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# BMJ Open

## **Geographical inequalities in the evolution of the COVID-19 pandemic: An ecological study of inequalities in mortality in the first wave and the effects of the first national lockdown in England**

Journal:	<i>BMJ Open</i>
Manuscript ID	bmjopen-2021-058658
Article Type:	Original research
Date Submitted by the Author:	23-Oct-2021
Complete List of Authors:	Welsh, Claire; Newcastle University Albani, Viviana; Newcastle University Matthews, Fiona; Newcastle University Faculty of Medical Sciences, Population Health Sciences Institute Bambra, Clare; Newcastle University
Keywords:	COVID-19, Epidemiology < INFECTIOUS DISEASES, Public health < INFECTIOUS DISEASES

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3 **1 Geographical inequalities in the evolution of the COVID-19 pandemic: An ecological study of**  
4 **2 inequalities in mortality in the first wave and the effects of the first national lockdown in England**

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10 **4 Claire E. Welsh PhD (0000-0001-9477-0775)<sup>1\*</sup>, Viviana Albani (0000-0001-9584-7631)<sup>1</sup>, Fiona E.**  
11  
12 **5 Matthews PhD (0000-0002-1728-2388)<sup>1,2</sup>, Clare Bamba PhD (0000-0002-1294-6851)<sup>1,2</sup>**  
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17

18 <sup>1</sup>Population Health Sciences Institute, Newcastle University, UK, NE4 5PL

19  
20 <sup>2</sup> Applied Research Collaboration North East and North Cumbria, Newcastle University, UK, NE4 5PL  
21  
22  
23  
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26 \*Corresponding author: [Claire.Welsh@newcastle.ac.uk](mailto:Claire.Welsh@newcastle.ac.uk), Room 2.38 Biomedical Research Building,  
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11 Campus for Aging and Vitality, Newcastle University, Newcastle, NE4 5PL.

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2  
3 **14 Conflicts of Interest Statement**  
4

5  
6 15 All authors have completed the ICMJE uniform disclosure form at [www.icmje.org/coi\\_disclosure.pdf](http://www.icmje.org/coi_disclosure.pdf)  
7  
8 16 and declare: no financial relationships with any organisations that might have an interest in the  
9  
10 17 submitted work in the previous three years; no other relationships or activities that could appear to  
11  
12 18 have influenced the submitted work.  
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14  
15 **19 Data Sharing Statement**  
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17 20 All data used are publicly freely available through the ONS. Code used in the analyses is available  
18  
19 21 upon request.  
20  
21

22 **22 Ethical Approval**  
23

24 23 This study was approved by the Newcastle University Ethics Committee (Ref: 7543/2020).  
25  
26

27 **24 Transparency declaration**  
28

29  
30 25 The lead author\* affirms that this manuscript is an honest, accurate, and transparent account of the  
31  
32 26 study being reported; that no important aspects of the study have been omitted; and that any  
33  
34 27 discrepancies from the study as planned (and, if relevant, registered) have been explained.  
35  
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40 29 \*The manuscript's guarantor.  
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45 **31 Funding**  
46

47 32 This work was supported by a grant from The Health Foundation (Ref: 2211473), who took no part in  
48  
49 33 the design, analysis or writing of this study.  
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52 34  
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55 **35 Keywords**  
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36 **COVID-19; geography; inequalities ;mortality;**

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For peer review only

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3 40 **Summary Box**  
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5  
6 41 **Section 1: What is already known on this subject**  
7

8 42 There are cross-sectional estimates of geographical inequalities in the severity of the COVID-19  
9  
10 43 pandemic in England in terms of cases, hospitalisations and deaths. But these studies have not  
11  
12 44 examined the evolution of the epidemic nor the impact of the national lockdown on inequalities in  
13  
14 45 COVID-19 related mortality.  
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16  
17 46 **Section 2: What this study adds**  
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19  
20 47 This study provides the first analysis of inequalities in the evolution of the pandemic in different  
21  
22 48 English local authorities and the impact of the first national lock down on them. We estimate  
23  
24 49 geographical inequalities by local authority in the evolution of age-standardised COVID-19 mortality  
25  
26 50 during the first wave of the pandemic in England (January to July 2020) and the impact on these  
27  
28 51 inequalities in the cumulative death rates of the first national lockdown. We found that more  
29  
30 52 deprived local authorities started to record COVID-19 deaths earlier, and that their death rates  
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32 53 increased faster. Cumulative COVID-19 mortality inequalities during the first wave of the pandemic  
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34 54 in England were moderately reduced by first national lockdown.  
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3 56 **Strengths and limitations of this study**  
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6 57 • **This study interrogates the evolution of inequalities in COVID-19 in the first wave of the**  
7  
8 58 **pandemic in England and the impact of the national lock down.**  
9  
10 59 • **National level official (ONS) data used, covering nearly all local authorities in England and**  
11  
12 60 **including all deaths that made any mention of COVID-19 on death certificates, requiring**  
13  
14 61 **sensitive data acquisition.**  
15  
16 62 • **Age-standardised deaths rates at lower geographies are not available at the time of**  
17  
18 63 **writing but could lend extra nuance to these findings.**  
19  
20 64 • **Ecological study not using individual level data, so unable to examine the individual level**  
21  
22 65 **risks for covid-19 mortality.**  
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27 66  
28 67 **Abstract**  
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30 68 **Objectives**  
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32 69 This is the first study to examine how geographical inequalities in COVID-19 mortality rates evolved  
33  
34 70 in England, and whether the first national lockdown modified them. This analysis provides  
35  
36 71 important lessons to inform public health planning to reduce inequalities in any future pandemics.  
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39 72 **Design**  
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42 73 Longitudinal ecological study  
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45 74 **Setting**  
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47 75 307 Lower-tier local authorities in England  
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50 76 **Primary outcome measure**  
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53 77 Age-standardised COVID-19 mortality rates by local authority and decile of index of multiple  
54  
55 78 deprivation.  
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**79 Results**

80 Local authorities that started recording COVID-19 deaths earlier tended to be more deprived, and  
81 more deprived authorities saw faster increases in their death rates. By 2020-04-06 (week 15, the  
82 time the March 23<sup>rd</sup> lockdown could have begun affecting deaths) the cumulative death rate in local  
83 authorities in the two most deprived deciles of IMD was 54% higher than the rate in the two least  
84 deprived deciles. By 2020-07-04 (week 27), this gap had narrowed to 29%. Thus, inequalities in  
85 mortality rates by decile of deprivation persisted throughout the first wave, but reduced somewhat  
86 during the lockdown.

**87 Conclusions**

88 This study found significant differences in the dynamics of COVID-19 mortality at the local authority  
89 level, resulting in inequalities in cumulative mortality rates during the first wave of the pandemic.  
90 The first lockdown in England was fairly strict – and the study found that it particularly benefited  
91 those living in the more deprived local authorities. Care should be taken to implement lockdowns  
92 early enough, in the right places - and at a sufficiently strict level- to maximally benefit all  
93 communities, and reduce inequalities.

94  
95 **Word Count: 3405**

## 96 Introduction

97 Since the early days of the SARS-CoV-2 pandemic in 2020, inequalities in case, hospitalisation and  
98 death rates have been noted internationally(1–7). The most deprived populations and areas in the  
99 USA, Europe and other high-income countries have suffered up to twice the mortality rates of the  
100 least deprived sections of society(2,8,9). In addition, inequalities in disease burden have been noted  
101 across levels of income, education, employment, sex, age, and especially between different ethnic  
102 groups, where people of Black and minority ethnic backgrounds have suffered many more cases  
103 (and deaths) than their white counterparts(10). However, the evolution of geographical inequalities  
104 in the pandemic over time - and the impact of national lock downs on them – has not previously  
105 been examined. This study addresses this evidence gap by providing the first analysis of inequalities  
106 in the evolution of the pandemic in different English local authorities and the impact of the first  
107 national lock down on them.

108  
109 Most countries employed national lockdowns of varying duration and severity to mitigate disease  
110 spread, alongside social distancing and hygiene-related advice. The factors used to determine when  
111 a lockdown should begin or cease were rarely transparent, but most appeared to reduce infection  
112 rates to some degree after a lag phase, and saw a rebound of varying size following their release(11–  
113 13). The first confirmed cases of COVID-19 were recorded in England in York in January 2020 and the  
114 first death in England was on March 5<sup>th</sup>. From 2020-04-23 until 2020-07-04, a national lockdown was  
115 implemented across England. In keeping with many other European countries, this was  
116 characterised by a 12 week ‘stay at home’ order (SI 350) - whereby people could only go outside for  
117 certain "very limited purposes" - to buy food, to exercise once a day, for medical reasons or to care  
118 for a vulnerable person, or to go to work if they absolutely could not work from home(12). Face-to-  
119 face education was suspended and many workplaces closed down - and staff furloughed -  
120 particularly in the hospitality, travel and retail sectors. As nationally cases, hospitalisation and death

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3 121 rates started to fall the lockdown was gradually released over a period of several months -  
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5 122 culminating in the so-called 'Super Saturday' on 2020-07-04 when pubs, restaurants, hairdressers,  
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7 123 and cinemas reopened – albeit with strict social distancing rules(13).  
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12 125 It has been noted that when national epidemic dynamics are used to examine population health,  
13  
14 126 they can mask important sub-national variation in disease spread, thus mitigation strategies that rely  
15  
16 127 solely on the national data to inform implementation timings could inadvertently worsen health  
17  
18 128 inequalities across geographical areas(11,13). Previous descriptive studies and reports of inequalities  
19  
20 129 in COVID-19 mortality have only focused on cumulative measures over set timespans, without  
21  
22 130 documenting the disparities in evolution of mortality rates(5,14,15), have been restricted to higher  
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24 131 geographies(18), or have not focussed on the effects of lockdowns (7,19). An understanding of how  
25  
26 132 the evolution of the pandemic differed by area and the impact of national mitigation strategies on  
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28 133 geographical inequalities in COVID-19 mortality could help inform future policies targeted at  
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30 134 minimising viral spread whilst preventing the widening (or even actively decreasing) health  
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32 135 inequalities.  
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39 137 This paper uses COVID-19 mortality data from the first wave of the pandemic in England to provide  
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41 138 the first interrogation of geographical inequalities in the evolution of the pandemic. It sets out the  
42  
43 139 first analysis of when death rates rose, peaked and fell in local authorities of differing levels of  
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45 140 deprivation, and it describes the effects – and the timing of - the first national lockdown on these  
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47 141 inequalities.  
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53 143 **Methods**  
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3 144 Weekly counts of COVID-19 deaths (based on any mention of Coronavirus on the death certificate)  
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5 145 for 312 lower-tier local authorities (excluding county councils) in England were obtained from the  
6  
7 146 Office for National Statistics (ONS) covering the period from 1<sup>st</sup> January 2020 to 4<sup>th</sup> July 2020, by date  
8  
9 147 of registration (16). Weekly COVID-19 death counts at the local authority level were not available per  
10  
11 148 age group, thus age-standardised rates were calculated via monthly age-standardised rates.  
12  
13 149 Monthly age-standardised COVID-19 mortality rates per local authority for the period March to July  
14  
15 150 2020 were similarly obtained from ONS(21). The monthly rate was divided between the constituent  
16  
17 151 weeks based on the share of monthly deaths in each week. Where all age-standardised rates for a  
18  
19 152 local authority were suppressed by ONS due to disclosure controls, the authority was excluded from  
20  
21 153 analyses (n=4). The level of deprivation of each local authority was determined by the rank of  
22  
23 154 average rank of the Index of Multiple Deprivation (IMD), which was converted into deciles (decile 1  
24  
25 155 contained the most deprived 10% of local authorities) from downloaded data(17). In addition, data  
26  
27 156 from the Isles of Scilly and the City of London were excluded due to well-known mortality data  
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29 157 quality issues and low population counts.  
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36 159 A number of metrics were calculated for each local authority; the 'starting week' was the first week  
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38 160 where 1 or more COVID-19 deaths were registered, the 'peak' was the highest weekly age-  
39  
40 161 standardised mortality rate per area using a 3-week rolling mean of weekly death rates, and the  
41  
42 162 'total mortality rate' was the cumulative sum of age-standardised weekly mortality rates over the  
43  
44 163 whole study period. The speed of increase was defined as the change in mortality rate between 25%  
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46 164 of peak and the peak rate, divided by the number of weeks between them, and similarly the speed  
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48 165 of descent was calculated using the peak rate and subsequent reduction to 50% of peak (25 and 50%  
49  
50 166 selected to include time window when epidemic peaks were visibly most stable). An assumption was  
51  
52 167 made that any change in population incidence of COVID-19 cases may begin to be seen 2 weeks later  
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54 168 in mortality data, thus analyses of the effect of lockdown focused on the period before or after week  
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3 169 15 (lockdown was announced in week 13 [March 2020] and ended on 'Super Saturday' [July 4<sup>th</sup>,  
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5 170 week 27], which is shown in timeline plots). The 'peak difference' was the difference in weeks  
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7 171 between the peak mortality rate and the week in which lockdown began to take effect (week 15).  
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12 173 Weekly age-standardised mortality rates per IMD decile were not available at the time of writing,  
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14 174 thus they were calculated from other existing data, in a similar but distinct method from local  
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16 175 authority rates. Firstly, the denominators from local authority-level monthly age standardised  
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18 176 mortality rates were calculated using the death counts and rates provided. These 'modified'  
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20 177 population estimates were summed across local authorities within the same IMD decile, and counts  
21  
22 178 of COVID-19 deaths were similarly summed by decile. Weekly age-standardised rates per 100,000  
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24 179 people were then calculated as the sum of deaths divided by the modified summed population  
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26 180 estimate, multiplied by 100,000.  
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32 182 Simple linear models were employed to analyse the associations between visually normally  
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34 183 distributed measures such as the total cumulative mortality rate with other metrics and IMD decile.  
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36 184 No model selection was employed, covariate inclusion was based on empirical knowledge.  
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42 186 Maps were drawn based on 2020 geographical boundaries from the ONS Open Geography  
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44 187 Portal(18).  
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50 189 All analyses were conducted in R statistical software version 3.6.2.  
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55 191 **Patient and Public Involvement**  
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3 192 Our public involvement panel inputted into project design and considered the research topic to be of  
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5 193 contemporary importance and value. The data used do not require patient permissions for use and  
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7 194 are publicly available.  
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## 11 12 196 **Results**

