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Mathematical Modeling of COVID-19 in Malawi

Quantifying the Potential Burden of Novel Coronavirus

March 31, 2020

Content

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Background

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As of March 31, 2020, the 2019 Novel Coronavirus (COVID-19) has:

Spread rapidly, causing a global pandemic reaching 178 countries

Infected more than 785,000 people.

Caused 35,000 deaths.

- Sub-Saharan Africa has had a seemingly late, slow, or mild outbreak – perhaps due to **climate, connectivity to the rest of the globe, or lack of testing**.
- Although Malawi has yet to report a single case of COVID-19, there is little doubt that the disease will **seed and spready widely** in the nation.
- With minimal COVID-19 testing capacity, it is **difficult to estimate** the current and future trajectory of disease in Malawi.

Objectives

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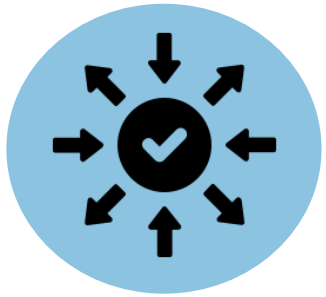
The aims of this analysis are:

Project Epidemic Scenarios

Use a mathematical model to project possible epidemic scenarios in terms of cases, hospitalizations, and mortality.



Understand Covariates

Understand how age and co-morbidities could affect severity of disease.

Mitigate Impact

Simulate possible mitigation scenarios and their impact on incidence and mortality.

Modeling Approach

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Modeling Approach

Susceptible-Exposed-Infected-Recovered (SEIR)

Created SEIR deterministic and compartmental model.

One day time-step

One day time-step, starting with first introduced case to day 365.

Infectious while asymptomatic

Individuals are assumed to be infectious in the exposed (asymptomatic) period.

No births or non-COVID-19 deaths

There are no births or non-COVID-19 related deaths and no additional imported cases than the index case.

Mild, Hospitalized, or Critical sub-state

Persons in the infected state can either be in either mild, hospitalized, or in critical care - with the latter susceptible to death.

Key parameters

Scenario analyses conducted on key parameters.

Parameters

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Model Parameters

CHALLENGE

Malawi does not yet have a documented case of COVID, and therefore has no data on case distribution or severity

ASSUMPTION

Malawi will have a different fatality rate of COVID-19 due to its substantially younger population than places hardest hit (and with data) on COVID-19 mortality.*

Parameter	CS Model
R_0	2.2
Infectious Period	5.2 days
Time to Hospitalization	6 days
Hospitalized Time - Severe Cases	8 days
Hospitalized Time - Critical Cases	16 days
Time to Death from Onset	21 days
Recovery Time - Mild Cases	14 days
Hospitalized Percent	3.0%-7.0%
IFR	Age-Standardized Rate Using: 0-9: 0.0016% 10-19: 0.007% 20-29: 0.031% 30-39: 0.084% 40-49: 0.16% 50-59: 0.60% 60-69: 1.90% 70-79: 4.30% 80+: 7.80% TA-Specific Age-Standardized Rates: 0.16% - 0.36%

**Advanced age is the greatest predictor for poor COVID-19 outcomes*

Estimation of Malawi-Specific Parameters

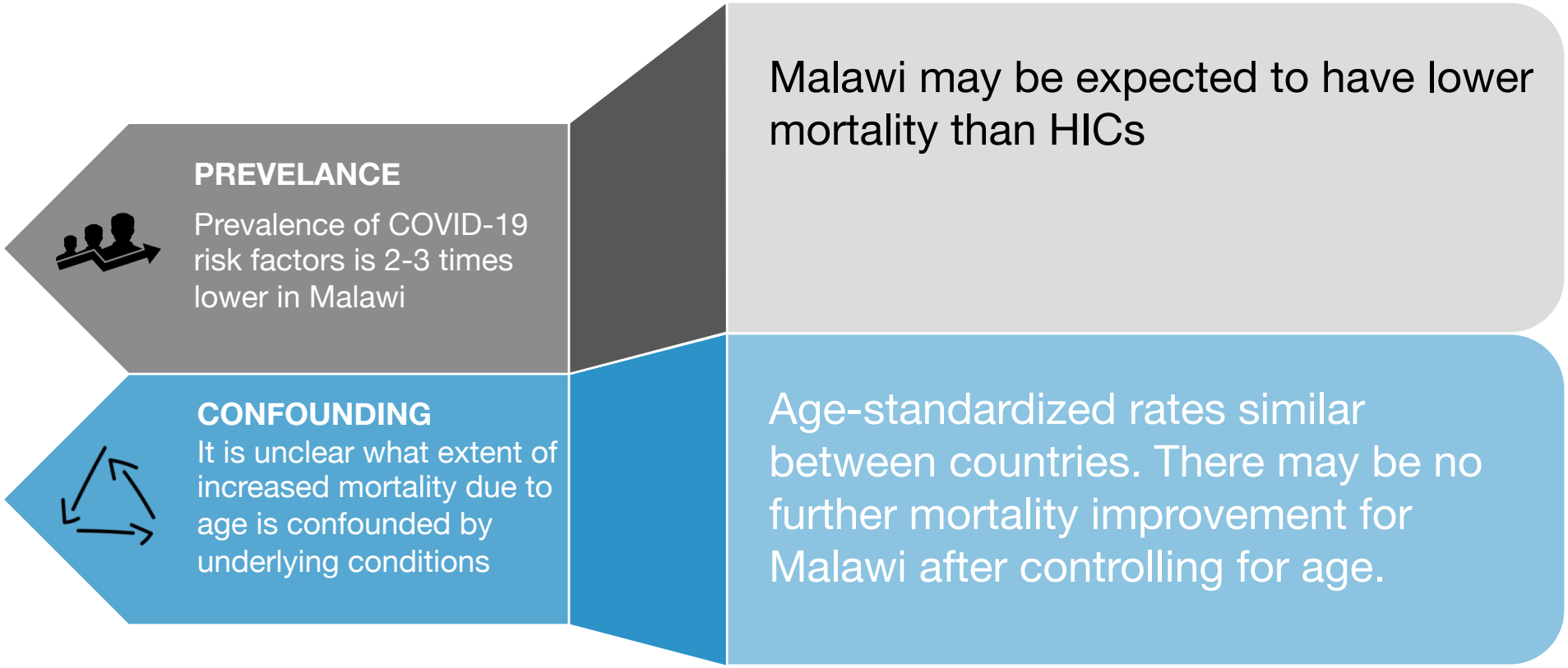
Approach for hospitalization and IFR

1. Standardize the age distribution of cases in Malawi relative to South Korea – a setting with widespread testing*
2. Estimate weighted average hospitalization rates and IFR using Chinese age-specific data at District & TA level

