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Neighbourhood material deprivation and severe maternal morbidity: A population-based cohort study in Ontario, Canada.

Journal:	BMJ Open
Manuscript ID	bmjopen-2020-046174
Article Type:	Original research
Date Submitted by the Author:	21-Oct-2020
Complete List of Authors:	Snelgrove, John; Sinai Health System, Obstetrics & Gynaecology; University of Toronto, Obstetrics & Gynaecology Lam, Melody; ICES Western Watson, Tristan; Institute for Clinical Evaluative Sciences, Richard, Lucie; Institute for Clinical Evaluative Sciences, N/A Fell, DB; CHEO Research Institute, Ottawa, Ontario, Canada; University of Ottawa, School of Epidemiology and Public Health Murphy, Kellie; Sinai Health System, Obstetrics & Gynaecology; University of Toronto, Obstetrics & Gynaecology Rosella, Laura; University of Toronto, Dalla Lana School of Public Health
Keywords:	EPIDEMIOLOGY, OBSTETRICS, PERINATOLOGY
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3 4	1	TITLE PAGE
5 6 7	2	Neighbourhood material deprivation and severe maternal morbidity:
, 8 9	3	A population-based cohort study in Ontario, Canada
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2 3 4 5	26	ABSTRACT
6 7	27	Objectives: Rates of age-associated severe maternal morbidity (SMM) have increased in
8 9 10	28	Canada, and an association with neighbourhood income is well established. Our aim was to
11 12	29	examine SMM trends according to neighbourhood material deprivation quintile, and to
13 14 15	30	assess whether neighbourhood deprivation effects are moderated by maternal age.
16 17 18	31	Design, setting, participants: A population-based retrospective cohort study using linked
19 20 21	32	administrative databases in Ontario, Canada. We included primiparous women with a live
21 22 23 24	33	birth or stillbirth at ≥20 weeks gestational age.
25 26	34	Primary outcome: SMM from pregnancy onset to 42 days postpartum. We calculated SMM
27 28 20	35	rate differences (RD) and rate ratios (RR) by neighbourhood material deprivation quintile for
29 30 31	36	each of four 4-year cohorts from 1 April 2002 to 31 March 2018. Log-binomial multivariable
32 33 34	37	regression adjusted for maternal age, demographic, and pregnancy-related variables.
35 36 37	38	Results: There were 1,048,845 primiparous births during the study period. The overall rate
38 39	39	of SMM was 18.0 per 1,000 births. SMM rates were elevated for women living in areas with
40 41 42	40	high material deprivation. In the final 4-year cohort, the RD between women living in high
43 44	41	versus low deprivation neighbourhoods was 3.91 SMM cases per 1,000 births (95% CI: 2.12,
45 46 47	42	5.70). This was higher than the difference observed during the first 4-year cohort (RD 2.09,
47 48 49	43	95% CI: 0.62, 3.56). SMM remained associated with neighbourhood material deprivation
50 51	44	following multivariable adjustment in the pooled sample (RR 1.16, 95% CI: 1.11, 1,21). There
52 53 54 55	45	was no evidence of interaction with maternal age.
55 56 57	46	Conclusion: SMM rate increases were more pronounced for primiparous women living in
58 59 60	47	neighbourhoods with high material deprivation compared to those living in low deprivation

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3	48	areas. This raises concerns of a widening social gap in maternal health disparities and
4 5		
6 7	49	highlights an opportunity to focus risk reduction efforts toward disadvantaged women
8	50	during pregnancy and postpartum.
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13 14		
14	52	Keywords: severe maternal morbidity; maternal mortality; maternal health; pregnancy;
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17	53	perinatal epidemiology; social epidemiology; social inequalities; deprivation
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23	55	Strengths and Limitations of this Study
24 25	55	Strengths and Emitations of this Study
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27	56	• Data were from population linked administrative and health registries that capture
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29 30	57	all hospital births in Ontario, Canada 🖴
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33	58	 Neighbourhood material deprivation was measured using the Ontario
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35 36	59	Marginalization Index, which was developed using theoretical frameworks on
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38	60	marginalization and deprivation specific to Ontario
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40 41	C1	• Limiting our study to priminarous women enabled the avaluation of nonvelation SMM
42	61	Limiting our study to primiparous women enabled the evaluation of population SMM
43	62	trands and reduced confounding from provinus hirths
44	62	trends and reduced confounding from previous births
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40 47	63	• It was not possible to control for all covariates associated with SMM, including body
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49	64	mass index and the use of assisted reproductive technology
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66 INTRODUCTION

Each year, approximately 4,000 Canadian women survive a maternal "near-miss"—a life-threatening event associated with pregnancy.[1] To characterize maternal near-misses in a standardized way, the World Health Organization proposed the concept of severe maternal morbidity (SMM), a composite of conditions that represent end-organ dysfunction or states of heightened maternal mortality risk associated with pregnancy, birth, or the postpartum period.[2, 3] Advances in the recognition and management of SMM have resulted in low maternal mortality rates in economically developed nations. Women living in high income countries are now more likely to survive a life-threatening pregnancy condition and, correspondingly, the rates of SMM are 100-fold higher than maternal mortality rates in Canada.[1] However, recent trends in Canada and other high income countries show an increase in SMM rates coinciding with advancing maternal age [4-7]. In a recent Canadian study, women from low-income neighbourhoods had a higher risk of SMM.[4] Women of advanced maternal age tend to come from more advantaged socioeconomic backgrounds and are more likely to have planned pregnancies.[8-10] The effects of maternal age and neighbourhood-level marginalization may therefore interact, with the highest SMM risk among older mothers living in neighbourhoods with higher material deprivation. Our first objective was to evaluate trends in SMM rates among primiparous women in