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15 197 All 307 lower-tier local authorities in England began registering deaths involving COVID-19 between  
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17 198 weeks 11 and 15. The proportion of areas of each IMD decile per 'starting week' is shown in Figure 1.  
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19 199 From this it can be seen that more deprived areas (most deprived decile = 1) tended to begin  
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21 200 recording COVID-19 deaths earlier than less deprived areas (least deprived decile = 10).  
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27 202 **Figure 1. Proportion of 312 English local authorities within each IMD decile that began recording**  
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29 203 **COVID-19 deaths between weeks 11 and 15 of 2020.**

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34 205 Figure 2 depicts the weekly mortality rates per 100,000 people for each IMD decile. After the first  
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36 206 two weeks of the epidemic, the two most deprived deciles (20% of local authorities) had the highest  
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38 207 speed of increase in age-standardised mortality rates and reached higher peak rates than less  
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40 208 deprived areas.  
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46 210 **Figure 2. Weekly age-standardised COVID-19 mortality rates per 100,000 in areas of each IMD**  
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48 211 **decile. Dotted line indicates the start of the first national lockdown (26<sup>th</sup> March).**

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54 213 From the week of their first COVID-19 deaths to week 15 (when lockdown could plausibly have  
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56 214 begun affecting death rates), local authorities in the two most deprived deciles had the highest  
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3 215 speed of increase in death rate (albeit not statistically significantly different), and the less deprived  
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5 216 deciles increased more slowly (Figure 3). The mean speed of increase in two the most deprived local  
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7 217 authorities was 4.03 deaths per 100,000 persons per week, and in the two least deprived local  
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9 218 authorities was 2.18 deaths per 100,000 persons per week (a difference of 46%).  
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17 221 **Figure 3. Simple linear gradient of age-standardised COVID-19 death rate per 100,000 people**  
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19 222 **between the first week of recorded COVID-19 deaths and week 15, across rank of average rank of**  
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21 223 **IMD deciles.**  
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27 225 All local authorities' death rate curves peaked and began to decline between 3 and 10 weeks  
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29 226 following the start of the first lockdown. Those local authorities whose death rates were increasing  
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31 227 faster before lockdown peaked sooner after lockdown commenced compared to slower local  
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33 228 authorities.  
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36 229 The total age-standardised cumulative mortality over the first wave (up to week 27, week  
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38 230 commencing 2020-06-28) varied from 119 to 2349 deaths per 100,000 persons per local authority.  
39  
40 231 Table 1 describes the multivariable linear model of total cumulative death rates per local authority.  
41  
42 232 It shows that, compared to the most deprived 10% of local authorities, less deprived areas (deciles 3-  
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44 233 10) recorded lower cumulative death rates, and that areas with higher speeds of increase - and more  
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46 234 weeks of recorded COVID-19 deaths before lockdown (plus those that peaked later) - saw higher  
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48 235 total death rates.  
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54 237 **Table 1. Linear multivariable model of the total cumulative age-standardised COVID-19 death rate**  
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56 238 **per 100,000 persons between weeks 1 and 27 of 2020, among 307 local authorities in England.**  
57

Metric	Coefficient (SE)	P-value
<b>IMD decile</b>		
<b>1 (most deprived)</b>	REF	
<b>2</b>	-41.16 (49.30)	0.40
<b>3</b>	-108.20 (50.46)	0.03
<b>4</b>	-132.11 (49.80)	0.008
<b>5</b>	-140.82 (50.83)	0.006
<b>6</b>	-183.66 (50.64)	<0.001
<b>7</b>	-225.06 (50.81)	<0.001
<b>8</b>	-170.43 (51.01)	<0.001
<b>9</b>	-213.73 (50.82)	<0.001
<b>10</b>	-262.16 (50.28)	<0.001
<b>Speed of increase (to week 15), deaths per 100,000 per week</b>	12.87 (0.47)	<0.001
<b>Weeks from week of first registered COVID-19 deaths to lockdown</b>	216.98 (13.04)	<0.001
<b>Weeks between peak and lockdown</b>	104.56 (17.38)	<0.001

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240 As mentioned, all local authorities began recording COVID-19 deaths between weeks 11 and 15, i.e.,  
 241 from 2 weeks before the announcement of the first lockdown, to 2 weeks after. The difference in  
 242 total cumulative death rates for areas grouped by starting week are as seen in Table 2.

243



244 **Table 2. Mean cumulative COVID-19 death rate per 100,000 persons over the first wave (weeks 1**  
 245 **to 27, 2020) of the pandemic among 307 local authorities in England.**

Timing of start week relative to week 13 (when lockdown 1 was announced)	Total cumulative age-standardised COVID-19 death rate per 100,000 persons for whole of wave 1 (weeks 1 to 27, 2020), (SD)	Number of local authorities
2 weeks before	465 (451)	14
1 week before	780 (324)	124
Same week	984 (407)	101
1 week after	1188 (505)	63
2 weeks after	1147 (255)	5

246

247

248 Figure 4 depicts the cumulative COVID-19 death rates of each IMD decile over the whole of the first  
 249 wave. Mortality rates in more deprived areas (deciles 1 and 2) were rising faster than others at the  
 250 start of lockdown (vertical dotted line), and the disparity in cumulative mortality grew as the  
 251 pandemic progressed.

252

253 **Figure 4. Cumulative COVID-19 death rates per 100,000 for areas of each IMD decile over the first**  
 254 **wave of the pandemic in 307 local authorities in England. Dotted line marks timing of the**  
 255 **announcement of the first lockdown, zoomed in area between weeks 13 and 14.**

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3 257 Up until week 15 when the effects of lockdown may have started to be seen in mortality data, the  
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5 258 cumulative death rate per 100,000 persons already differed by IMD decile. The two most deprived  
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7 259 deciles recorded 77.16 deaths per 100,000 persons by this time, whereas the two least deprived  
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9 260 deciles recorded only 50.01 deaths per 100,000 persons. This inequality reduced by the time the first  
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11 261 wave had passed (by week 27), but did not equalise, with the most deprived two deciles recording  
12  
13 262 316.14 total deaths per 100,000 persons, and the least deprived recording 245.10 deaths per 100,00  
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15 263 persons. These equate to an excess of 54% before lockdown versus 29% after lockdown.  
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21 265 Figure 5 illustrates the geographical distribution of deprivation based on IMD and the total  
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23 266 cumulative age-standardised COVID-19 death rate per 100,000 persons over the first wave of the  
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25 267 pandemic. London and the North West featured many of the areas with the highest overall death  
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27 268 rates. Although these areas featured many deprived local authorities, the distributions were not  
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29 269 identical.  
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35 271 **Figure 5. Average rank of the index of multiple deprivation (IMD) and total cumulative COVID-19**  
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37 272 **death rate per 100,000 persons over the first wave of the pandemic (weeks 1 to 27, 2020) per local**  
38  
39 273 **authority in England.**  
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43

## 44 275 Discussion

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47 276 This study has provided the first examination of the evolution of inequalities in the COVID-19  
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49 277 pandemic. It has found that inequalities in COVID-19 mortality rates by deprivation in England began  
50  
51 278 to appear early in the first wave. More deprived local authorities generally started recording COVID-  
52  
53 279 19 deaths earlier than less deprived areas, and mortality rates also increased faster in more deprived  
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55 280 areas, and rose to higher peak rates. All of the 307 lower-tier local authorities in England began  
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3 281 recording COVID-19 deaths as early as 2 weeks before first national lockdown in England was  
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5 282 announced, or up to 2 weeks afterwards, with the latter – less deprived - group of local authorities  
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7 283 recording fewer cumulative deaths over the whole of the first wave, compared to the former – more  
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9 284 deprived – group of local authorities.

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13  
14 286 The study has also provided the first assessment of the impacts of the first English national lock  
15  
16 287 down on the evolution of the pandemic. It has found that following the implementation of the  
17  
18 288 national lockdown, local authorities where death rates had been rising faster (i.e. more deprived  
19  
20 289 areas), peaked and began to descend earlier than the other – less deprived – local authorities.

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22 290 Cumulative death rates were higher in more deprived areas by the time lockdown began, but the  
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24 291 difference narrowed moderately towards the end of the first wave.

