

1 **Title: Impact of the COVID-19 lockdown on admissions and mortality in children**
2 **admitted to four referral hospitals in Durban, South Africa**

3

4 **Authors:**

5 Naidoo KL,^{1,2} Dorward J,^{3,4} Chinniah K,^{1,5} Lawler M,^{1,6} Nattar Y,^{1,7} Bottomley C,⁸ Archary
6 M^{1,2}

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8 ¹ Department of Paediatrics and Child Health, School of Clinical Medicine, College of Health
9 Sciences, University of KwaZulu-Natal, Durban, South Africa

10 ² King Edward VIII Hospital, Congella, Durban, South Africa

11 ³ Nuffield Department of Primary Care Health Sciences, University of Oxford, Oxford, United
12 Kingdom

13 ⁴ Centre for the AIDS Programme of Research in South Africa (CAPRISA), Durban, South
14 Africa

15 ⁵ Mahatma Gandhi Memorial Hospital, Phoenix, Durban, South Africa

16 ⁶ Prince Mshyeni Memorial Hospital, uMlazi, Durban, South Africa

17 ⁷ RK Khan Memorial Hospital, Chatsworth, Durban, South Africa

18 ⁸ London School of Hygiene & Tropical Medicine, London, United Kingdom

19

20 Corresponding author:

21 Dr KL Naidoo

22 Naidook9@ukzn.ac.za

23 +27 31 260 4350

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35 **ABSTRACT**

36 **Background**

37 Vulnerable children from poor communities with high HIV and Tuberculosis(TB) burdens
38 were negatively impacted by COVID-19 lockdowns. Concern was raised about the extent of
39 this impact and anticipated post-pandemic surges in mortality.

40 **Methods**

41 Interrupted time series segmented regression analyses were done using routinely collected
42 facility-level data of children admitted for medical conditions at four South African referral
43 hospitals. Monthly admission and mortality data over a 60-month period from 01 April 2018
44 to 31 January 2023 was analysed using models which included dummy lockdown level
45 variables, a dummy post-COVID period variable, Fourier terms to account for seasonality, and
46 excess mortality as a proxy for healthcare burden.

47 **Findings**

48 Of the 45 015 admissions analysed, 1237(2.75%) demised with significant decreases in
49 admissions during all the lockdown levels, with the most significant mean monthly decrease
50 of 450(95%, CI=657.3, -244.3) $p < 0.001$ in level 5 (the most severe) lockdown. There was
51 evidence of seasonality on a six-month scale during the pre-and post-COVID periods in total
52 admissions ($p = 0.002$), under-one-year-olds ($p = 0.034$) and under-five-year-olds ($p = 0.004$),
53 which was disrupted by the COVID lockdowns. No significant mortality changes during any
54 of the lockdown levels were found. Post-pandemic surges in admissions or mortality were not
55 identified in children with acute gastroenteritis, acute pneumonia and severe acute malnutrition.

56 **Interpretation**

57 Paediatric admissions from communities with high levels of HIV and TB decreased during
58 COVID-19 lockdowns, but there was no decrease in in-hospital deaths. Two postulates for
59 these findings are the altered transmission dynamics of childhood infections and an
60 exacerbation of existing delays in accessing healthcare. Anticipated post-pandemic surges in
61 communicable diseases and mortality have not transpired, indicating a need for studies to
62 identify the impact of persisting challenges in healthcare provision and that of pandemic control
63 strategies on vulnerable populations.

64

65 **Keywords:** Children; COVID-19, mortality, admissions

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69 **Evidence before**

70 Decreases in emergency room, primary preventative care, routine outpatient care, visits and
71 hospital admissions affected children's healthcare across all communities following the
72 introduction of COVID-19 lockdown measures. Multiple predictive models indicated expected
73 surges in communicable diseases and mortality, especially in vulnerable child populations post-
74 lockdown. Vulnerable child populations where HIV, Tuberculosis and poor fragile healthcare
75 are common were especially raised as areas of concern. Efforts to limit COVID-19
76 transmission may have affected transmission dynamics of common communicable childhood
77 diseases, although this impact in vulnerable populations was not clearly documented. Some
78 evidence of maintenance of child HIV viral loads through the pandemic were documented.

79

80 **The added value of this study**

81 Findings provide 60 months of longitudinal data, pre- and post-COVID-19 pandemic, from a
82 large cohort of sick children from vulnerable communities with high HIV and Tuberculosis
83 burdens who were subjected to strict lockdown measures. Interrupted time series segmented
84 regression analyses adjusting for excess mortality and seasonality document significant
85 decreases in hospitalisations but no changes in mortality. Disturbances to previous seasonality
86 are identified in a cohort of children admitted for complicated medical conditions and common
87 communicable childhood diseases causing acute gastroenteritis and acute pneumonia, and no
88 changes in malnutrition numbers were documented. The study identifies that anticipated surges
89 in post-pandemic mortality and morbidity have not occurred.

90

91 **Implications of this evidence**

92 Lockdown measures in the COVID-19 pandemic significantly impacted vulnerable
93 communities, and this needs further study as indications are that children behaved differently
94 compared to well-resourced societies with lower burdens of disease. Transmission dynamics
95 of common childhood communicable diseases seem to be affected by implementing wide-scale
96 mitigating strategies in infectious disease outbreaks in these communities. However, the
97 persistence of mortality and a lack of post-pandemic surges suggests that sub-populations of
98 children remain at greater risk, and this needs evaluation, especially regarding access to care
99 and evaluating the impact on the spread of communicable disease in all communities. Health
100 planning needs to build in these factors when developing policies and systems catering to
101 vulnerable children, especially in response to pandemics .

102

103 **Background**

104 The national lockdown regulations promulgated across the globe due to the COVID-19
105 pandemic disrupted essential healthcare services for most populations.¹ Healthcare visits,
106 including emergency outpatient visits and admissions, decreased sharply among children in all
107 countries, especially between February 2020 and December 2021.²⁻⁵ Decreases of 19%, 50%
108 and 56% in paediatric admissions were documented in Cameroon, South Africa (SA) and
109 across Europe, respectively, compared with pre-COVID-19 time periods.³⁻⁵ Vulnerable
110 populations, including children in lower- and middle-income countries (LMICs), were
111 especially negatively impacted due to these lockdown measures.²⁻⁴

112

113 The decrease in paediatric admissions documented has been more marked in children with
114 communicable (77%) compared with non-communicable diseases (37%).⁵ Children with lower
115 respiratory tract infections (LRTI), which includes those with highly communicable viral
116 bronchiolitis, also decreased.⁶⁻⁸ Changes in seasonal patterns of viral bronchiolitis when
117 compared with patterns identified in previous pre-COVID-19 years were noted.⁶ This was
118 postulated to occur due to reduced person-to-person transmission, and it raised concerns that a
119 rebound would occur when transmission mitigating strategies and lockdown levels were
120 curtailed.⁶

121

122 Visits to children's preventative health services decreased significantly across multiple
123 countries, especially after the start of the COVID-19 pandemic in February 2020.⁹ These
124 decreases were documented in both urban and rural primary healthcare facilities.¹⁰ Outpatient
125 visits for children with Human Immunodeficiency Virus (HIV) dropped by 41%, and
126 antiretroviral treatment initiation of newly diagnosed children also decreased in 2020 and
127 2021.¹¹ These changes in access and utilisation of both preventative healthcare and HIV
128 chronic care raised concerns for negative health consequences, especially in communities
129 where poverty, HIV and Tuberculosis (TB) are common.¹¹ HIV viral suppression rates,
130 however, were shown to be maintained among children, suggesting some chronic disease
131 programmes remained reasonably robust over this period.¹²

132

133 Overall, the COVID-19 pandemic disrupted healthcare provision and health-seeking behaviour
134 and was postulated to disproportionately impact specific subpopulations in low-income
135 countries with fragile health systems and pervasive social-structural vulnerabilities.¹³
136 Documentation of these indirect effects of the COVID-19 pandemic has been largely restricted

137 to the period during the peaks of the COVID-19 lockdowns between February 2020 and
138 December 2021 and not adequately documented in communities with high burdens of HIV,
139 Tuberculosis (TB) and malnutrition.¹¹ With this disruption of healthcare, concern was raised
140 about the deleterious effects on mortality and morbidity rates rising, specifically in these
141 vulnerable children in such communities after the removal of lockdown measures.¹⁴

142

143 Children hospitalised in specialist referral hospitals in LMICs generally include more complex
144 cases requiring higher levels of medical care and support, representing the sickest children
145 accessing healthcare.¹⁵ In contexts where there are high levels of HIV, TB and malnutrition,
146 in-hospital mortality and morbidity, including the need for admission in children with these
147 diagnoses within the public sector (non-fee paying), specialist referral hospitals reflect health
148 system failures to address both preventative and curative aspects of healthcare.¹⁵ This study
149 describes and analyses changes in admission and in-hospital mortality amongst children in
150 South African specialist referral hospitals during all the levels of national lockdowns associated
151 with the COVID-19 pandemic and the post-pandemic period. These changes are analysed by
152 age group and diagnostic categorisation. They are compared with a pre-pandemic period across
153 a large metropolitan area where there are high HIV, TB and malnutrition rates.

154

155 **METHODS**

156 **Study design and population**

157 We conducted an interrupted time series analysis of routinely collected facility-level data of
158 children below the age of 13 years hospitalised across all four of the largest public sector (non-
159 fee-paying) specialist referral hospitals in the city of Durban (eThekweni District), Kwa Zulu-
160 Natal(KZN). The data collected included those hospitalised with medical diagnoses only, thus
161 allowing analysis to reflect on the impact of the COVID-19 pandemic, specifically on
162 communicable diseases. In-born neonates and children hospitalised for surgical (general
163 surgery, trauma, ear nose and throat procedures, orthopaedic reasons) or other non-medical
164 reasons (psychiatric and social admissions for respite care or neglect) were purposefully
165 excluded from the analysis.