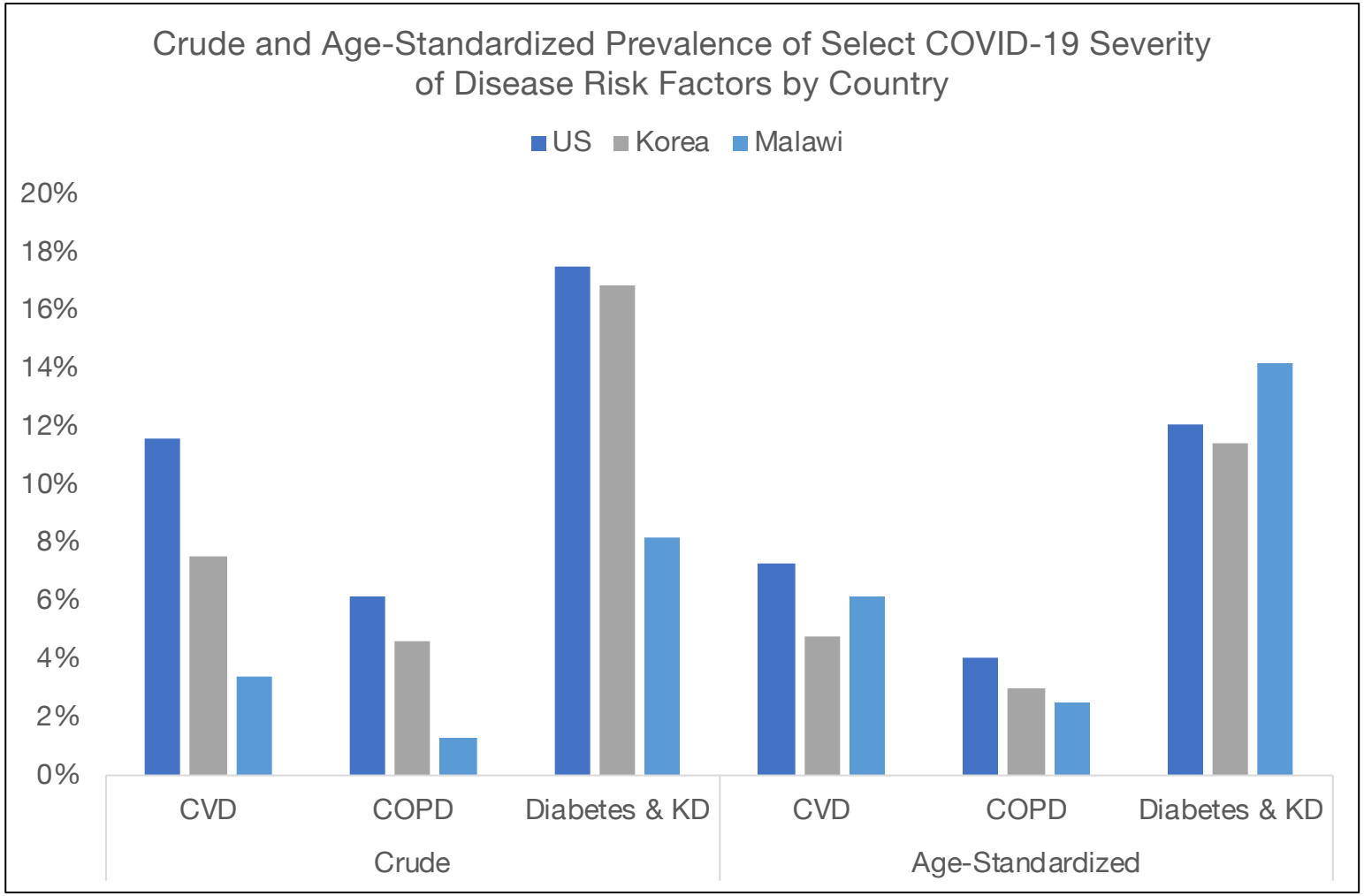
	Chitipa	Karonga	Nkhatabay	Rumphi	Mzimba	Likoma	Mzuzu City	Kasungu	Nkhotakota	Ntchisi	Dowa	Salima
Hospitalization	3.0%	2.9%	3.1%	3.0%	3.2%	3.1%	2.6%	2.9%	2.8%	3.0%	3.1%	2.9%
Critical Care	0.6%	0.6%	0.7%	0.6%	0.7%	0.6%	0.3%	0.5%	0.5%	0.6%	0.6%	0.6%
Crit of Hosp	20.55%	19.56%	21.21%	19.50%	21.31%	20.11%	12.94%	18.13%	19.14%	20.01%	20.08%	20.27%
IFR	0.37%	0.34%	0.39%	0.34%	0.40%	0.36%	0.19%	0.31%	0.32%	0.35%	0.36%	0.35%
IFR of Crit	59.12%	59.04%	59.15%	59.04%	59.15%	58.99%	58.25%	58.93%	58.99%	59.04%	59.05%	59.04%
IFR of Hosp	12.15%	11.55%	12.55%	11.51%	12.61%	11.86%	7.54%	10.69%	11.29%	11.82%	11.86%	11.97%

**Age-specific INCIDENCE is unknown in any setting, but this is a key driver of age-standardized rates*

Prevalence of Co-Morbidities



Co-Morbidity Prevalence



No additional adjustments to incidence, hospitalization, or survival due to distribution of co-morbidities

Many Uncertainties

Unknown Co-morbid Risk Factors

The bulk of data on COVID-19 cases has been in HICs, which do not have prevalence of many infections seen in Africa.

- These conditions could be a detriment to survival.
- Diseases which could plausibly harm COVID-19 patients include HIV & TB.

Uncertainties

Health System Capacity and Spillovers

What improvements in case fatality are due to health system quality in advanced economies?

- Malawi has 17 ventilators nationwide (1 per million) – a potentially life-saving piece of equipment for patients – hinting that case-fatality could be higher
- Reductions in other health service delivery, including HIV, TB, malaria, and MNCH treatment could lead to aggregate declines in life expectancy

Overall Results

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Total Cases, Hospitalizations, and Deaths

	Over 85%, or **16 million people,** will become infected over 1 Year
	Of those infected, it is anticipated that ~**483,000** people will be **Hospitalized**, and ~**85,000** people would need **Critical Care**
	Of those hospitalized & admitted to critical care, up to **50,000 people could die** directly from COVID-19. • This is conservative, not considering poorer survival for HIV or TB co-infection. • This does not capture negative consequences of disruption of other health services including HIV, TB, malaria, or MNCH.

District Results

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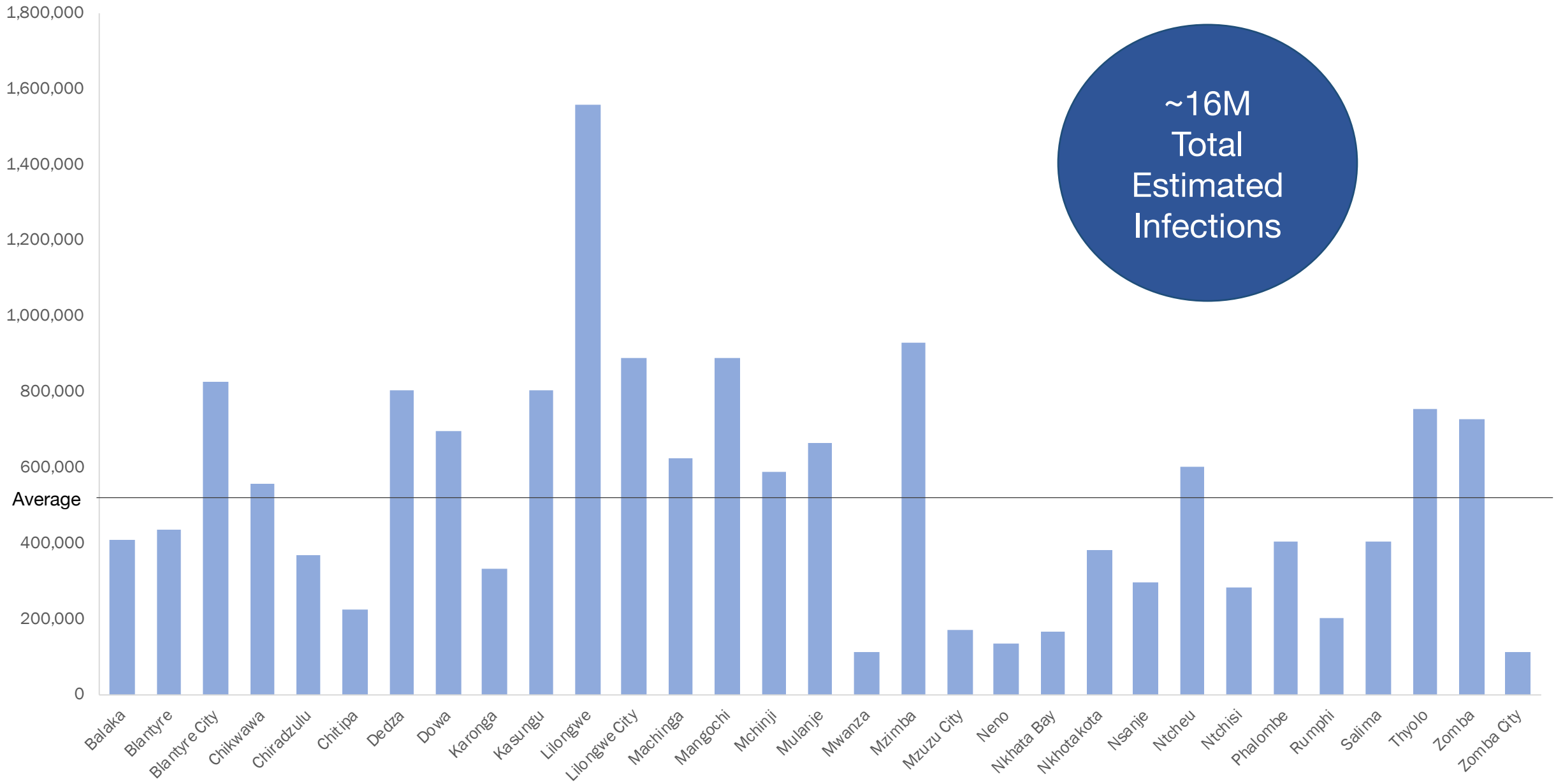
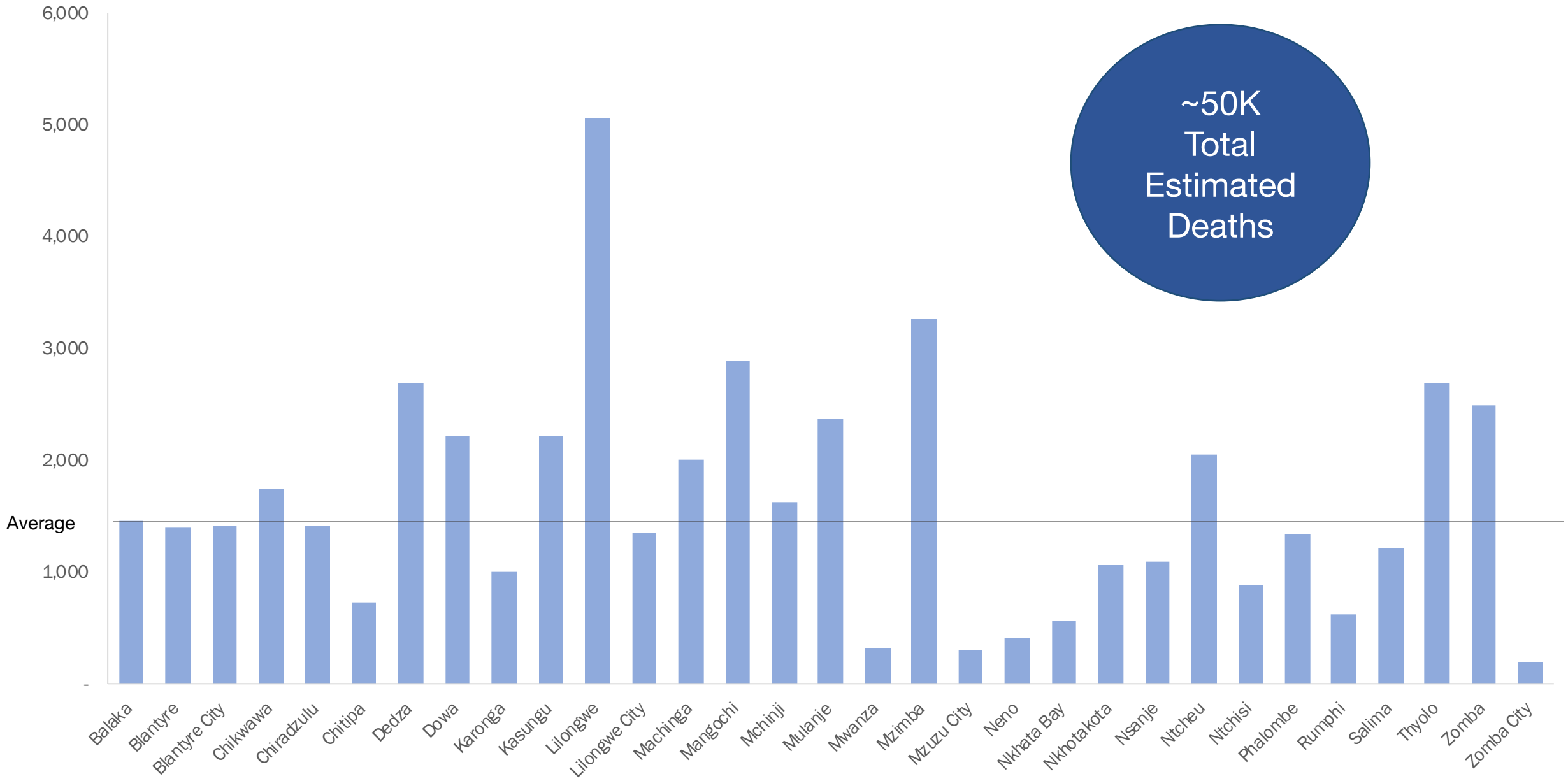
District – Estimated Total Cases