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33 294 England imposed a national lockdown during the first wave of the COVID-19 epidemic in March  
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35 295 2020(19). This measure aimed to drastically reduce instances of interpersonal contact between  
36  
37 296 infected individuals (whether symptomatic or not) and the wider susceptible population. Confining  
38  
39 297 the public to their homes, suspending face-to-face education and restricting travel placed great  
40  
41 298 burdens upon the health and welfare of many individuals and communities, through a number of  
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43 299 pathways that are still being elucidated, and which will continue to emerge(20–22). There is no  
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45 300 doubt that the economic implications of such lockdowns can be severe, and disruptions to usual  
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47 301 health care provision have led to increased mortality from non-COVID causes (23). However, the  
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49 302 risks posed to society of not imposing such lockdowns are likely much greater(24). Unchecked viral  
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51 303 spread would lead to mass fatalities, increased disability rates especially in the young from the  
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53 304 effects of non-fatal infection (so-called 'Long COVID'(25)), and an increased risk of viral mutation  
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3 305 into forms which may pose even greater threat(26). Importantly, the National Health Service (NHS)  
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5 306 could potentially be filled beyond capacity with COVID-19 patients, leaving insufficient resources for  
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7 307 non-COVID patients of all ages and diagnoses. Economic implications of unchecked viral spread are  
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9 308 likely to be considerably worse than those caused by national lockdowns, and could continue for  
10  
11 309 longer due to the likelihood of future outbreaks of mutated viral strains and multiple waves of  
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13 310 infection(24). A well-timed national lockdown has the ability to reduce case incidence to low levels  
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15 311 at which 'test, trace and isolate' programs can efficiently extinguish local outbreaks, and lends time  
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17 312 for mass vaccination to offer protection, especially to the most vulnerable. However, a lockdown  
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19 313 that is imposed too late, i.e. when disease incidence is already high and rising, needs to be  
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21 314 substantially more stringent and protracted to offer the same slowing effect on case numbers and,  
22  
23 315 subsequently, deaths(24).  
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29 317 Previous work has focused on comparing COVID-19 mortality rates between areas of England using  
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31 318 set time periods without considering the evolution of the inequalities reported(21), or have  
32  
33 319 identified inequalities in case rates and other metrics(13). Using mortality data removes some of the  
34  
35 320 uncertainty surrounding early case ascertainment, since early in the English epidemic, testing was  
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37 321 only being performed in hospitals on symptomatic individuals, and so many infections would not  
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39 322 have been recorded.  
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45 324 It has been noted internationally that the seeding of SARS-CoV-2 into a country tends to be via travel  
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47 325 by people at the upper end of the socio-economic spectrum, taking international holidays or  
48  
49 326 travelling for business(27,28). Cases then increase within these less deprived populations until social  
50  
51 327 distancing and national lockdowns are advised or mandated. At this point, the disease burden shifts  
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53 328 to the more deprived, who are less able to fully adhere to these guidelines due to less ability to work  
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55 329 from home, fewer resources, precarious work, higher population densities and other pre-existing  
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3 330 factors(27). These two 'phases' of pandemic spread likely apply to COVID-19 cases in England, where  
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5 331 the index cases were holidaymakers returning from skiing trips to Austria(29,30). Plümper *et al*  
6  
7 332 (2020) reported that in Germany, despite a somewhat reduced likelihood of infection for those in  
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9 333 more deprived areas in the first phase of the epidemic, these communities were nevertheless at  
10  
11 334 similar risk of death. This relative risk of mortality increases for more deprived areas once  
12  
13 335 transmission is established in 'phase 2' of the pandemic – due to population vulnerabilities including  
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15 336 poverty, overcrowding and pre-existing chronic conditions(6). Our analysis of early-stage mortality in  
16  
17 337 England confirmed this structure, in that mortality rates rose first to a small initial 'peak' in less  
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19 338 deprived areas, before being dominated by more deprived local authorities. The earliest data  
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21 339 available to the German study began more than 2 weeks following the implementation of  
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23 340 government lockdowns, whereas the analysis we present here predate the UK lockdown by a  
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25 341 number of months, and hence capture the very earliest data available on COVID-19 deaths.  
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31 343 We have shown that inequalities in cumulative death rates during the first wave of infection in  
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33 344 England existed from the earliest stages of COVID-19 mortality reporting, and were entrenched by  
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35 345 differences in the speed of increase, leading to unequal burdens of cumulative mortality at local  
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37 346 authority level by the time the first national lockdown was called. These inequalities reduced  
38  
39 347 marginally but were not abolished by the national control measures implemented in the lockdown.  
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41 348 The first national lockdown in England was fairly strict (e.g. a 'stay at home order') and it was a  
42  
43 349 universal intervention, enforced and applied to the whole population and thereby requiring little by  
44  
45 350 way of individual agency. Previous public health research has shown that such measures are more  
46  
47 351 likely to reduce inequalities in health than those that require individual choice/compliance(31). That  
48  
49 352 the lockdown did not completely eliminate geographical inequalities in COVID-19 mortality may well  
50  
51 353 be as a result of inequalities in (1) *vulnerability* (whereby more deprived areas had a higher burden  
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53 354 of clinical risk factors); (2) *susceptibility* (whereby immune response was lower in more deprived  
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3 355 populations due to the adverse consequences of long term exposures to harmful living and  
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5 356 environmental conditions); (3) *exposure* (inequalities in working conditions notably less ability to  
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7 357 work at home in the low income jobs predominating within more deprived local authorities); and (4)  
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9 358 *transmission* (higher rates of overcrowding and population density in the community may have  
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11 359 impacted on infection spread in more deprived areas)(6).  
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## 16 361 **Conclusion**

19 362 This study has found that inequalities in death rates during the first wave of infection in England  
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21 363 existed from the earliest stages of the COVID-19 pandemic, and were entrenched by differences in  
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23 364 the speed of increase. This led to a significant unequal burden in cumulative mortality between the  
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25 365 most and least deprived local authorities by the time the first national lockdown was implemented.  
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27 366 These inequalities reduced marginally - but were not abolished - during the national lockdown. It is  
28  
29 367 impossible to say with certainty whether an earlier – or longer - national lockdown could have  
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31 368 further reduced these inequalities, but it should be noted that, although the lockdown did reverse  
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33 369 the trend in mortality rates across the country, it had to do so at more advanced stages of the  
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35 370 epidemic in more deprived areas, compounding the unequal disease burden upon these  
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37 371 communities and local health care systems. Susceptibility to infection and fatality from COVID-19 is  
38  
39 372 undoubtedly closely associated with deprivation, but other factors also play an important part, as  
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41 373 well as the stochasticity implicit in viral spread. Nevertheless, our understanding of how deprivation  
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43 374 associates with mortality from a novel infectious disease within a virgin population it can help to  
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45 375 focus future public health attention on those communities most in need and at risk.  
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## 52 377 **Limitations**

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3 378 Weekly age-standardised mortality rates were not available at local authority level at the time of  
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5 379 writing. However, we were able to pro rata monthly age-standardised rates to weekly ones using  
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7 380 weekly death counts. Age-standardised weekly rates are unlikely to become available at lower  
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9 381 geography levels due to disclosure risks. Death counts did not include deaths of non-residents of  
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11 382 England, nor where place of residence was unknown, and was based on date of registration rather  
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13 383 than date of death.

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16 384 Deprivation is undoubtedly linked to COVID-19 mortality, it cannot explain all of the variation in  
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18 385 area-level mortality rates, hence COVID-19 mortality and IMD are not perfectly correlated. Many  
19  
20 386 other factors including comorbidity, healthcare provision, employment types and variation in  
21  
22 387 transport links all likely play a part in the causal web linking lockdowns to mortality inequalities. A  
23  
24 388 deeper analysis of these underlying associations was beyond the scope of the current paper, but  
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26 389 warrants further scrutiny.

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32 391 **Author Statement**

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35 392 FM, CB and CW designed the study. CW completed all analyses with input from FM and CB. CW, VA,  
36  
37 393 FM and CB all contributed to drafting the manuscript. The corresponding author attests that all listed  
38  
39 394 authors meet authorship criteria and that no others meeting the criteria have been omitted. CW is  
40  
41 395 guarantor of the analysis.

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44 396 The Corresponding Author has the right to grant on behalf of all authors and does grant on behalf of  
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12 406 **References**  
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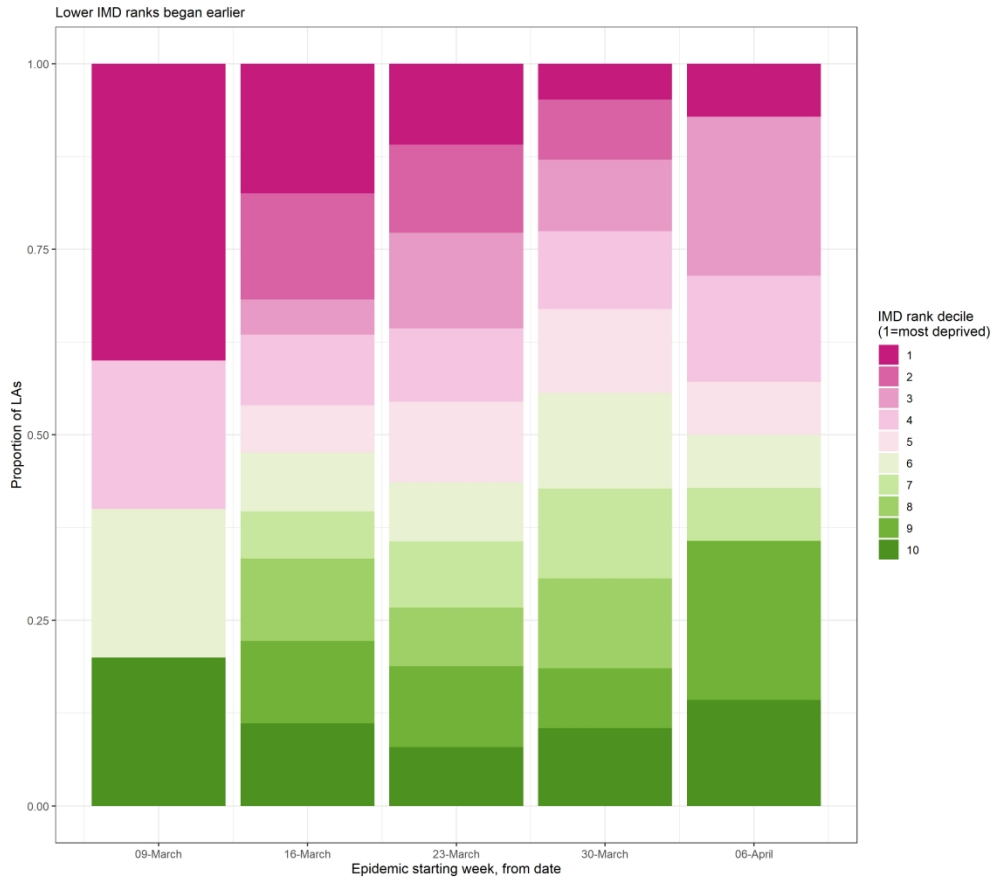
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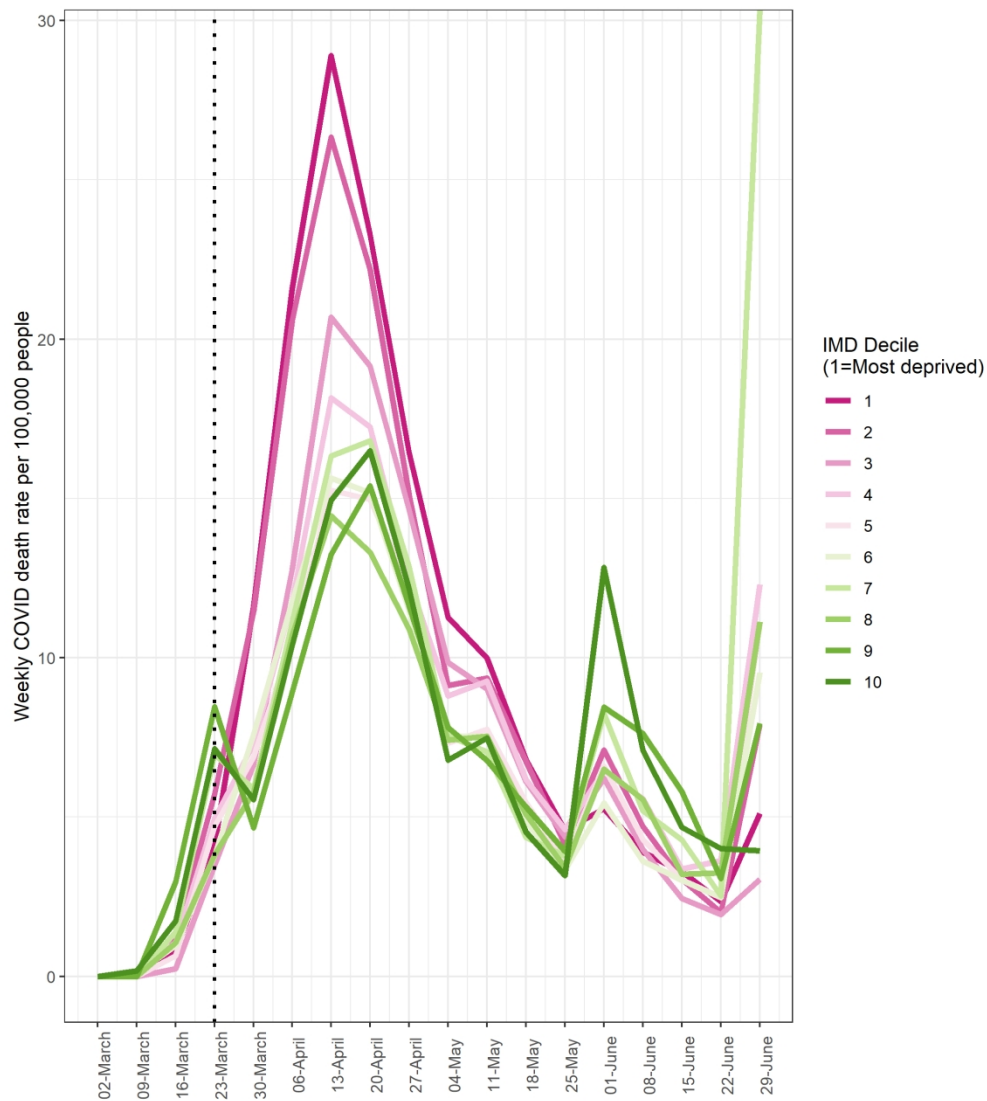
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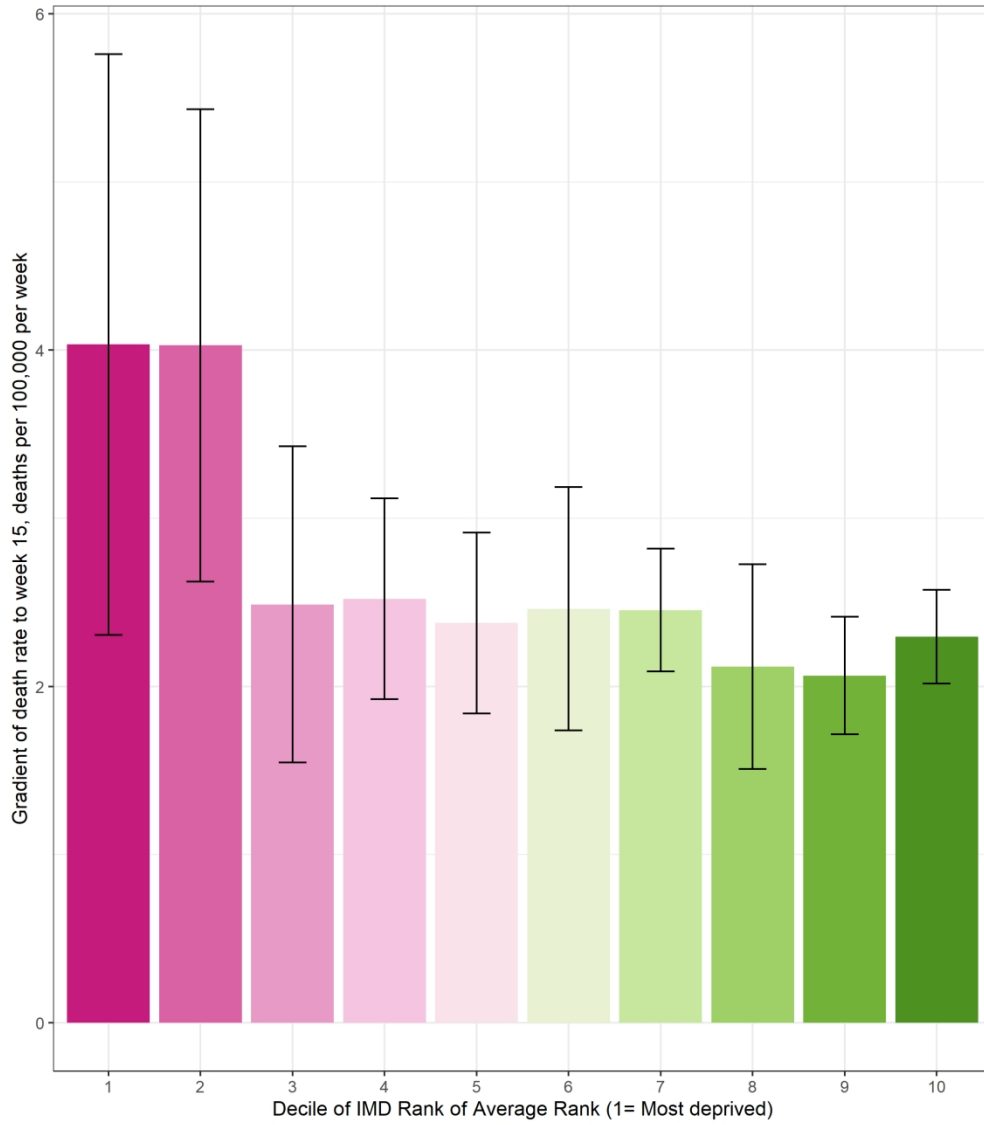
Proportion of 312 English local authorities within each IMD decile that began recording COVID-19 deaths between weeks 11 and 15 of 2020.