Ontario by neighbourhood material deprivation quintile between 1 April 2002 and 31 March
2018. Our second objective was to determine if maternal age moderates the effect of
neighbourhood material deprivation. We hypothesized that SMM rates would increase
disproportionately over time among women living in neighbourhoods with high material

deprivation. We further hypothesized that the highest risk of SMM would be among women of advanced maternal age living in neighbourhood with the highest material deprivation. **METHODS** This population-based retrospective cohort study used linked administrative datasets for Ontario, held at ICES, which is an independent non-profit research institute whose legal status under Ontario's health information privacy law allows it to collect and analyze health care and demographic data, without consent, for health system evaluation and improvement. The use of data in this project was authorized under section 45 of Ontario's Personal Health Information Protection Act, which does not require review by a Research Ethics Board. We followed the RECORD guidelines (REporting of studies Conducted using Observational Routinely-collected Data) for reporting this study.[11] Patient and public involvement There was no direct patient or public involvement in this study. Study population and data sources The Canadian Institute for Health Information Discharge Abstract Database (DAD) was used to capture all hospital admissions for birth and link to newborn records using the ICES-derived MOMBABY dataset. We included primiparous women aged 10-55 years who had a hospital birth in Ontario and were enrolled in the province's universal health insurance program (OHIP). We identified the first live birth or stillbirth delivery at a gestational age of ≥20 weeks. We used gestational age at birth to calculate pregnancy onset. Women were included if the onset of their first pregnancy was on or after 1 April 2002 and the

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corresponding birth occurred on or before 17 February 2018-allowing 42 days of postpartum follow-up through the study end date of 31 March 2018. Women who had a previous birth within 14 years prior to the index date were excluded. We linked these data with the Registered Persons Database (RPDB), DAD, and OHIP Claims Database to identify exposures and outcomes of interest. To identify women who had recently immigrated to Ontario, we used the Ontario portion of the federal Immigration, Refugees and Citizenship Canada (IRCC) Permanent Resident Database. For neighbourhood material deprivation, we used the 2001 and 2006 Canadian Census, and Ontario Marginalization Index (ON-MARG) database.[12] These datasets were linked using unique encoded identifiers and analyzed at ICES and are shown in Appendix 1.

Main outcome

The main outcome was a composite of medical conditions and interventions that comprise SMM. Previously validated indicators for Canada have been used to identify cases of SMM with diagnosis and procedural codes (International Statistical Classification of Diseases and Related Health Problems, 10th revision [ICD-10] and Canadian Classification of Health Interventions, respectively) within administrative databases.[9, 13-15] The composite SMM outcome included: 1) causes of direct obstetric death and conditions related to these (antepartum, intrapartum, and postpartum hemorrhage; hypertensive disorders of pregnancy; eclampsia, and HELLP syndrome; puerperal sepsis; uterine rupture; obstetric embolus); 2) severe organ system dysfunction (cardiac arrest, failure, or arrhythmia; renal or hepatic failure; coagulation defect; thromboembolism; respiratory failure; coma or noneclamptic seizure; psychosis); 3) procedures or interventions accompanying life-threatening conditions or health states (cesarean or postpartum hysterectomy; pelvic vessel ligation;

surgical repair of bowel, bladder, or urethra; endotracheal or tracheostomy ventilation;
dialysis; blood transfusion in the context of severe blood loss); and 4) deaths that were illdefined or sudden, as these could not reliably be classified as non-obstetric deaths.
Appendix 1 shows the list of SMM indicators for this study. We specified a binary SMM
outcome variable for the presence of one or more indicators occurring from the onset of
pregnancy up to and including 42 days after birth.

138 Exposures and covariates

Our main exposure of interest was neighbourhood material deprivation quintile from the Ontario Marginalization Index (ON-MARG).[12] The index is a neighbourhood-level composite measure of income, educational attainment, single-parent families, and housing guality and is based on Census data from 2001 and 2006. We used the 2001 material deprivation index for births between years 2002-2003, and the 2006 index for years 2004-2018. The change from mandatory Census reporting to the voluntary National Household Survey and resulting data quality concerns meant that the 2011 index was comprised from alternate data sources. [12] We used the 2006 version for all years after 2004 to avoid operationalizing this variable differently between study years. ON-MARG has been used to demonstrate inequalities in various health measures and is stable over time. [16-18] The ON-MARG index is a continuous variable which we modelled in guintiles, with guintile 1 representing neighbourhoods with the lowest material deprivation, and quintile 5 representing neighbourhoods with the highest deprivation. We included maternal age at birth, categorized in 5-year bands. We adjusted for rural setting using the 2004 and 2008 Rurality Index of Ontario (RIO).[19] We used the 2004 RIO

