FURTHER MODELLING CORONAVIRUS INFECTIONS PROGRESSION IN SOUTH AFRICA

BY

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ABSTRACT

There is still no cure for Coronavirus Disease (COVID-19). South Africa like many countries has adopted a monitoring strategy of COVID-19 that includes publications in media releases, statistical figures regarding COVID-19. Critical analysis of the official COVID-19 figures is important to inform policy and decision makers in the management of COVID-19 in the country. This study undertook a critical examination of the progression of COVID-19 infections and case fatality rates during lockdown levels 4, 3 and 2 in South Africa. The data consisted of the daily numbers of confirmed cases of COVID-19, deaths and total number of persons tested. The analysis was based on epidemiological/demographic modelling of the officially published figures. The results suggest that, although there was an exponential increase in cumulative COVID-19 infections during lockdown level 3 in South Africa, this began to wane during lockdown level 2. It appeared however, that the official figures of cumulative number of confirmed COVID-19 cases as well as the cumulative numbers of COVID-19 deaths may have understated the magnitude and severity of the virus during lockdown levels 4, 3 and 2 in the country. In the absence of massive testing for COVID-19 in South Africa, the inclusion of the number of daily screenings in the Media Releases on COVID-19, may assist in assessing the magnitude and progression of COVID-19 infections in the country.

INTRODUCTION

Background

The World Health Organisation (WHO) declared the coronavirus (COVID-19) a pandemic on 11 March 2020. According to reported Coronavirus figures published by the WHO, as of 16 October 2020, the Unites States of America, with an estimated population of approximately 331 million as of July 1 2020 (UN, 2019), accounted for about 20.3% (38.6 million) of the globally reported confirmed cases of COVID-19. For the same dates and from the same sources, Russia, with an estimated population of approximately 146 million, accounted for about 3.5% of reported global COVID-19 confirmed cases; Brazil and Mexico, with estimated populations of approximately 213 million and 129 million respectively, accounted for about 13.3% and 2.1%, respectively of globally reported cases; and South Africa with an estimated population of approximately 57.7 million as of 30 June 2020 (Udjo, 2019), accounted for about 1.8% of the globally reported cases.

The reported global figures of COVID-19 cases most probably underestimate the magnitude of the pandemic, as coverage and efficiency in screening and testing for COVID-19 vary from country to country. For example, according to a Punch newspaper headline (Punch, 2020), of the 36 states in Nigeria, only three states (Lagos, Kano, Ogun) and the Federal Capital Territory were still conducting COVID-19 tests as of 22 September 2020. The global figures of fatalities due to COVID-19 may also underestimate true figures, due to not only the limited testing capabilities, coverage and/or absence of death registration in some countries, but also the wide range of COVID-19's impacts on various health conditions. In some countries a death certificate is not required before burial: In these circumstances, statistics on COVID-19 deaths may not accurately reflect the true picture. It should also be noted that, aside from other capabilities, the relative contribution of each country to the global COVID-19 figures should be cautiously interpreted, because countries are at different stages of the pandemic, thus a country's relative contribution to the global COVID-19 figures would depend on the stage of the progression of the pandemic in that particular country.

Statement of the Research Problem

Although vaccine and other clinical trials for the treatment and prevention of COVID-19 are underway in several countries, there is still no cure. Though there is cautious optimism in several quarters, there is no guarantee that an effective treatment or cocktail of treatments will be found soon. Russia and

China have approved vaccines for COVID-19, with caution expressed by many in the medical fraternity, and pending further trials, their rollout on a global scale is still restricted. In the outcome stage of an epidemic/pandemic in a population, some people will survive or die with or without a vaccine. When the epidemic/pandemic has run its course, prevalence and case fatality rates may be low but may not necessarily return to the pre-epidemic\pandemic levels. In the case of HIV, though different from COVID-19, there is still no vaccine to protect against HIV virus. However, currently HIV prevalence and AIDS related death rates are at lower levels compared to some earlier stages of the epidemic in some populations such as Uganda, Kenya, Zimbabwe, and Botswana. Therefore, in the half-life of an epidemic/pandemic, the progression is like a sigmoid curve, but ultimately takes on a conical shape when the epidemic/pandemic has run its course. This indicates that the progression of epidemics/pandemics is the outcome of their natural course as well as interventions and behavioural changes, though the effectiveness of interventions in mitigating the progression of epidemics/pandemics is a work in progress. With COVID-19, many countries imposed the draconian intervention of a national lockdown, with varying degrees of severity and success. At the individual level, the wearing of face masks, washing of hands, avoidance of large crowds or physical distancing, are some of the behavioural non-pharmaceutical intervention (NPI) responses to mitigate the natural course of the COVID-19 pandemic.

Another intervention strategy various governments have adopted to mitigate the spread of COVID-19, is screening and testing of people for COVID-19 and quarantining those testing positive, as well as contact trace and testing campaigns for potential close contacts, who may be required to self-isolate as a precaution. As noted in an earlier study by this author (Udjo 2020a), this strategy presents challenges. It is not practically possible that all the possible contacts from a positive case can be identified. Thus, globally and in many individual countries, the number of COVID-19 cases continue to increase.

As like many countries, South Africa has adopted a monitoring strategy of the progression of COVID-19 and publishes statistical figures regarding COVID-19 daily, including the cumulative number of tests conducted, the number of positive cases identified, the total number of recoveries and the total deceased due to complications from the virus. Inappropriate interpretation of these official figures could misinform decision makers in the private and public sectors and consequently undermine effective intervention and management of COVID-19 in South Africa. Given that there is still no effective treatment for COVID-19, it is important that researchers provide critical examination and interpretation of the official COVID-19 figures to guide policy and decision makers in the management

of the pandemic. A previous study by this author studied and modelled the progression of COVID-19 infections during the first 71 days of the pandemic in South Africa, when the country was under full (level 5) national lockdown (Udjo 2020a).

Objectives

The overall objective of this study therefore was to provide a critical examination of the progression of COVID-19 infections in South Africa during lockdown levels 4, 3 and 2. Specifically, the study:

1. Assessed the overall progression of COVID-19 infections, comparing official and model figures in the different levels of lockdown.
2. Assessed the progression of COVID-19 infections amongst those tested, including prevalence and new incidence.
3. Assessed the progression in cumulative COVID-19 case fatality rates.

