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MASHA
MODELLING & SIMULATION HUB, AFRICA

Estimating cases and resource requirements for COVID-19 in South Africa

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23 March 2020

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Summary

The purpose of this report is to project the detected COVID-19 cases at a national and provincial level for the next 2 weeks. A dynamic stochastic compartmental model was used to simulate the transmission of local and imported Covid-19 based on publicly available data until 21 March. The model projects that by 1 April 2020, there is a 50% chance that cumulative detected cases could lie between 562 and 4217 *in the absence of intervention.* The model also projects that there is a 50% chance that cumulative detected cases will reach 1000 nationally between 29 March and 5 April, with Gauteng between (1 April and 8 April) and Western Cape between (5 April and 12 April). We further project that the number of general hospital beds will exceed 50 by 1 April, though wide interquartile ranges due to variability in treatment seeking behaviour suggest this may occur by 29 March.

All models are simplifications of reality that are designed to describe and predict system behaviour and are justified by the assumptions and data with which they are developed. Model robustness and predictions are likely to be improved as more data becomes available.

Findings

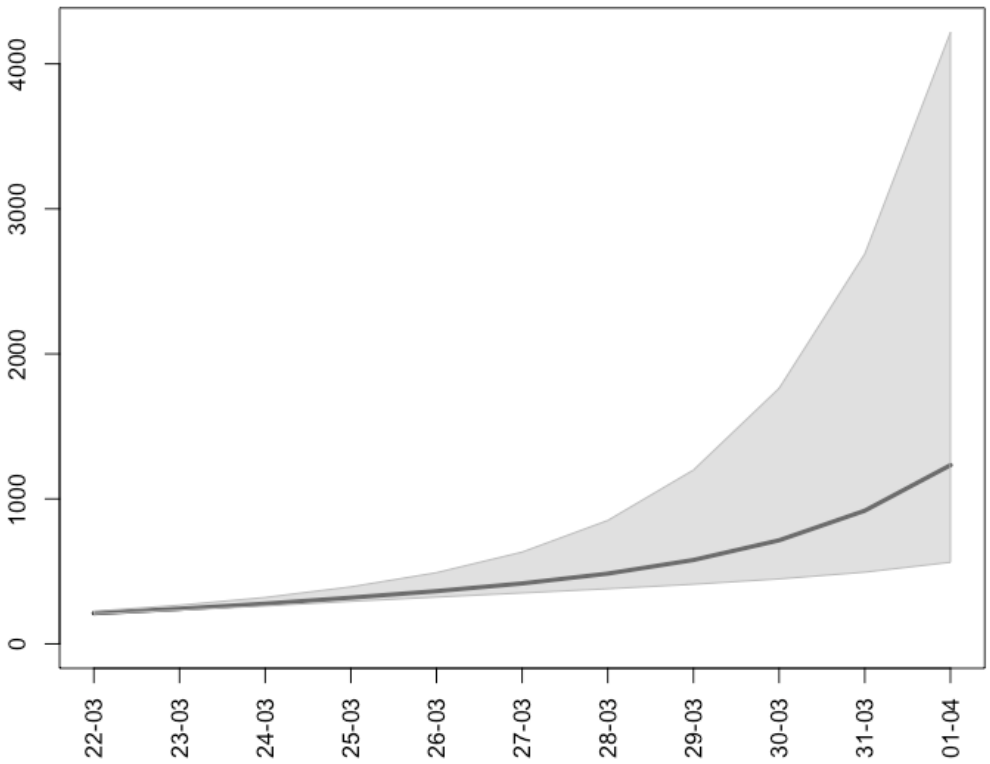


Figure 1. Estimated daily cumulative cases (National) - Median and interquartile range (25%, 75%)

Table 1. Estimated daily cumulative cases (National) - Median and interquartile range (25%, 75%)

Date	25th perc	50th perc	75th perc
22/03/2020	206	212	226
23/03/2020	232	242	267
24/03/2020	261	277	320
25/03/2020	293	319	393
26/03/2020	322	364	491
27/03/2020	351	417	633
28/03/2020	380	484	851
29/03/2020	411	578	1199
30/03/2020	448	714	1763
31/03/2020	494	918	2689
01/04/2020	562	1232	4217

Tables of provincial detected incidence by severity are available in the Appendix. Hospital beds and ICU beds predicted to be required daily until 1 April are shown in the tables below. Provincial estimates are available as Excel files.

