

Supplementary material February 2024

Technical appendix: Understanding differences in infant mortality rates across local areas

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Technical appendix

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Methods

Rapid literature review

We conducted a rapid literature review to identify themes and measures at the local authority level that have previously been shown to be associated with infant mortality. We searched MEDLINE, Embase and Social Sciences Citation Index (SSCI) for recent peer-reviewed articles using search terms developed iteratively, to return a pragmatic number of relevant publications [see Table 1 for the search terms].

We followed a process to refine the number of articles the searches returned [see Figure 1]. We reviewed the titles of the articles and excluded those relating to countries that are not part of the Organisation for Economic Co-operation and Development (OECD) and those that were unrelated to the topic. We reviewed the abstracts of the remaining articles for relevance and suitability, before selecting our final were reviewed for relevance and suitability before selecting our final full eight texts for review. We also conducted a ‘snowball’ search¹ which identified three further relevant articles [see Table 2 in the ‘Supporting data’ section for details of the articles].

In addition, we reviewed the existing conceptual models around child health and development [see Table 3 in the ‘Supporting data’ section for the models reviewed]. Finally, we searched grey literature for articles relevant to infant mortality using the phrase “infant mortality” and “death or mortality and child” [see Table 4 in the ‘Supporting data’ section for organisations searched]. From all these publications, we identified themes and measures relating to local authority characteristics that were proposed as being associated with infant mortality [see Table 5 in the ‘Supporting data’ section].

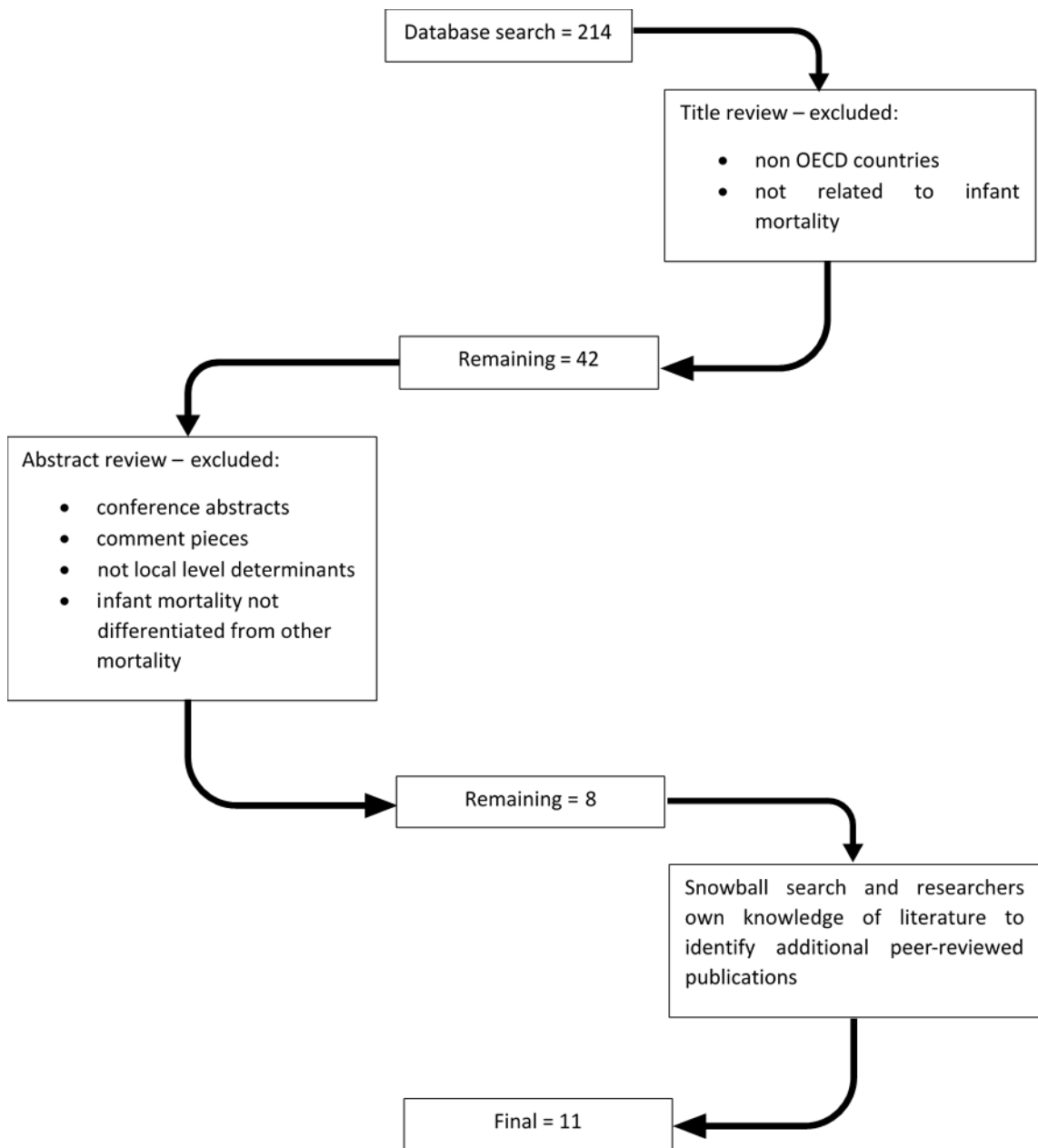
¹ A snowball search looks at the references in the literature identified in the original search to see if there are any more publications that are relevant to the work that the original search didn’t identify.