DATA AND LIMITATIONS

The data for the analysis consisted of the daily numbers of confirmed cases of COVID-19, number of deceased and total number of persons tested, as published in the Media Release statements by South Africa's Minister of Health. These numbers were captured in an EXCEL spreadsheet by the author in a manner amenable to analysis. For example, figures for Day 73 from the start of the pandemic has a reference date of 16 May 2020; being seventy-three days from the date of the first confirmed case (5 March 2020) of COVID-19 in South Africa.

Two limitations of the data need mentioning, with the first being coverage. Coverage of testing for COVID-19 is still extremely low. As at day 200 since the start of the pandemic (20 September 2020), the reported number of persons tested was 4,041,543 nationally. This constituted only about 7% of the estimated mid-2020 total population of South Africa (see Udjo, 2020b for the population estimates). The Second limitation was whether the 4,041,543 persons tested may be regarded as a representative sample of South Africa's population or not: These tested persons may have been predominantly those who showed symptoms, or who had been in close contact with persons who showed symptoms of COVID-19. It is possible therefore, that these may be biased towards persons in the high-risk categories and their contacts. These limitations should be borne in mind when interpreting the results presented in this study.

METHODS

Assessing the plausibility of the Official Numbers of COVID-19 Infections

Historical patterns of epidemics indicate that though an epidemic/pandemic curve may be exponential at the beginning, it eventually manifests as a stretched S or sigmoid curve in its half-life. This means that at the early stage the growth rate of the number of persons infected is high, but as it matures, the growth rate get lower, stabilises, and eventually declines, as it runs its course. The starting point in the modelling in this study therefore was to fit an exponential mathematical curve to the official numbers for the early stage of the pandemic in South Africa.

It was observed from this approach that, the best fit corresponded to the days17-19 from the start of the pandemic. However, to avoid generating exaggerated model numbers of COVID-19 infections it was assumed: (1) that persons tested for COVID-19 is a random representation of the population. This assumption is not necessarily true and as earlier noted, probably a higher risk group than in the general population. (2) The daily growth rates in the number of positive cases are better reflections than a single constant exponential growth and therefore more reasonable estimates of the rates of progression of positive cases of COVID-19 in the general population. Based on the above assumptions and starting from day 17, model numbers of COVID-19 infections were estimated based on the following equations:

$$r = LN((TestCOVID19^{o}_{dn}/TestCOVID19^{o}_{dn-1})/(d_n-d_{n-1})) \quad …………………(1)$$

where r is the rate of growth, $TestCOVID19^{o}$ is the official number of positive cases of COVID-19 among those tested for $COVID-19$ on a specified day d_n, LN is natural logarithm.

$$COVID19^{m}_{dn} = COVID19^{m}d_{n-1} * e^{rt} \quad …………………………………….(2)$$

Where $COVID19^{m}$ is the model estimate of the cumulative number of COVID-19 infections as at a specified date d_n, r is as defined above and varies rather than a constant, $t = d_n - d_{n-1}$ is as defined above and e is exponential function.

Assessing the Progression of COVID-19 cases

Highly selective measures were used to assess the progression of Covid-19 cases under lockdown levels 4, 3 and 2. Ideally, one would start with computing prevalence (total number of cases existing at a point in time) rates of COVID-19 (or any disease), followed by (general) incidence (the number of new cases) rates at a specified point in time. However, in the current context, these measures are likely to be biased, as they are dependent on the number of COVID-19 tests performed at different points in time. A scatter plot of the relationship between the number of new COVID-19 tests and number of new COVID-19 cases confirmed this. To avoid spurious trends and to control for the varying number of new tests at different points in time, the following measures were used in the assessment.

Cumulative Prevalence Per Thousand Persons Tested. This was computed as

$$CumPrevCOVID19^t = (CumCOVID19^t_c/CumPertested^t) * k \qquad ……………………(3)$$

Where $CumCOVID19^t$ is the cumulative prevalence rate at a specified point in time, $CumCOVID19^t_c$ is the cumulative number of confirmed COVID-19 cases (old plus new cases) existing at a specified point in time, $CumPertested^t$ is the cumulative number of persons tested as at the specified date and k is a constant arbitrarily set at 1,000.

Specific Incidence Rates Per Thousand New Tests: This refers to incidence rate among new tests and was computed as

$$NewINCOVID19^t = (NEWCOVID19^t_c/NewPertested^t) * k \qquad ……………………(4)$$

Where $NewINCOVID19^t$ is the incidence rate among new persons tested for COVID-19 at a specified time, $NEWCOVID19^t_c$ is the number of new positive cases of COVID-19 among new persons tested for COVID-19 at a specified time and $NewPertested^t$ is the number new persons tested for COVID-19 at a specified time.

Progression in COVID-19 Case Fatality and Estimating the Number of Deaths from COVID-19

This is a difficult subject as the reported number of COVID-19 related deaths may be influenced by several factors. Examining the progression in COVID-19 case fatality and estimating the number of

deaths from COVID-19 involved firstly, estimating cumulative crude case fatality rates and secondly, estimating the number of COVID-19 case fatalities as follows.

Cumulative Crude Case Fatality Rates.

This refers to the cumulative number of deaths that are COVID-19 related per thousand confirmed COVID-19 cases and computed as

$CumCFatRateCOVID19^t = (CumDeathCOVID19^t / CumCOVID19^t) * k$ ………..(5)

Where $CumCFatRateCOVID19^t$ is the cumulative crude case fatality rate from COVID-19 as at a specified time, $CumDeathCOVID19^t$ is the cumulative number of COVID-19 deaths among the cumulative number of those testing positive as at a specified time, $CumCOVID19^t$ is the cumulative number of confirmed COVID-19 cases among the cumulative number of tests conducted as at the specified time, k is a constant set at 1,000.

Estimating the Number of Deaths from COVID-19

The values of $CumCFatRateCOVID19^t$ began to stabilise from day 48 onwards (16.74 deaths per thousand persons tested) and by day 50, the cumulative crude case fatality rate among those testing positive was 18.97 per thousand persons tested. A scatter plot of the values of $CumCFatRateCOVID19^t$ was therefore made from day 50 onwards. The intercept, a, and slope, b of these values, were then estimated by fitting a straight line by least squares to the values. Using these constants, the cumulative crude fatality rates were projected to mid-2020. Based on earlier assumptions, the number of COVID-19 deaths as at a specified date in the general population was then estimated as

$EDeathCumCOVID19^t = (MidCumFatRateCOVID19^t/1000) * COVID19^m_{dn}$ ……… (6)

Where $EDeathCumCOVID19^t$ is the estimated Cumulative number of COVID-19 deaths in the population as at a specified time, $MidCumFatRateCOVID19^t$ is the estimated mid-year crude fatality rate due to COVID-19, $COVID19^m_{dn}$ is the model estimate of the number of cumulative COVID-19 infections as at a specified date from equation (2) above.