*Additional graphics available for; Hospitalization & Critical Care – Due to similarities, they have been put in appendix

District – Estimated Deaths



*Additional graphics available for; Hospitalization & Critical Care – Due to similarities, they have been put in appendix

District – Table

District	Infections	Hospitalizations	Critical Care	Deaths
Lilongwe	1,559,184	47,278	8,582	5,064
Mzimba	931,061	29,261	5,526	3,266
Lilongwe City	890,753	21,761	2,340	1,353
Mangochi	890,023	25,897	4,899	2,893
Blantyre City	826,040	20,992	2,438	1,415
Dedza	805,113	24,116	4,552	2,689
Kasungu	804,474	22,996	3,764	2,216
Thyolo	753,973	24,034	4,553	2,688
Zomba	728,055	22,426	4,209	2,484
Dowa	698,528	21,266	3,771	2,224
Mulanje	664,656	20,923	4,002	2,362
Machinga	626,508	18,111	3,408	2,012
Ntcheu	604,304	18,694	3,465	2,044
Mchinji	586,922	16,669	2,749	1,618
Chikwawa	556,537	16,487	2,961	1,746
Blantyre	435,088	13,290	2,357	1,389
Balaka	408,417	12,722	2,460	1,453
Phalombe	403,891	12,102	2,270	1,340
Salima	403,434	11,597	2,070	1,221
Nkhotakota	380,665	10,676	1,802	1,061
Chiradzulu	369,850	12,205	2,378	1,405
Karonga	333,323	9,696	1,691	997
Nsanje	299,184	9,260	1,848	1,093
Ntchisi	284,511	8,400	1,481	873
Chitipa	224,416	6,757	1,220	721
Rumphi	204,911	6,074	1,052	621
Mzuzu City	171,966	4,378	523	304
Nkhata Bay	165,276	5,065	946	559
Neno	137,073	4,001	695	410
Zomba City	113,311	2,909	340	197
Mwanza	112,511	3,183	532	313

TA Results

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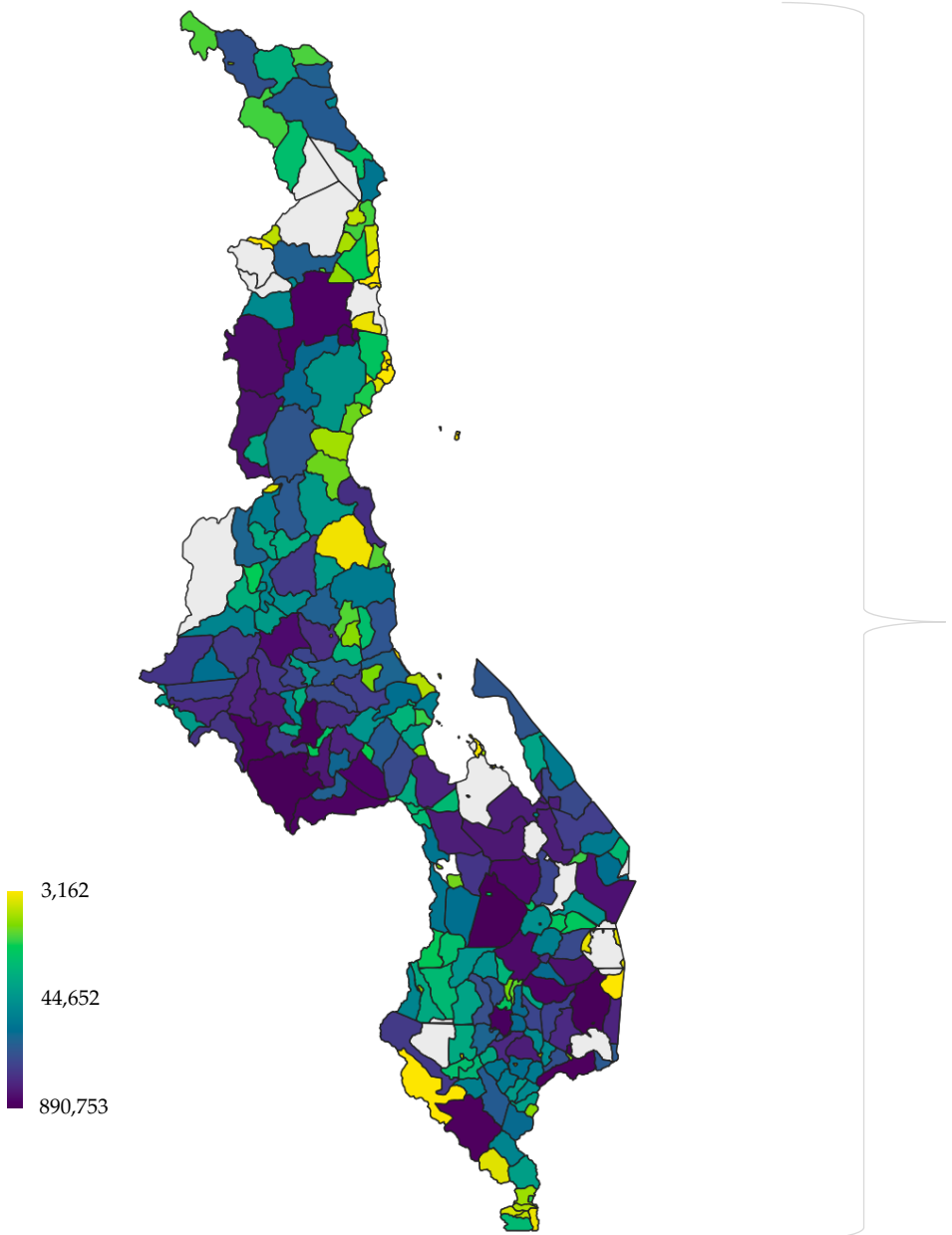
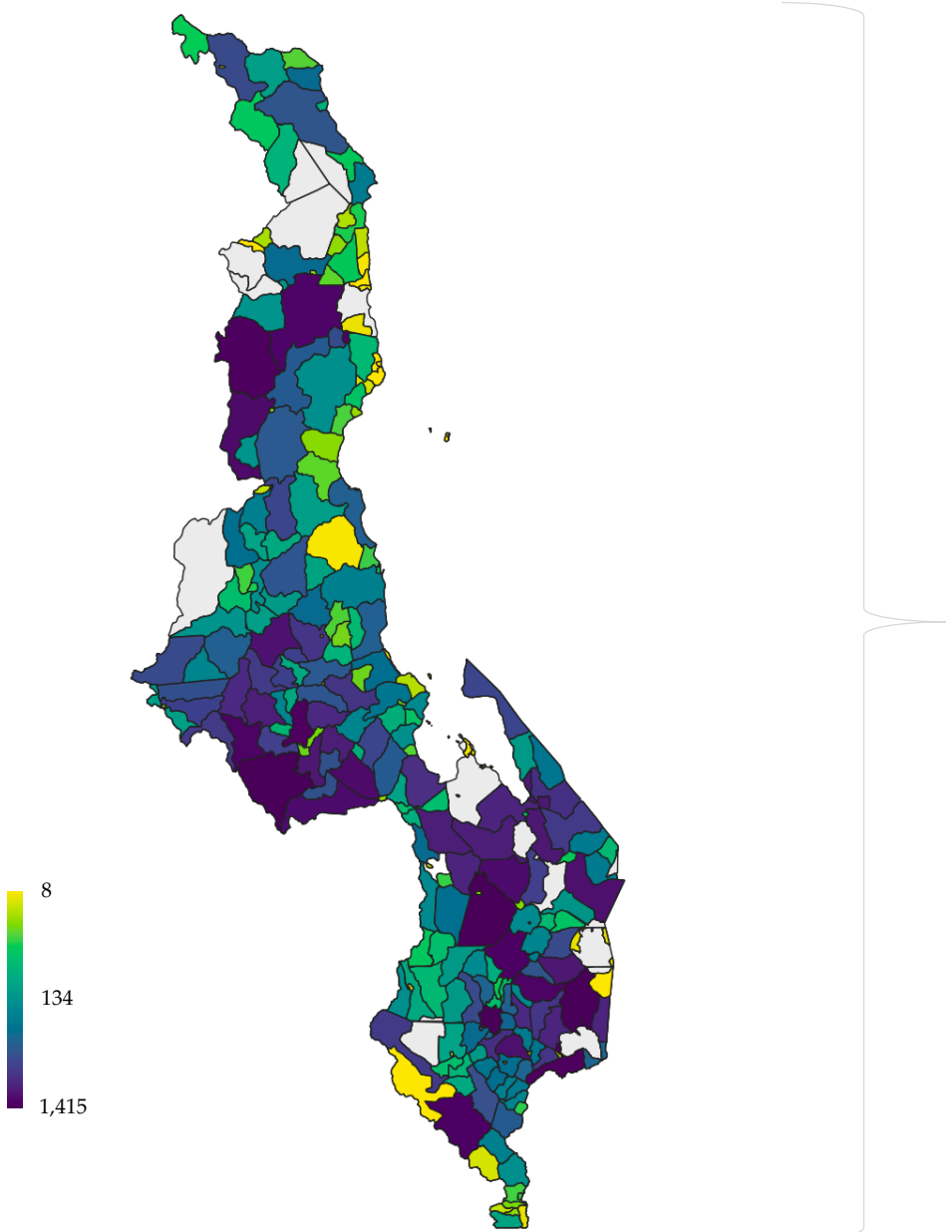
TA – Total Infections