Table 1: Database search terms for MEDLINE, Embase and the Social Sciences Citation Index (SSCI), with numbers of publications identified (n) where available

Search step	MEDLINE	Embase	Social Sciences Citation Index
1	(child\$ or neonat\$ or bab\$ or infan\$ or newborn\$).title. (969,403)	(child\$ or neonat\$ or bab\$ or infan\$ or newborn\$).title. (1,156,370)	(child* or neonat* or bab* or infan* or toddler* or pre-school* or preschool* or newborn).ti.AND (mortalit* or death or die or life expectancy).ti) (6,586)
2	limit 1 to (english language and humans and yr="2009 -Current") (257,053)	limit 1 to (english language and humans and yr="2009 -Current") (443,924)	(region* or loca* or area* or communit* or neighbour* or neighbor* or populat* or environment* or territor* or precinct* or district* or county or geograph* or place or circumstance* or socioeconomic or socio-economic or sociodemographic or socio-demographic or municipalit*).ti.OR (character\$ or attribute\$ or determin\$ or predict\$ or influen\$ or effect\$ or impact\$ or expos\$ or context\$ or factor\$ or risk\$ or cause\$ or associat\$ or variat\$ or pattern\$).ti (1,697,533)
3	(mortalit* or death or die or life expectancy).title. (205,502)	(mortalit* or death or die or life expectancy).title. (271,634)	(region* or loca* or area* or communit* or neighbour* or neighbor* or populat* or environment* or territor* or precinct* or district* or county or geograph* or place or circumstance* or socioeconomic or socio-economic or sociodemographic or socio-demographic or municipalit*).ti (590,807)
4	limit 3 to (english language and humans and yr="2009 - Current") (69,251)	limit 3 to (english language and humans and yr="2009 - Current") (120,848)	3 and 2 and 1 (935)
5	(region\$ or loca\$ or area\$ or communit\$ or neighbour\$ or neighbor\$ or populat\$ or environment\$ or territor\$ or precinct\$ or district\$ or county or geograph\$ or place or circumstance\$ or socioeconomic or socio-economic or sociodemographic or socio-	(region\$ or loca\$ or area\$ or communit\$ or neighbour\$ or neighbor\$ or populat\$ or environment\$ or territor\$ or precinct\$ or district\$ or county or geograph\$ or place or circumstance\$ or socioeconomic or socio-	limit 4 to (english language and yr="2009 - 2019") (368)

	demographic or municipalit\$.title. (1,042,913)	sociodemographic or socio-demographic or municipalit\$.title. (1,331,764)	
6	limit 5 to (english language and humans and yr="2009 -Current") (268,610)	limit 5 to (english language and humans and yr="2009 -Current") (456,234)	(preterm* or prem* or congenit* or gene* or pregnan* or stillbirth* or birth* or canc* or leuk* or HIV or AIDS).topic (1,119,146)
7	(character\$ or attribute\$ or determin\$ or predict\$ or influen\$ or effect\$ or impact\$ or expos\$ or context\$ or factor\$ or risk\$ or cause\$ or associat\$ or variat\$ or pattern\$.title. (4,939,277)	(character\$ or attribute\$ or determin\$ or predict\$ or influen\$ or effect\$ or impact\$ or expos\$ or context\$ or factor\$ or risk\$ or cause\$ or associat\$ or variat\$ or pattern\$.title. (6,474,408)	5 not 6 (142)
8	limit 7 to (english language and humans and yr="2009 -Current") (1,256,419)	limit 7 to (english language and humans and yr="2009 -Current") (2,214,629)	not (India or Ethiopia or South Africa or Peoples R China or Ghana).countries/regions (130)
9	6 or 8 (1,432,140)	6 or 8 (2,516,184)	
10	2 and 4 and 6 and 9 (522)	2 and 4 and 6 and 9 (738)	
11	(preterm* or prem* or congenit* or gene* or pregnan* or stillbirth* or birth* or canc* or leuk* or HIV or AIDS).multi-purpose. (8,392,177)	(preterm\$ or prem\$ or congenit\$ or gene\$ or pregnan\$ or stillbirth\$ or birth\$ or canc\$ or leuk\$ or HIV or AIDS).multi-purpose (11,529,344)	
12	10 not 11 (139)	10 not 11 (184)	
13	12 not (india\$ or africa\$ or chin\$.title,abstract. (115)	12 not (india\$ or africa\$ or chin\$.title,abstract. (153)	
14		limit 13 to embase (74)	

• Figure 1: Process of identification of peer-reviewed publications relating to childhood obesity, with attrition



Quantitative analysis

Infant mortality data

Statistics on the number of births and the number of deaths in the first year of life are available from the Office for National Statistics. We used this to calculate an infant mortality rate per 1,000 live births for each upper-tier local authority in England between 2008 and 2017. We used 2017 as our main outcome year for the analysis.

Local authority characteristics

For local authority characteristics, we used search engines to identify any real-world data that could represent the themes and suggested measures from the literature review. A full breakdown of the local authority characteristics that we were able to gather and from which data sources is available in Table 5 in the ‘Supporting data’ section. Key sources include: Office for National Statistics; Ministry for Housing, Communities and Local Government; and Public Health England.