717x632mm (118 x 118 DPI)



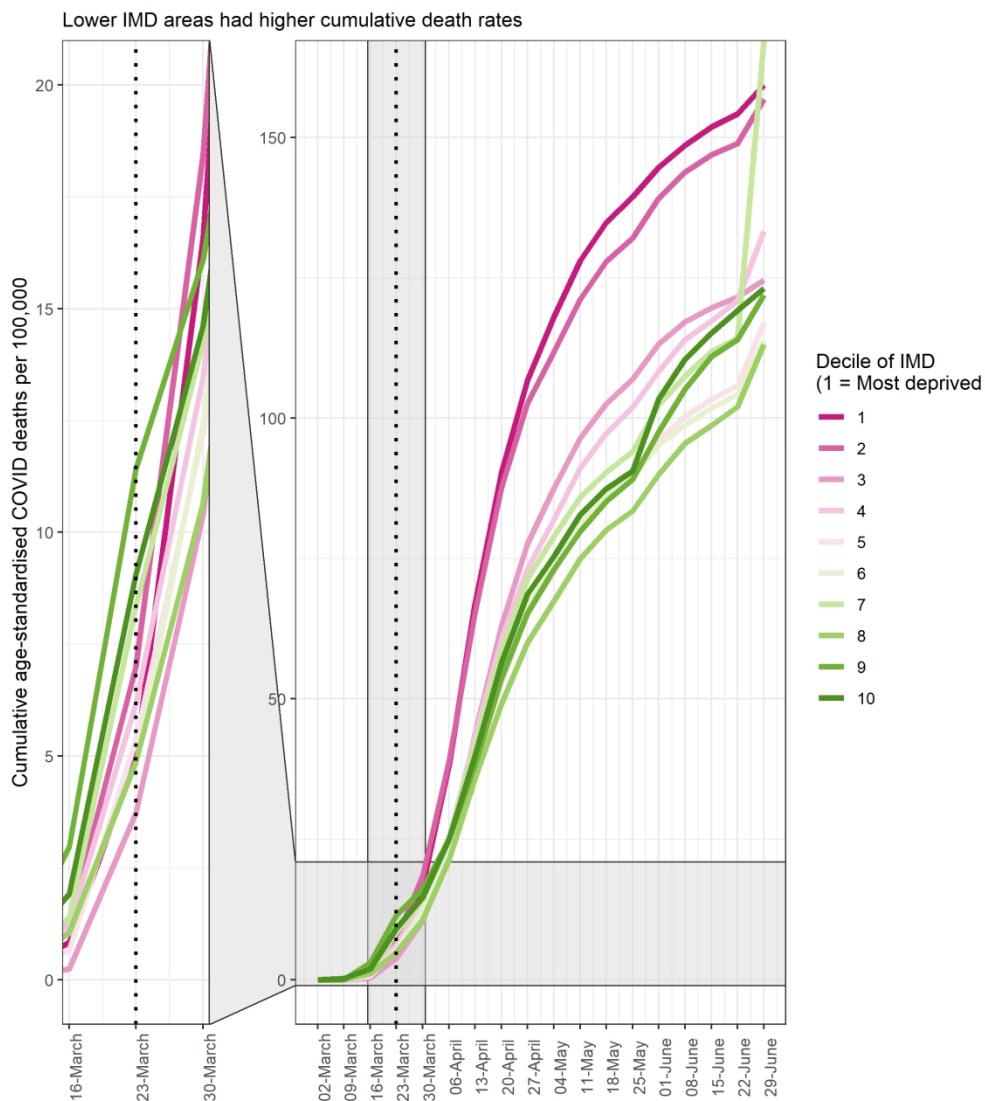
Weekly age-standardised COVID-19 mortality rates per 100,000 in areas of each IMD decile. Dotted line indicates the start of the first national lockdown (26th March).

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Simple linear gradient of age-standardised COVID-19 death rate per 100,000 people between the first week of recorded COVID-19 deaths and week 15, across rank of average rank of IMD deciles.

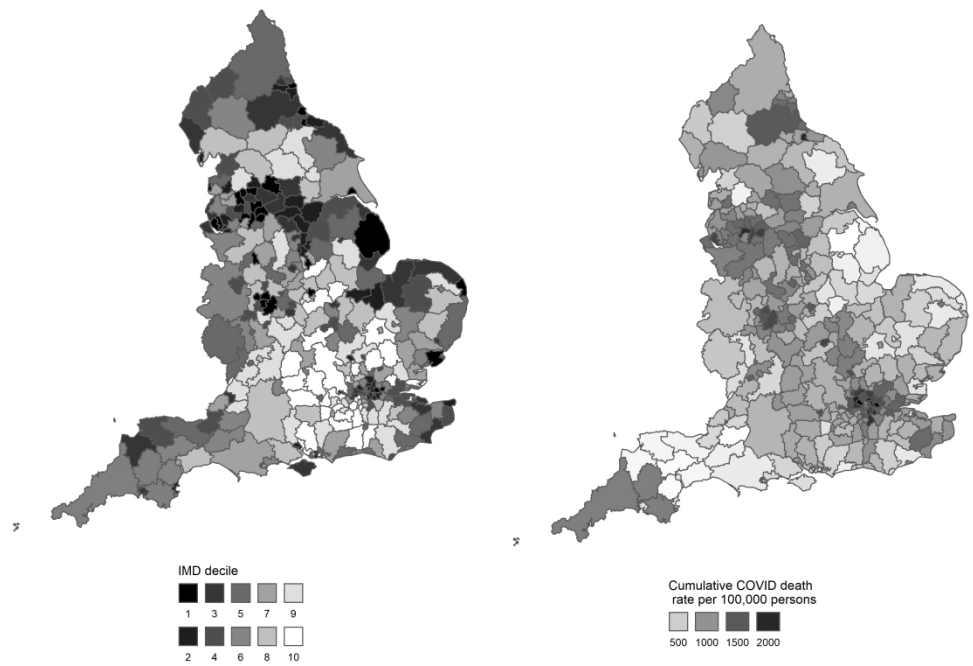
497x562mm (118 x 118 DPI)



Cumulative COVID-19 death rates per 100,000 for areas of each IMD decile over the first wave of the pandemic in 307 local authorities in England. Dotted line marks timing of the announcement of the first lockdown, zoomed in area between weeks 13 and 14.

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Average rank of the index of multiple deprivation (IMD) and total cumulative COVID-19 death rate per 100,000 persons over the first wave of the pandemic (weeks 1 to 27, 2020) per local authority in England.

774x562mm (118 x 118 DPI)

# Reporting checklist for cross sectional study.

Based on the STROBE cross sectional guidelines.

## Instructions to authors

Complete this checklist by entering the page numbers from your manuscript where readers will find each of the items listed below.

Your article may not currently address all the items on the checklist. Please modify your text to include the missing information. If you are certain that an item does not apply, please write "n/a" and provide a short explanation.