TA	District	Infections
Lilongwe City	Lilongwe City	890,753
Blantyre City	Blantyre City	826,040
TA Chiseka	Lilongwe	29,5017
TA Mkhumba	Phalombe	27,2155
TA Msamala	Balaka	21,9565
TA Mabuka	Mulanje	19,7742
TA Ngabu	Chikwawa	19,2631
TA Kalolo	Lilongwe	18,2357
TA Mtwalo	Mzimba	17,7811
TA Mbiza	Zomba	17,4822

*Additional graphics available for; Hospitalization & Critical Care – Due to similarities, they have been put in appendix. White areas are non-inhabited areas, national parks, lakes, and other unmapped areas.

TA – Estimated Deaths



TA	District	Deaths
Blantyre City	Blantyre City	1,415
Lilongwe City	Lilongwe City	1,353
TA Chiseka	Lilongwe	949
TA Mkhumba	Phalombe	890
TA Msamala	Balaka	813
TA Mabuka	Mulanje	686
TA Chindi	Mzimba	653
TA Ngabu	Chikwawa	652
TA Mlumbe	Zomba	615
TA Mbiza	Zomba	611

*Additional graphics available for; Hospitalization & Critical Care – Due to similarities, they have been put in appendix. White areas are non-inhabited areas, national parks, lakes, and other unmapped areas.

Scenario Analyses

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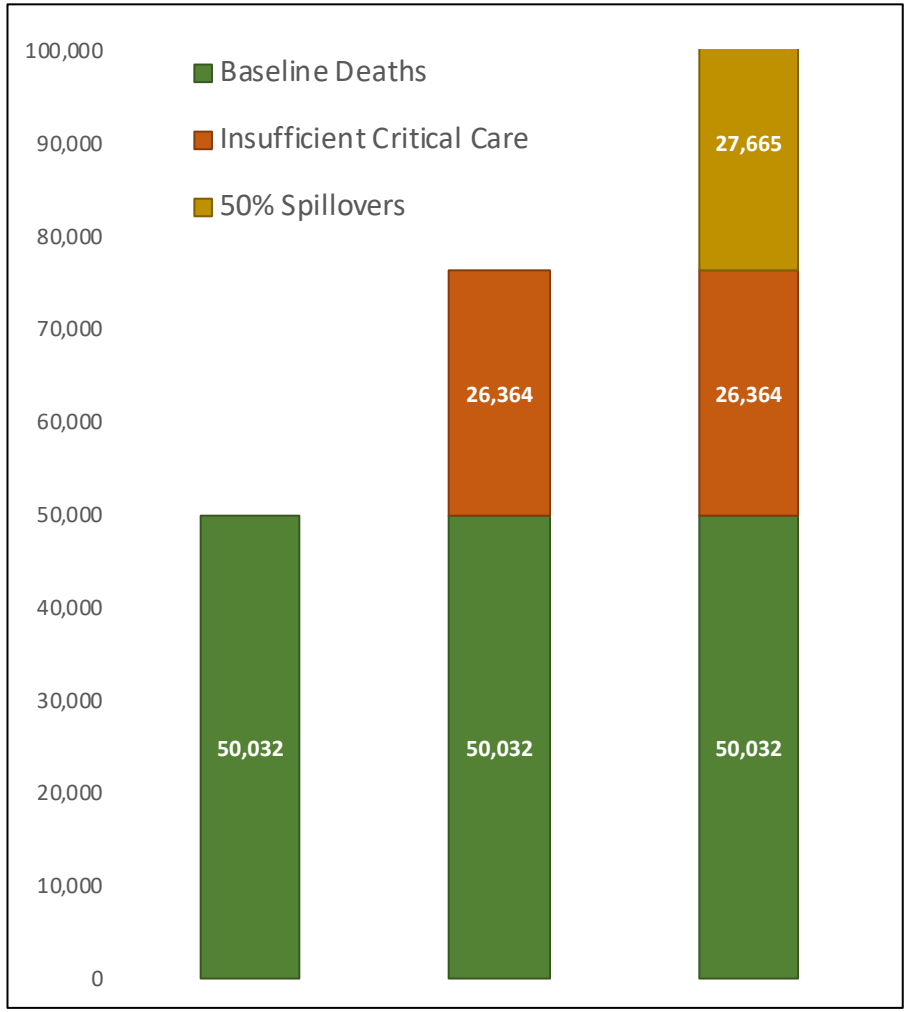
Insufficient Critical Care and Negative Spillovers

Insufficient Critical Care	Malawi has an estimated ~25 ICU beds nationally, each which could contain lifesaving equipment for critical COVID Cases Failure to receive adequate care could result in an increase of **26,000** deaths (50%)
Negative Spillovers	A COVID-19 epidemic has the potential to disrupt routine medical services through stressing the health system The 2014 Ebola outbreak resulted in an increase in TB mortality of 90% in Sierra Leone, Guinea, and Liberia A more modest spillover of a 50% increase in HIV, TB, Malaria, and MNCH deaths could increase mortality by **27,000**