We also had access to pseudonymised record-level Hospital Episode Statistics through a data-sharing agreement with NHS Digital. We used this to construct bespoke indicators at upper-tier local authority level on deliveries to different ethnic groups as the published version of this data was only available for ethnic minority groups as a whole rather than broken down.

Data preparation

Most of the data were already published at upper-tier local authority level but, in some cases, we had to aggregate to this level from lower-tier local authority or lower layer super output area. If raw counts were available, we recalculated the values; otherwise, we averaged the values. We also chose to combine Isles of Scilly with Cornwall and City of London with Hackney, to help manage the issue of small numbers from these areas and because many existing data collections already did this, which meant that data were not available for the four local authorities individually.

We assessed the completeness of all the local authority characteristics that we gathered and pooled multiple years of data if there was missing data for a particular local authority. If multiple years of data were not available, then we created two versions of the characteristics, imputing the mean, median or mode for the missing values, and kept the best-fitting version. This was required for the data on the 6 to 8-week and 12-month health check – six and four local authorities had missing data respectively and no alternative years of data were available at the time of the analysis. For the smoking status at time of delivery and Meningitis B vaccine we had to use the same values for both Leicestershire and Rutland as these had already been combined by PHE due to small numbers.

We also looked for outliers in the local authority characteristics and pooled data if we felt that a particular year of data had unusual data points. This was particularly relevant for the data on local authority spending where some local authorities had isolated large spends, presumably for one-off projects.

Analysis

We initially used summary statistics and plotting to examine the infant mortality data both at a national and local authority level, as well as looking at variation in local authority characteristics [see Table 10 in the ‘Supporting data’ section for descriptive statistics of the fully adjusted model variables]. We used regression modelling to assess whether there was any association between the local authority characteristics identified and the infant mortality rate at the local authority level. Infant mortality is count data and generally expressed as a rate, therefore we intended to use Poisson regression models with an offset to account for the number of live births. However, the data were over-dispersed and skewed due to infant death being a rare event so we instead used negative binomial regression models which can better handle this type of data.

In the first instance we constructed unadjusted models looking at the association between each local authority characteristic individually and the infant mortality rate. We then produced a set of models using all the characteristics in each of the seven themes identified by the literature review as well as the additional socioeconomic/ demographic theme. We applied stepwise selection both forwards and backwards with Akaike Information Criterion determining which set of characteristics in each theme best explained the local authority infant mortality rates. We ensured these theme models were free from strong multicollinearity using Pearson’s coefficient and the variance inflation factor. We also excluded overlapping local authority characteristics – where they represented the same topic (e.g. air pollution deprivation and PHE fine particulates measure) or were drawn from the same source (e.g. the individual domains of the Index of Multiple Deprivation contribute to the overall deprivation score, so the overall score was not included in models alongside the domains).

Finally, we built a model using all the remaining characteristics from each of the theme models and again applied stepwise selection to ensure only characteristics that added something to the fit of the model were retained, as well as checking for multicollinearity [see Table 8 in the ‘Supporting data’ section]. We tested the robustness of these final results by checking for influential data points and rerunning the models with these local authorities excluded. We also accounted for multiple p-value tests by creating false discovery rate adjusted p-values but this did not change the messaging from our final model. R-squared is not available for negative binomial regression models but to get an idea of the proportion of the variation in the infant mortality rate that was explained by our models we use the Kullback-Leibler-divergence-based- R^2 measure employed with the *rsq* package (Cameron & Windmeijer, 1997).

All analysis was conducted with R v3.6.1 in RStudio, with the exception of the deliveries to different ethnic groups indicators which were constructed with SAS v9.4.

Supporting data

Full-text-review-articles

Table 2: The final 11 peer reviewed publications identified by the search strategy

Article title	Author/s and year	Journal	DOI
• Correlation or causation? Income inequality and infant mortality in fixed effects models in the period 1960–2008 in 34 OECD countries	• (Avendano, 2012)	• Social Science & Medicine	• 10.1016/j.socsci.med.2012.04.017
• Local Public Health Delivery of Maternal Child Health Services: Are Specific Activities Associated with Reductions in Black-White Mortality Disparities?	• (Bekemeier, Grembowski, Yang, & Herting, 2012)	• Maternal and Child Health Journal	• 10.1007/s10995-011-0794-9
• Socio-economic factors associated with infant mortality in Italy: an ecological study	• (Dallolio et al., 2012)	• International Journal for Equity in Health	• 10.1186/1475-9276-11-45
• Environmental and socio-economic determinants of infant mortality in Poland: an ecological study.	• (Genowska et al., 2015)	• Environmental health: a global access science source	• 10.1186/s12940-015-0048-1
• Collaborating to Address Infant Mortality: Lessons Learned from the Brownsville Action Community for Health Equality.	• (Holden et al., 2011)	• Progress in Community Health Partnerships-Research Education and Action	• 10.1353/cpr.2011.0028
• The effects of housing and neighborhood conditions on child mortality.	• (Jacob et al., 2013)	• Journal of Health Economics	• 10.1016/j.jhealeco.2012.10.008
• The social determinants of infant mortality and birth outcomes in Western developed nations: a cross-country systematic review.	• (Kim & Saada, 2013)	• International Journal of Environmental Research and Public Health	• 10.3390/ijerph10062296
• Regional socioeconomic indicators and ethnicity as predictors of regional infant mortality rate in Slovakia.	• (Rosicova et al., 2011)	• International Journal of Public Health	• 10.1007/s00038-010-0199-3
• Community-academic partnerships to reduce black-white disparities in infant mortality in Florida	• (Salihu et al., 2011)	• Progress in Community Health	• 10.1353/cpr.2011.0009