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			Page Number
<b>Title and abstract</b>			
Title	<a href="#">#1a</a>	Indicate the study's design with a commonly used term in the title or the abstract	1
Abstract	<a href="#">#1b</a>	Provide in the abstract an informative and balanced summary of what was done and what was found	5
<b>Introduction</b>			
Background / rationale	<a href="#">#2</a>	Explain the scientific background and rationale for the investigation being reported	7,8
Objectives	<a href="#">#3</a>	State specific objectives, including any prespecified hypotheses	8
<b>Methods</b>			
Study design	<a href="#">#4</a>	Present key elements of study design early in the paper	9
Setting	<a href="#">#5</a>	Describe the setting, locations, and relevant dates, including periods of	9,10



recruitment, exposure, follow-up, and data collection

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2				
3	Eligibility criteria	<a href="#">#6a</a>	Give the eligibility criteria, and the sources and methods of selection of participants.	NA
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6		<a href="#">#7</a>	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	9,10
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10	Data sources /	<a href="#">#8</a>	For each variable of interest give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group. Give information separately for for exposed and unexposed groups if applicable.	9,10
11	measurement			
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17	Bias	<a href="#">#9</a>	Describe any efforts to address potential sources of bias	9,10
18				
19	Study size	<a href="#">#10</a>	Explain how the study size was arrived at	NA
20				
21	Quantitative	<a href="#">#11</a>	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why	9,10
22	variables			
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25	Statistical	<a href="#">#12a</a>	Describe all statistical methods, including those used to control for confounding	10
26	methods			
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29	Statistical	<a href="#">#12b</a>	Describe any methods used to examine subgroups and interactions	NA
30	methods			
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33	Statistical	<a href="#">#12c</a>	Explain how missing data were addressed	NA
34	methods			
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37	Statistical	<a href="#">#12d</a>	If applicable, describe analytical methods taking account of sampling strategy	9,10
38	methods			
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41	Statistical	<a href="#">#12e</a>	Describe any sensitivity analyses	NA
42	methods			
43				
44	<b>Results</b>			
45				
46	Participants	<a href="#">#13a</a>	Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed. Give information separately for for exposed and unexposed groups if applicable.	11
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55	Participants	<a href="#">#13b</a>	Give reasons for non-participation at each stage	NA
56				
57	Participants	<a href="#">#13c</a>	Consider use of a flow diagram	NA
58				
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1	Descriptive data	<a href="#">#14a</a>	Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders. Give information separately for exposed and unexposed groups if applicable.	11
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6	Descriptive data	<a href="#">#14b</a>	Indicate number of participants with missing data for each variable of interest	11
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10	Outcome data	<a href="#">#15</a>	Report numbers of outcome events or summary measures. Give information separately for exposed and unexposed groups if applicable.	11
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14	Main results	<a href="#">#16a</a>	Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	NA
15				
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19	Main results	<a href="#">#16b</a>	Report category boundaries when continuous variables were categorized	NA
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21	Main results	<a href="#">#16c</a>	If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	NA
22				
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25	Other analyses	<a href="#">#17</a>	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses	NA
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29	<b>Discussion</b>			
30				
31	Key results	<a href="#">#18</a>	Summarise key results with reference to study objectives	20
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34	Limitations	<a href="#">#19</a>	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias.	24
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39	Interpretation	<a href="#">#20</a>	Give a cautious overall interpretation considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence.	20
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44	Generalisability	<a href="#">#21</a>	Discuss the generalisability (external validity) of the study results	21:23
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47	<b>Other</b>			
48	<b>Information</b>			
49				
50				
51	Funding	<a href="#">#22</a>	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	3
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# BMJ Open

## **Inequalities in the evolution of the COVID-19 pandemic: An ecological study of inequalities in mortality in the first wave and the effects of the first national lockdown in England**

Journal:	<i>BMJ Open</i>
Manuscript ID	bmjopen-2021-058658.R1
Article Type:	Original research
Date Submitted by the Author:	09-Mar-2022
Complete List of Authors:	Welsh, Claire; Newcastle University Albani, Viviana; Newcastle University Matthews, Fiona; Newcastle University Faculty of Medical Sciences, Population Health Sciences Institute Bambra, Clare; Newcastle University
<b>Primary Subject Heading</b>:	Epidemiology
Secondary Subject Heading:	Health policy, Infectious diseases, Public health
Keywords:	COVID-19, Epidemiology < INFECTIOUS DISEASES, Public health < INFECTIOUS DISEASES

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3 1 **Inequalities in the evolution of the COVID-19 pandemic: An ecological study of inequalities in**  
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5 2 **mortality in the first wave and the effects of the first national lockdown in England**  
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11 4 **Claire E. Welsh PhD (0000-0001-9477-0775)<sup>1\*</sup>, Viviana Albani (0000-0001-9584-7631)<sup>1</sup>, Fiona E.**  
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13 5 **Matthews PhD (0000-0002-1728-2388)<sup>1,2</sup>, Clare Bambra PhD (0000-0002-1294-6851)<sup>1,2</sup>**  
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19 7 <sup>1</sup>Population Health Sciences Institute, Newcastle University, UK, NE4 5PL  
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22 8 <sup>2</sup> Applied Research Collaboration North East and North Cumbria, Newcastle University, UK, NE4 5PL  
23  
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28 10 \*Corresponding author: [Claire.Welsh@newcastle.ac.uk](mailto:Claire.Welsh@newcastle.ac.uk), Room 2.38 Biomedical Research Building,  
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30 11 Campus for Ageing and Vitality, Newcastle University, Newcastle, NE4 5PL.  
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3 **14 Conflicts of Interest Statement**  
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6 **15** All authors have completed the ICMJE uniform disclosure form at [www.icmje.org/coi\\_disclosure.pdf](http://www.icmje.org/coi_disclosure.pdf)  
7  
8 **16** and declare: no financial relationships with any organisations that might have an interest in the  
9  
10 **17** submitted work in the previous three years; no other relationships or activities that could appear to  
11  
12 **18** have influenced the submitted work.  
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16 **19 Data Sharing Statement**  
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18 **20** All data used are publicly freely available through the ONS. Code used in the analyses is available  
19  
20 **21** upon request.  
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24 **22 Ethical Approval**  
25

26 **23** This study was approved by the Newcastle University Ethics Committee (Ref: 7543/2020).  
27  
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30 **24 Transparency declaration**  
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32 **25** The lead author\* affirms that this manuscript is an honest, accurate, and transparent account of the  
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34 **26** study being reported; that no important aspects of the study have been omitted; and that any  
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36 **27** discrepancies from the study as planned (and, if relevant, registered) have been explained.  
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40 **28**  
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42 **29** \*The manuscript's guarantor.  
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46 **30**  
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48 **31 Funding**  
49

50 **32** This work was supported by a grant from The Health Foundation (Ref: 2211473), who took no part in  
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52 **33** the design, analysis or writing of this study.  
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56 **34**  
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58 **35 Keywords**  
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36 **COVID-19; geography; inequalities ;mortality;**

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## 40 **Strengths and limitations of this study**

- 41 • **This study examines the evolution of inequalities in COVID-19 in the first wave of the**  
42 **pandemic in England and the impact of the national lock down.**
- 43 • **National level official (ONS) data used, covering nearly all local authorities in England and**  
44 **including all deaths that made any mention of COVID-19 on death certificates, requiring**  
45 **sensitive data acquisition.**
- 46 • **Age-standardised deaths rates at lower geographies are not available at the time of**  
47 **writing but could lend extra nuance to these findings.**
- 48 • **Ecological study not using individual level data, so unable to examine the individual level**  
49 **risks for COVID-19 mortality.**

50

## 51 **Abstract**

### 52 **Objectives**

53 To examine how ecological inequalities in COVID-19 mortality rates evolved in England, and whether  
54 the first national lockdown impacted them. This analysis aimed to provide evidence for important  
55 lessons to inform public health planning to reduce inequalities in any future pandemics.

### 56 **Design**

57 Longitudinal ecological study

### 58 **Setting**

59 307 Lower-tier local authorities in England

### 60 **Primary outcome measure**

61 Age-standardised COVID-19 mortality rates by local authority, regressed on Index of Multiple  
62 Deprivation (IMD) and relevant epidemic dynamics.



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3 **63 Results**  
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6 64 Local authorities that started recording COVID-19 deaths earlier were more deprived, and more  
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8 65 deprived authorities saw faster increases in their death rates. By 2020-04-06 (week 15, the earliest  
9  
10 66 time that the March 23<sup>rd</sup> lockdown could have begun affecting death rates) the cumulative death  
11  
12 67 rate in local authorities in the two most deprived deciles of Index of Multiple Deprivation (IMD) was  
13  
14 68 54% higher than the rate in the two least deprived deciles. By 2020-07-04 (week 27), this gap had  
15  
16 69 narrowed to 29%. Thus, inequalities in mortality rates by decile of deprivation persisted throughout  
17  
18 70 the first wave, but reduced during the lockdown.  
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22 **71 Conclusions**  
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25 72 This study found significant differences in the dynamics of COVID-19 mortality at the local authority  
26  
27 73 level, resulting in inequalities in cumulative mortality rates during the first wave of the pandemic.  
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29 74 The first lockdown in England was fairly strict – and the study found that it particularly benefited  
30  
31 75 those living in the more deprived local authorities. Care should be taken to implement lockdowns  
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33 76 early enough, in the right places - and at a sufficiently strict level- to maximally benefit all  
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35 77 communities, and reduce inequalities.  
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42 **79 Word Count:**  
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## 80 Introduction

81 Since the early days of the SARS-CoV-2 pandemic in 2020, inequalities in case, hospitalisation and  
82 death rates have been noted internationally (1–8). The most deprived populations and areas in the  
83 USA, Europe and other high-income countries (in terms of a range of deprivation measures) have  
84 suffered up to twice the mortality rates of the least deprived sections of society (2,7,9–12). In  
85 addition, inequalities in disease burden have been noted across levels of income, education,  
86 employment, sex, age, and especially between different ethnic groups, where people of Black and  
87 minority ethnic backgrounds have suffered many more cases (and deaths) than their white  
88 counterparts (13). However, the evolution of ecological inequalities in the pandemic over time in  
89 England - and the impact of national lock downs on them – has not previously been examined. This  
90 study addresses this evidence gap by providing the first analysis of inequalities in the evolution of  
91 the pandemic in different English local authorities and the impact of the first national lock down on  
92 them.

93  
94 Most countries employed national lockdowns of varying duration and severity to mitigate disease  
95 spread, alongside social distancing and hygiene-related advice. The factors used to determine when  
96 a lockdown should begin or cease were rarely transparent, but most appeared to reduce infection  
97 rates to some degree after a lag phase, and saw a rebound of varying size following their release  
98 (14–16). The first confirmed cases of COVID-19 were recorded in England in York in January 2020  
99 and the first death in England was on March 5<sup>th</sup>. From 2020-04-23 until 2020-07-04, a national  
100 lockdown was implemented across England. In keeping with many other European countries, this  
101 was characterised by a 12 week ‘stay at home’ order (SI 350) - whereby people could only go outside  
102 for certain "very limited purposes" - to buy food, to exercise once a day, for medical reasons or to  
103 care for a vulnerable person, or to go to work if they absolutely could not work from home (17).  
104 Face-to-face education was suspended and many workplaces closed down - and staff furloughed -

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3 105 particularly in the hospitality, travel and retail sectors. As nationally cases, hospitalisation and death  
4  
5 106 rates started to fall the lockdown was gradually released over a period of several months -  
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7 107 culminating in the so-called 'Super Saturday' on 2020-07-04 when pubs, restaurants, hairdressers,  
8  
9 108 and cinemas reopened – albeit with strict social distancing rules (18).  
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15 110 It has been noted that when national epidemic dynamics are used to examine population health,  
16  
17 111 they can mask important sub-national variation in disease spread, thus mitigation strategies that rely  
18  
19 112 solely on the national data to inform implementation timings could inadvertently worsen health  
20  
21 113 inequalities across geographical areas (14,16). Previous descriptive studies and reports of  
22  
23 114 inequalities in COVID-19 mortality have only focused on cumulative measures over set timespans,  
24  
25 115 without documenting the disparities in evolution of mortality rates (5,19,20), have been restricted to  
26  
27 116 higher geographies (21), or have not focussed on the effects of lockdowns (7,22). An understanding  
28  
29 117 of how the evolution of the pandemic differed by area and the impact of national mitigation  
30  
31 118 strategies on ecological inequalities in COVID-19 mortality could help inform future policies targeted  
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33 119 at minimising viral spread whilst preventing the widening (or even actively decreasing) health  
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35 120 inequalities.  
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44 122 This paper uses COVID-19 mortality data from the first wave of the pandemic in England to provide  
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46 123 the first examination of ecological inequalities in the evolution of the pandemic in this country. It  
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48 124 sets out the first analysis of when death rates rose, peaked and fell in local authorities of differing  
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50 125 levels of deprivation, and it describes the effects – and the timing of - the first national lockdown on  
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52 126 these inequalities.  
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58 128 **Methods**  
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3 129 Weekly counts of COVID-19 deaths (based on any mention of Coronavirus on the death certificate)  
4  
5 130 for 312 lower-tier local authorities (excluding county councils) in England were obtained from the  
6  
7 131 Office for National Statistics (ONS) covering the period from 1<sup>st</sup> January 2020 to 4<sup>th</sup> July 2020, by date  
8  
9 132 of registration (local authorities are local government organisations covering variable population  
10  
11 133 sizes from just over 2000 to more than 1.5 million residents (23). Weekly COVID-19 death counts at  
12  
13 134 the local authority level were not available per age group, thus age-standardised rates were  
14  
15 135 calculated via monthly age-standardised rates. Monthly age-standardised COVID-19 mortality rates  
16  
17 136 per local authority for the period March to July 2020 were similarly obtained from ONS (24). The  
18  
19 137 monthly rate was divided between the constituent weeks based on the share of monthly deaths in  
20  
21 138 each week. Where all age-standardised rates for a local authority were suppressed by ONS due to  
22  
23 139 disclosure controls, the authority was excluded from analyses (n=4). The level of deprivation of each  
24  
25 140 local authority was determined by the rank of average rank of the Index of Multiple Deprivation  
26  
27 141 (IMD, a relative measure of deprivation across multiple dimensions at small local area level (25)),  
28  
29 142 which was converted into deciles (decile 1 contained the most deprived 10% of local authorities)  
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31 143 from downloaded data (26). In addition, data from the Isles of Scilly and the City of London were  
32  
33 144 excluded due to well-known mortality data quality issues and low population counts.  
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42 146 A number of metrics were calculated for each local authority; the 'starting week' was the first week  
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44 147 where 1 or more COVID-19 deaths were registered, the 'peak' was the highest weekly age-  
45  
46 148 standardised mortality rate per area using a 3-week rolling mean of weekly death rates, and the  
47  
48 149 'total mortality rate' was the cumulative sum of age-standardised weekly mortality rates over the  
49  
50 150 whole study period. The speed of increase was defined as the change in mortality rate between 25%  
51  
52 151 of the peak death rate and the peak rate itself, divided by the number of weeks between them, and  
53  
54 152 similarly the speed of descent was calculated using the peak death rate and subsequent reduction to  
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56 153 50% of this peak rate (25 and 50% selected to include time window when epidemic peaks were  
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3 154 visibly most stable). An assumption was made that any change in population incidence of COVID-19  
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5 155 cases may begin to be seen 2 weeks later in mortality data, thus analyses of the effect of lockdown  
6  
7 156 focused on the period before or after week 15 (lockdown was announced in week 13 [March 2020]  
8  
9  
10 157 and ended on 'Super Saturday' [July 4<sup>th</sup>, week 27], which is shown in timeline plots). The 'peak  
11  
12 158 difference' was the difference in weeks between the peak mortality rate and the week in which  
13  
14 159 lockdown began to take effect (week 15).