Table 2: Projected General Hospital beds required daily (National) - Median and interquartile range (25%, 75%)

Date	25th perc	50th perc	75th perc
22/03/2020	0	1	2
23/03/2020	0	1	3
24/03/2020	1	2	5
25/03/2020	1	3	8
26/03/2020	1	4	12
27/03/2020	2	6	20
28/03/2020	3	10	34
29/03/2020	4	15	55
30/03/2020	6	24	90
31/03/2020	9	37	149
01/04/2020	13	57	243

Table 3: Projected Critical care/ICU beds required daily (National) - Median and interquartile range (25%, 75%)

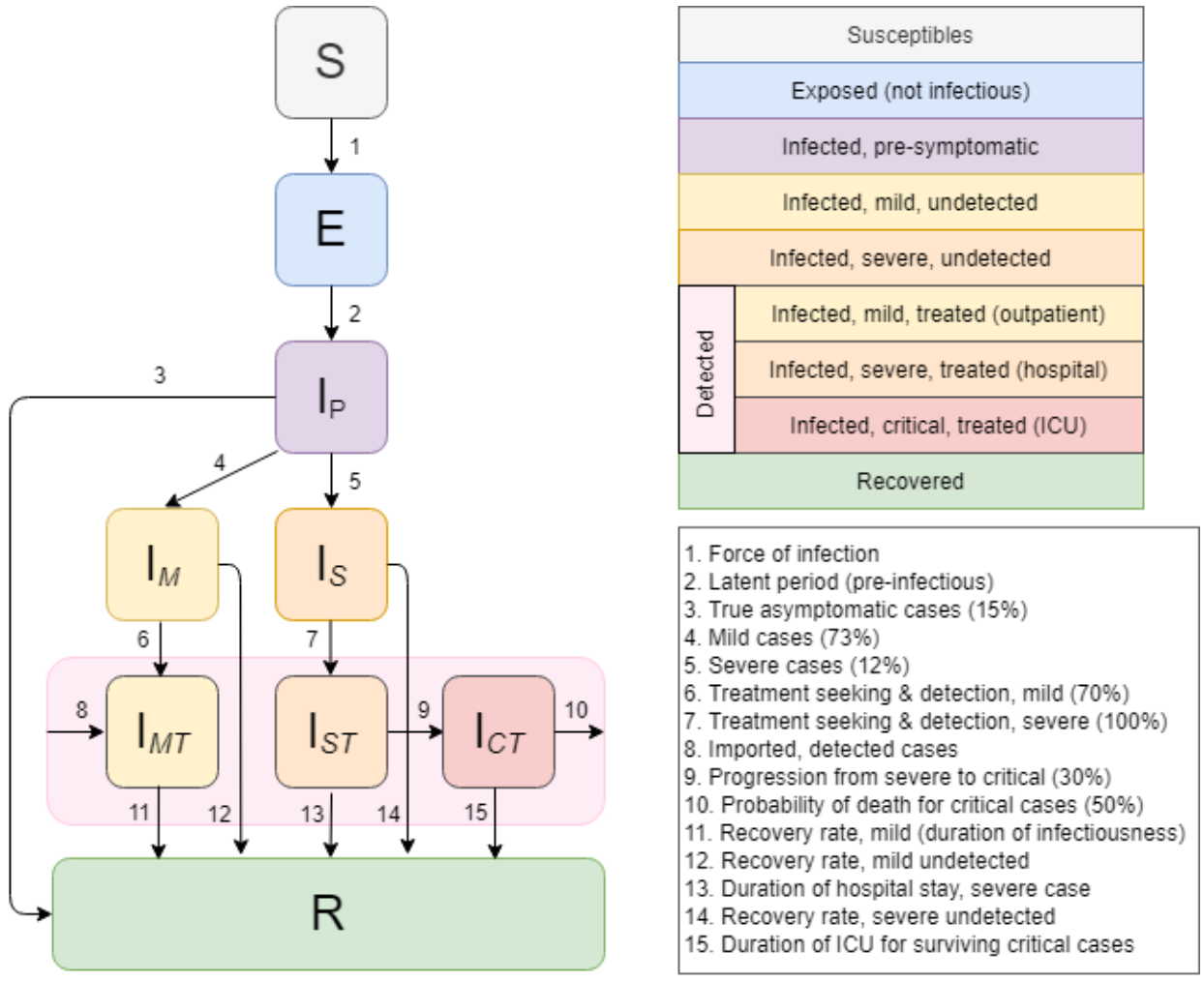
Date	25th perc	50th perc	75th perc
22/03/2020	0	0	0
23/03/2020	0	0	1
24/03/2020	0	0	1
25/03/2020	0	0	1
26/03/2020	0	1	2
27/03/2020	0	1	4
28/03/2020	1	2	6
29/03/2020	1	2	10
30/03/2020	1	4	17
31/03/2020	1	6	28
01/04/2020	2	9	46