• Differential neonatal and postneonatal infant mortality rates across US counties: the role of socioeconomic conditions and rurality.	• (Sparks et al., 2009)	• Journal of Rural Health	• 10.1111/j.1748-0361.2009.00241.x
• Infant mortality in Europe, socioeconomic determinants based on aggregate data.	• (Tavares, 2017)	• Applied Economics Letters	• 10.1080/13504851.2017.1364526

Conceptual models

Table 3 Conceptual models investigated

Article title	Author/s and year	Journal/organisation	DOI
• The ecology of human development: Experiments in nature and design.	• (Bronfenbrenner, 1979):	• Harvard University Press.	• NA
• Neighbourhood Effects Influencing Early Childhood Development: Conceptual Model and Trial Measurement Methodologies from the Kids in Communities Study	• (Goldfeld et al., 2015)	• Social Indicators Research	• 10.1007/s11205-014-0578-x
• Kids in Communities Study (KiCS) study protocol: a cross-sectional mixed-methods approach to measuring community-level factors influencing early child development in Australia.	• (Goldfeld et al., 2017)	• BMJ Open	• 10.1136/bmjopen-2016-014047
• Foundational Community factors for early childhood development: A report on the Kids in communities study.	• (Goldfeld et al., 2018)	• Murdoch Children's Research Institute	• NA
• Toward a Social Care Program of Research: A Population-Level Study of Neighborhood Effects on Child Development.	• (Kershaw, Forer, Irwin, Hertzman, & Lapointe, 2007)	• Early Education and Development,	• 10.1080/10409280701610929
• Early Child Development: A Powerful Equalizer. Final Report.	• (Lori, Arjumand, & Clyde, 2007)	• World Health Organisation	• NA
• The Total Environment Assessment Model of Early Child Development.	• (Siddiqi, G Irwin, & Hertzman, 2007)	• World Health Organisation	• NA
• The Kids in Community Study: measuring community level factors influencing children's development. Phase 1: methodologies and Measurements Pilot Study.	• (Talya, Sharon, Sally, Woolcock, &	• Murdoch Children's research institute.	• NA

Jenny,
2010)

Grey literature

Table 4: Organisations and bodies searched for grey literature with findings

Resource	Key information relating to infant mortality	Local area characteristics or other key determinants of infant mortality
<ul style="list-style-type: none"> Institute of Health Visiting 	<ul style="list-style-type: none"> Guidance: safer sleeping and spotting cancer. Referenced: Mothers and Babies: Reducing Risk through Audits and Confidential Enquiries across the UK (MBRRACE) 2018 data and Royal College of Paediatrics and Child Health (RCPCH) articles 	<ul style="list-style-type: none"> None
<ul style="list-style-type: none"> Royal College of Paediatrics and Child Health (RCPCH) 	<ul style="list-style-type: none"> Report: State of Child Health, and Child Health in 2040. Referenced: MBRRACE, Health Select Committee review of 1st 1,000 days, and Child Health Reviews - UK: Mortality and morbidity in children and young people 	<ul style="list-style-type: none"> None
<ul style="list-style-type: none"> National Public Health Bodies: Public Health England (PHE), Public Health Wales (PHW), Health & Social Care Public Health Scotland (PHS), Northern Ireland (HSC NI) 	<ul style="list-style-type: none"> PHE Report: Health profile for England: 2017 - Chapter 5: inequality in health PHE Guidance (2019): Pregnancy and early life: reducing stillbirth and infant death. PHE Report: Infant and 	<ul style="list-style-type: none"> Deprivation/child poverty Ethnicity Maternal smoking during pregnancy Tobacco smoke exposure in baby's early years Immunisations Access to health services, advice and support Maternal alcohol use and substance misuse (during pregnancy and in baby's early years) Some co-existing clinical conditions in mothers Maternal age (those younger than 18 years old and those aged 35 years or older) Low birth weight Breast feeding initiation and breast feeding at 6-8 weeks after birth.

Resource	Key information relating to infant mortality	Local area characteristics or other key determinants of infant mortality
	<p>perinatal mortality in the West Midlands (2016)</p> <ul style="list-style-type: none"> • PHE Presentation: Reducing infant mortality in London (2015) • PHW North Wales Public Health Priorities: Early Years • PHS: returned no information • HSCNI: referenced MBRRACE 	<ul style="list-style-type: none"> • Consanguinity and congenital abnormalities • Maternal occupation group
<ul style="list-style-type: none"> • National Quality Board 	<ul style="list-style-type: none"> • National Guidance on Learning from Deaths (2017) 	<ul style="list-style-type: none"> • Deprivation • Health care services • Pre-term births • Maternal health and age • Congenital malformations
<ul style="list-style-type: none"> • UK Parliament 	<ul style="list-style-type: none"> • Research briefing: Infant Mortality and Stillbirth in the UK 	<ul style="list-style-type: none"> • Maternal smoking during pregnancy • Tobacco smoke exposure in baby's early years • Overweight and obesity in pregnancy • Social inequality • Ethnicity • Maternal age (those younger than 20 years old and those aged 35 years or older) • Previous stillbirth • Infection • Congenital anomalies • Multiple pregnancy
<ul style="list-style-type: none"> • Marmot report 2010 	<ul style="list-style-type: none"> • NA 	<ul style="list-style-type: none"> • Deprivation • Births outside marriage • Ethnicity of infant • Maternal age (those younger than 20 years old) • Paid parental leave • Male gender of infant • Joined up maternity and neonatal health care services