166

167 We used data from the King Edward VIII, Mahatma Gandhi Memorial, Prince Mshyeni
168 Memorial and R K Khan Memorial hospitals, which provide 240 in-patient paediatric medical
169 specialist care beds (including designated high care and beds for interim invasive ventilation)
170 for approximately 1,1 million children (35.2% of the total city's 3,05 million total

171 population).^{15,16} The children admitted to these hospitals are referred by primary healthcare
172 providers (nurse-run day-clinics, family practitioners, non-specialist district hospitals) and are
173 generally complex cases requiring higher care levels. Children who require longer-term
174 invasive ventilation (>72 hours) are referred to paediatric intensive care units located at the
175 quaternary hospital.¹⁵ The majority of the children who attend and are hospitalised in these four
176 referral hospitals are from lower socio-economic communities and are drawn from 88% of
177 Durban's population who do not subscribe to private medical programmes.¹⁵ The HIV antenatal
178 seroprevalence of the population served by these hospitals is high at 44.3%(CI;41.6-46.7),
179 reflecting a high burden of both HIV-exposed infants and HIV-infected children.^{16,17}

180

181 The study period spanned 60 months and included 23 months in the pre-COVID-19 period (01
182 April 2018 to 28 February 2020), 23 months of the designated COVID-19 period (01 March
183 2020 to 31 January 2022), during which one of the five lockdown stages were promulgated and
184 14 months post COVID-19 period (01 February 2022 to 31 January 2023), when no lockdowns
185 were in place. South Africa announced a national lockdown on 23 March 2020, implemented
186 on 27 March 2020.^{18,19} Starting at level 5, the lockdown was one of the most severe globally,
187 with restrictions on movement and cancellation of public transport, although travel to receive
188 healthcare was allowed.¹⁹ The lockdown was eased to level 4 on May 1, 2020, when public
189 transport was allowed, and to level 3 on 01 June 2020, which allowed some economic activity
190 to resume. Over the 23-month COVID-19 period, lockdown levels vacillated depending on the
191 authorities' anticipated need to prevent community transmission.^{18,19} Monthly data in the
192 COVID period were thus stratified according to the predominant lockdown level in each of the
193 23 months in this period.

194

195 **Data collection**

196 The admission diagnosis of children included in the facility-level monthly data was obtained
197 from in-patient records that an attending paediatrician validated. Data on hospitalised children
198 included children in all age groups below 13 years of age (SA's referral hospitals have a 13-
199 year-old cut-off for paediatric care), those below one year of age (infant) and those between
200 one and five years of age. Data on hospitalised children under the age of five years with lower
201 respiratory tract infections (LRTI) or acute gastroenteritis (AGE) as their main diagnosis were
202 specifically tracked. In this study, the term LRTI as a diagnostic category includes patients
203 with lobar or bronchopneumonia, bronchiolitis and bronchitis. This categorisation was based
204 on a standardised nomenclature used by clinicians across all sampled hospitals in admission

205 diagnoses and mortality classification. LRTI excludes upper respiratory tract infections (URTI)
206 or upper airway obstruction, asthma or recurrent wheezing.²⁰ In addition, monthly admission
207 numbers of children categorised as having severe acute malnutrition (SAM) using the WHO
208 guidelines were also collected. In all four hospitals, the categorisation of a child under five
209 years of age with SAM is verified by a paediatrician and then independently corroborated by
210 an attending dietician within 72 hours post-admission. This dual verification for nutritional
211 categorisation enables weights post-rehydration to be utilised and for lengths or heights to be
212 rechecked for accuracy. In the WHO nutritional classification system, children are classified
213 as either having severe acute malnutrition (SAM), moderate acute malnutrition (MAM), not
214 acutely malnourished but considered at risk (NAM@risk), or not acutely malnourished (NAM)
215 or as overweight or obese.^{21,22} The SAM definition was based on weight-for-length z score
216 and/or the presence of nutritional oedema as documented by an attending paediatrician.²² The
217 mid-upper arm circumference (MUAC) scores were not used in this study as the documentation
218 was inconsistent in the reviewed source documents.^{21,22} The numbers of children who demised
219 monthly in all age categories and specifically those with a diagnosis of LRTI, AGE or SAM
220 under the age of five years were also collected.

221

222 *Verification of data*

223 Four independent databases were utilised over the study periods.²³ These databases
224 corroborated and validated information and ensured minimal missing data. Each hospital's
225 paediatric department has an in-hospital database used as the primary database. A specialist
226 paediatrician in each hospital is responsible for verifying and entering all weekly admissions
227 tallies and death information (categorised by age and diagnosis) from original case records into
228 this primary database. Admission and mortality data is also verified monthly by paediatricians
229 in the department from a standardised admission and deaths daily register and then submitted
230 to a facility information officer, which feeds this data to a central district-wide district health
231 information system database (DHIS).²³ In this study, we validated the DHIS data obtained with
232 source data in each hospital from the primary database that the attending paediatricians held to
233 avoid inconsistencies. The third database was the Child Healthcare Problem Identification
234 Programme (Child PIP). Paediatric departments across many SA hospitals utilise this database
235 to record and systematically review child deaths independently, emphasising assessing
236 modifiable factors related to these deaths.²⁴ Mortality figures per hospital were corroborated
237 using the Child PIP and DHIS and verified at each hospital. The fourth database used verified
238 nutritional categorisation of all in-hospital patients, and in-hospital dietitians maintained these

239 databases in each hospital. The databases were rechecked and then verified with the hospital
240 records for discrepancies.

241

242 **Data analysis and interpretation**

243 We used descriptive statistics to summarise data and present summaries of admission, mortality
244 and case fatality rates before, during and after the COVID-19 period with lockdowns. We did
245 an interrupted time series segmented regression analysis by fitting linear regression models
246 with the outcome of monthly paediatric admissions. The models included dummy lockdown
247 level variables indicating 1 or 0 for each level 1 (least severe) to 5 (most severe) of lockdown
248 and a dummy variable for the post-COVID-19 period. COVID-19 waves could also have
249 caused an increased burden on the healthcare system, which may have affected paediatric
250 healthcare use and admissions independently from lockdowns. We, therefore, modelled this by
251 including a continuous variable for excess mortality in eThekweni for each month as a proxy
252 for COVID-19-related burden on the healthcare system. To account for seasonal changes due
253 to RSV and other respiratory virus outbreaks and Rotavirus and other viral causes of AGE, we
254 included two pairs of sine and cosine terms (Fourier terms) in the models to account for
255 seasonality. This approach takes account of pre-lockdown trends and allows estimation of the
256 effect of each level of lockdown and whether there was a change in admissions during the
257 period following the cessation of all lockdowns post-COVID. We built separate models by age
258 (under one year, under five years and between 5 and 13 years) and diagnosis (LRTI, AGE and
259 SAM). Age-specific changes thus do not sum to the total change because the total admissions
260 (and deaths) were analysed as a separate time series. We checked for auto-correlation by
261 calculating the auto-correlation and partial autocorrelation functions. We analysed data using
262 R4.0 (R Foundation for Statistical Computing, Vienna, Austria; appendix).

263

264 **RESULTS**

265 During the 60-month study period that extended from 01 April 2018 to 31 March 2023, 45 015
266 children were admitted across all four specialist hospitals in Durban (eThekweni district). Of
267 these, 20 490 (45.5%) were <1 year of age (infants), 16 549 (36.8%) were children between
268 one and below five years, and 7976 (17.7%) were children between five and below 13 years.
269 Across all these age groups, 1237 children died in hospital during the 60 months of the study
270 period, with 733 (59.3%) being infants, 346 (28%) between one and below five years and
271 158 (12.7%) between five and 13 years. Table 1 compares unadjusted mean monthly admission
272 and mortality numbers and raw case fatality rates during the three assessed periods. While the

273 mean monthly admission appeared marginally lower in the COVID-19 period, there was less
274 of a decrease in mean monthly deaths. The case fatality rates for LRTI, AGE and SAM in the
275 under-five-year group were higher during COVID-19.

276

277 **[Table 1 Unadjusted mean monthly admission and mortality numbers during all**
278 **lockdown levels and post-COVID period]**

279

280 **Interrupted time series analysis**

281 **Adjusted admission and mortality monthly numbers by age group**

282 The analysis showed a significant decrease in total admissions for children under 1, 1-to-5-
283 year-olds, and 5-13-year-olds. Level 5 lockdowns saw the most significant mean monthly
284 decreases of 450(95% CI=-657.3--244.3) $p<0.001$, 213.2(-349--76.8) $p=0.003$, 376.4(-
285 566.3--186.4) $p<0.0001$ in total, under-1-year-old and 1-to-5-year-old admissions
286 respectively. Level-1-lockdowns had the lowest mean monthly decreases. The trend was
287 similar for school-going children (5-13-year olds) to all other age groups. There was also
288 evidence of seasonality on a 6-month scale during the pre-and post-COVID periods in total
289 admissions ($p=0.002$), under-1-year-olds ($p=0.034$) and 1-to-5-year olds ($p=0.004$) which was
290 not evident during the COVID-19 lockdown periods. In the segmented regression model, there
291 was no evidence that excess monthly mortality in SA was associated with changes in admission
292 numbers in any age group. Figures 1(a),1(b),1(c) and 1(d) illustrates these findings.

293

294 In the post-COVID-19 period, total admissions remained slightly lower than during the pre-
295 COVID-19 period (decrease of 68, 95% CI=-134.2--2.4, $p=0.0430$). This was mainly due to
296 a decrease in the 1-5-age group (-60.9, 95% CI=-121.5--0.2, $p=0.049$), with no evidence of a
297 difference in the under-1-age group (+6.5, -50.1--37.0, $p=0.765$), nor 5-13-year olds (-9.6, -
298 26.8--7.7, $p=0.270$).

299

300 The segmented regression analysis showed no significant change in monthly mortality in all
301 ages nor specifically in the age categories of under-1-year-olds and 1-to-5-year-olds and 5-13-
302 year age groups during any lockdown levels, nor the post-COVID period. (Table 2, Figure 2(a),
303 2(b), and 2(c) provide the data and illustrate the trends, respectively)

304

305 **[Table 2, Changes in mean monthly admissions and mortality in lockdown levels 1 to 5 in**
306 **all age groups]**

307 **[Figure 1 Interrupted time series analysis of admissions by age group, all ages 1(a), under**
308 **12 months 1(b), under 60 months 1(c) and between 5 and 13 years old (1d).]**

309 **[Figure 2 Interrupted time series analysis of mortality rates by age group all ages 2(a),**
310 **under 12 months 2(b) and under 60 months 2(c).]**

311

312 **Admission and mortality rates for children with acute gastroenteritis (AGE), lower**
313 **respiratory tract infections (LRTI) and severe acute malnutrition (SAM)**

314 Significant decreases in admissions were seen during most of the lockdown levels in the
315 COVID-19 period in children hospitalised with AGE, LRTI or SAM (Table 3). Level 5
316 lockdowns saw decreases of 82.8(95%, CI=156.3--9.3) $p=0.028$, 132.8(-238.6--
317 27.0) $p=0.015$ and 25.7(95%, -47.4--3.9), $p=0.022$ in AGE, LRTI and SAM cases. The terms
318 for seasonality provided evidence of seasonal variation on both a 6-month ($p=0.032$) and 12-
319 month ($p=0.003$) scale for AGE admissions, a 6-month scale for LRTI admissions ($p=0.004$)
320 and a 12-month scale for SAM admissions ($p<0.001$).

321

322 Figures 3(a), 3(b) and 3(c) illustrate these changes and loss of the seasonal patterns in AGE
323 and LRTI seen during the COVID-19 period .