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index for pregnancies between years 2002 and 2006, and the 2008 index for years 2007 to 2018. We adjusted for number of years since immigration using data from the IRCC. Additional demographic and pregnancy related variables included delivery mode and multiple gestations. For multiple gestation pregnancies, delivery mode was specified based on highest level of intervention: unassisted vaginal birth of all fetuses (lowest), assisted vaginal birth of one or more fetuses, assisted vaginal breech birth of one or more fetuses, and caesarean birth of one or more fetuses (highest). We examined SMM rates by gestational age at birth, induction of labour, and the use of epidural analgesia, however these variables were not adjusted-for in the multivariable models. **Statistical analysis** We summarized baseline characteristics and SMM rates overall for the study population. Due to low birth counts for ages 10-14 years, we collapsed these into an age <20 years group for analysis. We plotted SMM rates by year for the whole study population, and then to evaluate changes over time, we divided the population into four, 4-year cohorts based on pregnancy onset: 1 April 2002 to 31 March 2006 (cohort 1); 1 April 2006 to 31 March 2010 (cohort 2); 1 April 2010 to 31 March 2014 (cohort 3); and 1 April 2014 to 31 March 2018 (cohort 4). To address our first objective, we calculated average annual SMM rates for each 4-year cohort by neighbourhood material deprivation quintile. Within each cohort, we estimated unadjusted absolute rate differences (RD) and rate ratios (RR) with 95% confidence intervals (CI) comparing women in quintile 5 (highest deprivation) with women in quintile 1 (lowest deprivation).

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175	Our second objective was to evaluate the effect of neighbourhood material deprivation,
176	adjusting for covariates and testing for interaction with maternal age for the overall study
177	population. We constructed multivariable log-binomial regression models. We initially fit a
178	model with neighbourhood material deprivation, adjusting only for year of pregnancy onset
179	(model 1). We then added maternal age (model 2), followed by demographic and
180	pregnancy-related covariates, immigration status, and rurality (model 3). We tested for
181	interaction between material deprivation and maternal age using a cross product term. We
182	did not adjust for stillbirth or gestational age at birth, as these are variables are considered
183	colliders rather than true confounders of outcomes associated with SMM.[20] We did not
184	include induction of labour or epidural analgesia, as these interventions are associated with
185	clinical decisions surrounding birth rather than SMM risk factors. We excluded women with
186	missing information for neighbourhood material deprivation from the multivariable analysis,
187	as these women represented less than 2 percent of the study population (n=17,130).
188	We performed two additional analyses evaluating SMM rate trends (RD and RR) over the
189	study period, comparing the 4-year average annual rates during cohort 4 to cohort 1
190	separately by maternal age and by neighbourhood material deprivation quintile. We also
191	examined the 4-year average rates of SMM excluding cases defined by HIV disease. This was
192	done in reference to recently proposed changes to the Canadian SMM composite indicator
193	excluding chronic, asymptomatic HIV disease.[21, 22] Statistical analyses were performed
194	using SAS (version 7.15, SAS Institute Inc., Cary, NC) and STATA (version 13, StataCorp.,
195	College Station, TX).
196	RESULTS

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There were 2,143,045 hospital-based births in Ontario between 1 April 2002 and 17 197 February 2018, of which 1,048,845 were primiparous births and included in the study 198 199 (Figure 1). The overall SMM rate across the study period was 18.0 per 1,000 births, and 200 increased from 16.7 per 1,000 births in 2002/03 (95% CI: 15.6, 17.9) to 23.0 per 1,000 births in 2017/18 (95% CI: 21.2, 25.0, Supplementary Figure 1). Baseline characteristics and SMM 201 202 rates for each characteristic are presented in **Table 1**. SMM rates were higher at the 203 extremes of maternal age, and among women living in neighbourhoods with the highest material deprivation. 204

Table 2 presents SMM rates by material deprivation quintile for each of the four 4-year 205 206 cohorts. The RD was 2.09 cases per 1,000 births (95% CI: 0.62, 3.56), corresponding with a RR of 1.13 (95% CI: 1.04, 1.23) comparing women in quintile 5 with women in quintile 1 207 208 during the first 4-year cohort. This increased to a RD of 3.91 cases per 1,000 births (95% CI: 209 2.12, 5.70) and RR of 1.21 (95% CI: 1.11, 1.32) in the final 4-year cohort of the study period. 210 Average annual SMM rates increased between cohort 1 and cohort 4 for women aged 30-34, and \geq 40 years (Supplementary Table 1, Supplementary Figure 2). For the latter group, 211 212 the absolute increase was 14.69 cases per 1,000 births (95% CI: 7.96-21.43, Supplementary 213 Table 2). SMM rates increased over time for women in each quintile of neighbourhood 214 deprivation, and this increase was most pronounced for women in the highest quintile of 215 neighbourhood deprivation (RD 4.19 cases per 1,000 births 95% CI: 4.13-4.24,

216 Supplementary Table 2).

In the multivariable regression analysis for the overall study population, women living in
 neighbourhoods with the highest material deprivation had higher rates of SMM compared
 those in neighbourhoods with the lowest after adjusting for pregnancy year (RR: 1.11, 95%)

CI: 1.06, 1.16, **Table 3**). Full adjustment for age, demographic, pregnancy-related variables,
and rurality had minimal effect on the association between material deprivation and SMM
rates (adjusted RR: 1.16, 95% CI: 1.11, 1.21, **Table 3**). The association between age and SMM
persisted in the fully adjusted model, with higher risk for women <20 and ≥30 years of age.
We did not find evidence of statistical interaction between maternal age and

225 neighbourhood material deprivation quintile.

