in August 2020.4

Although our analysis indicates that global rCFR due to COVID-19 is declining, it does not mean that the rCFR is decreasing in every country and it should not be confused with Infection Fatality Rate or IFR (in other words, a lower risk of dying when being infected). In many countries, rCFR remains high and / or rising. For example, in Yemen,62 a country with a fragile health system it is experiencing a rCFR above 28.9% as of 31st December 2020 when the global rCFR is estimated at 2.20%.4 Our findings also do not indicate that the virus is becoming less severe. A study on genetic characteristics of SARS-CoV-2 indicates that the virus had a mutation with the G614 spike has replaced D614 and become the dominant variant of the virus around the world.63 The mutation is likely associated with increase infectivity, however, the pathogenicity of the variant remains unknown.63 More research is needed to measure the host-level pathogenicity of the virus.

**Limitation:**

We collected publicly available COVID-19 data on reported tests, cases, and deaths from WHO and other sources. These publicly available data probably contain under-reported values both in the numerator (COVID-19 deaths) and denominator (COVID-19 cases). There are variations in capacities and readiness of countries in testing and reporting COVID-19 cases and mortality records, which might have affected overall data quality. We estimated the cumulative rCFR, which tends to underestimate the actual risk of death because the deaths that will occur in the future are not included in the dataset. Both are universal limitations of rCFR estimated used in most of the studies using global COVID-19 data. One of the key hypotheses is that a higher proportion of younger populations are being infected with COVID-19 at the later phase of the pandemic. However, we could not test whether the median age of the population is changing over time and whether these changes are contributing to lowering the rCFR. While this study shows a declining rate of rCFR, our data cannot determine if IFR might be declining as well.