Validations

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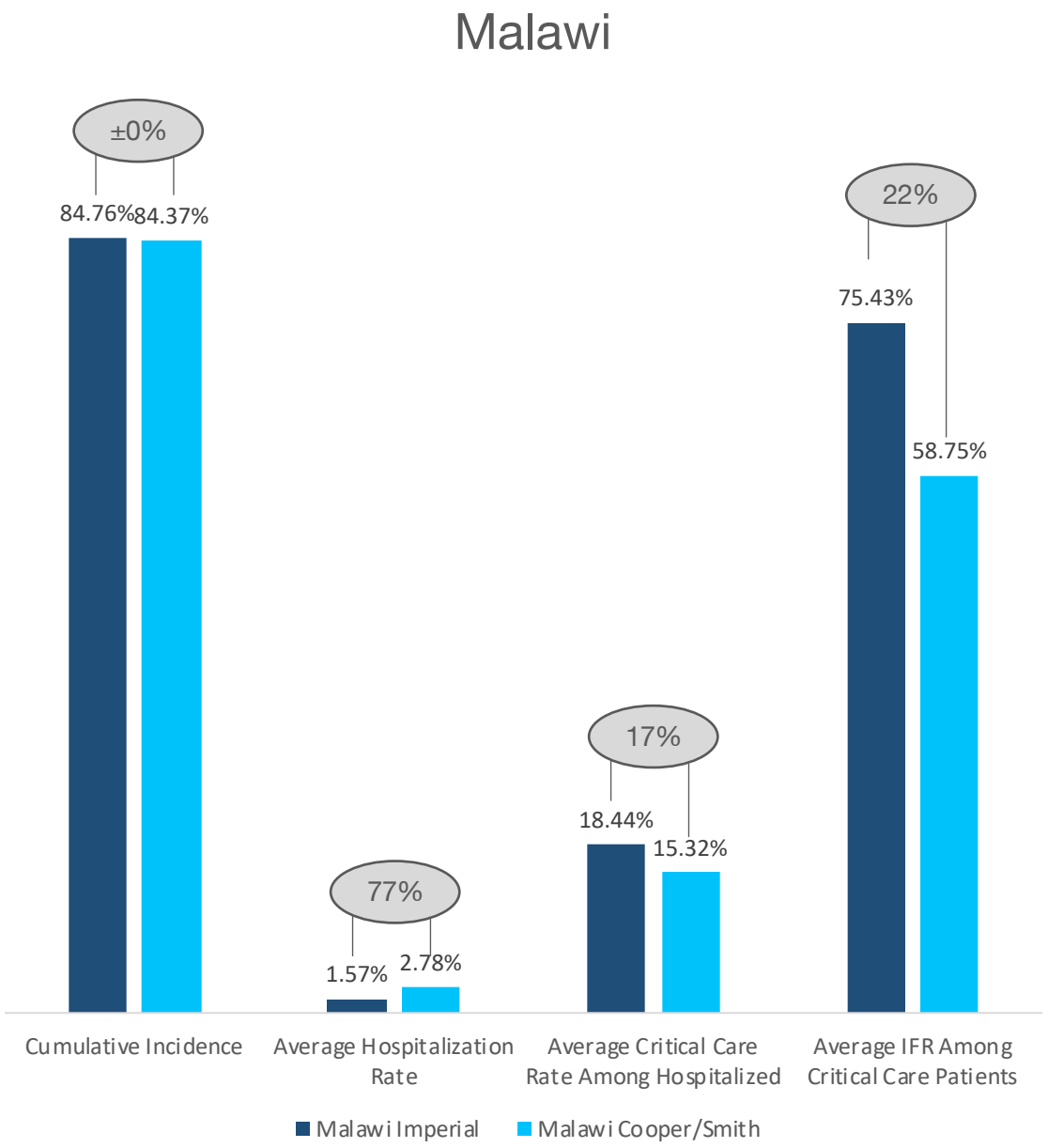
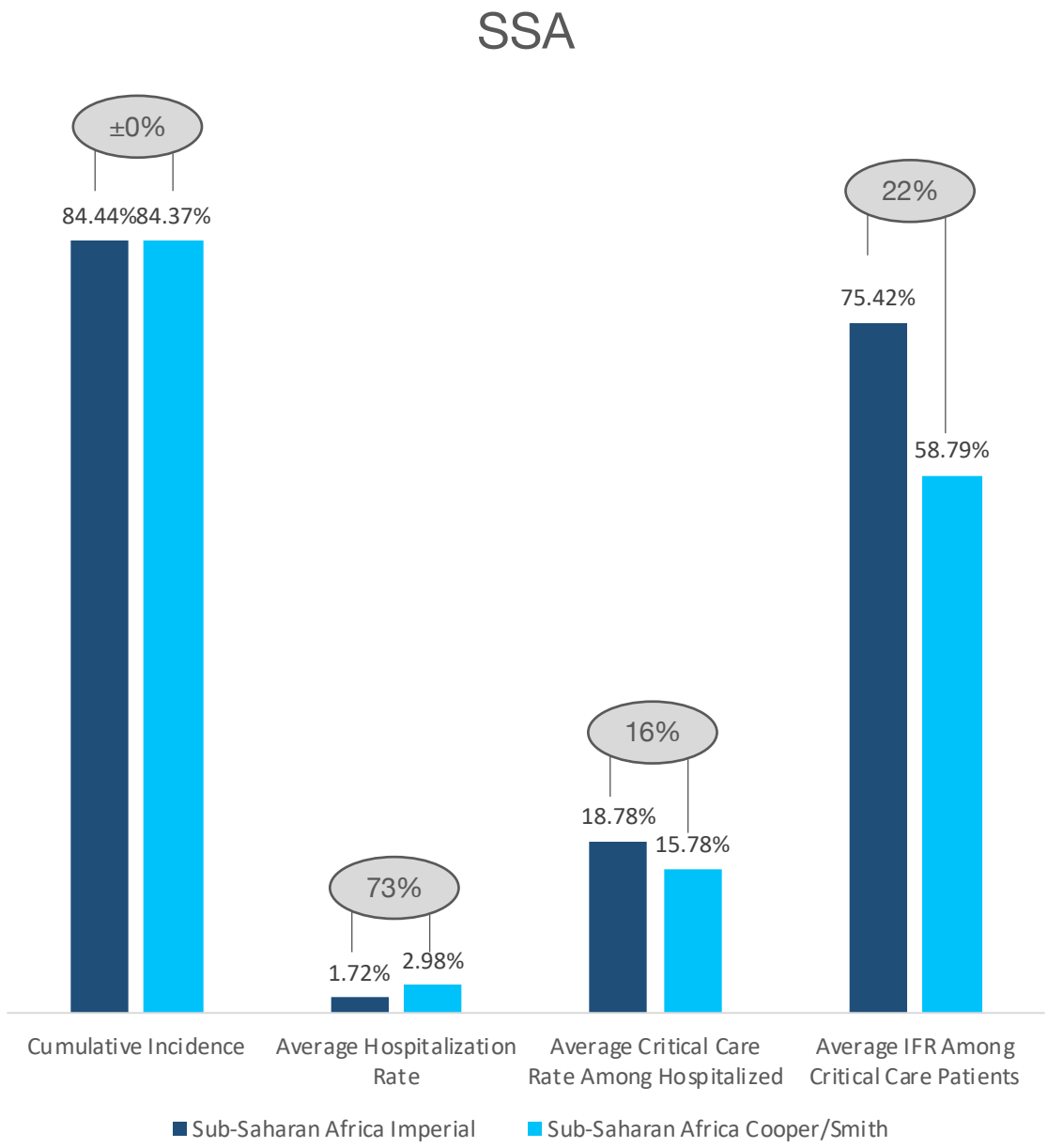
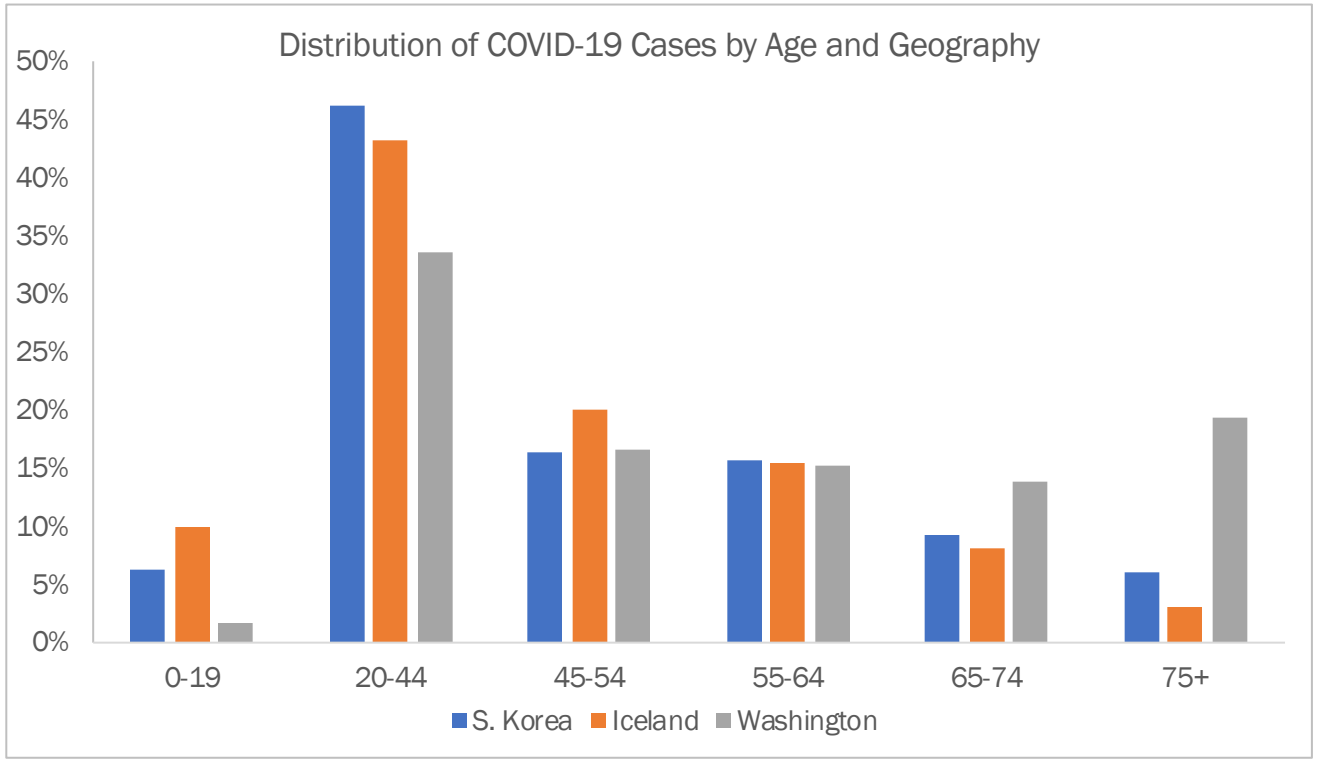
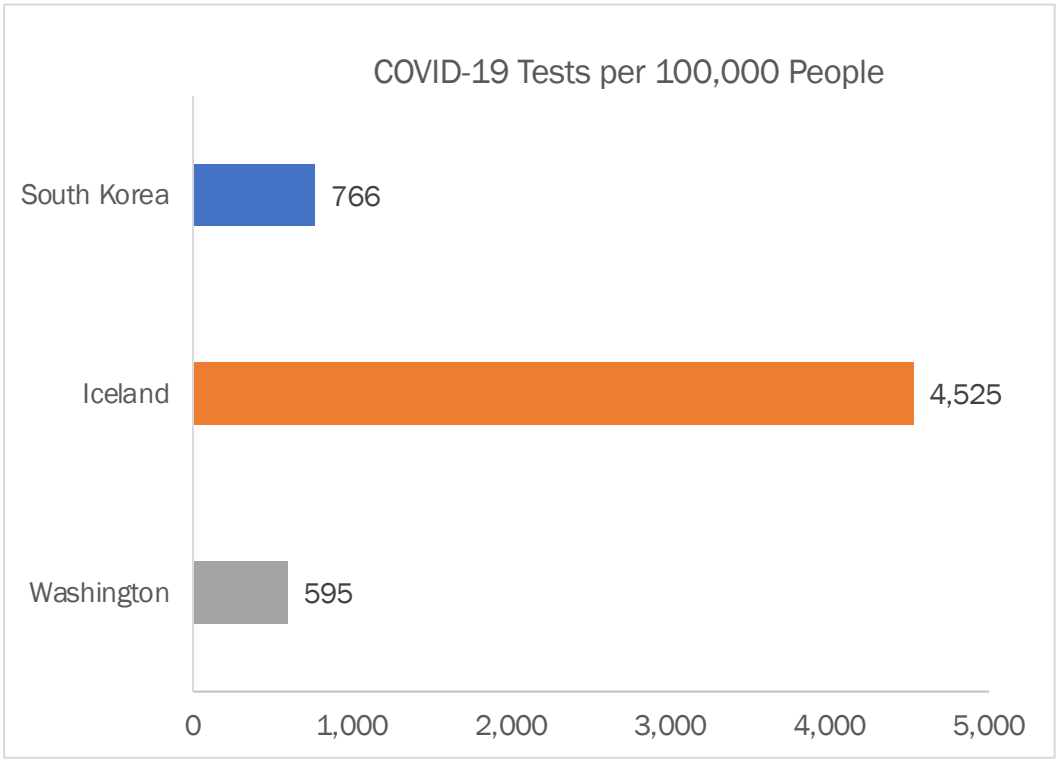
Cooper/Smith & Imperial Models (SSA & Malawi)