About the model

We have developed a stochastic compartmental transmission model to estimate the total and reported incidence of COVID-19 in the nine provinces of South Africa. These estimates are adjusted by age-severity[1,2] and age-fatality[3] profiles to reflect the age distribution of the South African population[4] . Provincial health insurance profiles are also used to reflect the likely uninsured caseload. The outputs of the model may be used to inform resource requirements and predict where gaps could arise based on the available resources within the South African health system.

Due to the rapidly changing nature of the outbreak globally and in South Africa, we provide estimates for the next two weeks only. This model has been developed using publicly available data, which is subject to a degree of uncertainty (including some instances where travel history was pending). Transmission has been modelled at a provincial level resulting in model predictions providing broad-stroke provincial guidance rather than informing localised strategy. All models are simplifications of reality that are designed to describe and predict system behaviour and are justified by the assumptions and data with which they are developed.

Our model follows a generalised Susceptible-Exposed-Infectious-Recovered (SEIR) structure accounting for disease severity and treatment pathway. It is similar in structure and disease flow to several published COVID-2019 models[5–8]. Our model structure and treatment pathways are summarised in Figure 2.



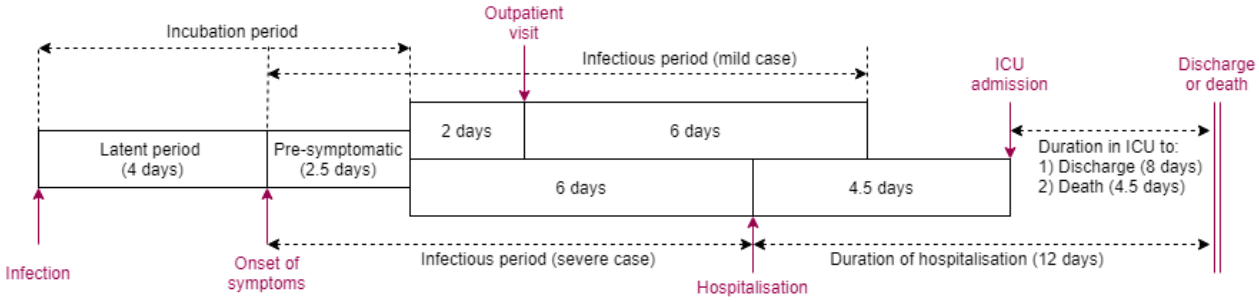


Figure 2. Model structure and treatment pathways

Key Model Assumptions

Model set-up:

- The model is seeded with imported and undetected cases between 5 and 13 March assuming that each imported case generated 2 additional local cases[9].
- While cases are yet to be detected in the Northern Cape and North Western provinces, for the purposes of projection until 1 April, one imported case was introduced in each of these provinces on 21 March to start the epidemic.
- With limited evidence available on COVID-19 in South Africa, we assume that the clinical presentation and pathology of COVID-19 is the same globally and inform our model with parameters determined from studies conducted in other countries.
- Imported cases are treated separately from local cases and are included as an inflow of exogenous cases directly into the detected classes (mild or severe).
- Imported cases are assumed to continue at current rates (21 March) until 25 March (one week after the introduction of the travel ban on high risk countries), thereafter decreasing steadily until 1 April.
- Hospitalised cases are assumed to be removed from the infectious reservoir.
- Current interventions such as social-distancing, and self-isolation measures are assumed to have no effect on transmission owing to their recent implementation.

These assumptions will be adjusted in updates to the model as more data becomes available.

Demographic factors:

- The South African population size and age distribution (national and provincial) are sourced from StatsSA's 2019 mid-year report[4].
- We combine and normalise age-specific probabilities of hospitalisation, critical care and death[1,2] with the provincial age distributions from South Africa to acquire contextual age-distributed risks. The age-specific probabilities used to inform our model are include in Table 9 in the Appendix.
- We assume the risk of getting a mild to moderate infection is independent of age[10].
- The proportion of South Africa's medically uninsured population (used to estimate the resource requirements within the public health sector) by province is captured in Table 4 (CHAI, personal communication).

Table 4. Provincial breakdown of medically uninsured population

Province	Uninsured population	Proportion of total
Eastern Cape	5,950,324	0.89
Free State	2,579,886	0.89
Gauteng	11,673,163	0.77
Kwazulu Natal	10,203,245	0.90
Limpopo	5,414,004	0.90
Mpumalanga	4,019,611	0.88
Northern Cape	1,054,657	0.83
North West	3,481,868	0.86
Western Cape	5,224,209	0.76
Total	**49,600,972**	0.84

Severity of cases & treatment seeking behaviour:

- Following infection, 15% of cases are assumed to be asymptomatic[11,12], 73% of cases mild to moderate, and 12% of cases severe[3].
- We use treatment seeking behaviour of influenza-like illnesses in South Africa to inform our model[13–15]. Of mild to moderate cases, 70% will seek treatment. All severe cases will seek treatment.
- We assume that all COVID-19 cases that seek treatment will receive a confirmed diagnosis. This implicitly assumes that there will be enough laboratory tests and capacity, and that there will be no false negatives.
- All diagnosed, severe cases will be admitted to hospital. Of these, 30% will become critical. Fifty percent of critical cases will die. No mild or severe cases will die.

The above assumptions reflect a case distribution of 80% Mild, 14% Severe, and 6% Critical, with a case fatality rate (deaths/confirmed cases) of 3%[3].

- Pre-symptomatic and asymptomatic cases are assumed to be 50% as infectious as symptomatic cases[2].
- Cases in hospitals do not contribute to onward transmission due to isolation protocols. As such, the duration of infectiousness for severe cases is until admission to hospital.

Time frames captured in the model:[3,16–20]

- Time from infection to onset of infectiousness (latent period): 4 days (2·0-9·0)
- Time from onset of infectiousness to onset of symptoms: 2.5 days (1·0-3·9)
- Time from onset of symptoms to first consultation: 2 days (1·0-5·0)
- Time from onset of symptoms to hospitalisation: 6 days (4·0–8·0)
- Time from onset of symptoms to ICU admission: 10·5 days (8·0–17·0)
- Duration of hospital stay: 12 days (7·0–16·0)
- Duration from ICU to discharge: 8 days (4·0–12·0)
- Duration from ICU admission to death: 4.5 days (1·0–12·5)

Major sources of uncertainty

Diagnosis and treatment-seeking: The publicly available data used to seed and validate the epidemic trajectory may be subject to biases in the lead time from testing to confirmation of result. For example, cases detected in one province on date X may have been reported earlier/later, were they tested in another province. Further, until capacity to test is increased across provinces, backlogs in testing may be experienced, which influence confirmation of diagnosis. It is also unclear at this point if cases that were confirmed in a province, originated in the same province. Travel history was not always available for all positive cases. This impacts the estimates of general hospital beds and ICU beds required. While the model assumes that treatment seeking behaviour will be similar to that of influenza-like illness in South Africa, it may be the case that behaviour changes with increased awareness of the disease.