RESULTS

Lockdown Dates and Features

To enable the interpretation of the results more meaningfully, Table 1 presents the dates and duration of the national lockdown levels 4, 3 and 2. The main features of the lockdown regulations in these levels are shown in Appendix 1. The focus of this study, as can be deduced from Table 1, are days 71-200 from the start of the pandemic, corresponding to the period 1 May 2020 – 20 September 2020.

As seen from Appendix 1, there was a gradual relaxation of lockdown restrictions by the South African Government as it moved the country from a higher level of lockdown to a lower level.

Table 1. Lockdown Dates and Start of Infections in Lockdown Level

Lockdown Level	Beginning Date of Lockdown	Beginning Day of Level From Start of Pandemic	Beginning Day of Start of Infection in Level*	Infections days in Level*
4	01/05/2020	58	71	71-102
3	01/06/2020	89	102	102-180
2	18/06/2020	167	180	180-200

* Assumes incubation period of COVID-19 is 14 days.
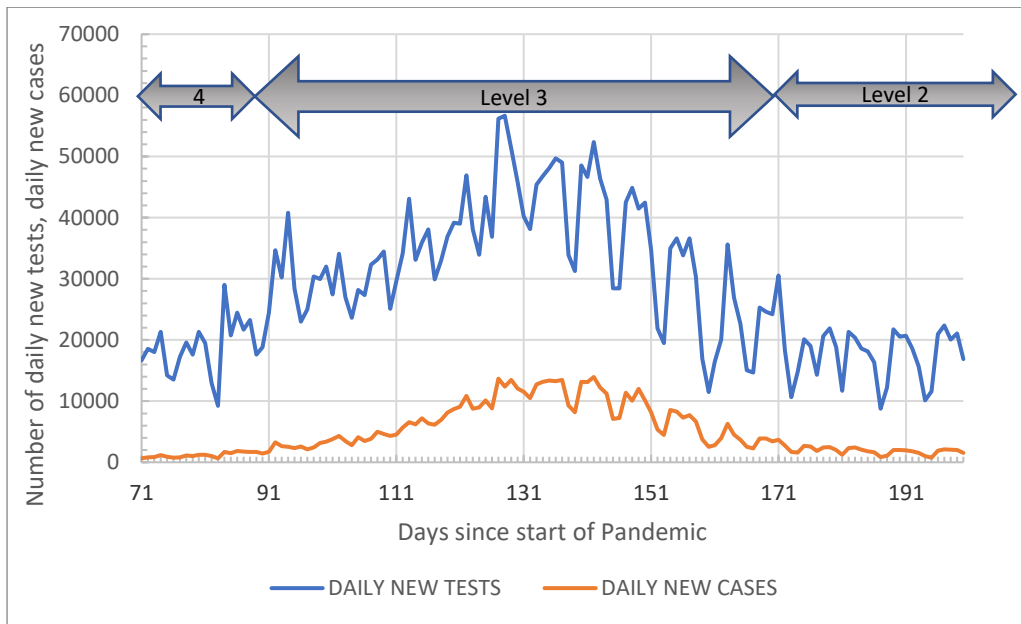Source: Author's compilation

Relationship Between Numbers of New COVID-19 Tests and New COVID-19 Cases

It was noted above that highly selective measures were used to assess the progression of Covid-19 cases in South Africa to control for the varying numbers of new tests at different points in time. The rationale for this is illustrated in Figures 1 and 2. Figure 1 compares the numbers of new COVID-19 tests and new COVID-19 cases over time.

As seen in the graph, although the absolute numbers are different, the shape of the curve of the numbers of new COVID-19 tests is identical with the shape of the curve of the numbers of new cases. Between day 120 and day 158 (i.e. 2 July – 9 August 2020), the daily numbers of new tests were at their highest, ranging between 39,188 – 52,382 new tests per day. Similarly, the daily numbers of new confirmed cases were at their highest during this period ranging between 8,124 – 13,944 new confirmed cases per day. From day 159 (i.e. 10 August 2020), onwards the daily numbers of new COVID-19 tests dropped drastically (apart from day 163) ranging between 8,759 – 30,560 daily new

tests. Similarly, apart from day 163, the daily numbers of new confirmed cases dropped drastically during the same period ranging between 772 – 3,946 confirmed daily new COVID-19 cases.

Figure 1: Comparison of Line Plot of the Daily Numbers of New COVID-19 Tests and New COVID-19 Cases
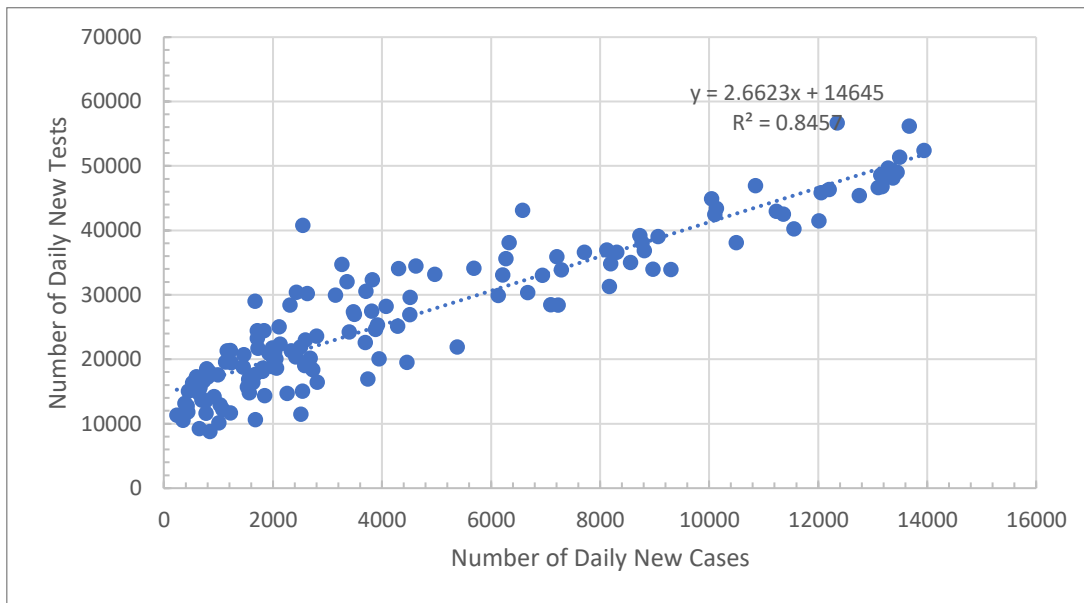

Source: Author's graph from official numbers

Figure 2 is another way of examining the relationship between the daily numbers of new COVID-19 tests and daily numbers of new COVID-19 confirmed cases. The scatter plot shows that, apart from of a few outliers, the lower the number of daily new COVID-19 tests, the lower the number of daily new confirmed COVID-19 cases. The correlation coefficient between these two variables is extremely high (0.92).