Local authority characteristics and sources

Table 5: Suggested themes and measures, with identified characteristics

Theme	Suggested measures	Identified characteristic	Year(s)	Source
Maternal risk factors	• Weight	• Percentage of adults age 18 and over classified as underweight	• 2015/16 – 2017/18	• Active Lives Survey, Sport England
		• Percentage of adults age 18 and over classified as overweight or obese	• 2015/16 – 2017/18	• Active Lives Survey, Sport England
		• Percentage of adults age 18 and over classified as severely obese	• 2015/16 – 2017/18	• Active Lives Survey, Sport England
	• Drug and alcohol misuse	• -	• -	• -
	• Educational attainment level	• -	• -	• -
	• Personal employment status	• -	• -	• -
	• Ethnicity	• Proportion of deliveries to Black African mothers	• 2004/05 - 2017/18	• Hospital Episode Statistics, NHS Digital
		• Proportion of deliveries to Black Caribbean mothers	• 2004/05 - 2017/18	• Hospital Episode Statistics, NHS Digital
		• Proportion of deliveries to Bangladeshi mothers	• 2004/05 - 2017/18	• Hospital Episode Statistics, NHS Digital
		• Proportion of deliveries to Indian mothers	• 2004/05 - 2017/18	• Hospital Episode Statistics, NHS Digital
		• Proportion of deliveries to Pakistani mothers	• 2004/05 - 2017/18	• Hospital Episode Statistics, NHS Digital
	• Maternal age	• Percentage of delivery episodes where mothers is under 20	• 2009 - 2018	• Office for National Statistics
		• Percentage of delivery episodes where mothers is over 35	• 2009 - 2018	• Office for National Statistics
• Smoking	• Proportion of mothers smoking at time of delivery	• 2010/11 – 2018/19	• Public Health England	
Individual infant characteristics	• Congenital abnormalities	• -	• -	

Theme	Suggested measures	Identified characteristic	Year(s)	Source
	• Low birth weight	• Proportion of live births with a birth weight under 2500g at 37 weeks+ gestation	• 2006 – 2017	• Office for National Statistics
	• Prematurity	• Proportion of live births that are premature	• 2006/08 – 2015/17	• Office for National Statistics
Health care provision	• Health care spending	• Net public health expenditure per 1,000 population	• 2014/15 – 2018/19	• Ministry for Housing, Communities and Local Government
	• Important health checks	• Proportion of new birth visits within 14 days	• 2017/18 – 2018/19	• Public Health England
		• Proportion of infants receiving 6 to 8-week health check on time	• 2017/18 – 2018/19	• Public Health England
		• Proportion of children receiving 12-month health check on time	• 2017/18 – 2018/19	• Public Health England
Parental behaviours	• Breastfeeding	• Breastfeeding prevalence at 6-8 weeks after birth	• 2015/16 – 2018/19	• Public Health England
	• Immunisations	• Meningitis B vaccination coverage at 12 months	• 2017/18 – 2018/19	• Public Health England
		• Pneumococcal conjugate vaccine coverage at 12 months	• 2010/11 – 2018/19	• Public Health England
		• Combination vaccine coverage at 12 months	• 2010/11 – 2018/19	• Public Health England
	• Safe sleeping	• -	• -	• -
Immediate environmental factors	• Residential and occupational pollution	• Air pollution deprivation	• 2015	• Ministry for Housing, Communities and Local Government
	• Housing quality	• Housing condition deprivation	• 2015	• Ministry for Housing, Communities and Local Government
		• Housing affordability deprivation	• 2015	• Ministry for Housing, Communities and Local Government
		• Housing central heating deprivation	• 2015	• Ministry for Housing, Communities and Local Government

Theme	Suggested measures	Identified characteristic	Year(s)	Source
	• Overcrowding	• Household overcrowding deprivation	• 2015	• Ministry for Housing, Communities and Local Government
		• Dwellings per person	• 2015 - 2018	• Valuation Office Agency
Local area factors	• Commissioning for early years	• Net expenditure on early years and sure start per child under 5	• 2010/11 – 2018/19	• Education and Skills Funding Agency
		• Net expenditure on children's social care family support services per child under 15	• 2015/16 – 2018/19	• Ministry for Housing, Communities and Local Government
	• Local priorities	• Net expenditure on substance misuse per adult	• 2016/17 – 2018/19	• Ministry for Housing, Communities and Local Government
Wider societal factors	• Child poverty	• Income deprivation	• 2015	• Ministry for Housing, Communities and Local Government
	• Population employment	• Employment deprivation	• 2015	• Ministry for Housing, Communities and Local Government