True asymptomatic burden: Due to the limited availability of evidence worldwide and the difficulty of estimating the number of asymptomatic cases in the population, we consider a range for true asymptomatic cases (in contrast to pre-symptomatic cases) of 0 - 30%[11,12]. Recent evidence suggests that asymptomatic cases may represent up to 80% of all cases[21]. This parameter has considerable influence on the clinical burden of COVID-19 and would benefit from further discussion with the modelling/expert team.

Intervention effectiveness: Interventions like social distancing and self-isolation are dependent on individual behaviour and differ by country and setting (for example formal versus informal settlements). We can take lessons from other countries but emphasise the differences in approach and setting. Given that these measures only came into effect on 18 March, social-distancing, and self-isolation measures are assumed to have no effect on transmission yet. As data accumulates over the next few weeks, we will be able to update our model and provide increasingly robust estimates.

Planned updates

As the outbreak continues and more data becomes available, we intend to extend our model in several ways:

- Increase the level of spatial detail from 9 provinces (current model) to 226 local municipalities. This will enable us to provide more accurate estimates of the spread of the disease throughout the country.
- Include a South African specific age-risk profile. As South Africa has a high HIV burden and unique co-morbidity distribution, tailoring our model to factor this in will make the model more contextually relevant.
- Modelling the impact of current interventions. As more information becomes available following the introduction of the South African National Government's response to the COVID-19 situation on 15 March 2020 (taking effect 18 March), we will adjust our model to include the effectiveness of these on the trajectory of the outbreak.

Data sources

Our model is informed by published and pre-print academic literature, global COVID-19 case information (specifically from the European CDC, World Health Organization and China CDC), South African population statistics from Stats SA's 2019 mid-year report, and national case details from the South African National Institute for Communicable Diseases and https://sacoronavirus.co.za/category/press-releases-and-notices/.