The important point about the two above graphs, is that any measure used in assessing the progression of COVID-19 infections after the early stage of the pandemic needs to control for bias introduced by varying numbers of daily new tests. This the justification for the choice of the measures used in the current study. One may ask: why did the daily new number of COVID-19 tests in South Africa drop dramatically after 9 August 2020? A probable answer to this question is provided in the last section of this paper.

**Figure 2: Scatter Plot of the Daily Numbers of New COVID-19 Tests and New COVID-19 Cases**

Source: Author's graph from official numbers

Progression of COVID-19 Infections and Comparison of Official and Model Numbers

Figure 3 shows the progression of COVID-19 infections since the first confirmed case of COVID-19 in South Africa. Since the current focus is on progression during lockdown levels 4, 3 and 2, let us examine the progression during days 71– 200. It can be seen from the official figures in the graph that there was an exponential increase in the cumulative numbers of COVID-19 infections during days 110 – 160. This was the period 22 June 2020 to 11 August 2020 during lockdown level 3, when lockdown regulations were still strict (see Appendix 1). The official cumulative COVID-19 infection figures therefore suggest that lockdown level 3 was a more COVID-19 infectious period than lockdown levels 4 and 2. This is probably due to a combination of factors including the natural course of the pandemic, and the weather. The official cumulative number of COVID-19 infections ranged between 4,266 – 13,944 daily new COVID-19 infections, but it should also be noted that this was also the period that the daily numbers of new tests were at their highest, ranging between 25,116 – 56,170 daily new tests.

Figure 3: Cumulative Numbers of COVID-19 Infections
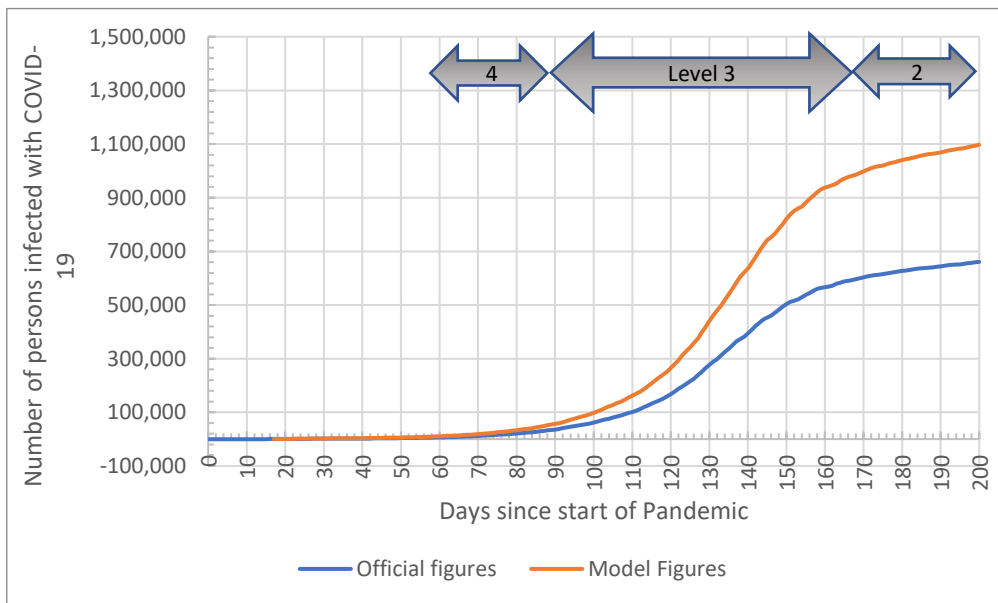
Source: Author's graph from official numbers

Assuming a 14-day incubation period for COVID-19, the official number of infections manifested in the early part of lockdown level 3, i.e. between days 71 and 101, may have been 'carried over' infections from lockdown level 4. The carried over infections from lockdown level 4 might also be due to the length of time people were sick before presenting themselves for test at a health facility. However, the portion of Figure 3 depicting the exponential increase in COVID-19 cumulative number of infections (days 120 – 150), reflect some of the infections that occurred during lockdown level 3.

The official cumulative figures, as seen from Figure 3, suggest that the virulence of COVID-19 infections began to wane after day 170 (i.e. during lockdown level 2) and began to plateau thereafter, but this was also the period that the daily numbers of new tests were at their lowest in comparison with lockdown level 3 (ranging between 8,759 – 24,224 daily new tests). One may ask, to what extent is the apparent plateauing of COVID-19 progression during lockdown level 2 a reflection of the low numbers of daily tests during the period? Some insight to this question is provided in the next section.

The foregoing analysis has been about the official numbers. A comparison of the official and model figures in Figure 3 suggests that the official figures understate the magnitude of the cumulative numbers of COVID-19 infections during lockdown levels 4, 3 and 2 in the country. A comparison of the official and model cumulative numbers of COVID-19 at selected dates during levels 4, 3 and 2 are summarised in Table 2

Table 2 Comparison of Cumulative Numbers of Official and Model Numbers of COVID-19 Infections

| Lockdown Level	Date	Day from Start of Pandemic	Cumulative Numbers of COVID-19 Infection		
			Official	Model*	Difference*
4	15/5/2020	72	13,524	21,201	7,677
4	29/5/2020	86	29,240	45,605	16,365
3	15/6/2020	103	83,890	133,824	49,934
3	29/6/2020	117	144,264	229,887	85,623
2	1/9/2020	181	628,259	1,043,543	415,284
2	15/9/2020	195	651,521	1,082,998	431,477

*Source: Author's estimation from official numbers extracted from Figure 3

As seen from the table, while the official number of COVID-19 cases as at 15 May 2020 in South Africa was reported as 13,524, the model estimate of the magnitude as at that date was 21,201 COVID-19 cumulative infections, a difference of 7,677 between the official and model figures. As at 15 September 2020 (i.e. 195 days from the start of the pandemic in South Africa), the Ministry of Health reported there were 651,521 confirmed cases of COVID-19 in the country, whereas the model estimate of the magnitude of cumulative number of infections was 1,082,998 as at that date. Figure 3 and Table 2 suggest that the official cumulative numbers of COVID-19 cases systematically understated the magnitude of cumulative number of infections of COVID-19 during lockdown levels 4, 3 and 2 in the country. This was also the case during the full national lockdown level 5 (Udjo 2020).