Table 6: Sources of additional socioeconomic and demographic characteristics

Theme	Suggested measures	Identified characteristic	Year(s)	Source
Socioeconomic and demographic	• Community environment	• Proportion of under 5s living in areas with the worst accidents involving pedestrians and cyclists deprivation score	• 2015	• Ministry for Housing, Communities and Local Government
		• Average crime deprivation score	• 2015	• Ministry for Housing, Communities and Local Government
		• Average distance to store deprivation score	• 2015	• Ministry for Housing, Communities and Local Government
	• Health	• Proportion of the population living in	• 2015	• Ministry for Housing,

Theme	Suggested measures	Identified characteristic	Year(s)	Source
		areas with the worst health deprivation score		Communities and Local Government
	• Education	• Proportion of the population living in areas with the worst adult skills deprivation score	• 2015	• Ministry for Housing, Communities and Local Government
		• Proportion of the population living in areas with the worst children's education deprivation score	• 2015	• Ministry for Housing, Communities and Local Government

Staged negative binomial regression model results

Table 7: Standardised coefficients and level of significance for unadjusted, theme-adjusted and fully adjusted negative binomial regression models

Theme	Suggested measure	Characteristic	Year(s)	Unadjusted	Theme adjusted	Fully adjusted	
Maternal risk factors	Maternal age	Proportion of births to mothers under 20	2017	0.007**	0.005*		
		Proportion of births to mothers over 35	2017	-0.007**			
	Smoking	Proportion of mothers smoking at birth	2016/17	0.005*			
	Ethnicity		Proportion of deliveries to Black Caribbean mothers	2016/17	0.003	0.003	
			Proportion of deliveries to Black African mothers	2016/17	0.002		
			Proportion of deliveries to Indian mothers	2016/17	0.006**	0.004*	1.193
			Proportion of deliveries to Pakistani mothers	2016/17	0.010***	0.008***	1.060*
			Proportion of deliveries to Bangladeshi mothers	2016/17	0.002		
			Weight	Proportion of population severely obese	2016/17	0.006**	0.005*
		Proportion of population obese	2016/17	0.008**			
		Proportion of population underweight	2016/17	0.000			
	Individual infant characteristics	Low birth weight	Proportion of births that are low weight	2017	0.010***	0.007**	
		Prematurity	Proportion of births that are premature	2015 - 2017	0.009***	0.006**	
Health care provision	Health care spending	Spend on public health per person	2015/16 - 2018/19	0.007**	0.007**	0.007***	
	Important health checks	Proportion of new birth visits within 14 days	2017/18	0.000			
		Proportion of infants receiving 6 to 8 week health check on time	2017/18	0.002			
		Proportion of children receiving 12 month health check on time	2017/18	0.001			

Theme	Suggested measure	Characteristic	Year(s)	Unadjusted	Theme adjusted	Fully adjusted
Parental behaviours	Breastfeeding	Proportion of infants breastfed at 6 to 8 weeks	2015/16 - 2018/19	-0.003	-0.003	
	Immunisations	Proportion of children with PCV vaccine at 12 months	2017/18	-0.001	0.013	
		Proportion of children with combination vaccine at 12 months	2017/18	-0.001	-0.012	
		Proportion of children with Meningitis B vaccine at 12 months	2017/18	-0.001	-0.003	
Immediate environmental factors	Residential and occupational pollution	Average air pollution deprivation score	2015	0.006**	0.007*	
	Housing quality	Proportion of under 5s living in areas with the worst housing affordability deprivation score	2015	0.005*	-0.005	-0.526**
		Proportion of under 5s living in areas with the worst housing condition deprivation score	2015	0.003	0.003	
		Proportion of under 5s living in areas with the worst central heating availability deprivation score	2015	0.008***	0.009***	0.477**
		Overcrowding	Proportion of under 5s living in areas with the worst household crowding deprivation score	2015	0.001	
	Dwellings per person	2017	-0.006**	-0.010**	-4.044**	
Local authority factors	Commissioning for early years	Spend on early years per child under 5	2017/18	-0.003	-0.004	-0.001**
		Spend on substance misuse per adult population	2016/17 - 2018/19	0.004*	0.005*	
		Spend on children's social care family support services per under 15 population	2015/16 - 2018/19	-0.001		
Wider societal	Child poverty	Proportion of under 5s living in areas with the worst	2015	0.010***	0.010***	

Theme	Suggested measure	Characteristic	Year(s)	Unadjusted	Theme adjusted	Fully adjusted
		income deprivation score				
	Population employment	Proportion of population living in areas with the worst employment deprivation score	2015	0.010***		
Socioeconomic and demographic	Community environment	Proportion of under 5s living in areas with the worst accidents involving pedestrians and cyclists deprivation score	2015	0.001		
		Average crime deprivation score	2015	0.007**	0.004*	
		Average distance to store deprivation score	2015	-0.008**		
	Health	Proportion of the population living in areas with the worst health deprivation score	2015	0.009***		
	Education	Proportion of the population living in areas with the worst adult skills deprivation score	2015	0.011***	0.010***	
		Proportion of the population living in areas with the worst children's education deprivation score	2015	0.006**		

P-value: * significant at the 5% level, ** significant at the 1% level, *** significant at the 0.01% level

Fully adjusted negative binomial regression model results

Table 8: Fully adjusted negative binomial regression model results with false discovery rate (FDR) adjusted p-values