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Appendix

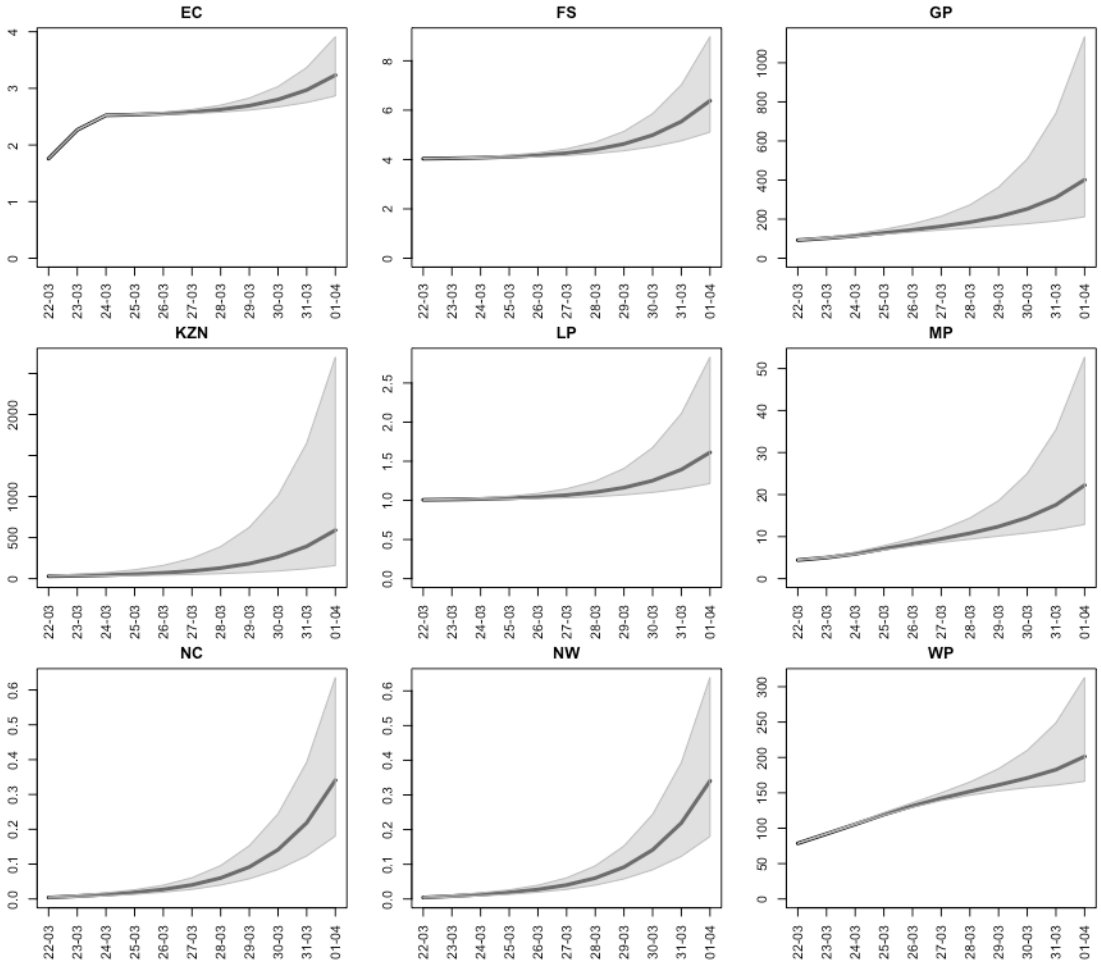

Figure 3: Estimated daily cumulative cases (Provincial) - Median and interquartile range (25%, 75%)

Table 5. Mild cases by age and province, weekly

	EC	FS	GP	KZN	LP	MP	NC	NW
Week 22-23 March								
0-9	0	0	13	19	0	1	0	0
10-19	0	0	11	17	0	1	0	0
20-29	0	0	16	16	0	1	0	0
30-39	0	0	16	14	0	1	0	0
40-49	0	0	10	9	0	1	0	0
50-59	0	0	7	6	0	0	0	0
60-69	0	0	4	4	0	0	0	0
70-79	0	0	2	2	0	0	0	0
80+	0	0	0	1	0	0	0	0
TOTAL	1	0	81	88	0	5	0	0
Uninsured	1	0	62	80	0	5	0	0
Week 29 March – 4 April								
0-9	0	1	129	360	0	8	0	0
10-19	0	1	110	314	0	7	0	0
20-29	0	1	153	307	0	7	0	0
30-39	0	1	155	269	0	7	0	0
40-49	0	1	99	168	0	4	0	0
50-59	0	1	66	119	0	3	0	0
60-69	0	0	42	82	0	2	0	0
70-79	0	0	18	42	0	1	0	0
80+	0	0	5	14	0	0	0	0
TOTAL	2	7	778	1674	2	40	1	1
Uninsured	2	6	599	1513	2	35	1	1

Table 6. Severe (hospital admission) cases by age and province, weekly

	EC	FS	GP	KZN	LP	MP	NC	NW
Week 22 – 23 March								
0-9	0	0	0	0	0	0	0	0
10-19	0	0	0	0	0	0	0	0
20-29	0	0	1	1	0	0	0	0
30-39	0	0	2	2	0	0	0	0
40-49	0	0	2	2	0	0	0	0
50-59	0	0	3	3	0	0	0	0
60-69	0	0	3	3	0	0	0	0
70-79	0	0	2	2	0	0	0	0
80+	0	0	1	1	0	0	0	0
TOTAL	0	0	13	13	0	1	0	0
Uninsured	0	0	10	12	0	1	0	0
Week 29 March – 4 April								
0-9	0	0	0	1	0	0	0	0
10-19	0	0	1	4	0	0	0	0
20-29	0	0	6	14	0	0	0	0
30-39	0	0	17	33	0	1	0	0
40-49	0	0	17	31	0	1	0	0
50-59	0	0	23	46	0	1	0	0
60-69	0	0	24	52	0	1	0	0
70-79	0	0	15	39	0	1	0	0
80+	0	0	4	15	0	0	0	0
TOTAL	0	1	109	236	0	5	0	0
Uninsured	0	1	84	214	0	5	0	0