324

325 In the post-COVID period, there was no evidence that AGE, LRTI, or SAM admissions
326 changed compared to pre-COVID numbers. Figures 3(a), 3(b) and 3(c) illustrate a return to
327 seasonal patterns in the post-COVID period for cases of AGE and LRTI.

328

329 When analysing changes in mortality in those hospitalised with either AGE, LRTI or SAM, no
330 significant changes were noted in all the lockdown levels. Table 3 and Figures 4(a), 4(b) and
331 4(c) illustrates these findings.

332

333 **[Table 3 Changes in adjusted mean monthly admission and case mortality numbers in 1-**
334 **5-year-old children with Acute Gastroenteritis and Lower Respiratory tract infections**
335 **during all lockdown levels and post-Covid -period]**

336 **[Figure 3 Interrupted time series analysis of admissions by diagnosis in 1-5 year old with**
337 **acute gastroenteritis 3(a), lower respiratory tract infections 3(b) and severe acute**
338 **malnutrition 3(c).]**

339 [Figure 4 Interrupted time series analysis of mortality rates per admission diagnosis in
340 1-5 years-olds with acute gastroenteritis 4(a), lower respiratory tract infections 4(b) and
341 severe acute malnutrition 4(c).]

342

343 DISCUSSION

344 This study describes changes in patterns of admissions and deaths among sick and vulnerable
345 SA children over five years straddling the COVID-19 pandemic. Despite significant decreases
346 in admissions and changes in seasonal patterns of communicable diseases during the COVID-
347 19 lockdowns, there was neither a concomitant decrease in in-hospital deaths in this period nor
348 a post-pandemic surge in admissions or mortality.

349

350 Several modelling studies and early reviews from LMICs have raised concerns about the
351 impact of the COVID-19 pandemic on vulnerable populations, especially those where fragile
352 healthcare systems exacerbate delayed access to care.^{3,4,10} In this study reflecting children
353 drawn from low-income neighbourhoods and communities with high rates of HIV, TB and
354 malnutrition, similar trends in admission, as was documented in high-income countries,
355 occurred following the promulgation of stringent lockdowns.^{5,13,25} This cohort also includes
356 socially marginalised segments of the population (families living in informal high-population-
357 density settlements with poor access to municipal services) where access to healthcare has
358 been compromised even prior to the COVID-19 pandemic.¹⁵

359

360 Similar to decreases in admissions, visits to government primary health clinics were also
361 decreased in the COVID-19 period⁴. These findings may reflect the influence on the decreased
362 transmission of common childhood communicable diseases, possibly affected by decreased
363 social interactions and mitigating strategies to prevent COVID-19 transmission.^{9,10} Of concern,
364 however, is that the documented decrease in primary care visits and admissions could also
365 reflect decreased access to healthcare for sick children. Whilst lockdown laws permitted the
366 seeking of healthcare and all facilities remained open through the COVID-19 pandemic, the
367 significant decreases in the admission of sick children, as is the case in this study, raises the
368 likelihood of both these scenarios playing out in vulnerable populations and marginalised
369 groups.

370

371 Concern that many sick children demised at home without accessing acute medical care during
372 these periods is not borne out by any significant increase in excess childhood mortality as seen

373 in age-specific annualised excess death rates (per 1000 population) documented over this
374 period.²⁶ In this study, that reflects children admitted at referral hospitals, including those with
375 complex problems and diagnoses, mortality numbers in all age groups and children with AGE,
376 LRTI and SAM did not decrease during the lockdown period, unlike previously reported from
377 this geographical area.¹⁰ Our finding of this persistence of mortality numbers despite significant
378 decreases in admissions has been documented elsewhere.³ It supports the postulate that sick
379 children did access healthcare and possibly did so later than they should have.²⁷ We postulate
380 that our large cohort of children hospitalised in public sector referral hospitals consists of
381 multiple sub-groups. They include children who access care timeously through available
382 pathways and those with delayed access to care for a multiplicity of reasons. This latter group
383 has been previously documented as experiencing delays in accessing standard healthcare
384 despite the availability of free public health services.²⁷ Many caregivers here are noted to
385 utilise multiple other sources of care, including allopathic, indigenous and home treatments
386 prior to presenting at public services.²⁷ It is possible that caregivers in this sub-group would
387 have persisted with late presentation for acute care, similar to pre-pandemic behaviours or
388 delayed their access to hospital care even later. Further exploration is thus required to determine
389 how these various sub-groups were uniquely affected by the challenges posed both by the
390 COVID-19 pandemic and the associated lockdowns.

391

392 In this study, we specifically compared the admission of children with a diagnosis of AGE and
393 LRTI with pre-pandemic patterns. We found a significant decrease in admissions for AGE and
394 LRTI in most lockdown periods. AGE and LRTI cases hospitalised in the four referral
395 hospitals generally have complications requiring specialist care, e.g., cases with hypernatremic
396 dehydration or LRTI requiring non-invasive respiratory support.²⁸ While our findings are
397 similar to the general decreases seen in admissions worldwide observed at all levels of
398 hospitals, our study documents that children with complicated common childhood diseases also
399 saw decreases in the need for admission.^{5,6,10,29} It has been postulated that increased
400 preventative hygiene habits adopted during the COVID-19 period, like masking, regular hand
401 washing, creche and school closures, and other restrictions impacting person-to-person spread
402 of infections, resulted in modified seasonal patterns of communicable diseases like Rotavirus
403 associated AGE and Respiratory syncytial Virus associated LRTI.^{6,8,29} Whilst we cannot
404 definitively attribute the cases of AGE and LRTI in this cohort to specific viral aetiologies, the
405 overall decrease in admissions does raise the possibility that transmission of these commonly
406 occurring pathogens decreased, changing previous seasonal patterns, and this also occurred

407 within vulnerable populations where higher population densities are the norm. It also suggests
408 that the complication rates in these commonly occurring communicable diseases possibly
409 decreased.

410

411 Our study also documents that the expected surge in malnutrition cases during the lockdown
412 period did not occur, unlike those reported in other studies from developing countries.^{10,30} The
413 persistence of high mortality rates in SAM similar to pre-pandemic levels cases despite the
414 decreased admission also suggests that sick children did get to healthcare; however, they could
415 have done so later than was previously the case.^{22,26}

416

417 The great concern expressed across the world following the decreased utilisation of
418 preventative services and, specifically for vulnerable populations where TB and HIV are
419 endemic, was an expected post-pandemic surge.¹¹ With the disruption of seasonal patterns of
420 viral bronchiolitis, an expected surge in LRTI was also anticipated.³¹ In this study, which
421 analysed data over a longer post-pandemic period than most other studies, we do not show this
422 anticipated surge in admissions in under-1-year and 1-to-5-year-old children as well as in cases
423 of AGE, LRTI and SAM. The trend identified in the post-pandemic period may reflect a
424 gradual increase in admissions back to pre-COVID levels. Our postulates that multiple sub-
425 groups of vulnerable children are served by referral hospitals, including the sickest cohort of
426 children, i.e. those at the highest risk of death and who traditionally present late for acute
427 healthcare persisted. There is also a possibility that in the communities that these hospitals
428 serve, where there are high population densities with cramped living, any benefits of decreased
429 infections with lockdown occurred to a lesser degree than in households with low population
430 densities. The lack of a post-pandemic surge seen with most of the children in this cohort could
431 be explained by this possibility. The role of strategies to provide catch-up immunisation thus
432 needs to be explored. Further studies specifically targeting these populations and utilising
433 microbiological testing may be required to unpack children's behaviours under differing
434 contexts. This study may help determine the epidemiological patterns of vulnerable children
435 when faced with communicable disease outbreaks in greater detail.

436

437 Strengths of our study include the large cohort of children hospitalised specifically for medical
438 diagnoses in public sector referral hospitals. We reflected on acutely sick and vulnerable
439 children susceptible to communicable diseases. Our use of long-term routine data considers
440 pre-COVID, all the COVID lockdown levels, and substantial post-COVID periods, whilst most

441 studies have largely focused on the COVID-19 period. However, due to the use of retrospective
442 facility-level data, we were not able to verify definitive microbiological, virologic and formal
443 HIV and TB results; instead, we relied on retrospective diagnoses provided by source
444 documents and by paediatricians on site. We did not focus on neonatal or non-medical or
445 children admitted to referral intensive care units (ICU) requiring prolonged ventilation. It must
446 be noted that access to paediatric intensive care beds is very limited, and the cohorts assessed
447 in this study reflect a larger population than those who are admitted to ICU care only. We could
448 not assess the definitive socio-economic status and inferred this based on previous usage
449 patterns in public sector hospitals. The retrospective data reflects in-hospital mortality
450 specifically and does not include community-based death data.

451
452 In conclusion, our findings suggest that, in one of the regions most affected by HIV,
453 Tuberculosis and malnutrition, admission of acutely sick children referred for specialist care
454 for medical causes decreased during the COVID-19 lockdowns. A decrease in in-hospital
455 mortality, however, was not similarly documented, suggesting sick children from vulnerable
456 communities were presenting to care possibly later than usual. Anticipated post-pandemic
457 surges in admission and mortality have not been observed thus far. This study provides
458 evidence that mitigating strategies to reduce infectious disease outbreaks possibly affected
459 transmission dynamics of common communicable childhood diseases, leading to decreased
460 needs for all levels of medical care and disruption in seasonal patterns. Anticipated surges in
461 admissions and mortality were not seen in this cohort; rather, a return to previous patterns.
462 Further studies in this vulnerable population are needed to identify longer-term changes due to
463 persisting challenges in healthcare provision.

464

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472 The data used for this analysis cannot be shared publicly because of legal and ethical
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475 Department of Health (contact details obtainable upon request to the corresponding author).

476 **Authors' contributions**

477 KLN, JD and MA conceptualised the study. KLN, KC, ML and YN oversaw data collection.
478 KLN, KC, ML and YN oversaw the curation of the data. JD, CB and KLN analysed the data.
479 KLN drafted the manuscript. JD, CB and KLN verified the underlying data. All authors
480 critically reviewed and edited the manuscript and consented to final publication. KLN and JD
481 had full access to all the data, and all authors had final responsibility for the decision to submit
482 for publication.

483 **Disclaimer**

484 The views and opinions expressed in this article are those of the authors and do not necessarily
485 reflect the official policy or position of any affiliated agency of the authors.

486 **Ethical consideration**

487 Adherence to ethical guidelines was ensured throughout the research process. The study was
488 approved by the University of KwaZulu-Natal Biomedical Research Ethics Committee
489 (BREC/00002981/2021), the KwaZulu-Natal Department of Health's Provincial Health
490 Research Ethics Committee, eThekweni District Health Department and the Child Health
491 Identification Programme (National committee) with a waiver for informed consent for
492 analysis of anonymised, routinely collected data.