226 DISCUSSION

227 Main findings

This study demonstrated an association between neighbourhood material deprivation and severe maternal morbidity among primiparous women in Ontario from 2002-2018. Rates of SMM increased across all material deprivation quintiles, and we found some evidence that women in the highest deprivation quintile experienced a higher magnitude SMM rate increase over the 16-year study period compared with women in the lowest deprivation quintile. This finding suggests a possible widening of the gap between the most and least deprived.

235 Strengths/ limitations

The current study was a population-based analysis of all primiparous hospital births at ≥20
 weeks' gestational age in Ontario. Hospital births account for over 98% of births in the
 province. We used a measure of neighbourhood marginalization that includes income along
 with other measures of material resources, and that is stable across different health
 outcomes.[16, 23] Our study nonetheless had some limitations. We were unable to account
 for births prior to 20 weeks' gestation or births that occurred outside of the province. Our

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242	measure of SMM was based on validated perinatal health data for Canada.[9, 15] A revision
243	of the Canadian SMM composite was recently proposed which resolves issues surrounding
244	the inclusion of some pre-eclampsia and HELLP syndrome measures, as well as the exclusion
245	of HIV infection—a condition that is unlikely to represent SMM when asymptomatic [21,
246	22]. We elected to use the former SMM composite for comparison with other world
247	literature, recognizing this may complicate direct comparison with recent Canadian studies
248	[4, 6, 21, 22]. The proportion of women with SMM defined by HIV disease was around 2%
249	for each of the 4-year cohorts, and thus we do not believe these cases substantively altered
250	the results of this study. Several patient-related risk factors, including pre-pregnancy co-
251	morbidities and obesity, contribute to rising SMM rates.[24] Additionally, increased use of
252	assisted reproductive technologies may partially explain SMM trends.[25, 26]. Unfortunately
253	we were unable to control for these factors. Information on immigrants arriving prior to
254	1985 is not captured in the IRCC Permanent Resident Database. In addition, the IRCC
255	database available at ICES is not able to identify immigrants who landed in other provinces
256	and subsequently moved to Ontario. Although we used a measure of neighbourhood
257	material deprivation developed for Ontario [12], the ON-MARG index does not include
258	individual-level indicators of marginalization or socioeconomic status. Important social
259	determinants may differ among individuals living in areas characterized by similar measures
260	of neighbourhood deprivation.[27]
261	Interpretation

The present study contributes to our understanding of the association between
 neighbourhood marginalization and SMM and provides preliminary evidence of a possible
 widening of this health disparity over time in Ontario. The association between

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2	265	neighbourhood-level measures of inequality and risk of SMM has been demonstrated
2	266	previously in several high-income countries. [6, 26, 28-34] Notably in Canada, Aoyama and
2	267	colleagues reported a rise in SMM linked to the relative increase in maternal age and found
2	268	a significant association between SMM and neighbourhood income quintile.[4]. Our study
2	269	confirms this finding using a measure that encompasses income along with additional
2	270	measures of neighbourhood material deprivation. Moreover, we extend the current
2	271	understanding of this association by providing evidence suggesting a possible
2	272	disproportionate rise in SMM risk experienced by women living in marginalized
2	273	neighbourhoods over time. We interpret this last finding with caution, however, as our
2	274	study showed significant rate differences by neighbourhood marginalization only during the
2	275	first and final 4-year cohorts of the 16-year study period. SMM risks have been
2	276	demonstrated among other social determinants of health; For example, lower occupational
2	277	class, Black ethnicity,[35] and non-private health insurance[29] are associated with higher
2	278	risk of SMM in the US. Interaction between socioeconomic indicators—including ethnicity,
2	279	education, and poverty—likely contribute to the social gradient of risk such that the
2	280	protective effects afforded by higher education and income do not fully ameliorate racial
2	281	disparities in SMM.[30] Our study showed an association between neighbourhood
2	282	deprivation and SMM suggesting the effects of marginalization persist even in the context of
2	283	universal healthcare. This is a consistent finding across countries that have similar publicly
2	284	funded healthcare systems.[33, 36, 37] The factors contributing to social inequality are
2	285	myriad; ethnicity and country of origin, rurality and access to care, income, material
2	286	resources, education, and psychosocial supports all have worrisome associations with
2	287	maternal reproductive health risks.[6, 22, 29, 30, 33, 35-41] How these factors contribute to

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2 3	200	widening health gans, and what interventions may attenuate their offects will be importained
4	288	widening health gaps, and what interventions may attenuate their effects will be imperative
5 6 7	289	lines of inquiry going forward as the global challenge to lower SMM continues.
8 9 10	290	Conclusion
11 12 13	291	Our study found that women living in areas with higher neighbourhood material
14 15 16	292	deprivation experienced the highest risk of SMM, and this was not fully explained by
17 18	293	maternal age. Additionally, women living in high-deprivation neighbourhoods may have
19 20 21	294	experienced a disproportionate increase in the risk of SMM over time. Future work must
22 23	295	focus on addressing the widening social gap in maternal health disparities.
24 25 26 27	296	focus on addressing the widening social gap in maternal health disparities.
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TABLES

Table 1. Baseline characteristics of the study population, 2002/03-2017/18. N=1,048,845

309 births.