Table 7. Critical (ICU admission) cases by age and province, weekly

	EC	FS	GP	KZN	LP	MP	NC	NW
Week 22 – 23 March								
0-9	0	0	0	0	0	0	0	0
10-19	0	0	0	0	0	0	0	0
20-29	0	0	0	0	0	0	0	0
30-39	0	0	0	0	0	0	0	0
40-49	0	0	0	0	0	0	0	0
50-59	0	0	1	0	0	0	0	0
60-69	0	0	1	1	0	0	0	0
70-79	0	0	1	1	0	0	0	0
80+	0	0	1	1	0	0	0	0
TOTAL	0	0	4	3	0	0	0	0
Uninsured	0	0	3	3	0	0	0	0
Week 29 March – 4 April								
0-9	0	0	0	0	0	0	0	0
10-19	0	0	0	0	0	0	0	0
20-29	0	0	0	1	0	0	0	0
30-39	0	0	1	1	0	0	0	0
40-49	0	0	1	2	0	0	0	0
50-59	0	0	3	5	0	0	0	0
60-69	0	0	6	12	0	0	0	0
70-79	0	0	6	14	0	0	0	0
80+	0	0	3	9	0	0	0	0
TOTAL	**0**	**0**	**20**	**42**	**0**	**1**	**0**	**0**
Uninsured	0	0	15	38	0	1	0	0

Table 8. Deaths by age and province, weekly

	EC	FS	GP	KZN	LP	MP	NC	NW
Week 22 – 23 March								
0-9	0	0	0	0	0	0	0	0
10-19	0	0	0	0	0	0	0	0
20-29	0	0	0	0	0	0	0	0
30-39	0	0	0	0	0	0	0	0
40-49	0	0	0	0	0	0	0	0
50-59	0	0	0	0	0	0	0	0
60-69	0	0	0	0	0	0	0	0
70-79	0	0	0	0	0	0	0	0
80+	0	0	0	1	0	0	0	0
TOTAL	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**
Uninsured	0	0	0	1	0	0	0	0
Week 29 March – 4 April								
0-9	0	0	0	0	0	0	0	0
10-19	0	0	0	0	0	0	0	0
20-29	0	0	0	0	0	0	0	0
30-39	0	0	0	0	0	0	0	0
40-49	0	0	0	1	0	0	0	0
50-59	0	0	1	1	0	0	0	0
60-69	0	0	2	3	0	0	0	0
70-79	0	0	2	4	0	0	0	1
80+	0	0	1	3	0	0	0	0
TOTAL	**0**	**0**	**6**	**12**	**0**	**0**	**0**	1
Uninsured	0	0	4	11	0	0	0	1

Table 9. Estimates for severity of cases, breakdown be age-group[2]

Age-group (years)	% symptomatic cases requiring hospitalisation	% hospitalised cases requiring critical care	Infection Fatality Ratio
0-9	0.10%	5.00%	0.00%
10-19	0.30%	5.00%	0.01%
20-29	1.20%	5.00%	0.03%
30-39	3.20%	5.00%	0.08%
40-49	4.90%	6.30%	0.15%
50-59	10.20%	12.20%	0.60%
60-69	16.60%	27.40%	2.20%
70-79	24.30%	43.20%	5.10%
80\+	27.30%	70.90%	9.30%
0-9	0.10%	5.00%	0.00%
10-19	0.30%	5.00%	0.01%