493 **Consent for publication**

494 Not applicable.

495 **Competing interests**

496 The author(s) declare that they have no financial or personal relationship(s) that may have
497 inappropriately influenced them in writing this article.

498

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610

611

612

1 **Title: Impact of the COVID-19 lockdown on admissions and mortality in children**
2 **admitted to four referral hospitals in Durban, South Africa**

3
4 **ABSTRACT**

5 **Background**

6 Vulnerable children from poor communities with high HIV and Tuberculosis(TB) burdens
7 were negatively impacted by COVID-19 lockdowns. Concern was raised about the extent of
8 this impact and anticipated post-pandemic surges in mortality.

9 **Methods**

10 Interrupted time series segmented regression analyses were done using routinely collected
11 facility-level data of children admitted for medical conditions at four South African referral
12 hospitals. Monthly admission and mortality data over a 60-month period from 01 April 2018
13 to 31 January 2023 was analysed using models which included dummy lockdown level
14 variables, a dummy post-COVID period variable, Fourier terms to account for seasonality, and
15 excess mortality as a proxy for healthcare burden.

16 **Findings**

17 Of the 45 015 admissions analysed, 1237(2.75%) demised with significant decreases in
18 admissions during all the lockdown levels, with the most significant mean monthly decrease
19 of 450(95%, CI=-657.3, -244.3) $p<0.001$ in level 5 (the most severe) lockdown. There was
20 evidence of seasonality on a six-month scale during the pre-and post-COVID periods in total
21 admissions ($p=0.002$), under-one-year-olds ($p=0.034$) and under-five-year-olds ($p=0.004$),
22 which was disrupted by the COVID lockdowns. No significant mortality changes during any
23 of the lockdown levels were found. Post-pandemic surges in admissions or mortality were not
24 identified in children with acute gastroenteritis, acute pneumonia and severe acute malnutrition.

25 **Interpretation**

26 Paediatric admissions from communities with high levels of HIV and TB decreased during
27 COVID-19 lockdowns, but there was no decrease in in-hospital deaths. Two postulates for
28 these findings are the altered transmission dynamics of childhood infections and an
29 exacerbation of existing delays in accessing healthcare. Anticipated post-pandemic surges in
30 communicable diseases and mortality have not transpired, indicating a need for studies to
31 identify the impact of persisting challenges in healthcare provision and that of pandemic control
32 strategies on vulnerable populations.

33
34 **Keywords:** Children; COVID-19, mortality, admissions

35 **Evidence before**

36 Decreases in emergency room, primary preventative care, routine outpatient care, visits and
37 hospital admissions affected children's healthcare across all communities following the
38 introduction of COVID-19 lockdown measures. Multiple predictive models indicated expected
39 surges in communicable diseases and mortality, especially in vulnerable child populations post-
40 lockdown. Vulnerable child populations where HIV, Tuberculosis and poor fragile healthcare
41 are common were especially raised as areas of concern. Efforts to limit COVID-19
42 transmission may have affected transmission dynamics of common communicable childhood
43 diseases, although this impact in vulnerable populations was not clearly documented. Some
44 evidence of maintenance of child HIV viral loads through the pandemic were documented.

45

46 **The added value of this study**

47 Findings provide 60 months of longitudinal data, pre- and post-COVID-19 pandemic, from a
48 large cohort of sick children from vulnerable communities with high HIV and Tuberculosis
49 burdens who were subjected to strict lockdown measures. Interrupted time series segmented
50 regression analyses adjusting for excess mortality and seasonality document significant
51 decreases in hospitalisations but no changes in mortality. Disturbances to previous seasonality
52 are identified in a cohort of children admitted for complicated medical conditions and common
53 communicable childhood diseases causing acute gastroenteritis and acute pneumonia, and no
54 changes in malnutrition numbers were documented. The study identifies that anticipated surges
55 in post-pandemic mortality and morbidity have not occurred.

56

57 **Implications of this evidence**

58 Lockdown measures in the COVID-19 pandemic significantly impacted vulnerable
59 communities, and this needs further study as indications are that children behaved differently
60 compared to well-resourced societies with lower burdens of disease. Transmission dynamics
61 of common childhood communicable diseases seem to be affected by implementing wide-scale
62 mitigating strategies in infectious disease outbreaks in these communities. However, the
63 persistence of mortality and a lack of post-pandemic surges suggests that sub-populations of
64 children remain at greater risk, and this needs evaluation, especially regarding access to care
65 and evaluating the impact on the spread of communicable disease in all communities. Health
66 planning needs to build in these factors when developing policies and systems catering to
67 vulnerable children, especially in response to pandemics .

68

69 **Background**

70 The national lockdown regulations promulgated across the globe due to the COVID-19
71 pandemic disrupted essential healthcare services for most populations.¹ Healthcare visits,
72 including emergency outpatient visits and admissions, decreased sharply among children in all
73 countries, especially between February 2020 and December 2021.²⁻⁵ Decreases of 19%, 50%
74 and 56% in paediatric admissions were documented in Cameroon, South Africa (SA) and
75 across Europe, respectively, compared with pre-COVID-19 time periods.³⁻⁵ Vulnerable
76 populations, including children in lower- and middle-income countries (LMICs), were
77 especially negatively impacted due to these lockdown measures.²⁻⁴

78

79 The decrease in paediatric admissions documented has been more marked in children with
80 communicable (77%) compared with non-communicable diseases (37%).⁵ Children with lower
81 respiratory tract infections (LRTI), which includes those with highly communicable viral
82 bronchiolitis, also decreased.⁶⁻⁸ Changes in seasonal patterns of viral bronchiolitis when
83 compared with patterns identified in previous pre-COVID-19 years were noted.⁶ This was
84 postulated to occur for years due to reduced person-to-person transmission, and it raised
85 concerns that a rebound would occur when transmission mitigating strategies and lockdown
86 levels were curtailed.⁶

87

88 Visits to children's preventative health services decreased significantly across multiple
89 countries, especially after the start of the COVID-19 pandemic in February 2020.⁹ These
90 decreases were documented in both urban and rural primary healthcare facilities.¹⁰ Outpatient
91 visits for children with Human Immunodeficiency Virus (HIV) dropped by 41%, and
92 antiretroviral treatment initiation of newly diagnosed children also decreased in 2020 and
93 2021.¹¹ These changes in access and utilisation of both preventative healthcare and HIV
94 chronic care raised concerns for negative health consequences, especially in communities
95 where poverty, HIV and Tuberculosis (TB) are common.¹¹ HIV viral suppression rates,
96 however, were shown to be maintained among children, suggesting some chronic disease
97 programmes remained reasonably robust over this period.¹²

98

99 Overall, the COVID-19 pandemic disrupted healthcare provision and health-seeking behaviour
100 and was postulated to disproportionately impact specific subpopulations in low-income
101 countries with fragile health systems and pervasive social-structural vulnerabilities.¹³
102 Documentation of these indirect effects of the COVID-19 pandemic has been largely restricted

103 to the period during the peaks of the COVID-19 lockdowns between February 2020 and
104 December 2021 and not adequately documented in communities with high burdens of HIV,
105 Tuberculosis (TB) and malnutrition.¹¹ With this disruption of healthcare, concern was raised
106 about the deleterious effects on mortality and morbidity rates rising, specifically in these
107 vulnerable children in such communities after the removal of lockdown measures.¹⁴

108

109 Children hospitalised in specialist referral hospitals in LMICs generally include more complex
110 cases requiring higher levels of medical care and support, representing the sickest children
111 accessing healthcare.¹⁵ In contexts where there are high levels of HIV, TB and malnutrition,
112 in-hospital mortality and morbidity, including the need for admission in children with these
113 diagnoses within the public sector (non-fee paying), specialist referral hospitals reflect health
114 system failures to address both preventative and curative aspects of healthcare.¹⁵ This study
115 describes and analyses changes in admission and in-hospital mortality amongst children in
116 South African specialist referral hospitals during all the levels of national lockdowns associated
117 with the COVID-19 pandemic and the post-pandemic period. These changes are analysed by
118 age group and diagnostic categorisation. They are compared with a pre-pandemic period across
119 a large metropolitan area where there are high HIV, TB and malnutrition rates.

120

121 **METHODS**

122 **Study design and population**

123 We conducted an interrupted time series analysis of routinely collected facility-level data of
124 children below the age of 13 years hospitalised across all four of the largest public sector(non-
125 fee-paying) specialist referral hospitals in the city of Durban (eThekweni District), Kwa Zulu-
126 Natal(KZN). The data collected included those hospitalised with medical diagnoses only, thus
127 allowing analysis to reflect on the impact of the COVID-19 pandemic, specifically on
128 communicable diseases. In-born neonates and children hospitalised for surgical (general
129 surgery, trauma, ear nose and throat procedures, orthopaedic reasons) or other non-medical
130 reasons (psychiatric and social admissions for respite care or neglect) were purposefully
131 excluded from the analysis.

132

133 We used data from the King Edward VIII, Mahatma Gandhi Memorial, Prince Mshyeni
134 Memorial and R K Khan Memorial hospitals, which provide 240 in-patient paediatric medical
135 specialist care beds (including designated high care and beds for interim invasive ventilation)
136 for approximately 1,1 million children (35.2% of the total city's 3,05 million total

137 population).^{15,16} The children admitted to these hospitals are referred by primary healthcare
138 providers (nurse-run day-clinics, family practitioners, non-specialist district hospitals) and are
139 generally complex cases requiring higher care levels. Children who require longer-term
140 invasive ventilation (>72 hours) are referred to paediatric intensive care units located at the
141 quaternary hospital.¹⁵ The majority of the children who attend and are hospitalised in these four
142 referral hospitals are from lower socio-economic communities and are drawn from 88% of
143 Durban's population who do not subscribe to private medical programmes.¹⁵ The HIV antenatal
144 seroprevalence of the population served by these hospitals is high at 44.3%(CI=41.6–46.7),
145 reflecting a high burden of both HIV-exposed infants and HIV-infected children.^{16,17}

146

147 The study period spanned 60 months and included 23 months in the pre-COVID-19 period (01
148 April 2018 to 28 February 2020), 23 months of the designated COVID-19 period (01 March
149 2020 to 31 January 2022), during which one of the five lockdown stages were promulgated and
150 14 months post COVID-19 period (01 February 2022 to 31 January 2023), when no lockdowns
151 were in place. South Africa announced a national lockdown on 23 March 2020, implemented
152 on 27 March 2020.^{18,19} Starting at level 5, the lockdown was one of the most severe globally,
153 with restrictions on movement and cancellation of public transport, although travel to receive
154 healthcare was allowed.¹⁹ The lockdown was eased to level 4 on May 1, 2020, when public
155 transport was allowed, and to level 3 on 01 June 2020, which allowed some economic activity
156 to resume. Over the 23-month COVID-19 period, lockdown levels vacillated depending on the
157 authorities' anticipated need to prevent community transmission.^{18,19} Monthly data in the
158 COVID period were thus stratified according to the predominant lockdown level in each of the
159 23 months in this period.