SMM rate per		Number of	
1,000 births	Percent	births	Variable
18.00	100	1,048,845	Overall study population
			Maternal age at birth, years
26.32	0.1	1,330	10-14
17.79	6.9	72,579	15-19
15.07	17.0	178,074	20-24
15.57	32.6	342,003	25-29
18.48	29.2	305,898	30-34
24.39	11.8	123,698	35-39
34.68	2.4	25,263	≥40
			Gestational age at birth, weeks
53.44	0.3	2,751	20-23
73.59	0.4	4,158	24-27
62.42	1.7	17,688	28-33
33.30	5.6	59,040	34-36
15.89	91.7	961,322	37-41
20.33	0.4	3,886	≥42
21.20	26.2	275,262	Induced labour
16.35	62.5	655,107	Epidural
			Delivery mode
11.01	55.3	579,814	Vaginal unassisted
17.42	14.9	156,383	Vaginal assisted
40.81	0.2	2,328	Vaginal breech
31.18	29.6	310,320	Caesarean
54.53	2.0	20,850	Multiple gestations
54.60	0.3	3,645	Stillbirth
			Rurality
17.93	94.7	993,282	Urban
19.19	5.3	55,563	Rural
			Immigration Status
17.89	70.5	739,252	Non-immigrant / before 1985
18.68	5.9	62,381	Immigrated >10 years
20.12	5.9	62,090	Immigrated 5-10 years
17.52	17.7	185,122	Immigrated <5 years
	17.7	185,122	Immigrated <5 years Neighbourhood material deprivation

	Quintile 1 (least deprived)	237,877	22.7	17.58
	Quintile 2	186,550	17.8	16.68
	Quintile 3	189,575	18.1	17.55
	Quintile 4	191,376	18.2	17.89
	Quintile 5 (most deprived)	226,337	21.6	19.43
1	Missing	17,130	1.6	25.57

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Table 2. Four-year average SMM rates per 1,000 births for neighbourhood material

313 deprivation quintiles, by study period cohort.

	SMM rates	by materia	l deprivatio	n quintile		<i>Q5 vs Q1</i> Rate difference (95%	
Cohort ^a	Q1 (least)	Q2	Q3	Q4	Q5 (most)	CI)	Rate ratio (95% CI
1	16.05	16.36	17.46	16.49	18.14	2.09 (0.62, 3.56)**	1.13 (1.04, 1.23)**
2	16.58	15.97	15.73	16.37	17.32	0.75 (-0.70, 2.20)	1.05 (0.96, 1.14)
3	19.36	16.17	18.34	19.19	20.78	1.41 (-0.20, 3.02)	1.07 (0.99, 1.16)
4	18.41	18.52	18.99	20.18	22.32	3.91 (2.12, 5.70)***	1.21 (1.11, 1.32)**
314 315 °C	cohort 1: 1 Ap	ril 2002 to :	31 March 2	006; coho	rt 2: 1 April 2	006 to 31 March 2010	; cohort 3:
	April 2010 to						
317 [*] r	o<0.05 <i>,</i> **p<0.0	01 <i>,</i> ***p<0.(001				
318							
319							
320							

Table 3. Neighbourhood material deprivation and risk of SMM: Adjusted multivariable

models, RR (95% CI). N=1,031,715 births.