Theme	Characteristic	Coefficient	Standard error	T-statistic	P-value	FDR p-value
-	(Intercept)	-4.35	0.58	-7.47	<0.0001	0.0000
Maternal risk factors	Proportion of deliveries to Indian mothers	1.19	0.63	1.91	0.0567	0.0567
	Proportion of deliveries to Pakistani mothers	1.06	0.44	2.43	0.0153	0.0172
	Proportion of population severely obese	6.66	2.37	2.81	0.0049	0.0074
Health care provision	Spend on public health per person	0.01	0.002	4.27	<0.0001	0.0001
	Proportion of under 5s living in areas	0.48	0.13	3.55	0.0004	0.0012

Theme	Characteristic	Coefficient	Standard error	T-statistic	P-value	FDR p-value
Immediate environmental factors	with the worst central heating availability deprivation score					
	Proportion of under 5s living in areas with the worst housing affordability deprivation score	-0.53	0.18	-2.86	0.0042	0.0074
	Dwellings per person	-4.04	1.39	-2.92	0.0035	0.0074
Local authority factors	Spend on early years per child under 5	-0.001	0.0002	-2.63	0.0087	0.0111
Adjusted R-squared				39.0%		

Table 9: Proportion of variance (adjusted R-squared) explained by each local authority characteristic in the fully adjusted model

Characteristic	Proportion of variance explained
1. Proportion of deliveries to Pakistani mothers	47%
2. Proportion of population severely obese	15%
3. Proportion of under 5s living in areas with the worst housing affordability deprivation score	9%
4. Proportion of under 5s living in areas with the worst central heating availability deprivation score	8%
5. Spend on early years per child under 5	8%
6. Spend on public health per person	7%
7. Proportion of deliveries to Indian mothers	6%
8. Dwellings per person	1%
Total	100%

Descriptive statistics for local authority characteristics, fully adjusted model

Table 10: Descriptive statistics of the outcome and the local areas characteristics included in the final regression model

Theme	Characteristic	Minimum	Median	Maximum	Mean	Standard deviation
Outcome	Infant mortality rate	0.00	3.51	7.89	3.81	1.48
Maternal risk factors	Proportion of deliveries to Indian mothers	0.001	0.01	0.31	0.03	0.04
	Proportion of deliveries to Pakistani mothers	0.00	0.01	0.33	0.04	0.06
	Proportion of population severely obese	0.005	0.02	0.06	0.02	0.01
Health care provision	Spend on public health per person	31.61	61.24	141.42	65.75	24.28
	Proportion of under 5s living in areas	0.00	0.16	0.86	0.22	0.20

Theme	Characteristic	Minimum	Median	Maximum	Mean	Standard deviation
Immediate environmental factors	with the worst central heating availability deprivation score					
	Proportion of under 5s living in areas with the worst housing affordability deprivation score	0.00	0.20	0.94	0.28	0.23
	Dwellings per person	0.32	0.43	0.57	0.43	0.03
Local authority factors	Spend on early years per child under 5	-7.30	162.76	719.24	181.43	120.73

Sensitivity analyses

Table 11: Coefficients, levels of significance, false discovery rate (FDR) adjusted significance and adjusted R-squared for the fully adjusted model and fully adjusted model excluding nine influential local authorities

Theme	Characteristic	Coefficient	Standard error	T-statistic	P-value	FDR p-value
-	(Intercept)	-3.65	0.60	-6.04	<0.0001	<0.0001
Maternal risk factors	Proportion of deliveries to Indian mothers	1.01	0.92	1.10	0.2719	0.2719
	Proportion of deliveries to Pakistani mothers	1.22	0.46	2.65	0.0081	0.0104
	Proportion of population severely obese	8.01	2.34	3.42	0.0006	0.0011
Health care provision	Spend on public health per person	0.01	0.00	4.94	<0.0001	<0.0001
Immediate environmental factors	Proportion of under 5s living in areas with the worst central heating availability deprivation score	0.43	0.13	3.35	0.0008	0.0012
	Proportion of under 5s living in areas with the worst housing affordability deprivation score	-0.67	0.18	-3.85	0.0001	0.0003
	Dwellings per person	-5.79	1.44	-4.03	0.0001	0.0002
Local authority factors	Spend on early years per child under 5	-0.001	0.0002	-2.59	0.0095	0.0107
Adjusted R-squared				47.9%		

P-value: * significant at the 5% level, ** significant at the 1% level, *** significant at the 0.01% level

Additional characteristics tested

Table 12: Additional characteristics tested with year, source, standardised coefficient and level of significance in the unadjusted model