Progression of COVID-19 Infections Among those Tested

The cumulative prevalence rates among those tested for COVID-19 are summarised in Figure 4. Due to missing data, the starting point of the cumulative prevalence in Figure 4 is day 37 (which was part of the full national lockdown level 5). Focusing on lockdown levels 4, 3 and 2, the following trend can be seen from the graph. The official figures suggest that there was a sharp increase in cumulative prevalence rates during lockdown level 3. It increased from about 58 persons testing positive for every 1,000 persons tested as at day 100 (12 June 2020) to about 168 persons testing positive for every 1,000 tested as at day 150 (1 August 2020). The official figures further suggest that the prevalence rates amongst persons tested for COVID-19 began a downward trend from day 160 (11 August 2020) onwards. Thus, the entire period of lockdown level 2 apparently experienced a downward trend in COVID-19 prevalence rates among those tested.

Figure 4: Cumulative COVID-19 Prevalence Rates Per Thousand Persons Tested
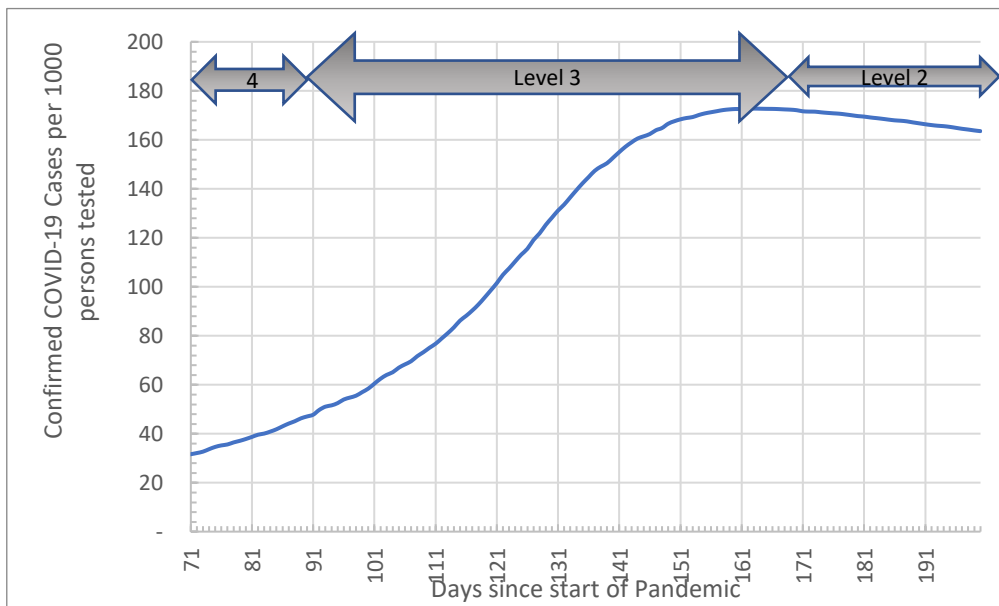
Source: Author's graph from official numbers

The official figures from which Figure 5 was derived appear to suggest that specific incidence of COVID-19, i.e. daily incidence of new cases of COVID-19 amongst those tested increased from about 105 new confirmed cases for every 1,000 new tests on day 100 (12 June 2020), to about 238 new confirmed cases for every 1,000 new tests on day 150 (1 August 2020). The daily incidence rate of new cases among daily new tests for COVID-19 depicted in Figure 5 is cone-shaped with a steep increase and a peak during lockdown 3, followed by an apparent steep decline during lockdown level 2. It appears from Figure 5 regarding new cases, that the most infections period of COVID-19 was during lockdown level 3 compared with lockdown levels 4 and 2.

**Figure 5: COVID-19 Incidence Rates Per Thousand Persons Tested**
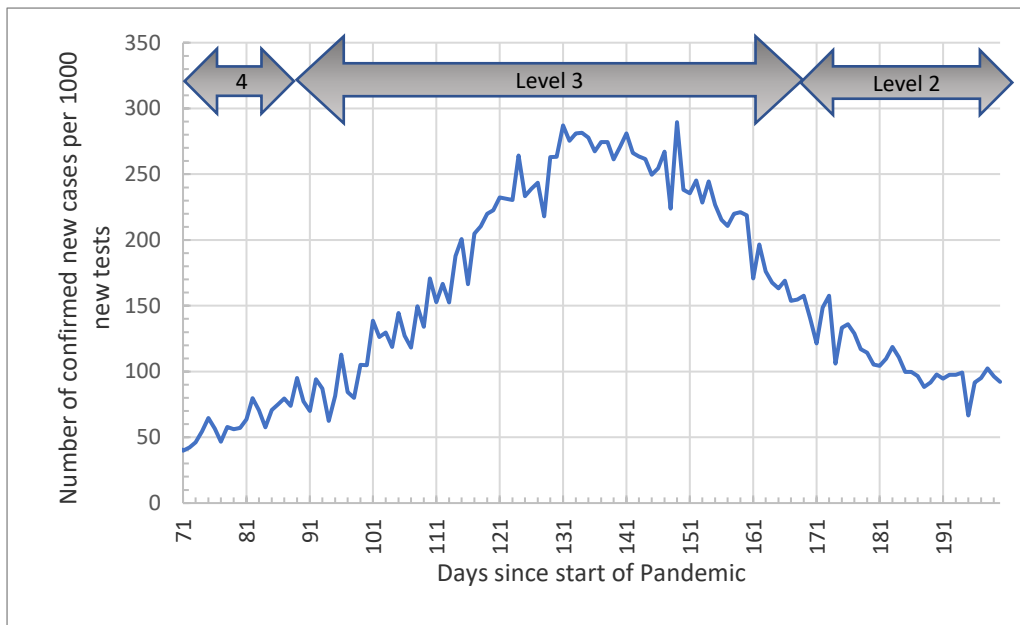
Source: Author's graph from official numbers

Progression in Cumulative COVID-19 Case Fatality Rates

Figure 6 shows the progression in cumulative COVID-19 case fatality rates. The official cumulative deaths attributable to COVID-19 suggest that the cumulative crude death rates from COVID-19 increased during the period 83 – 100 days (i.e. between 26 May 2020 and 12 June 2020), which was during lockdown level 4. Thereafter, the cumulative crude death rates apparently declined up to day 138 (i.e. between 13 June 2020 and 20 July 2020).