) 10		Variable	Model 1ª	Model 2 ^b	Model
1		Maternal age (years)			
2		<20		1.05 (0.99, 1.12)	1.20 (1.13, 1.28)
3		20-24		0.95 (0.90, 0.99)	1.01 (0.96, 1.06)
4		25-29		1 (ref)	1 (ref)
5 6		30-34		1.19 (1.14, 1.23)	1.10 (1.06, 1.15)
7		35-39		1.56 (1.49, 1.63)	1.34 (1.28, 1.40)
8		≥40		2.21 (2.06, 2.37)	1.73 (1.61, 1.86)
9		Material deprivation			
20		Quintile 1 (least)	1 (ref)	1 (ref)	1 (ref)
1		Quintile 2	0.95 (0.91, 0.99)	0.97 (0.93, 1.02)	0.97 (0.92, 1.01)
3		Quintile 3	1.00 (0.96, 1.05)	1.04 (0.99, 1.08)	1.03 (0.98, 1.07)
4		Quintile 4	1.02 (0.98, 1.07)	1.07 (1.02, 1.12)	1.06 (1.01, 1.11)
5		Quintile 5 (most)	1.02 (0.98, 1.07)	1.17 (1.12, 1.22)	1.16 (1.11, 1.21)
26				1.17 (1.12, 1.22)	1.10 (1.11, 1.21)
7 8		^a adjusted for pregnancy ye	ear		
29		^b adjusted for pregnancy ye			
0		^c adjusted for pregnancy ye		ultiple	
1		gestations, immigration sta	atus, rurality		
2	324				
3 4					
85	325				
86	525				
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55	331				
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3 4	333	FIGURE CAPTIONS
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6	224	Figure 1 Chudu inclusion / avaluation flow about principarous births
7	334	Figure 1. Study inclusion / exclusion flow chart, primiparous births.
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9 10	335	
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13	336	SUPPLEMENTARY MATERIAL CAPTIONS
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16	337	Supplementary Appendix 1. Data sources for the project.
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20	338	Supplementary Figure 1. Annual crude SMM rate per 1,000 births, 2002/03-2017/18.
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23	339	Supplementary Figure 2. Average annual SMM rates per 1,000 births by maternal age.
24 25		
26	240	Supplementary Table 1 Four war average SMM rates per 1,000 births by age and by
27	340	Supplementary Table 1. Four-year average SMM rates per 1,000 births by age and by
28	244	material departmention, and note all and a standard structures in d
29	341	material deprivation, and rate change over study period.
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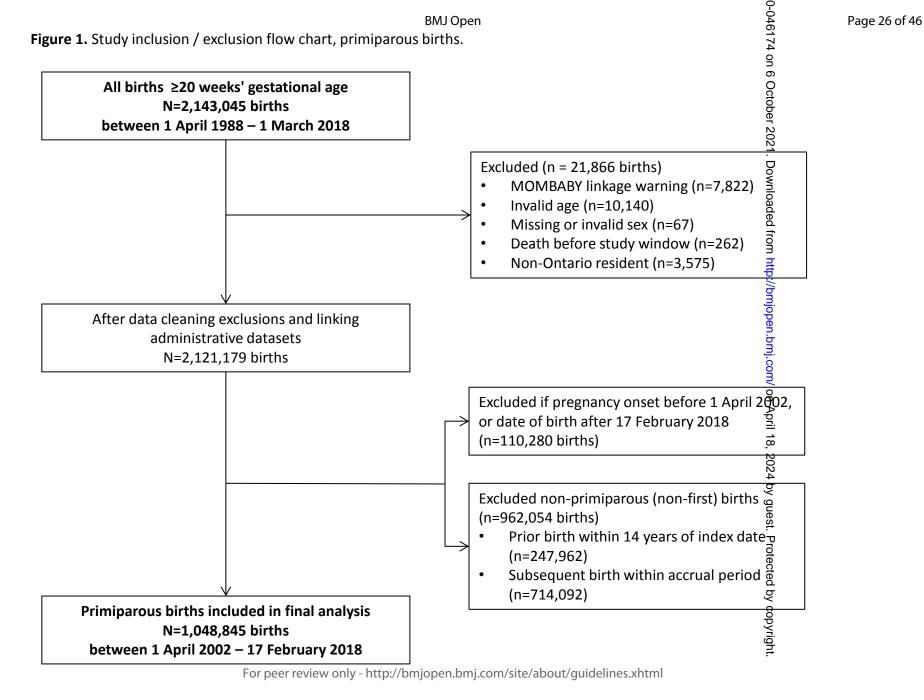
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2 3 4 5	351	Acknowledgements
6 7	352	The authors would like to thank Josie Chundamala, Scientific Grant Editor funded by the
8 9	353	Department of Obstetrics and Gynecology at Mount Sinai Hospital, for assistance editing
10 11 12 13	354	and preparing this manuscript for submission.
14 15 16	355	Declaration of competing interests
17 18 19	356	The authors declare no conflicts of interest.
20 21 22 23	357	Author contributions
24 25	358	JWS, DF, KEM, and LCR contributed to the overall conception of the study. JWS, ML, LR, DF,
26 27 28	359	and LCR contributed to study design and protocol. TW had full access to data used in the
29 30	360	study. JWS, TW, and LCR take responsibility for the integrity of the data analysis. JWS wrote
31 32 33	361	the manuscript. All authors made substantial contributions to the data analysis
34 35	362	interpretation, and manuscript editing and revising for this project. All authors approve the
36 37 38	363	final submitted version and agree to be accountable for all aspects of the work.
39 40 41	364	Ethical approval
42 43 44	365	ICES is a prescribed entity under section 45 of Ontario's Personal Health Information
45 46	366	Protection Act. Section 45 authorizes ICES to collect personal health information, without
47 48 49	367	consent, for the purpose of analysis or compiling statistical information with respect to the
50 51	368	management of, evaluation or monitoring of, the allocation of resources to or planning for
52 53 54	369	all or part of the health system. Projects conducted under section 45, by definition, do not
55 56	370	require review by a Research Ethics Board. This project was conducted under section 45,
57 58	371	and approved by ICES' Privacy and Legal Office.
59 60		20