Theme	Suggested measures	Identified characteristic	Source	Year(s)	Unadjusted
Maternal risk factors	Ethnicity	Proportion of deliveries to Black mothers	Hospital Episode Statistics, NHS Digital	2016/17	0.0017
		Proportion of deliveries to Asian mothers	Hospital Episode Statistics, NHS Digital	2016/17	0.0089***
Individual infant characteristics	Very low birth weight	Proportion of live births with a birth weight under 1500g at 37 weeks+ gestation	Office for National Statistics	2017	0.0094***
Health care provision	Health care spending	Net expenditure on children's 0-5 services (prescribed) per 1,000 population 0-5	Ministry for Housing, Communities and Local Government	2015/16 – 2018/19	0.0045*
		Net expenditure on children's 0-5 services (non-prescribed) per 1,000 population 0-5	Ministry for Housing, Communities and Local Government	2015/16 – 2018/19	0.0021
Immediate environmental factors	Residential and occupational pollution	Mean concentration of human-made fine particulate matter	Public Health England	2016	0.0025
		Proportion of under 5's living in areas with the worst air pollution deprivation score	Ministry for Housing, Communities and Local Government	2015	0.0041*
		Proportion of the population living in areas with the worst air pollution deprivation score	Ministry for Housing, Communities and Local Government	2015	0.004*
	Housing quality	Average housing affordability deprivation score	Ministry for Housing, Communities and Local Government	2015	0.0019
		Proportion of the population living in areas with the worst housing affordability deprivation score	Ministry for Housing, Communities and Local Government	2015	0.0043*
		Average housing condition deprivation score	Ministry for Housing, Communities and Local Government	2015	0.0003
		Proportion of the population living in areas with the worst housing condition deprivation score	Ministry for Housing, Communities and Local Government	2015	0.0015
		Average central heating deprivation score	Ministry for Housing, Communities and Local Government	2015	0.0067**
		Proportion of the population living in areas with the worst	Ministry for Housing, Communities and Local Government	2015	0.0074**

Theme	Suggested measures	Identified characteristic	Source	Year(s)	Unadjusted
		central heating deprivation score			
	Overcrowding	Average household crowding deprivation score	Ministry for Housing, Communities and Local Government	2015	0.0007
		Proportion of the population living in areas with the worst household crowding deprivation score	Ministry for Housing, Communities and Local Government	2015	0.0008
Local area factors	Commissioning for early years	Net expenditure on children's social care per child under 18	Ministry for Housing, Communities and Local Government	2014/15 – 2018/19	0.0023
		Net expenditure on sure start centres per child under 5	Ministry for Housing, Communities and Local Government	2015/16 – 2018/19	-0.0018
Wider societal factors	Deprivation	Average deprivation score	Ministry for Housing, Communities and Local Government	2015	0.0097***
		Proportion of under 5s living in areas with the worst deprivation score	Ministry for Housing, Communities and Local Government	2015	0.0102***
		Proportion of the population living in areas with the worst deprivation score	Ministry for Housing, Communities and Local Government	2015	0.01***
	Child poverty	Proportion of under 5's living in out of work benefit households	Department for Work and Pensions	2017	0.0081***
		Proportion of children living in low income families	HM Revenue and Customs	2016	0.0085***
		Average income deprivation affecting children score	Ministry for Housing, Communities and Local Government	2015	0.0078***
		Proportion of under 5's living in the worst areas for income deprivation affecting children score	Ministry for Housing, Communities and Local Government	2015	0.0076***
		Proportion of the population living in the worst areas for income deprivation affecting children score	Ministry for Housing, Communities and Local Government	2015	0.0071**
		Average income deprivation score	Ministry for Housing, Communities and Local Government	2015	0.0094***
		Proportion of the population living in areas with the worst income deprivation score	Ministry for Housing, Communities and Local Government	2015	0.0094***
	Population employment	Average employment deprivation score	Ministry for Housing, Communities and Local Government	2015	0.0092***
		Proportion of under 5's living in areas with the	Ministry for Housing, Communities and Local Government	2015	0.0096***

Theme	Suggested measures	Identified characteristic	Source	Year(s)	Unadjusted		
		worst employment deprivation score					
Socioeconomic and demographic	Community environment	Average accidents involving pedestrians and cyclists deprivation score	Ministry for Housing, Communities and Local Government	2015	0.0011		
		Proportion of the population living in areas with the worst accidents involving pedestrians and cyclist deprivation score	Ministry for Housing, Communities and Local Government	2015	0.0011		
		Proportion of under 5's living in areas with the worst crime deprivation score	Ministry for Housing, Communities and Local Government	2015	0.0069**		
		Proportion of the population living in areas with the worst crime deprivation score	Ministry for Housing, Communities and Local Government	2015	0.0064**		
		Proportion of under 5's living in areas with the worst distance to store deprivation score	Ministry for Housing, Communities and Local Government	2015	0.0017		
		Proportion of the population living in areas with the worst distance to store deprivation score	Ministry for Housing, Communities and Local Government	2015	0.0089***		
		Health	Average health deprivation score	Ministry for Housing, Communities and Local Government	2015	0.0094***	
			Proportion of under 5's living in areas with the worst health deprivation score	Ministry for Housing, Communities and Local Government	2015	0.0045*	
		Education		Average adult skills deprivation score	Ministry for Housing, Communities and Local Government	2015	0.0021
				Proportion of under 5's living in areas with the worst adult skills deprivation score	Ministry for Housing, Communities and Local Government	2015	0.0025
Average children's education deprivation score	Ministry for Housing, Communities and Local Government			2015	0.0041*		
Proportion of under 5's living in areas with the worst children's education deprivation score	Ministry for Housing, Communities and Local Government			2015	0.004*		
Average education deprivation score	Ministry for Housing, Communities and Local Government			2015	0.0019		
Proportion of under 5's living in areas with the worst education deprivation score	Ministry for Housing, Communities and Local Government			2015	0.0043*		

Theme	Suggested measures	Identified characteristic	Source	Year(s)	Unadjusted
		Proportion of the population living in areas with the worst education deprivation score	Ministry for Housing, Communities and Local Government	2015	0.0003

P-value: * significant at the 5% level, ** significant at the 1% level, *** significant at the 0.01% level

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