COVID Incidence by Age & Testing





Incidence of disease by age is unknown in any setting. However, distribution of cases in countries with widespread testing may provide insight. Iceland and Korea have high testing coverage and depict higher case loads among those <45. Relative incidence among <45 will be a key driver given this demographic comprises nearly 90% of Malawi's population.

Next Steps

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Next Steps

- Continue to validate model and improve parameter estimates.
- Explore scenarios of improved and worsened survival due to differing mixes of co-morbidities.
- Estimate health system capacity for COVID-19 patient management.
- Estimate potential aggregate fall in life-expectancy due to disruption of routine health services.
- Predict reductions in health burden due to non-pharmaceutical interventions like social distance and quarantine

Appendix

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Comparison of Parameters

Parameter	CS Model	Imperial
R_0	2.2	3.0 (2.4-3.3)
Infectious Period	5.2 days	4.58 days
Time to Hospitalization	6 days	5 days
Hospitalized Time - Severe Cases	8 days	8 days
Hospitalized Time - Critical Cases	16 days	16 days
Time to Death from Onset	21 days	21 days
Recovery Time - Mild Cases	14 days	?
Hospitalized Percent	2.4% - 3.4%	1.60%
Critical Care Percent of Hospitalized	10% - 21%	18%
IFR of Critical Care	57% - 59%	75%

District – Table (Top 15)