160

161 **Data collection**

162 The admission diagnosis of children included in the facility-level monthly data was obtained
163 from in-patient records that an attending paediatrician validated. Data on hospitalised children
164 included children in all age groups below 13 years of age (SA's referral hospitals have a 13-
165 year-old cut-off for paediatric care), those below one year of age (infant) and those between
166 one and five years of age. Data on hospitalised children under the age of five years with lower
167 respiratory tract infections (LRTI) or acute gastroenteritis (AGE) as their main diagnosis were
168 specifically tracked. In this study, the term LRTI as a diagnostic category includes patients
169 with lobar or bronchopneumonia, bronchiolitis and bronchitis. This categorisation was based
170 on a standardised nomenclature used by clinicians across all sampled hospitals in admission

171 diagnoses and mortality classification. LRTI excludes upper respiratory tract infections (URTI)
172 or upper airway obstruction, asthma or recurrent wheezing.²⁰ In addition, monthly admission
173 numbers of children categorised as having severe acute malnutrition (SAM) using the WHO
174 guidelines were also collected. In all four hospitals, the categorisation of a child under five
175 years of age with SAM is verified by a paediatrician and then independently corroborated by
176 an attending dietician within 72 hours post-admission. This dual verification for nutritional
177 categorisation enables weights post-rehydration to be utilised and for lengths or heights to be
178 rechecked for accuracy. In the WHO nutritional classification system, children are classified
179 as either having severe acute malnutrition (SAM), moderate acute malnutrition (MAM), not
180 acutely malnourished but considered at risk (NAM@risk), or not acutely malnourished (NAM)
181 or as overweight or obese.^{21,22} The SAM definition was based on weight-for-length z score
182 and/or the presence of nutritional oedema as documented by an attending paediatrician.²² The
183 mid-upper arm circumference (MUAC) scores were not used in this study as the documentation
184 was inconsistent in the reviewed source documents.^{21,22} The numbers of children who demised
185 monthly in all age categories and specifically those with a diagnosis of LRTI, AGE or SAM
186 under the age of five years were also collected.

187

188 *Verification of data*

189 Four independent databases were utilised over the study periods.²³ These databases
190 corroborated and validated information and ensured minimal missing data. Each hospital's
191 paediatric department has an in-hospital database used as the primary database. A specialist
192 paediatrician in each hospital is responsible for verifying and entering all weekly admissions
193 tallies and death information (categorised by age and diagnosis) from original case records into
194 this primary database. Admission and mortality data is also verified monthly by paediatricians
195 in the department from a standardised admission and deaths daily register and then submitted
196 to a facility information officer, which feeds this data to a central district-wide district health
197 information system database (DHIS).²³ In this study, we validated the DHIS data obtained with
198 source data in each hospital from the primary database that the attending paediatricians held to
199 avoid inconsistencies. The third database was the Child Healthcare Problem Identification
200 Programme (Child PIP). Paediatric departments across many SA hospitals utilise this database
201 to record and systematically review child deaths independently, emphasising assessing
202 modifiable factors related to these deaths.²⁴ Mortality figures per hospital were corroborated
203 using the Child PIP and DHIS and verified at each hospital. The fourth database used verified
204 nutritional categorisation of all in-hospital patients, and in-hospital dietitians maintained these

205 databases in each hospital. The databases were rechecked and then verified with the hospital
206 records for discrepancies.

207

208 **Data analysis and interpretation**

209 We used descriptive statistics to summarise data and present summaries of admission, mortality
210 and case fatality rates before, during and after the COVID-19 period with lockdowns. We did
211 an interrupted time series segmented regression analysis by fitting linear regression models
212 with the outcome of monthly paediatric admissions. The models included dummy lockdown
213 level variables indicating 1 or 0 for each level 1 (least severe) to 5 (most severe) of lockdown
214 and a dummy variable for the post-COVID-19 period. COVID-19 waves could also have
215 caused an increased burden on the healthcare system, which may have affected paediatric
216 healthcare use and admissions independently from lockdowns. We, therefore, modelled this by
217 including a continuous variable for excess mortality in eThekweni for each month as a proxy
218 for COVID-19-related burden on the healthcare system. To account for seasonal changes due
219 to RSV and other respiratory virus outbreaks and Rotavirus and other viral causes of AGE, we
220 included two pairs of sine and cosine terms (Fourier terms) in the models to account for
221 seasonality. This approach takes account of pre-lockdown trends and allows estimation of the
222 effect of each level of lockdown and whether there was a change in admissions during the
223 period following the cessation of all lockdowns post-COVID. We built separate models by age
224 (under one year, under five years and between 5 and 13 years) and diagnosis (LRTI, AGE and
225 SAM). Age-specific changes thus do not sum to the total change because the total admissions
226 (and deaths) were analysed as a separate time series. We checked for auto-correlation by
227 calculating the auto-correlation and partial autocorrelation functions. We analysed data using
228 R4.0 (R Foundation for Statistical Computing, Vienna, Austria; appendix).

229

230 **RESULTS**

231 During the 60-month study period that extended from 01 April 2018 to 31 March 2023, 45 015
232 children were admitted across all four specialist hospitals in Durban (eThekweni district). Of
233 these, 20 490 (45.5%) were <1 year of age (infants), 16 549 (36.8%) were children between
234 one and below five years, and 7976 (17.7%) were children between five and below 13 years.
235 Across all these age groups, 1237 children died in hospital during the 60 months of the study
236 period, with 733 (59.3%) being infants, 346 (28%) between one and below five years and
237 158 (12.7%) between five and 13 years. Table 1 compares unadjusted mean monthly admission
238 and mortality numbers and raw case fatality rates during the three assessed periods. While the

239 mean monthly admission appeared marginally lower in the COVID-19 period, there was less
240 of a decrease in mean monthly deaths. The case fatality rates for LRTI, AGE and SAM in the
241 under-five-year group were higher during COVID-19.

242

243 **[Table 1 Unadjusted mean monthly admission and mortality numbers during all**
244 **lockdown levels and post-COVID period]**

245

246 **Interrupted time series analysis**

247 **Adjusted admission and mortality monthly numbers by age group**

248 The analysis showed a significant decrease in total admissions for children under 1, 1-to-5-
249 year-olds, and 5-13-year-olds. Level 5 lockdowns saw the most significant mean monthly
250 decreases of 450(95% CI=-657.3--244.3) $p<0.001$, 213.2(-349--76.8) $p=0.003$, 376.4(-
251 566.3--186.4) $p<0.0001$ in total, under-1-year-old and 1-to-5-year-old admissions
252 respectively. Level-1-lockdowns had the lowest mean monthly decreases. The trend was
253 similar for school-going children (5-13-year olds) to all other age groups. There was also
254 evidence of seasonality on a 6-month scale during the pre-and post-COVID periods in total
255 admissions ($p=0.002$), under-1-year-olds ($p=0.034$) and 1-to-5-year olds ($p=0.004$) which was
256 not evident during the COVID-19 lockdown periods. In the segmented regression model, there
257 was no evidence that excess monthly mortality in SA was associated with changes in admission
258 numbers in any age group. Figures 1(a),1(b),1(c) and 1(d) illustrates these findings.

259

260 In the post-COVID-19 period, total admissions remained slightly lower than during the pre-
261 COVID-19 period (decrease of 68, 95% CI=-134.2--2.4, $p=0.0430$). This was mainly due to
262 a decrease in the 1-5-age group (-60.9, 95% CI=-121.5--0.2, $p=0.049$), with no evidence of a
263 difference in the under-1-age group (+6.5, -50.1--37.0, $p=0.765$), nor 5-13-year olds (-9.6, -
264 26.8--7.7, $p=0.270$).

265

266 The segmented regression analysis showed no significant change in monthly mortality in all
267 ages nor specifically in the age categories of under-1-year-olds and 1-to-5-year-olds and 5-13-
268 year age groups during any lockdown levels, nor the post-COVID period. (Table 2, Figure 2(a),
269 2(b), and 2(c) provide the data and illustrate the trends, respectively)

270

271 **[Table 2, Changes in mean monthly admissions and mortality in lockdown levels 1 to 5 in**
272 **all age groups]**

273 **[Figure 1 Interrupted time series analysis of admissions by age group, all ages 1(a), under**
274 **12 months 1(b), under 60 months 1(c) and between 5 and 13 years old (1d).]**

275 **[Figure 2 Interrupted time series analysis of mortality rates by age group all ages 2(a),**
276 **under 12 months2(b) and under 60 months 2(c).]**

277

278 **Admission and mortality rates for children with acute gastroenteritis (AGE), lower**
279 **respiratory tract infections (LRTI)and severe acute malnutrition (SAM)**

280 Significant decreases in decreased were seen during most of the lockdown levels in the
281 COVID-19 period in children hospitalised with AGE, LRTI or SAM (Table 3). Level 5
282 lockdowns saw decreases of 82.8(95%, CI=156.3--9.3) $p=0.028$, 132.8(-238.6--
283 27.0) $p=0.015$ and 25.7(95%, CI=-47.4--3.9), $p=0.022$ in AGE, LRTI and SAM cases. The
284 terms for seasonality provided evidence of seasonal variation on both a 6-month ($p=0.032$) and
285 12-month ($p=0.003$) scale for AGE admissions, a 6-month scale for LRTI admissions
286 ($p=0.004$) and a 12-month scale for SAM admissions ($p<0.001$).

287

288 Figures 3(a), 3(b) and 3(c) illustrate these changes and loss of the seasonal patterns in AGE
289 and LRTI during the COVID-19 period .

290

291 In the post-COVID period, there was no evidence that AGE, LRTI, or SAM admissions
292 changed compared to pre-COVID numbers. Figures 3(a), 3(b) and 3(c) illustrate a return to
293 seasonal patterns in the post-COVID period for cases of AGE and LRTI.

294

295 When analysing changes in mortality in those hospitalised with either AGE, LRTI or SAM, no
296 significant changes were noted in all the lockdown levels. Table 3 and Figures 4(a), 4(b) and
297 4(c) illustrates these findings.

298

299 **[Table 3 Changes in adjusted mean monthly admission and case mortality numbers in 1-**
300 **5-year-old children with Acute Gastroenteritis and Lower Respiratory tract infections**
301 **during all lockdown levels and post-Covid -period]**

302 **[Figure 3 Interrupted time series analysis of admissions by diagnosis in 1-5 year old with**
303 **acute gastroenteritis 3(a), lower respiratory tract infections 3(b) and severe acute**
304 **malnutrition 3(c).]**

305 [Figure 4 Interrupted time series analysis of mortality rates per admission diagnosis in
306 1-5 years-olds with acute gastroenteritis 4(a), lower respiratory tract infections 4(b) and
307 severe acute malnutrition 4(c).]