It is puzzling why the cumulative death rates declined during this period. A possible reason is underreporting of COVID-19 related deaths during the period. Figure 6 further indicates that there was a systematic increase in cumulative crude death rates during the period 140 – 200 days from the start of the pandemic (i.e. between 22 July 2020 and 20 September 2020), which were within part of lockdown levels 3 and 2. During the period, the COVID-19 cumulative crude death rate increased from 15 for every 1,000 confirmed cases (as of 22 July 2020) to 24 per thousand confirmed cases (as of 20 September 2020).

Figure 6: Cumulative Case Fatality Rates
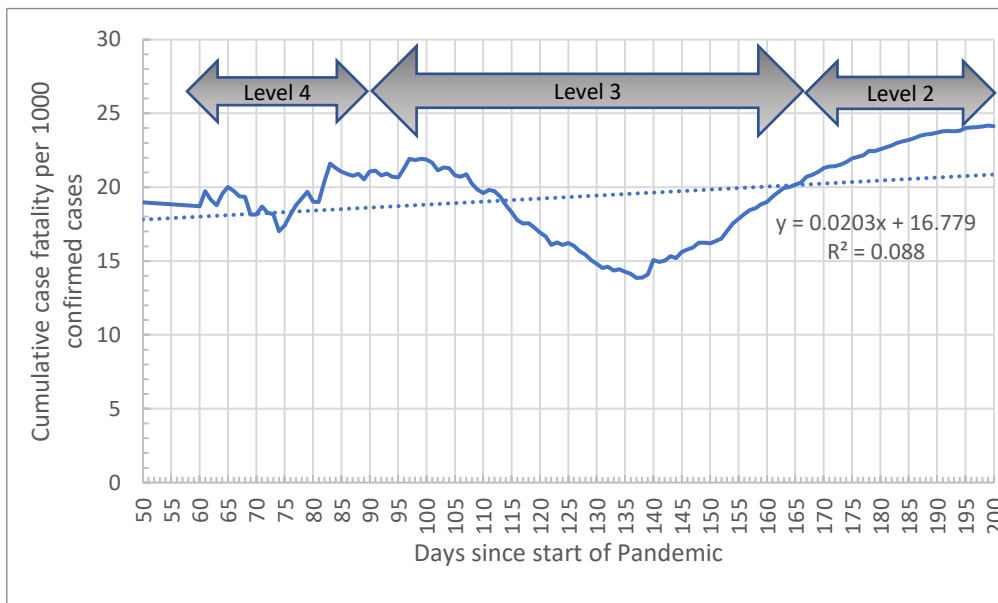
Source: Author's graph from official numbers

Fitting a straight line by least squares to the values corresponding to the period depicted in the graph suggests a slightly upward trend overall in cumulative crude case fatality rates derived from the official numbers during lockdown levels 4, 3 and 2. The coefficients of the fitted line indicate an average of 17 COVID-19 deaths daily per thousand confirmed COVID-19 cases during the period 23 April 2020 (later part of lockdown level 5) and 20 September 2020 (end of lockdown level 2).

As a means of assessing the accuracy of the official cumulative numbers of COVID-19 related deaths, Table 3compares the official numbers with those from the model based on equation 6 above at selected dates. The differences appear to suggest that the official figures understated the magnitudes of cumulative numbers of COVID-19 related deaths at different points in time.

Table 3 Comparison of Official and Model Cumulative Crude Death Rates from COVID-19

Lockdown Level	Date	Cumulative Numbers of COVID-19 Infection		
		Official	Model*	Difference*
4	15/5/2020	247	385	138
4	29/5/2020	611	828	217
3	15/6/2020	1,568	2,117	549
3	29/6/2020	2,529	4,175	1,646
2	1/9/2020	14,263	18,950	4,687
2	15/9/2020	15,641	19,476	3,835

*Source: Author's estimation based on Figure 3 and equation 6.

The trends depicted in the second half of Figures 4 and 5 (i.e. from day 140 onwards from 22 July 2020) are inconsistent with the corresponding trend in Figure 6. While the official figures suggest that cumulative prevalence and new incidence rates from COVID-19 declined from day 140 onwards, the cumulative crude fatality rates on the other hand increased in the same period. This further casts doubt on the accuracy of the official numbers of COVID-19 confirmed cases. Although the official cumulative numbers of COVID-19 deaths appeared to be underreported as shown above, the official numbers of COVID-19 confirmed cases throughout lockdown levels 4, 3 and 2 (as well as in lockdown level 5) may also be substantially underreported.

DISCUSSION AND CONCLUSION

The focus of this study was a critical examination of the progression of COVID-19 infections and case fatality rates during lockdown levels 4, 3 and 2 in South Africa. The results suggest that there was an exponential increase in cumulative numbers of COVID-19 infections during lockdown level 3. The results further suggest that the virulence of COVID-19 infections began to wane during lockdown level 2. It appeared from the modelling that the official figures of cumulative numbers of both confirmed COVID-19 cases and deaths understated the magnitude and severity of the virus in the country during lockdown levels 4, 3 and 2.