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Lilongwe	1,559,184	47,278	8,582	5,064
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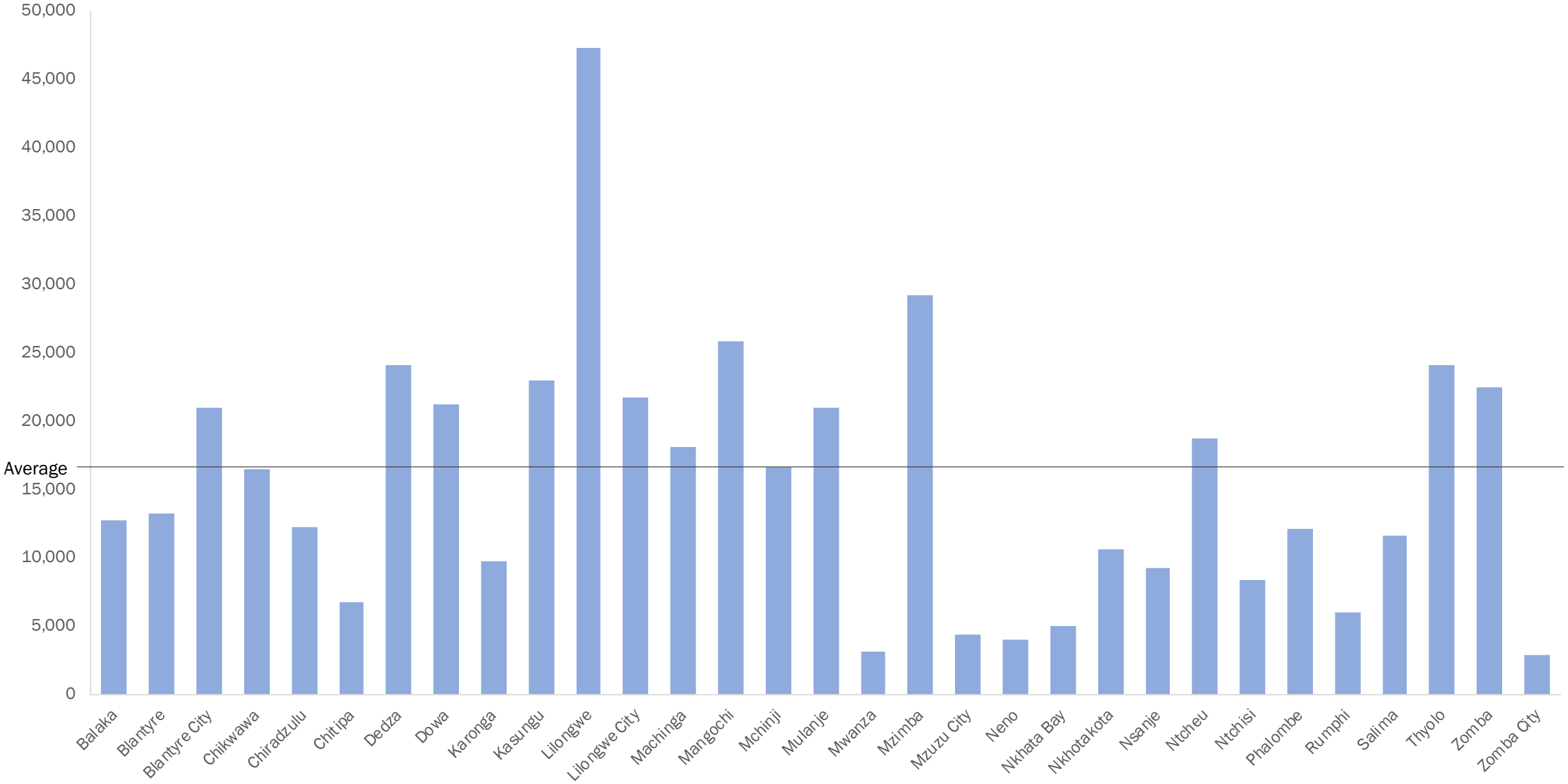
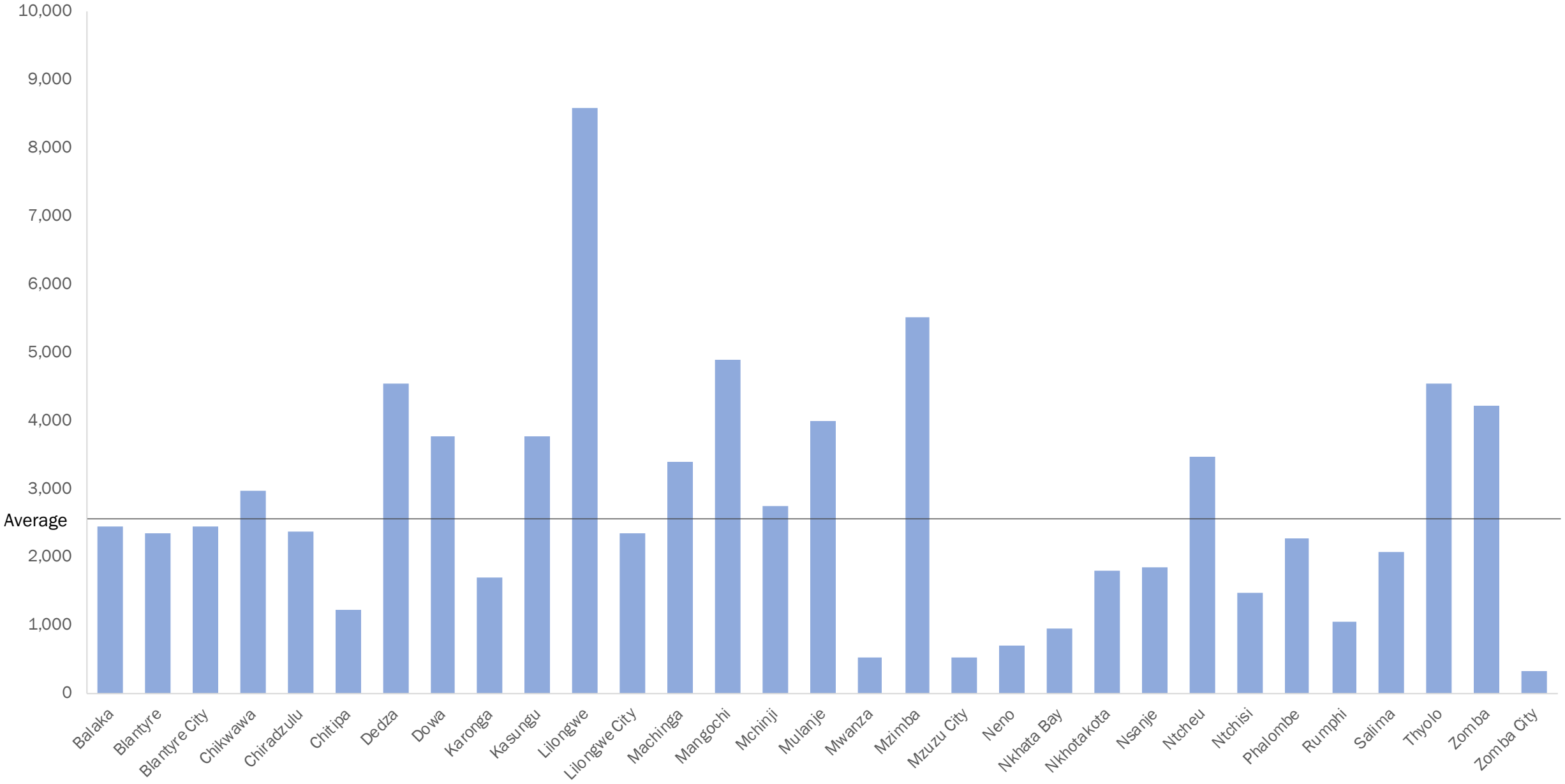
Salima	403,434	11,597	2,070	1,221
Nkhotakota	380,665	10,676	1,802	1,061