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20 161 Weekly age-standardised mortality rates per IMD decile (as opposed to per local authority) were not  
21  
22 162 available at the time of writing, thus they were calculated from the age-standardised estimates from  
23  
24 163 the local authority data (please see supplement for more details).

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30 165 Simple linear models were employed to analyse the associations between visually normally  
31  
32 166 distributed measures such as the total cumulative mortality rate with other metrics (e.g. the speed  
33  
34 167 of increase in death rate) and IMD decile. The purpose of these simple models was to understand  
35  
36 168 the relative contribution of deprivation (measured by IMD) and relevant epidemic dynamics (e.g.  
37  
38 169 date of first recorded COVID-19 deaths) to the metric of interest, therefore no model selection was  
39  
40 170 employed, and covariate inclusion was based on empirical knowledge. Any covariates found to fall  
41  
42 171 above the threshold of statistical significance (Wald p-value >0.05 in multivariable models) would be  
43  
44 172 removed from the model (however no covariates needed to be removed in this way). Differences  
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46 173 between mean speed of increase or decrease per IMD decile were assessed by non-overlap of 95%  
47  
48 174 confidence intervals.

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56 176 Maps were drawn based on 2020 geographical boundaries from the ONS Open Geography Portal  
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58 177 (27).

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56 179 All analyses were conducted in R statistical software version 3.6.2.  
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1112 181 **Patient and Public Involvement**  
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15 182 Our public involvement panel inputted into project design and considered the research topic to be of  
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17 183 contemporary importance and value. The data used do not require patient permissions for use and  
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19 184 are publicly available.  
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2122 185  
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2425 186 **Results**  
2627  
28 187 All 307 lower-tier local authorities in England began registering deaths involving COVID-19 between  
29  
30 188 weeks 11 and 15. The proportion of areas of each IMD decile per 'starting week' is shown in Figure 1.  
31  
32 189 From this it can be seen that more deprived areas (most deprived decile = 1) tended to begin  
33  
34 190 recording COVID-19 deaths earlier than less deprived areas (least deprived decile = 10).  
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3637 191  
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3940 192 **Figure 1. Proportion of 312 English local authorities within each IMD decile that began recording**  
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42 193 **COVID-19 deaths between weeks 11 and 15 of 2020.**  
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4445 194  
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4748  
49 195 Figure 2 depicts the weekly mortality rates per 100,000 people for each IMD decile. After the first  
50  
51 196 two weeks of the epidemic, the two most deprived deciles (20% of local authorities) had the highest  
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53 197 speed of increase in age-standardised mortality rates and reached higher peak rates than less  
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55 198 deprived areas.  
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3 200 **Figure 2. Weekly age-standardised COVID-19 mortality rates per 100,000 in areas of each IMD**  
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5 201 **decile. Dotted line indicates the start of the first national lockdown (26<sup>th</sup> March).**  
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202  
203 From the week of their first COVID-19 deaths to week 15 (when lockdown could plausibly have  
204 begun affecting death rates), local authorities in the two most deprived deciles had the highest  
205 speed of increase in death rate (albeit not statistically significantly different), and the less deprived  
206 deciles increased more slowly (Figure 3). The mean speed of increase in the two most deprived IMD  
207 deciles was 4.03 deaths per 100,000 persons per week, and in the two least deprived deciles was  
208 2.18 deaths per 100,000 persons per week (a difference of 46%).  
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211 **Figure 3. Simple linear gradient of age-standardised COVID-19 death rate per 100,000 people**  
212 **between the first week of recorded COVID-19 deaths and week 15, across rank of average rank of**  
213 **IMD deciles.**  
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215 All local authorities' death rate curves peaked and began to decline between 3 and 10 weeks  
216 following the start of the first lockdown. Those local authorities whose death rates were increasing  
217 faster before lockdown peaked sooner after lockdown commenced compared to slower local  
218 authorities.

219 The total age-standardised cumulative mortality over the first wave (up to week 27, week  
220 commencing 2020-06-28) varied from 119 to 2349 deaths per 100,000 persons per local authority.  
221 Table 1 describes the multivariable linear model of total cumulative death rates per local authority.  
222 It shows that, compared to the most deprived 10% of local authorities, less deprived areas (deciles 3-  
223 10) recorded lower cumulative death rates, and that areas with higher speeds of increase - and more

224 weeks of recorded COVID-19 deaths before lockdown (plus those that peaked later) - saw higher  
225 total death rates.

226

227 **Table 1. Linear multivariable model of the total cumulative age-standardised COVID-19 death rate**  
228 **per 100,000 persons between weeks 1 and 27 of 2020, among 307 local authorities in England.**

Metric	Adjusted Beta Coefficient (SE)	P-value
<b>IMD decile</b>		
<b>1 (most deprived)</b>	REF	
<b>2</b>	-41.16 (49.30)	0.40
<b>3</b>	-108.20 (50.46)	0.03
<b>4</b>	-132.11 (49.80)	0.008
<b>5</b>	-140.82 (50.83)	0.006
<b>6</b>	-183.66 (50.64)	<0.001
<b>7</b>	-225.06 (50.81)	<0.001
<b>8</b>	-170.43 (51.01)	<0.001
<b>9</b>	-213.73 (50.82)	<0.001
<b>10</b>	-262.16 (50.28)	<0.001
<b>Speed of increase (to week 15), deaths per 100,000 per week</b>	12.87 (0.47)	<0.001
<b>Weeks from week of first registered COVID-19 deaths to lockdown</b>	216.98 (13.04)	<0.001



<b>Weeks between peak and lockdown</b>	104.56 (17.38)	<0.001
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230 As mentioned, all local authorities began recording COVID-19 deaths between weeks 11 and 15, i.e.,  
 231 from 2 weeks before the announcement of the first lockdown, to 2 weeks after. The difference in  
 232 total cumulative death rates for areas grouped by starting week are as seen in Table 2.

233

234 **Table 2. Mean cumulative COVID-19 death rate per 100,000 persons over the first wave (weeks 1**  
 235 **to 27, 2020) of the pandemic among 307 local authorities in England.**

<b>Timing of start week relative to week 13 (when lockdown 1 was announced)</b>	<b>Total cumulative age-standardised COVID-19 death rate per 100,000 persons for whole of wave 1 (weeks 1 to 27, 2020), (SD)</b>	<b>Number of local authorities</b>
<b>2 weeks before</b>	465 (451)	14
<b>1 week before</b>	780 (324)	124
<b>Same week</b>	984 (407)	101
<b>1 week after</b>	1188 (505)	63
<b>2 weeks after</b>	1147 (255)	5

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238 Figure 4 depicts the cumulative COVID-19 death rates of each IMD decile over the whole of the first  
 239 wave. Mortality rates in more deprived areas (deciles 1 and 2) were rising faster than others at the

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3 240 start of lockdown (vertical dotted line), and the disparity in cumulative mortality grew as the  
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5 241 pandemic progressed.

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11 243 **Figure 4. Cumulative COVID-19 death rates per 100,000 for areas of each IMD decile over the first**  
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13 244 **wave of the pandemic in 307 local authorities in England. Dotted line marks timing of the**  
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15 245 **announcement of the first lockdown, zoomed in area between weeks 13 and 14.**

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21 247 Up until week 15 when the effects of lockdown may have started to be seen in mortality data, the  
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23 248 cumulative death rate per 100,000 persons already differed by IMD decile. The two most deprived  
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25 249 deciles recorded 77.16 deaths per 100,000 persons by this time, whereas the two least deprived  
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27 250 deciles recorded only 50.01 deaths per 100,000 persons. This inequality reduced by the time the first  
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29 251 wave had passed (by week 27), but did not equalise, with the most deprived two deciles recording  
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31 252 316.14 total deaths per 100,000 persons, and the least deprived recording 245.10 deaths per 100,00  
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33 253 persons. These equate to an excess of 54% before lockdown versus 29% after lockdown.

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41 255 Figure 5 illustrates the geographical distribution of deprivation based on IMD and the total  
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43 256 cumulative age-standardised COVID-19 death rate per 100,000 persons over the first wave of the  
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45 257 pandemic. London and the North West featured many of the areas with the highest overall death  
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47 258 rates. Although these areas featured many deprived local authorities, the distributions were not  
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49 259 identical.