This study could not reconcile the apparent decline in cumulative prevalence and new incidence rates from COVID-19 during part of lock down 3 and lockdown 2 on the one hand, and with the increasing cumulative crude fatality rates during the same period on the other hand. Several probable factors may account for the contradictory trends:

(1) *Reduced numbers of daily screenings:* Persons tested for COVID-19 come from a pool of persons that were screened for symptoms of COVID-19 and persons that were in contact with persons testing positive for COVID-19. Thus, if in absolute terms, the daily numbers of screenings for COVID-19 became fewer, this would have resulted in fewer daily numbers of persons tested for COVID-19, because there would have been fewer numbers of symptomatic cases daily, and in turn resulted in fewer numbers of confirmed cases daily, even if the virulence of COVID-19 was still high. In this scenario, the prevalence and incidence of COVID-19 would be understated thus giving a misleading trend in the progression of the virus. This is because, technically, the numerators for computing the prevalence and incidence relative are biased downwards relative to the population at risk (the mid-

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year population) in this kind of scenario. To minimise this bias, the prevalence and incidence of COVID-19 in this study were computed only among those tested to ensure the numerators and the denominators of the computations are from the same universe. Despite this, it is possible that the probable bias was not eliminated entirely. It was not possible to determine whether the daily number of screenings for COVID-19 decreased over time, due to either lack of data on cumulative or daily numbers of screenings. One may deduce from the following statement: "As of today, we have conducted over 580,000 coronavirus tests and more than 12 million screenings" (Union Buildings 2020) that the data on the numbers of screenings exist. Unfortunately, the cumulative or daily number of screenings have not been part of the regular data published in the Media Releases on COVID-19 in South Africa.

(2) *COVID-19 symptoms mistaken for flu symptoms.* It is possible that some symptomatic people may have passed off COVID-19 symptoms they experienced as flu symptoms, and instead of going to test for COVID-19, resorted to self-medication for flu. It is possible that some of these people had COVID-19 and the symptoms got worse, but by the time they went to a medical facility for treatment, it was too late and they died.

(3) *Stigma:* Some COVID-19 symptomatic people may not have gone for COVID-19 test due to perceived stigma of having caught COVID-19. Depending on the severity of the symptoms, some may have died.

Any one or combination of the above factors, if correct, could have resulted in declining COVID-19 prevalence and incidence rates, but increasing COVID-19 case fatality rates. Should there be a second exponential increase in COVID-19 infections in South Africa and if any of the above factors is true, it might be difficult to accurately assess the magnitude of the second wave of COVID-19 infections. Assuming no duplicates in the number of COVID-19 tests (i.e. one test per persons) and as already noted, as of 20 September 2020, the number of persons tested for COVID-19 constituted only about 7% of the South African population at mid-year in 2020. It is however unlikely that there were not duplicate tests. In the absence of mass testing for COVID-19 in the population, the inclusion of the cumulative or daily numbers of screenings as part of the regular data on COVID-19 numbers published in Media Releases on COVID-19 in South Africa, would contribute to additional assessments of the magnitude and progression of COVID-19 infections in the country.

ACKNOWLEDGMENTS

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Appendix 1: Some Features of the Regulations Governing the Levels of Lockdown.

Source: https://www.gov.za. Note that Annexures, Tables and Forms referred to in the regulations are not shown in this paper.

LEVEL 4 (1 – 31 May 2020).

- Every person is confined to his or her place of residence.
- A person may only leave their place of residence to--
- (a) perform an essential or permitted service, as allowed in Alert Level 4;
  (b) go to work where a permit which corresponds with Form 2 of Annexure A, has been issued;
  (c) buy permitted goods;
  (d) obtain services that are allowed to operate as set out in Table 1 to the Regulations;
  (e) move children, as allowed;
  (f) walk, run or cycle between the hours of 06H00 to 09H00, within a five kilometre radius of their place of residence; Provided that this is not done in organised groups
- Every person is confined to his or her place of residence from 20H00 until 05H00 daily, except where a person has been granted a permit to perform an essential or permitted service.
- Movement between provinces, metropolitan areas and districts are prohibited except-
- (a) for workers who have a permit to perform an essential or permitted service who have to commute to and from work on a daily basis;
  (b) the attendance of a funeral, as allowed;
  (c) the transportation of mortal remains; and
  (d) for learners who have to commute to and from school or higher education institutions on a daily basis during periods when those institutions are permitted to operate.
- Any person who was not at their place of residence, or work before the lockdown period and who could not travel between provinces, metropolitan and district areas during the lockdown, will be permitted, on a once-off basis, to return to their places of residence or work and will be required to stay in such place until the end of Alert Level 4.
- Movement between a province, metropolitan area or district by a person wishing to attend a funeral shall only be permitted if that person so wishing to attend the funeral is a-
  (a) spouse or partner of the deceased;
  (b) child of the deceased, whether biological, adopted or stepchild;
  (c) child-in-law of the deceased;
  (d) parent of the deceased whether biological, adopted or stepparent;
  (e) sibling, whether biological, adopted or stepbrother or sister of the deceased; (f) or grandparent of the deceased;
- Attendance at a funeral is limited to 50 people and will not be regarded as a prohibited gathering.
- Night vigils at a funeral is banned.
- All borders of the Republic remain closed during the period of Alert Level 4, except for ports of entry designated by the Cabinet member responsible for home affairs and for the transportation of fuel, cargo and goods during the period of Alert Level 4.
- Rail, ocean, air and road transport is permitted for the movement of cargo to other countries and within the Republic of South Africa, subject to national legislation, for the transportation of the following goods-
  (a) essential goods for import as set out in Annexure B to the Regulations;
  (b) the import of materials and components required for manufacturing activities

allowed under Alert Level 4;
(c) cargo at ports of entry;
(d) goods cleared at ports of entry for removal in transit through the Republic destined for neighbouring countries;
(e) permitted goods for export as set out in Annexure C to the Regulations;
(f) transport of goods within the Republic of South Africa; and
(g) any other goods as set out in Directions by the relevant Cabinet member; taking into account health risks, constrained capacity at ports of entry and other factors relevant to the health; public order and economic effects of Covid -19.

- All gatherings are banned, except-
(a) for funerals;
(b) when at a workplace; or
(c) when buying or obtaining goods and services.
- Any place or premises normally open to the public where religious, cultural, sporting, entertainment. recreational, exhibitional, organisational or similar activities may take place. is closed.
- The sale, dispensing and distribution of liquor is prohibited.
- The transportation of liquor is prohibited, except where alcohol is required for industries producing hand sanitizers, disinfectants, soap, alcohol for industrial use and household cleaning products.
- The transportation of liquor for export purposes is permitted.
- The sale of tobacco, tobacco products, e-cigarettes and related products is prohibited.
- Businesses and other entities as set out in Table 1 may commence operations.
- To ensure the continuous supply of energy and petroleum products to society as referred to in Table 1-
(a) collieries that supply Eskom may continue to operate at full capacity; and
(b) refineries and other facilities providing energy and fuel may operate at full capacity to avoid shortage of fuel and energy, and such operations may include fuel storage, smelters, plants and furnaces.