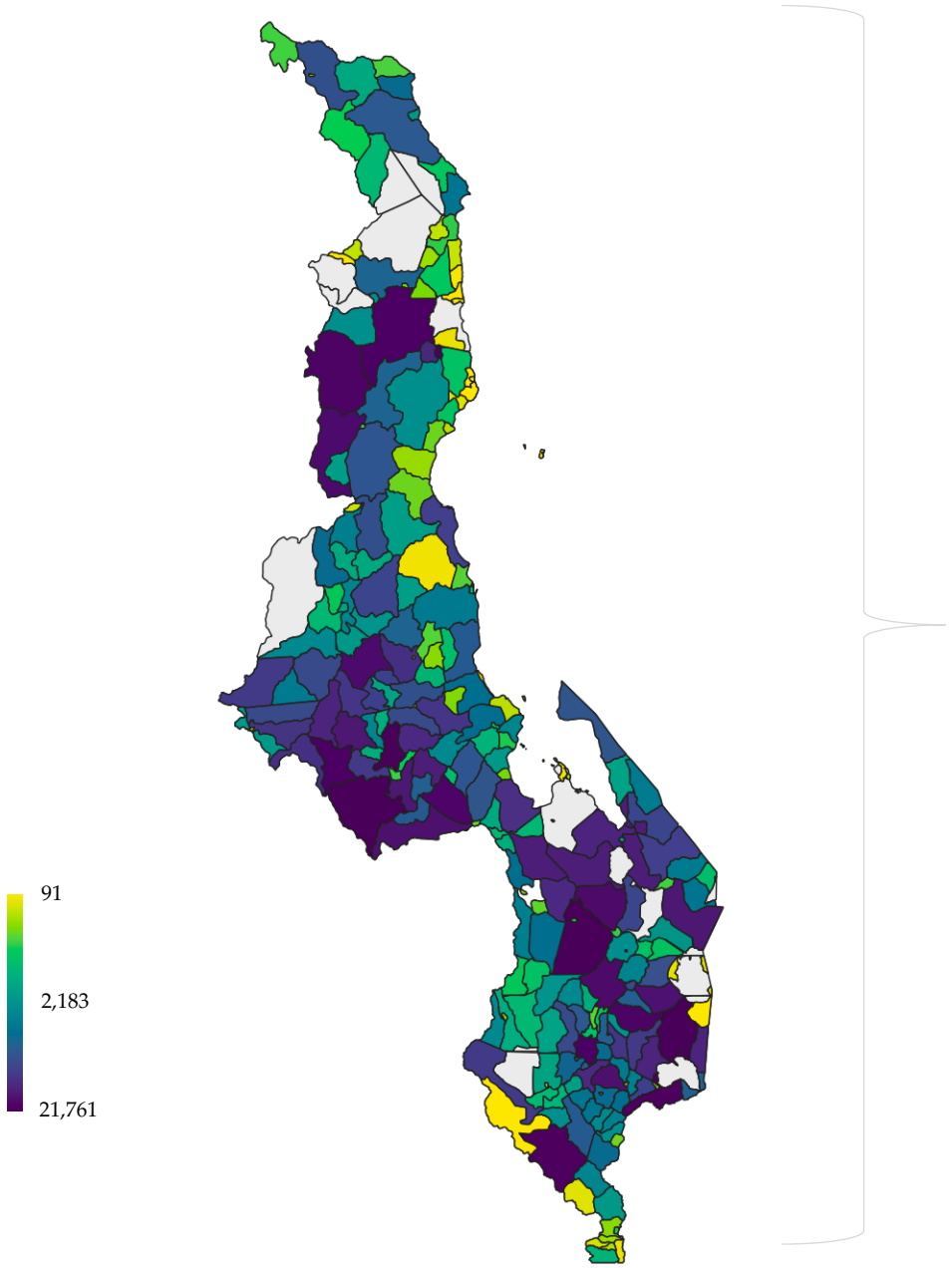
District –Estimated Hospitalizations



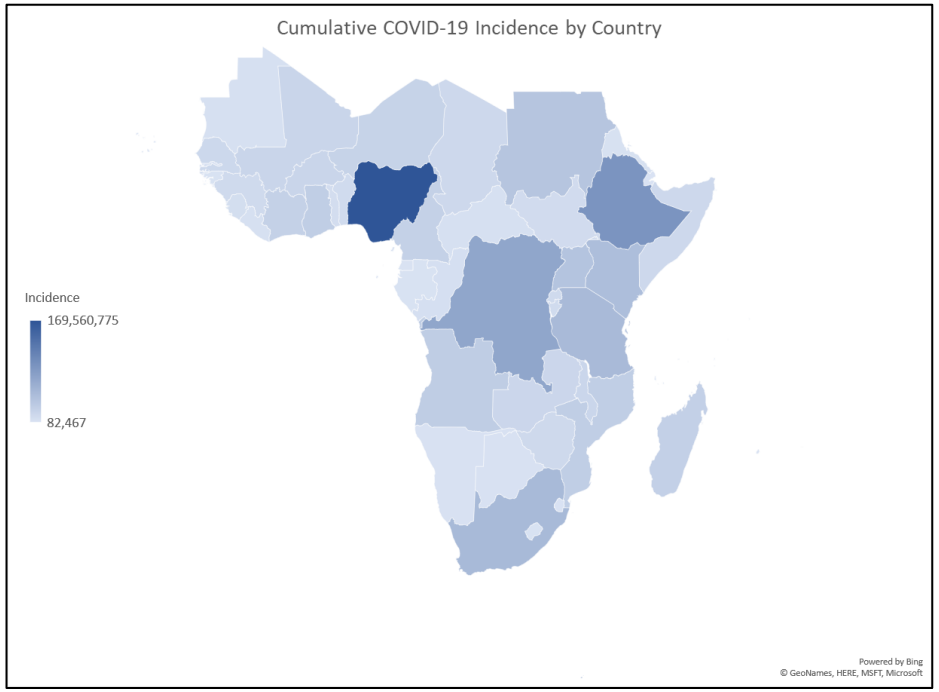
District –Estimated Critical Care Cases



TA – Estimated Hospitalizations



TA	District	Hospitalizations
Lilongwe City	Lilongwe City	21,761
Blantyre City	Blantyre City	20,992
TA Chiseka	Lilongwe	8,852
TA Mkhumba	Phalombe	8,124
TA Msamala	Balaka	6,994
TA Mabuka	Mulanje	6,174
TA Ngabu	Chikwawa	5,839
TA Kalolo	Lilongwe	5,575
TA Mtwalo	Mzimba	5,562
TA Mbiza	Zomba	5,490


Cumulative COVID-19 Incidence by Country
Incidence
169,560,775
82,467
Powered by Bing
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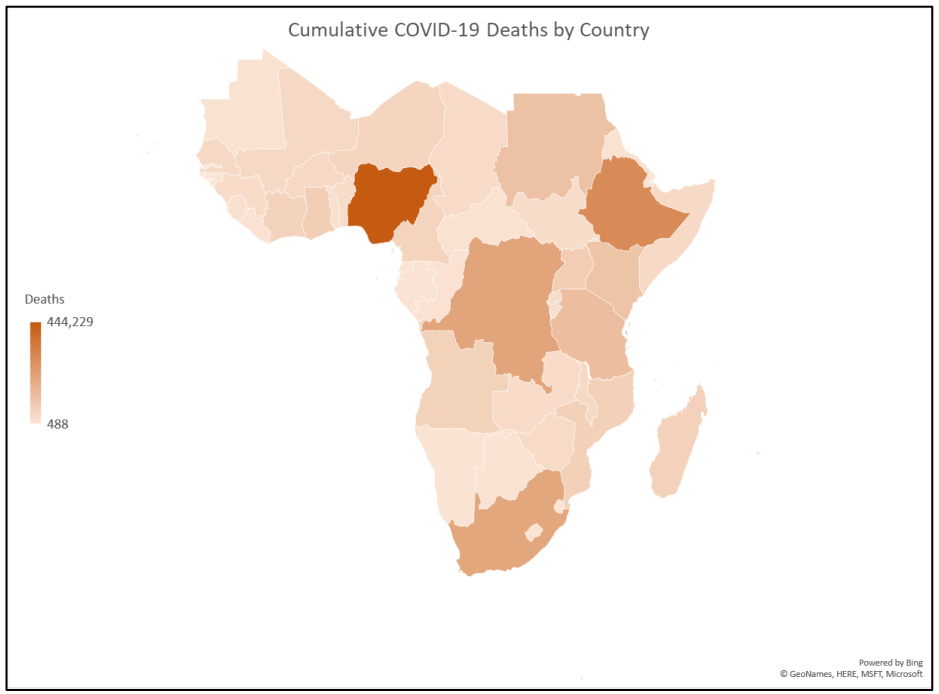
Cumulative COVID-19 Deaths by Country
Deaths
444,229
488
Powered by Bing
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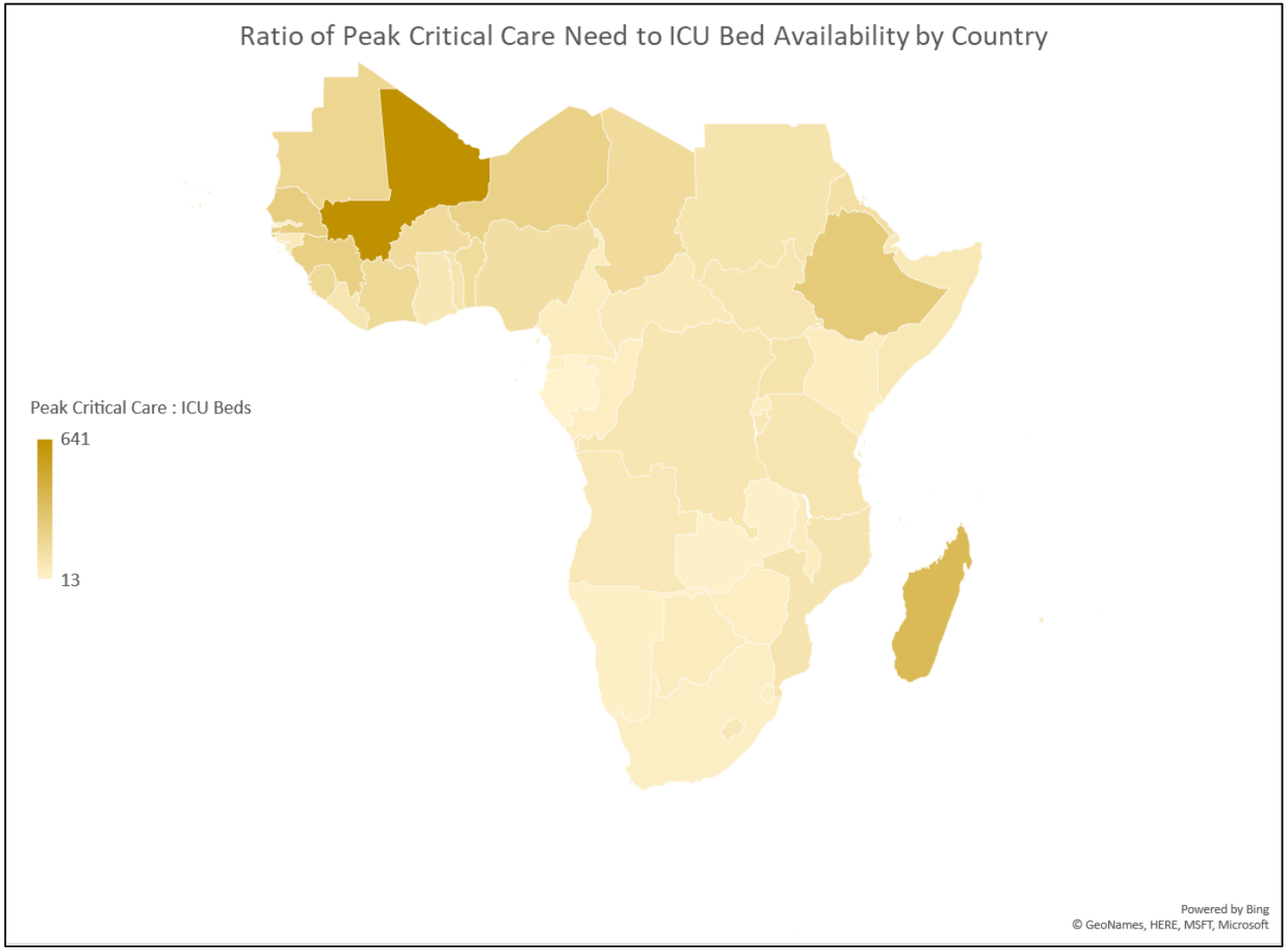
Ratio of Peak Critical Care Need to ICU Bed Availability by Country
Peak Critical Care : ICU Beds
641
13
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