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55 261 **Figure 5. Average rank of the index of multiple deprivation (IMD) and total cumulative COVID-19**  
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57 262 **death rate per 100,000 persons over the first wave of the pandemic (weeks 1 to 27, 2020) per local**  
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59 263 **authority in England.**

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56 265 **Discussion**  
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9 266 This study has provided the first examination of the evolution of inequalities in the COVID-19  
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11 267 pandemic. It has found that inequalities in COVID-19 mortality rates by deprivation in England began  
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13 268 to appear early in the first wave. More deprived local authorities generally started recording COVID-  
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15 269 19 deaths earlier than less deprived areas, and mortality rates also increased faster in more deprived  
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17 270 areas, and rose to higher peak rates. All of the 307 lower-tier local authorities in England began  
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19 271 recording COVID-19 deaths as early as 2 weeks before first national lockdown in England was  
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21 272 announced, or up to 2 weeks afterwards, with the latter – less deprived - group of local authorities  
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23 273 recording fewer cumulative deaths over the whole of the first wave, compared to the former – more  
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25 274 deprived – group of local authorities.  
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32 276 The study has also provided the first assessment of the impacts of the first English national lock  
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34 277 down on the evolution of the pandemic. It has found that following the implementation of the  
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36 278 national lockdown, local authorities where death rates had been rising faster (i.e. more deprived  
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38 279 areas), peaked and began to descend earlier than the other – less deprived – local authorities.  
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40 280 Cumulative death rates were higher in more deprived areas by the time lockdown began, but the  
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42 281 difference narrowed moderately towards the end of the first wave.  
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52 284 England imposed a national lockdown during the first wave of the COVID-19 epidemic in March 2020  
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54 285 (28). This measure aimed to drastically reduce instances of interpersonal contact between infected  
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56 286 individuals (whether symptomatic or not) and the wider susceptible population. Confining the public  
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58 287 to their homes, suspending face-to-face education and restricting travel placed great burdens upon  
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3 288 the health and welfare of many individuals and communities, through a number of pathways that  
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5 289 are still being elucidated, and which will continue to emerge (29–31). There is no doubt that the  
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7 290 economic implications of such lockdowns can be severe, and disruptions to usual health care  
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9 291 provision have led to increased mortality from non-COVID causes (32). However, the risks posed to  
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11 292 society of not imposing such lockdowns are likely much greater (33). Unchecked viral spread would  
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13 293 lead to mass fatalities, increased disability rates especially in the young from the effects of non-fatal  
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15 294 infection (so-called 'Long COVID'(34)), and an increased risk of viral mutation into forms which may  
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17 295 pose even greater threat (35). Importantly, the National Health Service (NHS) could potentially be  
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19 296 filled beyond capacity with COVID-19 patients, leaving insufficient resources for non-COVID patients  
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21 297 of all ages and diagnoses. Economic implications of unchecked viral spread are likely to be  
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23 298 considerably worse than those caused by national lockdowns, and could continue for longer due to  
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25 299 the likelihood of future outbreaks of mutated viral strains and multiple waves of infection (33). A  
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27 300 well-timed national lockdown has the ability to reduce case incidence to low levels at which 'test,  
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29 301 trace and isolate' programs can efficiently extinguish local outbreaks, and lends time for mass  
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31 302 vaccination to offer protection, especially to the most vulnerable. However, a lockdown that is  
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33 303 imposed too late, i.e. when disease incidence is already high and rising, needs to be substantially  
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35 304 more stringent and protracted to offer the same slowing effect on case numbers and, subsequently,  
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37 305 deaths (33).  
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47 307 Previous work has focused on comparing COVID-19 mortality rates between areas of England using  
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49 308 set time periods without considering the evolution of the inequalities reported (36), or have  
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51 309 identified inequalities in case rates and other metrics (16). Using mortality data removes some of  
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53 310 the uncertainty surrounding early case ascertainment, since early in the English epidemic, testing  
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55 311 was only being performed in hospitals on symptomatic individuals, and so many infections would  
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57 312 not have been recorded.  
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6 314 It has been noted internationally that the seeding of SARS-CoV-2 into a country tends to be via travel  
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8 315 by people at the upper end of the socio-economic spectrum, taking international holidays or  
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10 316 travelling for business (37,38). Cases then increase within these less deprived populations until social  
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12 317 distancing and national lockdowns are advised or mandated. At this point, the disease burden shifts  
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14 318 to the more deprived, who are less able to fully adhere to these guidelines due to less ability to work  
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16 319 from home, fewer resources, precarious work, higher population densities and other pre-existing  
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18 320 factors (37). These communities may also face barriers to health system access and differences in  
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20 321 treatment or care. These two 'phases' of pandemic spread likely apply to COVID-19 cases in  
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22 322 England, where the index cases were holidaymakers returning from skiing trips to Austria (39,40).  
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24 323 Plümper *et al* (2020) reported that in Germany, despite a somewhat reduced likelihood of infection  
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26 324 for those in more deprived areas in the first phase of the epidemic, these communities were  
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28 325 nevertheless at similar risk of death. This relative risk of mortality increases for more deprived areas  
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30 326 once transmission is established in 'phase 2' of the pandemic – due to population vulnerabilities  
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32 327 including poverty, overcrowding and pre-existing chronic conditions (a so-called 'syndemic'  
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34 328 pandemic) (41). Our analysis of early-stage mortality in England confirmed this structure, in that  
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36 329 mortality rates rose first to a small initial 'peak' in less deprived areas, before being dominated by  
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38 330 more deprived local authorities. The earliest data available to the German study began more than 2  
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40 331 weeks following the implementation of government lockdowns, whereas the analysis we present  
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42 332 here predate the UK lockdown by a number of months, and hence capture the very earliest data  
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44 333 available on COVID-19 deaths.  
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54 335 We have shown that inequalities in cumulative death rates during the first wave of infection in  
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56 336 England existed from the earliest stages of COVID-19 mortality reporting, and were entrenched by  
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58 337 differences in the speed of increase, leading to unequal burdens of cumulative mortality at local  
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3 338 authority level by the time the first national lockdown was called. These inequalities reduced  
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5 339 marginally but were not abolished by the national control measures implemented in the lockdown.  
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7 340 The first national lockdown in England was fairly strict (e.g. a 'stay at home order') and it was a  
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9 341 universal intervention, enforced and applied to the whole population and thereby requiring little by  
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11 342 way of individual agency. Previous public health research has shown that such measures are more  
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13 343 likely to reduce inequalities in health than those that require individual choice/compliance (42). That  
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15 344 the lockdown did not completely eliminate ecological inequalities in COVID-19 mortality may well be  
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17 345 as a result of inequalities in (1) *vulnerability* (whereby more deprived areas had a higher burden of  
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19 346 clinical risk factors); (2) *susceptibility* (whereby immune response was lower in more deprived  
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21 347 populations due to the adverse consequences of long term exposures to harmful living and  
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23 348 environmental conditions); (3) *exposure* (inequalities in working conditions notably less ability to  
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25 349 work at home in the low income jobs predominating within more deprived local authorities); and (4)  
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27 350 *transmission* (higher rates of overcrowding and population density in the community may have  
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29 351 impacted on infection spread in more deprived areas (41)).  
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### 38 353 **Conclusion**

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41 354 This study has found that inequalities in death rates during the first wave of infection in England  
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43 355 existed from the earliest stages of the COVID-19 pandemic, and were entrenched by differences in  
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45 356 the speed of increase. This led to a significant unequal burden in cumulative mortality between the  
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47 357 most and least deprived local authorities by the time the first national lockdown was implemented.  
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49 358 These inequalities reduced marginally - but were not abolished - during the national lockdown. It is  
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51 359 impossible to say with certainty whether an earlier – or longer - national lockdown could have  
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53 360 further reduced these inequalities, but it should be noted that, although the lockdown did reverse  
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55 361 the trend in mortality rates across the country, it had to do so at more advanced stages of the  
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57 362 epidemic in more deprived areas, compounding the unequal disease burden upon these  
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3 363 communities and local health care systems. Susceptibility to infection and fatality from COVID-19 is  
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5 364 undoubtedly closely associated with deprivation, but other factors also play an important part, as  
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7 365 well as the stochasticity implicit in viral spread. Nevertheless, our understanding of how deprivation  
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9 366 associates with mortality from a novel infectious disease within a virgin population it can help to  
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12 367 focus future public health attention on those communities most in need and at risk.  
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### 17 369 **Limitations**

20 370 Weekly age-standardised mortality rates were not available at local authority level at the time of  
21  
22 371 writing. However, we were able to pro rata monthly age-standardised rates to weekly ones using  
23  
24 372 weekly death counts. Age-standardised weekly rates are unlikely to become available at lower  
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26 373 geography levels due to disclosure risks. Death counts did not include deaths of non-residents of  
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28 374 England, nor where place of residence was unknown, and was based on date of registration rather  
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30 375 than date of death.  
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35 376 Deprivation is undoubtedly linked to COVID-19 mortality, it cannot explain all of the variation in  
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37 377 area-level mortality rates, hence COVID-19 mortality and IMD are not perfectly correlated. Many  
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39 378 other factors including comorbidity, healthcare provision, employment types and variation in  
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41 379 transport links all likely play a part in the causal web linking lockdowns to mortality inequalities. A  
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43 380 deeper analysis of these underlying associations was beyond the scope of the current paper, but  
44  
45 381 warrants further scrutiny.  
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49 382 Testing was limited to hospitalised patients in the earliest months of the pandemic in England. This  
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51 383 may have introduced bias to our initial analyses since deaths from COVID-19 may not have been  
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53 384 correctly attributed, had the person not received a positive test prior to death. However, we were  
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55 385 unable to retrospectively account for this, and it would have applied to a small number of deaths in  
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57 386 the earliest time period. Given consistency of trends across areas that began recording deaths at  
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3 387 different stages of the national pandemic, we do not believe that this would have introduced serious  
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5 388 bias.

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14 391 **Author Statement**

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17 392 FM, CB and CW designed the study. CW completed all analyses with input from FM and CB. CW, VA,  
18  
19 393 FM and CB all contributed to drafting the manuscript. The corresponding author attests that all listed  
20  
21 394 authors meet authorship criteria and that no others meeting the criteria have been omitted. CW is  
22  
23 395 guarantor of the analysis.

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26 396 The Corresponding Author has the right to grant on behalf of all authors and does grant on behalf of  
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50 406 **References**

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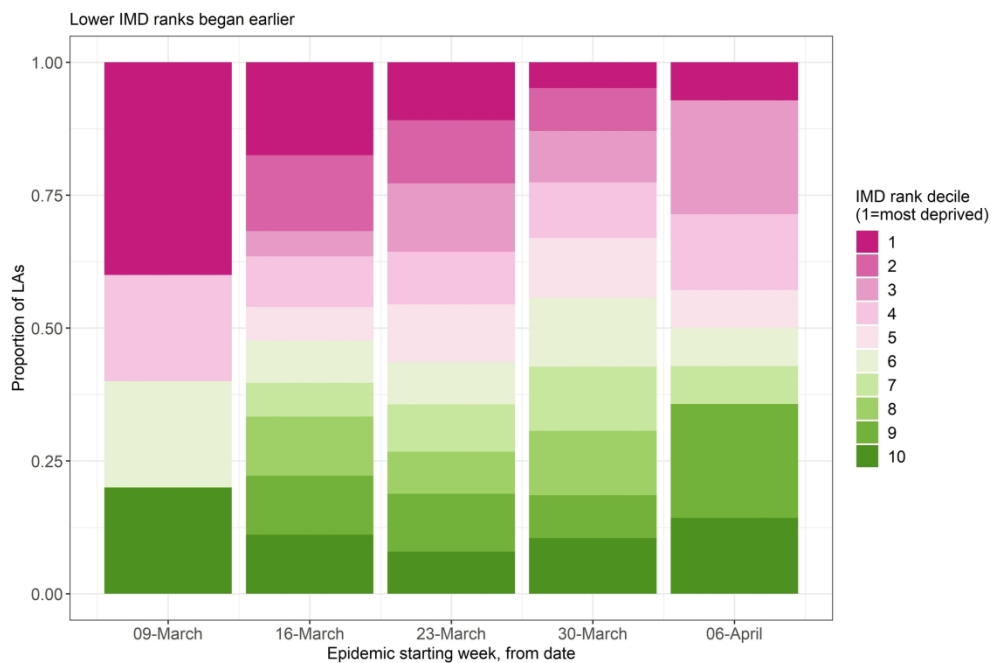


Figure 1. Proportion of 312 English local authorities within each IMD decile that began recording COVID-19 deaths between weeks 11 and 15 of 2020.

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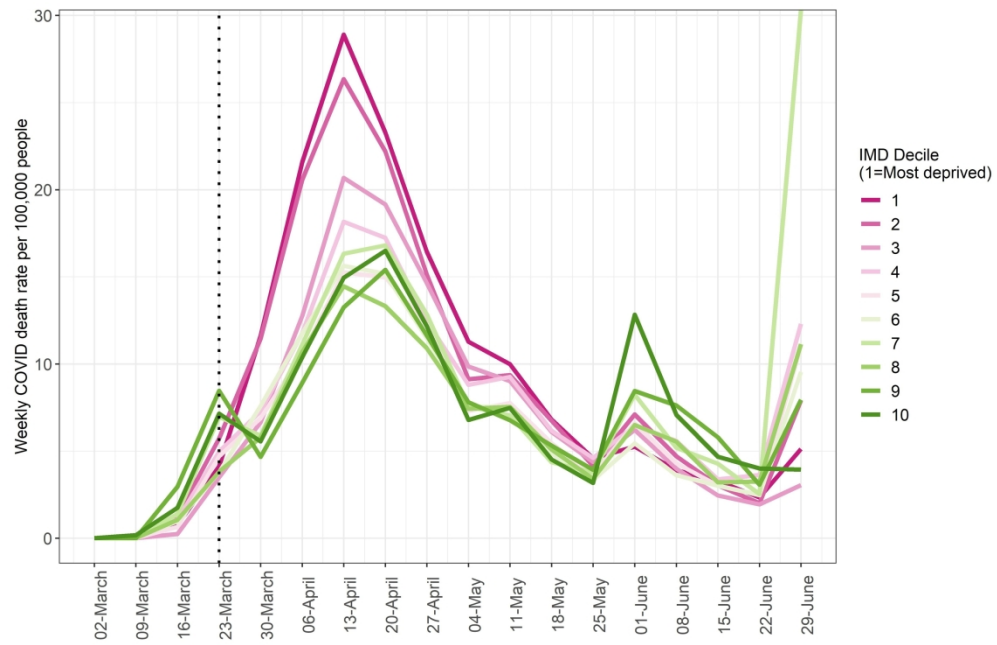


Figure 2. Weekly age-standardised COVID-19 mortality rates per 100,000 in areas of each IMD decile. Dotted line indicates the start of the first national lockdown (26th March).