(https://www.gov.za/covid-19/about/disaster-management-act-regulations-alert-level-4-during-coronavirus-covid-19-lockdown).

LEVEL 3 (1 June – 17 August 2020).

- A person may leave his or her place of residence to-
(a) perform any service, as permitted under Alert Level 3;
(b) travel to and from work;
(c) buy goods or obtain services, as permitted under Alert Level 3;
(d) move children, as allowed;
(e) exercise between the hours of 06h00 to 18h00: Provided that the exercise is not done in organised groups of more than four people and adheres to health protocols and social distancing measures;
(f) attend a place of worship in the same or another metropolitan area or district within the same province;
(g) attend a school or learning institution, once these are opened; and

(h) travel for leisure purposes as allowed under Alert Level 3.

- Every person is confined to his or her place of residence from 21H00 until 04H00 daily, except where a person has been granted a permit, to perform a service permitted under Alert Level 3, or is attending to a security or medical emergency.
- A person must when in a public place, wear a cloth face mask or a homemade item that covers the nose and mouth, or another appropriate item to cover the nose and mouth.
- Movement of persons between provinces is prohibited, except for
(a) persons doing so in the course of carrying out work responsibilities or performing any service permitted under Alert Level 3, provided that such person is in possession of a permit issued by the employer which corresponds with Form 2 of Annexure A;
(b) persons travelling for purposes of-
(i) moving to a new place of residence; or
(ii) caring for an immediate family member: Provided that such person is in possession of an affidavit which corresponds with Form 6 of Annexure A;
(c) members of Parliament performing oversight responsibilities;
(d) learners or students referred to in regulation 34(5) who have to commute to and from those schools or institutions of higher learning during periods when those schools or institutions are permitted to operate;
(e) the attendance of funerals as provided for in regulation 35;
(f) the transportation of mortal remains;
(g) obtaining medical treatment;
(h) persons who are returning to their place of residence from a quarantine or isolation facility; or
(i) any movement permitted under regulation 41.
- Movement between provinces, metropolitan areas or districts by a person intending to attend a funeral is only permitted if the person is a-
(a) spouse or partner of the deceased;
(b) child or grandchild of the deceased, whether biological, adopted. stepchild, or a foster child;
(c) child-in-law of the deceased;
(d) parent of the deceased whether biological, adopted or stepparent;
(e) sibling, whether biological, adopted or stepbrother or sister of the deceased; or
(f) grandparent of the deceased;
- (2) Attendance at a funeral is limited to 50 persons and is not regarded as a prohibited gathering.
- (3) Night vigils are prohibited.
- All gatherings are prohibited except a gathering at-
(a) a faith-based institution, which is limited to 50 persons or less, depending on the size of the place of worship
 (b) a funeral, subject to regulation 35;
A place or premises normally open to the public, where cultural, sporting entertainment, leisure, exhibitional, organisational or similar activities may take place, is closed to the public, and all gatherings at these places or premises are prohibited save for the exceptions in subregulation (2) and in regulation 37.
- During the national state of disaster all borders of the Republic must be closed, except for ports of entry designated by the Cabinet member responsible for home affairs, for
(a) the transportation of fuel, cargo and goods; and
(b) humanitarian operations, repatriations, evacuations, medical emergencies, movement of staff of diplomatic and international organisations and other exceptions as may be determined by the relevant Cabinet member by directions.

- Bus and taxi services may operate under the following conditions: (a) may not carry more than 70% of the licensed capacity for long distance intra-provincial and permitted inter-provincial travel, and (b) may carry 100% of the licensed capacity for any trip not regarded as long distance travel. Long distance is a trip of 200 km or more whether the travel is within a province or inter-provincial.
- The sale, dispensing and distribution of liquor is prohibited.
- The transportation of liquor is prohibited except (a) if alcohol required for industries producing hand sanitizers, disinfectants, soap or alcohol for industrial use and household cleaning products, (b) for export purposes, (c) from manufacturing plants to storage facilities.
- The sale of tobacco, tobacco products, e-cigarettes and related products is prohibited.
- The sale of tobacco, tobacco products, e-cigarettes and related products for export is permitted.
- Businesses and other institutions may operate except those set out in Table 2.

(https://www.gov.za/documents/disaster-management-act-regulations-alert-level-3-during-coronavirus-covid-19-lockdown-28).

LEVEL 2 (18 August – 20 September 2020).

- Physical distancing and restrictions on leisure and social activities to prevent a resurgence of the virus.
- Every person is confined to his or her place of residence from 22H00 until 04H00 daily, except where a person has been granted a permit, which corresponds with Form 2 of Annexure A, to perform a service other than a service related to an activity listed under Table 3, or is attending to a security or medical emergency.
- A person -
  (a) must when in a public place, wear a face mask; and
  (b) may not be allowed to be in a public place, use any form of public transport, or enter a public building, place or premises, if that person is not wearing a face mask.
- Attendance at a funeral is limited to 50 persons and will not be regarded as a prohibited gathering. Night vigils are not allowed. During a funeral, a person must wear a face mask and adhere to all health protocols and social distancing measures.
- All gatherings are prohibited except a gathering at a faith-based institution, which is limited to 50 persons or less, depending on the size of the place of worship: Provided that all health protocols and social distancing measures are being adhered to.
- During the national state of disaster all borders of the Republic must be closed, except for ports of entry designated by the Cabinet member responsible for home affairs for (a) the transportation of fuel, cargo and goods;(b) the entry of foreign sea crew for the purposes of the exchange of sea crew in the Republic; or(c) humanitarian operations, repatriations, evacuations, medical emergencies, the movement of staff of diplomatic and international organisations and other exceptions as may be determined by the relevant Cabinet member by directions.
- Bus and taxi services -
  (a) may not carry more than 70% of the licensed capacity for long distance travel; and
  (b) may carry 100% of the licensed capacity for any trip not regarded as long distance travel in terms.
- The sale of liquor-
  (a) by a licensed premises for off-consumption, is permitted from 09h00 to 17h00, from Mondays to Thursdays, excluding Fridays, Saturdays, Sundays and public holidays;

(b) by a licensed premises for on-site consumption is permitted, subject to strict adherence to the curfew contemplated in regulation 50(1).

- Businesses may operate except for those set out in Table 3.

(https://www.gov.za/coronavirus/alert-level-2).