308

309 DISCUSSION

310 This study describes changes in patterns of admissions and deaths among sick and vulnerable
311 SA children over five years straddling the COVID-19 pandemic. Despite significant decreases
312 in admissions and changes in seasonal patterns of communicable diseases during the COVID-
313 19 lockdowns, there was neither a concomitant decrease in in-hospital deaths in this period nor
314 a post-pandemic surge in admissions or mortality.

315

316 Several modelling studies and early reviews from LMICs have raised concerns about the
317 impact of the COVID-19 pandemic on vulnerable populations, especially those where fragile
318 healthcare systems exacerbate delayed access to care.^{3,4,10} In this study reflecting children
319 drawn from low-income neighbourhoods and communities with high rates of HIV, TB and
320 malnutrition, similar trends in admission, as was documented in high-income countries,
321 occurred following the promulgation of stringent lockdowns.^{5,13,25} This cohort also includes
322 socially marginalised segments of the population (families living in informal high-population-
323 density settlements with poor access to municipal services) where access to healthcare has
324 been compromised even before the COVID-19 pandemic.¹⁵

325

326 Similar to decreases in admissions, visits to government primary health clinics were also
327 decreased in the COVID-19 period.⁴ These findings may reflect the influence on the decreased
328 transmission of common childhood communicable diseases, possibly affected by decreased
329 social interactions and mitigating strategies to prevent COVID-19 transmission.^{9,10} Of concern,
330 however, is that the documented decrease in primary care visits and admissions could also
331 reflect decreased access to healthcare for sick children. Whilst lockdown laws permitted the
332 seeking of healthcare and all facilities remained open through the COVID-19 pandemic, the
333 significant decreases in the admission of sick children, as is the case in this study, raises the
334 likelihood of both these scenarios playing out in vulnerable populations and marginalised
335 groups.

336

337 Concern that many sick children demised at home without accessing acute medical care during
338 these periods is not borne out by any significant increase in excess childhood mortality as seen

339 in age-specific annualised excess death rates (per 1000 population) documented over this
340 period.²⁶ In this study, that reflects children admitted at referral hospitals, including those with
341 complex problems and diagnoses, mortality numbers in all age groups and children with AGE,
342 LRTI and SAM did not decrease during the lockdown period, unlike previously reported from
343 this geographical area.¹⁰ Our finding of this persistence of mortality numbers despite significant
344 decreases in admissions has been documented elsewhere.³ It supports the postulate that sick
345 children did access healthcare and possibly did so later than they should have.²⁷ We postulate
346 that our large cohort of children hospitalised in public sector referral hospitals consists of
347 multiple sub-populations. They include children who access care timeously through available
348 pathways and those with delayed access to care for a multiplicity of reasons. This latter group
349 has been previously documented as experiencing delays in accessing standard healthcare
350 despite the availability of free public health services.²⁷ Many caregivers here are noted to utilise
351 multiple other sources of care, including allopathic, indigenous and home treatments, before
352 presenting at public services.²⁷ It is possible that caregivers in this sub-group would have
353 persisted with late presentation for acute care, similar to pre-pandemic behaviours or delayed
354 their access to hospital care even later. Further exploration is thus required to determine how
355 these various sub-groups were uniquely affected by the challenges posed by the COVID-19
356 pandemic and the associated lockdowns.

357

358 In this study, we specifically compared the admission of children with a diagnosis of AGE and
359 LRTI with pre-pandemic patterns. We found a significant decrease in admissions for AGE and
360 LRTI in most lockdown periods. AGE and LRTI cases hospitalised in the four referral
361 hospitals generally have complications requiring specialist care, e.g., cases with hypernatremic
362 dehydration or LRTI requiring non-invasive respiratory support.²⁸ While our findings are
363 similar to the general decreases seen in admissions worldwide observed at all levels of
364 hospitals, our study documents that children with complicated common childhood diseases also
365 saw decreases in the need for admission.^{5,6,10,29} It has been postulated that increased
366 preventative hygiene habits adopted during the COVID-19 period, like masking, regular hand
367 washing, creche and school closures, and other restrictions impacting person-to-person spread
368 of infections, resulted in modified seasonal patterns of communicable diseases like Rotavirus
369 associated AGE and Respiratory syncytial Virus associated LRTI.^{6,8,29} Whilst we cannot
370 definitively attribute the cases of AGE and LRTI in this cohort to specific viral aetiologies, the
371 overall decrease in admissions does raise the possibility that transmission of these commonly
372 occurring pathogens decreased, changing previous seasonal patterns, and this also occurred

373 within vulnerable populations where higher population densities are the norm. It also suggests
374 that the complication rates in these commonly occurring communicable diseases possibly
375 decreased.

376

377 Our study also documents that the expected surge in malnutrition cases during the lockdown
378 period did not occur, unlike those reported in other studies from developing countries.^{10,30} The
379 persistence of high mortality rates in SAM similar to pre-pandemic levels cases despite the
380 decreased admission also suggests that sick children did get to healthcare; however, they could
381 have done so later than was previously the case.^{22,26}

382

383 The great concern expressed across the world following the decreased utilisation of
384 preventative services and, specifically for vulnerable populations where TB and HIV are
385 endemic, was an expected post-pandemic surge.¹¹ With the disruption of seasonal patterns of
386 viral bronchiolitis, an expected surge in LRTI was also anticipated.³¹ In this study, which
387 analysed data over a longer post-pandemic period than most other studies, we do not show this
388 anticipated surge in admissions in under-1-year and 1-to-5-year-old children as well as in cases
389 of AGE, LRTI and SAM. The trend identified in the post-pandemic period may reflect a
390 gradual increase in admissions back to pre-COVID levels. Our postulates that multiple sub-
391 groups of vulnerable children are served by referral hospitals, including the sickest cohort of
392 children, i.e. those at the highest risk of death and who traditionally present late for acute
393 healthcare persisted. There is also a possibility that in the communities that these hospitals
394 serve, where there are high population densities with cramped living, any benefits of decreased
395 infections with lockdown occurred to a lesser degree than in households with low population
396 densities. The lack of a post-pandemic surge seen with most of the children in this cohort could
397 be explained by this possibility. The role of strategies to provide catch-up immunisation thus
398 needs to be explored. Further studies specifically targeting these populations and utilising
399 microbiological testing may be required to unpack children's behaviours under differing
400 contexts. This study may help determine the epidemiological patterns of vulnerable children
401 when faced with communicable disease outbreaks in greater detail.

402

403 Strengths of our study include the large cohort of children hospitalised specifically for medical
404 diagnoses in public sector referral hospitals. We reflected on acutely sick and vulnerable
405 children susceptible to communicable diseases. Our use of long-term routine data considers
406 pre-COVID, all the COVID lockdown levels, and substantial post-COVID periods, whilst most

407 studies have largely focused on the COVID-19 period. However, due to the use of retrospective
408 facility-level data, we were not able to verify definitive microbiological, virologic and formal
409 HIV and TB results; instead, we relied on retrospective diagnoses provided by source
410 documents and by paediatricians on site. We did not focus on neonatal or non-medical or
411 children admitted to referral intensive care units (ICU) requiring prolonged ventilation. It must
412 be noted that access to paediatric intensive care beds is very limited, and the cohorts assessed
413 in this study reflect a larger population than those who are admitted to ICU care only. We could
414 not assess the definitive socio-economic status and inferred this based on previous usage
415 patterns in public sector hospitals. The retrospective data reflects in-hospital mortality
416 specifically and does not include community-based death data.

417

418 In conclusion, our findings suggest that, in one of the regions most affected by HIV,
419 Tuberculosis and malnutrition, admission of acutely sick children referred for specialist care
420 for medical causes decreased during the COVID-19 lockdowns. A decrease in in-hospital
421 mortality, however, was not similarly documented, suggesting sick children from vulnerable
422 communities were presenting to care possibly later than usual. Anticipated post-pandemic
423 surges in admission and mortality have not been observed thus far. This study provides
424 evidence that mitigating strategies to reduce infectious disease outbreaks possibly affected
425 transmission dynamics of common communicable childhood diseases, leading to decreased
426 needs for all levels of medical care and disruption in seasonal patterns. Anticipated surges in
427 admissions and mortality were not seen in this cohort; rather, a return to previous patterns.
428 Further studies in this vulnerable population are needed to identify longer-term changes due to
429 persisting challenges in healthcare provision.

430

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442 **Authors' contributions**

443 [name deleted to maintain the integrity of the review process] conceptualised the study. [name
444 deleted to maintain the integrity of the review process] oversaw data collection. [name deleted
445 to maintain the integrity of the review process] oversaw the curation of the data. [name deleted
446 to maintain the integrity of the review process] analysed the data. [name deleted to maintain
447 the integrity of the review process] drafted the manuscript. [name deleted to maintain the
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452 **Disclaimer**

453 The views and opinions expressed in this article are those of the authors and do not necessarily
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456 Adherence to ethical guidelines was ensured throughout the research process. The study was
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468

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Table 1 Unadjusted mean monthly admission and mortality numbers during all lockdown levels and post-COVID-period.]