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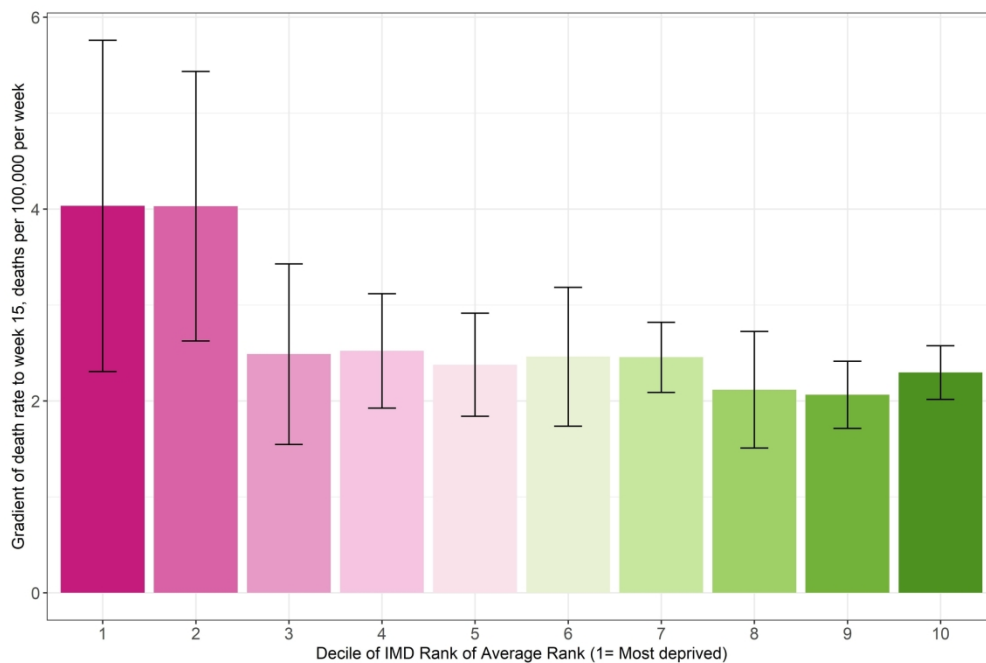


Figure 3. Simple linear gradient of age-standardised COVID-19 death rate per 100,000 people between the first week of recorded COVID-19 deaths and week 15, across rank of average rank of IMD deciles.

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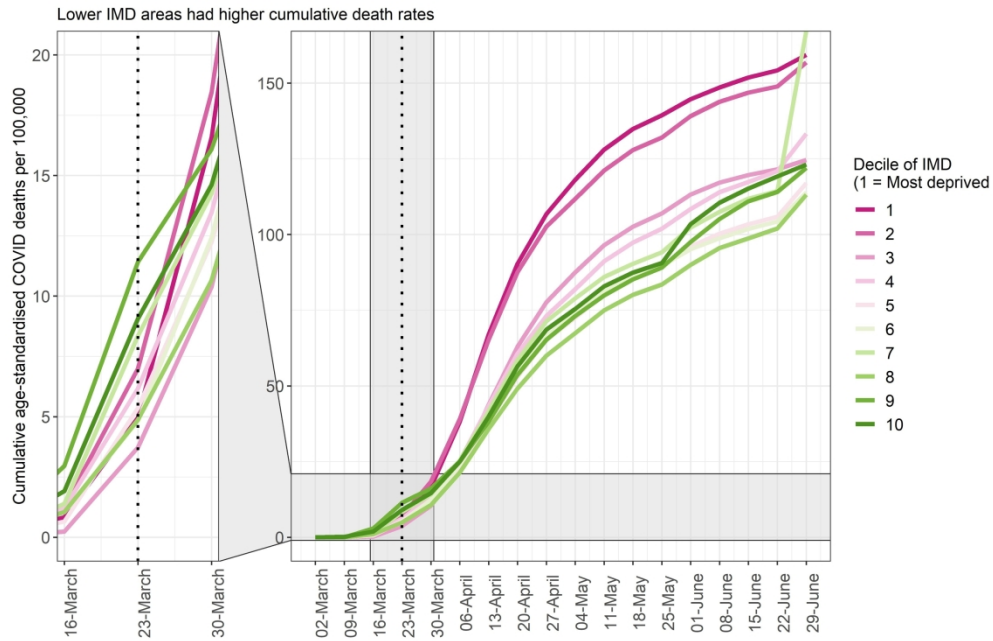


Figure 4. Cumulative COVID-19 death rates per 100,000 for areas of each IMD decile over the first wave of the pandemic in 307 local authorities in England. Dotted line marks timing of the announcement of the first lockdown, zoomed in area between weeks 13 and 14.

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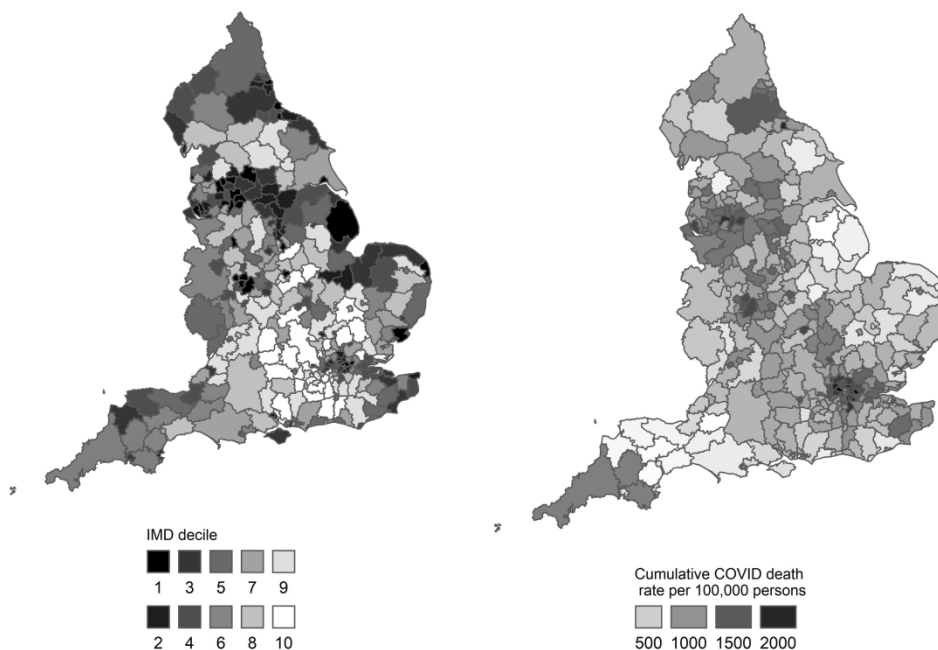


Figure 5. Average rank of the index of multiple deprivation (IMD) and total cumulative COVID-19 death rate per 100,000 persons over the first wave of the pandemic (weeks 1 to 27, 2020) per local authority in England.

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### Supplemental material

#### S1. Supplementary methods.

**Weekly age-standardised mortality rates per IMD decile (as opposed to per local authority) were not available at the time of writing, thus they were calculated from other existing data, in a similar but distinct method from local authority rates. This method is as follows: Firstly, the denominators from local authority-level monthly age standardised mortality rates were calculated using the death counts and rates provided. These 'age-standardised' population estimates were summed across local authorities within the same IMD decile, and counts of COVID-19 deaths were similarly summed by decile. Weekly age-standardised rates per 100,000 people were then calculated as the sum of deaths divided by the modified summed population estimate, multiplied by 100,000.**

# Reporting checklist for cross sectional study.

Based on the STROBE cross sectional guidelines.

## Instructions to authors

Complete this checklist by entering the page numbers from your manuscript where readers will find each of the items listed below.

Your article may not currently address all the items on the checklist. Please modify your text to include the missing information. If you are certain that an item does not apply, please write "n/a" and provide a short explanation.

Upload your completed checklist as an extra file when you submit to a journal.

In your methods section, say that you used the STROBE cross sectional reporting guidelines, and cite them as:

von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement: guidelines for reporting observational studies.

		Reporting Item	Page Number
<b>Title and abstract</b>			
Title	<a href="#">#1a</a>	Indicate the study's design with a commonly used term in the title or the abstract	1
Abstract	<a href="#">#1b</a>	Provide in the abstract an informative and balanced summary of what was done and what was found	5
<b>Introduction</b>			
Background / rationale	<a href="#">#2</a>	Explain the scientific background and rationale for the investigation being reported	7,8
Objectives	<a href="#">#3</a>	State specific objectives, including any prespecified hypotheses	8
<b>Methods</b>			
Study design	<a href="#">#4</a>	Present key elements of study design early in the paper	9
Setting	<a href="#">#5</a>	Describe the setting, locations, and relevant dates, including periods of	9,10

recruitment, exposure, follow-up, and data collection

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3	Eligibility criteria	<a href="#">#6a</a>	Give the eligibility criteria, and the sources and methods of selection of participants.	NA
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6		<a href="#">#7</a>	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	9,10
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10	Data sources /	<a href="#">#8</a>	For each variable of interest give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group. Give information separately for for exposed and unexposed groups if applicable.	9,10
11	measurement			
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17	Bias	<a href="#">#9</a>	Describe any efforts to address potential sources of bias	9,10
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19	Study size	<a href="#">#10</a>	Explain how the study size was arrived at	NA
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21	Quantitative	<a href="#">#11</a>	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why	9,10
22	variables			
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25	Statistical	<a href="#">#12a</a>	Describe all statistical methods, including those used to control for confounding	10
26	methods			
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29	Statistical	<a href="#">#12b</a>	Describe any methods used to examine subgroups and interactions	NA
30	methods			
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33	Statistical	<a href="#">#12c</a>	Explain how missing data were addressed	NA
34	methods			
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37	Statistical	<a href="#">#12d</a>	If applicable, describe analytical methods taking account of sampling strategy	9,10
38	methods			
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41	Statistical	<a href="#">#12e</a>	Describe any sensitivity analyses	NA
42	methods			
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44	<b>Results</b>			
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46	Participants	<a href="#">#13a</a>	Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed. Give information separately for for exposed and unexposed groups if applicable.	11
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55	Participants	<a href="#">#13b</a>	Give reasons for non-participation at each stage	NA
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57	Participants	<a href="#">#13c</a>	Consider use of a flow diagram	NA
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1	Descriptive data	<a href="#">#14a</a>	Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders. Give information separately for exposed and unexposed groups if applicable.	11
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6	Descriptive data	<a href="#">#14b</a>	Indicate number of participants with missing data for each variable of interest	11
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10	Outcome data	<a href="#">#15</a>	Report numbers of outcome events or summary measures. Give information separately for exposed and unexposed groups if applicable.	11
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14	Main results	<a href="#">#16a</a>	Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	NA
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19	Main results	<a href="#">#16b</a>	Report category boundaries when continuous variables were categorized	NA
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21	Main results	<a href="#">#16c</a>	If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	NA
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25	Other analyses	<a href="#">#17</a>	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses	NA
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29	<b>Discussion</b>			
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31	Key results	<a href="#">#18</a>	Summarise key results with reference to study objectives	20
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34	Limitations	<a href="#">#19</a>	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias.	24
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39	Interpretation	<a href="#">#20</a>	Give a cautious overall interpretation considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence.	20
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44	Generalisability	<a href="#">#21</a>	Discuss the generalisability (external validity) of the study results	21:23
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47	<b>Other</b>			
48	<b>Information</b>			
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51	Funding	<a href="#">#22</a>	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	3
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