1 2		
3 4 5	372	Patient consent for publication
6 7 8	373	None required.
9 10 11	374	Data availability statement
12 13 14	375	The dataset from this study is held securely in coded form at ICES. While data sharing
15 16	376	agreements prohibit ICES from making the dataset publicly available, access may be granted
17 18 19	377	to those who meet pre-specified criteria for confidential access, available at
20 21	378	www.ices.on.ca/DAS. The full dataset creation plan and underlying analytic code are
22 23	379	available from the authors upon request, understanding that the computer programs may
24 25 26	380	rely upon coding templates or macros that are unique to ICES and are therefore either
27 28 29	381	inaccessible or may require modification.
30 31 32	382	Funding
33 34 35	383	John Snelgrove received funding for this project through an internal grant from the
36 37 38	384	Department of Obstetrics & Gynaecology, University of Toronto, and Department of
38 39 40	385	Obstetrics & Gynaecology, Mount Sinai Hospital. This study was supported by ICES, which is
41 42	386	funded by an annual grant from the Ontario Ministry of Health and Long-Term Care
43 44 45	387	(MOHLTC). This study was completed at the ICES University of Toronto site and ICES
46 47	388	Western site—where core funding is provided by the Academic Medical Organization of
48 49 50	389	Southwestern Ontario, the Schulich School of Medicine and Dentistry, Western University,
51 52	390	and the Lawson Health Research Institute. Parts of this material are based on data and
53 54 55	391	information compiled and provided by the Canadian Institute for Health Information, and by
56 57	392	Immigration, Refugees and Citizenship Canada (IRCC). The analyses, conclusions, opinions
58 59 60		21

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3	393	and statements expressed herein are solely those of the authors and do not reflect those of
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6	394	the funding or data sources; no endorsement is intended or should be inferred.
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Supplementary Appendix 1. Data sources for project

Discharge Abstract Database (DAD)

The DAD is compiled by the Canadian Institute for Health Information and contains administrative, clinical (diagnoses and procedures/interventions), demographic, and administrative information for all admissions to acute care hospitals, rehab, chronic, and day surgery institutions in Ontario. At ICES, consecutive DAD records are linked together to form 'episodes of care' among the hospitals to which patients have been transferred after their initial admission.

MOMBABY

The ICES MOMBABY Database is an ICES-derived cohort that links the DAD inpatient admission records of delivering mothers and their newborns. From 2002 onward, this linkage is performed deterministically using a maternal-newborn chart matching number. Prior to 2002, mothers were linked to their children by matching on the institutions they were admitted, their postal codes, and their admission/discharge dates.

Registered Persons Database (RPDB)

The RPDB provides basic demographic information (age, sex, location of residence, date of birth, and date of death for deceased individuals) for those issued an Ontario health insurance number. The RPDB also indicates the time periods for which an individual was eligible to receive publicly funded health insurance benefits and the best known

Ontario Health Insurance Plan (OHIP)

The OHIP claims database contains information on inpatient and outpatient services provided to Ontario residents eligible for the province's publicly funded health insurance system by fee-for-service health care practitioners (primarily physicians) and "shadow billings" for those paid through non-fee-for-service payment plans. The main data elements include patient and physician identifiers (encrypted), code for service provided, date of service, associated diagnosis, and fee paid.

Immigration, Refugees, and Citizenship Canada's (IRCC) Permanent Resident Database

The Ontario portion of the IRCC Permanent Resident Database includes immigration application records for people who initially applied to land in Ontario since 1985. The dataset contains permanent residents' demographic information such as country of citizenship, level of education, mother tongue, and landing date. New immigrants who are currently residing in Ontario but originally landed in another province are not captured in this dataset.

Ontario Marginalization Index (ONMARG)

ONMARG is a geographically (census) based index developed to quantify the degree of marginalization occurring across the province of Ontario. It is comprised of four major dimensions thought to underlie the construct of marginalization: residential instability, material deprivation, dependency, and ethnic concentration. The dataset contains census divisions (CD), census tracts (CT), census subdivisions (CSD), consolidated municipal service manager areas (CMSM), public health units (PHU), local health integration networks (LHIN), sub-LHINs, and dissemination areas (DA).

These datasets were linked using unique encoded identifiers and analyzed at ICES.

The dataset from this study is held securely in coded form at ICES. While data sharing agreements prohibit ICES from making the dataset publicly available, access may be granted to those who meet pre-specified criteria for confidential access, available at www.ices.on.ca/DAS. The full dataset creation plan and underlying analytic code are available from the authors upon request, understanding that the computer programs may rely upon coding templates or macros that are unique to ICES and are therefore either inaccessible or may require modification.

Neighbourhood material deprivation and severe maternal morbidity: A population-based cohort study in Ontario, Snelgrove JW et al. Canada

Concept	Data Sources	Code Type	Window	Notes (including Dataset references)
Inclusion Criteria	1	1	-	
Hospital birth (live or stillbirth) at gestational age ≥20 weeks	DAD, MOMBABY	ICD-10 main patient service code for "Obstetrical birth"	Accrual window: 1 April 2002 – 17 Feb 2018	Canadian Institute for Health Information Discharge Abstract Database (DAD, linked to newborn record in MOMBABY dataset) See: <u>https://datadictionary.ices.on.ca/Ap ations/DataDictionary/Library.aspx/ ary=MOMBABY</u>
Exclusion Criteria				
Missing or invalid IKN	RPDB	0	Index date	Registered Persons Database See: <u>https://datadictionary.ices.on.ca//</u> <u>lications/DataDictionary/Library.as</u> ?Library=RPDB
MOMBABY linkage warning	MOMBABY	C C	Index date	
Missing or invalid age (<10 or >55)	RPDB		Index date	
Missing or invalid sex	RPDB		Index date	
Death before the index date	RPDB		Index date	
Non-Ontario residents / invalid OHIP number	RPDB		Index date	
Any births with an index date occurring outside of the accrual period	MOMBABY		Accrual window	Pregnancy onset before 1 April 200
Any births occurring after accrual end date	MOMBABY		Accrual window	Births after 17 February 2018
Not first birth	MOMBABY		14 years prior to index date	Prior record in MOMBABY within pa 14 years of index date
Not first birth in accrual period	MOMBABY		Accrual window	Subsequent records in MOMBABY