Mean Monthly numbers	Pre-COVID	COVID	Post -COVID
	1st April 2018 to 28th Feb 2020	1st March 2020 to 31st January 2022	1st February 2022 to 31st January 2023
Admissions - children less than 13 years of age	871.3	589.8	814.8
Admissions - children between 5 and 13-years of age	155	101.3	148.7
Admissions – children below the age of 5 years	716.3	488.5	666.1
Admissions below the age of one year	382.9	274.3	383.9
Lower -respiratory tract infections admissions in 1-5-years olds	194.9	131.3	209.4
Acute Gastroenteritis admissions in 1-5-years olds	154.7	102.1	139.9
Severe acute malnutrition admissions in 1-5-years olds	42.7	28.1	40.2
Deaths - children less than 13 years of age	22.0	19.1	20.8
Deaths - children below the age of 5-years of age	19	16,6	18,6
Deaths - children less than 1 year of age	12.4	10.9	14.1
Acute Gastroenteritis (case fatality rates in under-5- year olds)	2.0	2.8	2.3
Lower-respiratory tract infections (case fatality rates in under-5- year in olds)	1.7	2.7	2.1
Severe acute malnutrition (case fatality rates in under-5- year -olds)	9.5	12.1	10.5

Table 2, Changes in mean monthly admissions and mortality in lockdown levels 1 to 5 in all age groups

Changes in adjusted mean monthly admission and mortality numbers during all lockdown levels and post-Covid -period						
	Total (all below 13 years)		Under-1-year		1-5 year	
	Admissions	Mortality	Admissions	Mortality	Admissions	Mortality
Level 1	-188.1 CI -267.8, -108.4 p<0.001	-1.0 CI -5.7, 3.7 p=0.657	-58.9 CI -111.5 ,-6.3 p=0.029	-0.4 CI-3.7 ,2.9 p=0.795	-144.7 CI-218.0,-71.4 p<0.001	-0.4 CI -4.8-4.0 p=0.852
Level 2	-423.8 CI -556.9,- 290.7 p<0.001	-8.0 CI-15.9, -0.2 p=0.045	-167.2 CI-255.2,-79.3 p<0.001	-4.4 CI -9.9 ,1.1 p=0.114	-336.3 CI -458.8,-213.9 p<0.001	-7.0 CI -14.- 0.4 p=0.064
Level 3	-371.7 CI -482.2,-261.1 p<0.001	-4.8 CI -11.3,1.7 p=0.146	-178.3 CI -251.3,-105.2 p<0.001	-1.1 CI -5.7 ,3.4 p=0.628	-311.1 CI-412.8, -209.4 p<0.001	-4.3 CI -10.4-1.9 p=0.167
Level 4	-365.9 CI-516.1,-215.7 p<0.001	-2.7 CI -11.5,6.2 p=0.546	-148.8 CI-248.1,-49.6 p=0.004	-0.6 CI -6.8 ,5.6 p=0.845	-304.7 CI-442.9, -166.5 p<0.001	-0.3 CI -8.7 -8.0 p=0.935
Level 5	-450.8 CI 657.3,-244.3 p<0.001	-2.5 CI -14.7 ,9.6 p=0.677	-213.2 CI-349.6, -76.8 p=0.003	-3.0 CI-11.5 ,5.5 p=0.483	-376.4 CI-566.3, -186.4 p<0.001	0.8 CI -10.6 -12.3 p=0.885
Post-COVID period	-68.3 CI-134.2, -2.4 p=0.043	-0.8 CI -4.7, 3.0 p=0.665	6.5 CI -50.1,37.0 p=0.765	2.0 CI -0.8 ,4.7 p=0.155	-60.9 CI -121.5, -0.2 p=0.049	-0.1 CI -3.8 -3.5 p=0.950

Table 3 Changes in adjusted mean monthly admission and case mortality numbers in 1-5 years old children with Acute Gastroenteritis and Lower Respiratory tract infections during all lockdown levels and post-COVID -period

Changes in adjusted mean monthly admission and case mortality numbers in under-5-year old children with Acute Gastroenteritis and Lower Respiratory tract infections and Severe Acute Malnutrition during all five lockdown levels and the post-COVID -period						
	Acute Gastroenteritis		Lower Respiratory tract infections		Severe acute Malnutrition	
	Admissions	Mortality	Admissions	Mortality	Admissions	Mortality
Level 1	-26.0 CI-54.4 ,2.4 P=0.071	0.3 CI-1.4,1.9 p=0.764	-47.7 CI -88.5, -6.9 p=0.023	0.8 CI -1.1 ,2.6 p=0.428	-9.7 CI-18.1, -1.3 p=0.024	-0.1 CI-1.8, 1.6 p=0.906
Level 2	-123.7 CI -171.1, -76.3 p<0.001	-1.1 CI -3.9,1.8 p=0.453	-89.3 CI-157.5, -21.1 p=0.011	-3.1 CI-6.3 ,0.0 p=0.051	-15.6 CI-29.6, -1.6 p=0.030	0.7 CI-2.2 ,3.5 p=0.632
Level 3	-107.0 CI -146.3, -67.6 p<0.001	-2.2 CI -4.6 ,0.1 p=0.065	-121.1 CI-177.7, -64.5 p<0.001	0.7 CI-2.0 ,3.3 p=0.618	-19.2 CI-30.9,-7.6 p=0.002	-0.4 CI-2.8 ,1.9 p=0.726
Level 4	-52.7 CI-106.1,0.8 p=0.053	1.5 CI-1.6 ,4.7 p=0.335	-99.8 CI-176.8, -22.8 p=0.012	0.0 CI -3.6 ,3.5 p=0.994	-14.0 CI -29.8,1.8 P=0.082	0.8 CI -2.4 ,4.0 p=0.617
Level 5	-82.8 CI -156.3, -9.3 p=0.028	-1.4 CI-5.8 ,3.0 p=0.527	-132.8 CI -238.6,-27.0 p=0.015	-2.9 CI-7.8 ,2.0 p=0.244	-25.7 CI -47.4, -3.9 p=0.022	2.7 CI-1.7 ,7.1 p=0.224
Post-COVID period	-19.3 CI -42.7,4.2 p=0.105	-0.2 CI-1.6,1.2 p=0.808	9.0 CI -24.7 ,42.8 p=0.593	1.2 CI -0.3 ,2.8 p=0.123	-4.3 CI -11.3,2.6 p=0.216	0.1 CI -1.3 ,1.5 p=0.898

Fig 1a. Total admissions

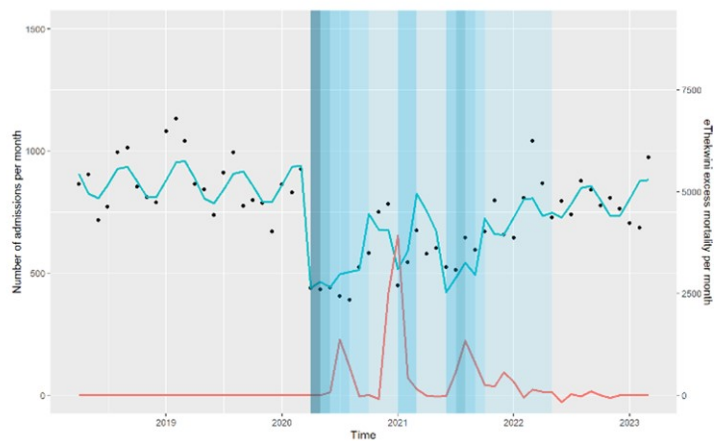


Fig 1b. Under 1 admissions

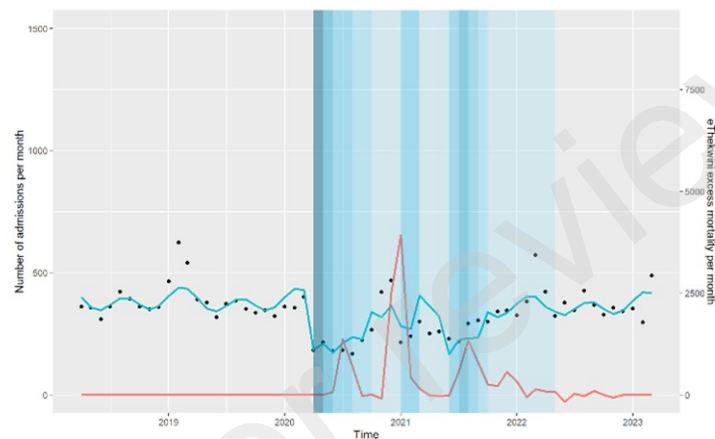


Fig 1c. Under 5 admissions

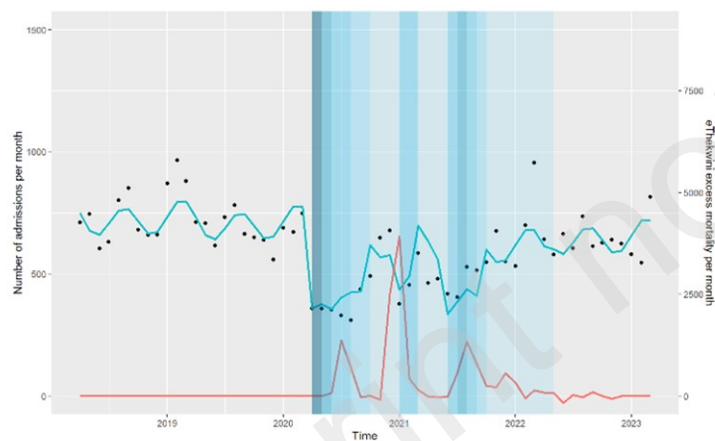
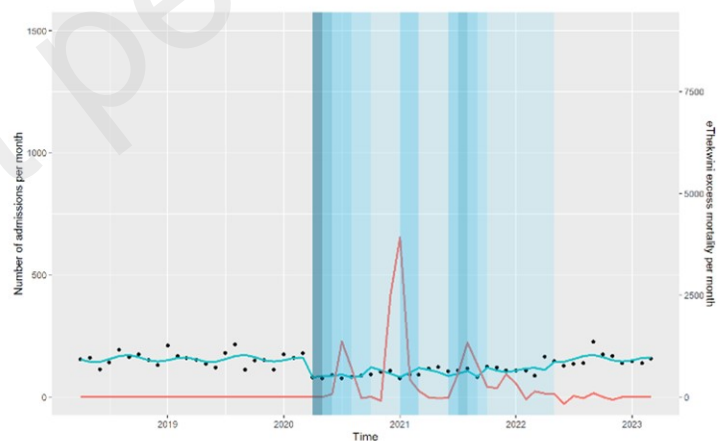


Fig 1d. 5-13 year old admissions



- Level 1 lockdown
- Level 2 lockdown
- Level 3 lockdown
- Level 4 lockdown
- Level 5 lockdown

- Excess mortality
- Modeled number of admissions

Fig 2a. Total deaths

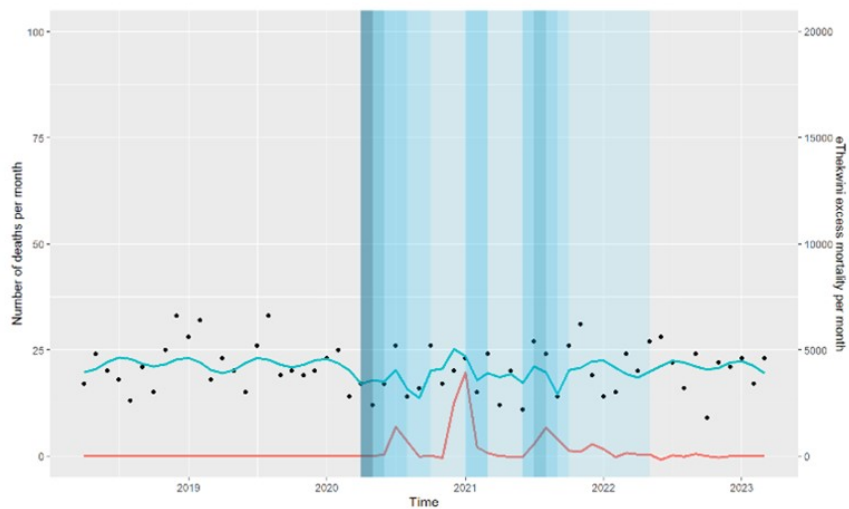


Fig 2b. Under 1 deaths

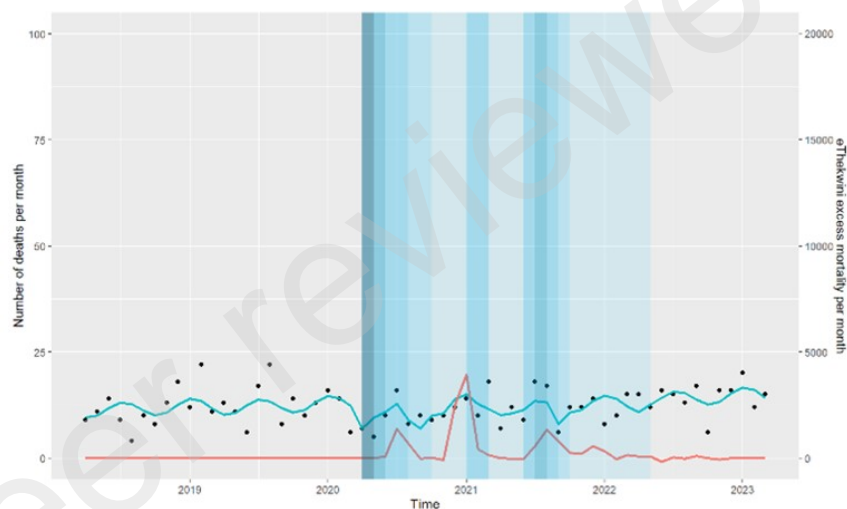


Fig 2c. Under 5 deaths

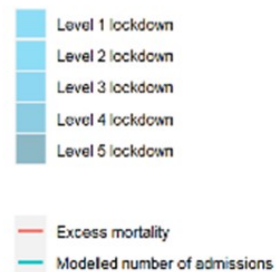
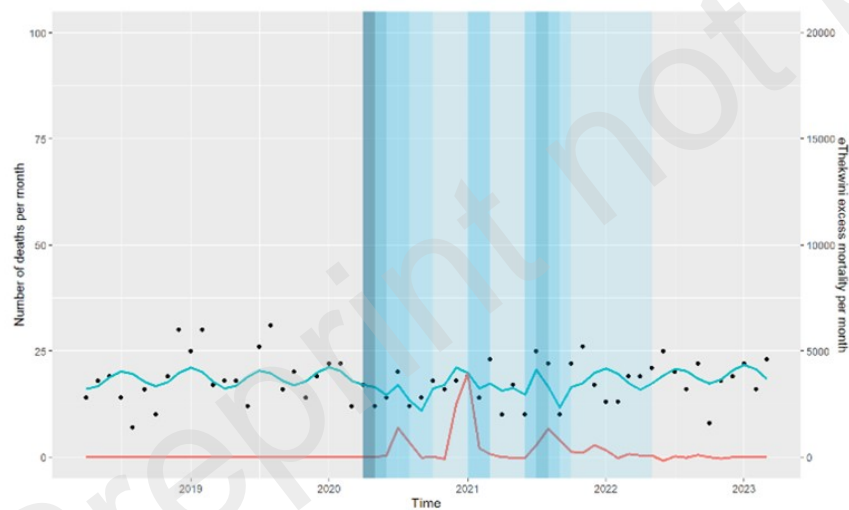


Fig 3a. Under 5 GE admissions

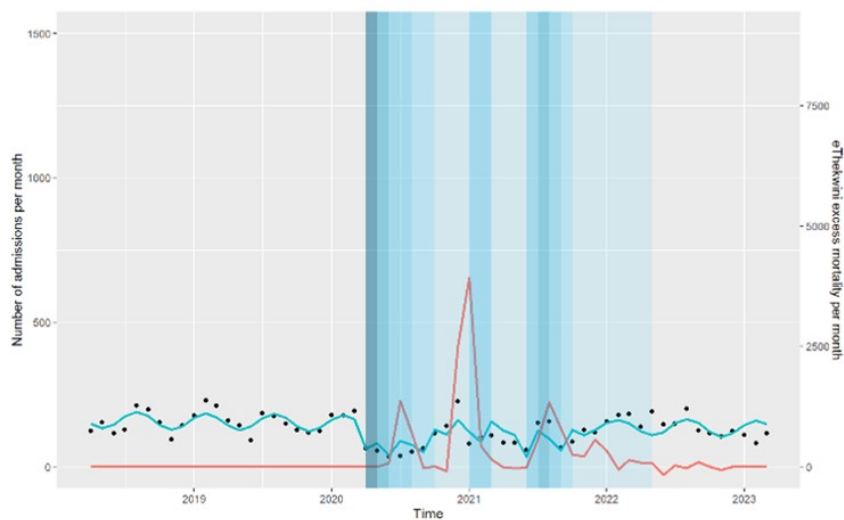


Fig 3b. Under 5 LRTI admissions

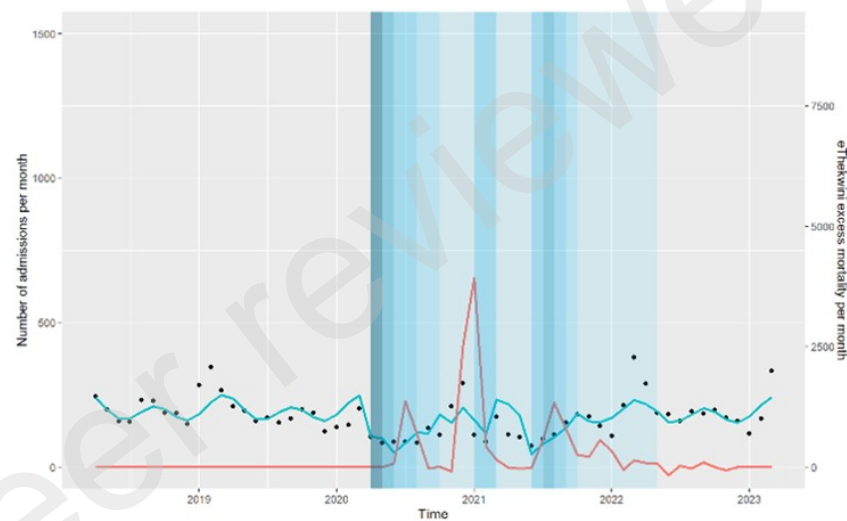


Fig 3c. Under 5 SAM admissions

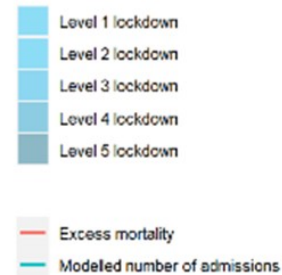
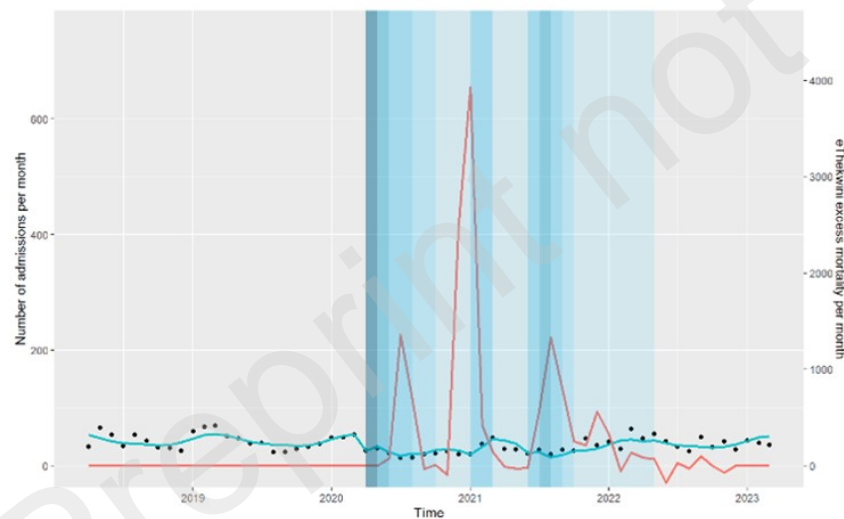


Fig 4a. Under 5 GE deaths

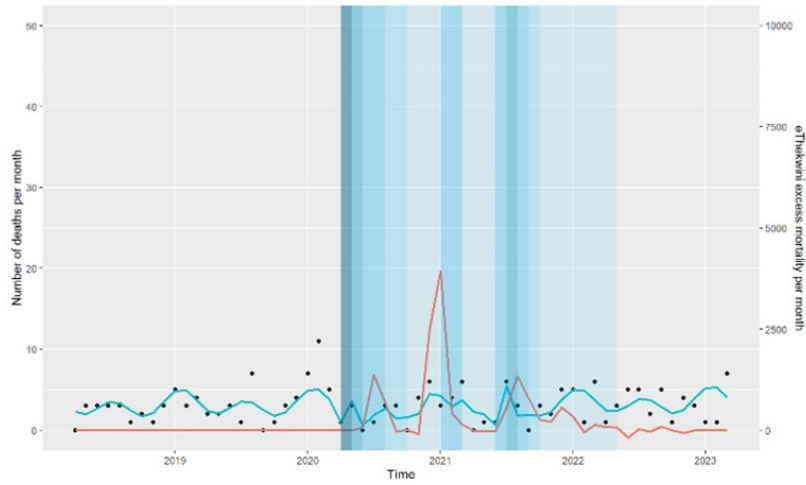


Fig 4b. Under 5 LRTI deaths

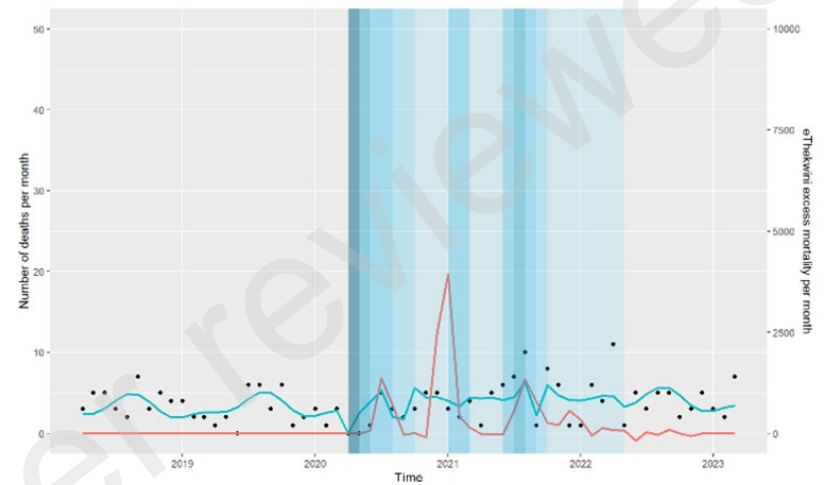


Fig 4c. Under 5 SAM deaths