Page 2

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5 6	Outcome				
7	Concept	Data	Code Type	Window	Notes
8		Sources			(including Dataset references)
9	Severe maternal	DAD	ICD 10	Start of lookback	Patient considered to have outcome IF ANY
10 11	morbidity (SMM)		CCI	period ("pregnancy onset" = index date	code in ANY of the following:
12				– gestational age	1) Obstetric/ ill-defined or sudden death
13				at birth) to end of	2) Hypertensive heart/renal disease
14				observation	3) Eclampsia
15				window (42 days	4) Cerebral venous thrombosis
16				following index	5) Complications of anaesthesia – non-
17 18				date)	cardiac
18			A Dee		6) Complications of anaesthesia – cardiac
20					7) Cardiac diseases (cardiac arrest,
21					infarction, failure, pulmonary edema)
22					8) Placental abruption c/ coagulation defect
23					 9) Antepartum hemorrhage c/ coagulation defect
24					10) Intrapartum hemorrhage c/ coagulation
25					defect
26					11) Uterine rupture – before labour
27					12) Uterine rupture – during labour
28					13) Obstetric shock (including septic shock)
29 30					14) Septecemia during labour
30 31					15) Puerperal sepsis
32					16) Pulmonary embolism
33					17) Obstetric embolism
34					18) Cardiomyopathy
35				9	19) Acute renal failure
36					20) HIV disease
37					21) Cerebrovascular disease
38					22) Acute respiratory distress syndrome
39					23) Acute abdomen 24) Hepatic failure
40					25) Acute psychosis
41					26) Cerebral edema, coma
42 43					27) Disseminated intravascular coagulation
45 44					28) Sickle cell anemia crisis
44					29) Status asthmaticus
46					30) Status epilepticus
47					31) Assisted ventilation (endotracheal tube
48					or tracheostomy)
49					32) Caesarean hysterectomy
50					33) Postpartum hysterectomy
51					34) Dialysis
52					35) Evacuation of incisional hematoma
53					36) Surgical repair of bladder, urethra,
54 55					intestine
55 56					37) Intrapartum hemorrhage with no coagulation defect AND blood transfusion
50 57					38) Postpartum hemorrhage AND blood
57		1		Page 2	56) Postpartum nemormage AND Dioou
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Neighbourhood material deprivation and severe maternal morbidity: A population-based coh	ort study in Ontario,
Canada	Snelgrove JW et al.

		transfusion 39) Placenta previa AND blood transfusion 40) Embolization/ ligation/ suturing AND postpartum hemorrhage
		See: Joseph KS et al, 2009, ¹ Joseph KS et al, 2010, ² ICD-10CA, 2009, ³ and CCHI, 2012. ⁴

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Concept	Data	Code Type	Window	Notes
	Sources			(including Dataset references)
Age	RPDB		Index date	
Index year	DAD		Index date	
Material deprivation	ONMARG		Index date	Ontario Marginalization Index, Material
index				Deprivation, in quintiles.
				Use version of ONMARG closest to year of index date: 2001 for 2002-2003 2006 for 2004-2018 See: <u>https://datadictionary.ices.on.ca/Applicat</u> <u>s/DataDictionary/Library.aspx?Library=ON</u> ARG
Income quintile	RPDB		Index date	Ontario Census area profile: income quinti
	Census	, Ģ		Use Census closest to year of index date: 2001 for 2002-2003 2006 for 2004-2018 See: <u>https://datadictionary.ices.on.ca/Applicat</u> <u>s/DataDictionary/Library.aspx?Library=CEL</u> <u>US</u>
Rurality	RPDB		Index date	Rurality Index for Ontario (RIO). Use version of RIO closest to year of index date: RIO2004 for 2002-2006 RIO2008 for 2007-2018
Gestational age at birth	MOMBABY		Index date	
Induction of labour	DAD	CCI code	Within index hospitalization	Canadian Classification of Health Interventions (CCI)
Epidural	DAD OHIP	CCI code OHIP fee code	Within index hospitalization	Canadian Classification of Health Interventions (CCI); Ontario Health Insura Plan Claims Database (OHIP)
Delivery mode	DAD	CCI code	Within index hospitalization	
Multiple gestations	MOMBABY		Within index hospitalization	
Stillbirth	MOMBABY		Within index hospitalization	
Immigration status	IRCC		Index date	Immigration, Refugees and Citizenship

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Neighbourhood material deprivation and severe maternal morbidity: A population-based cohort study in Ontario, Canada Snelgrove JW et al.

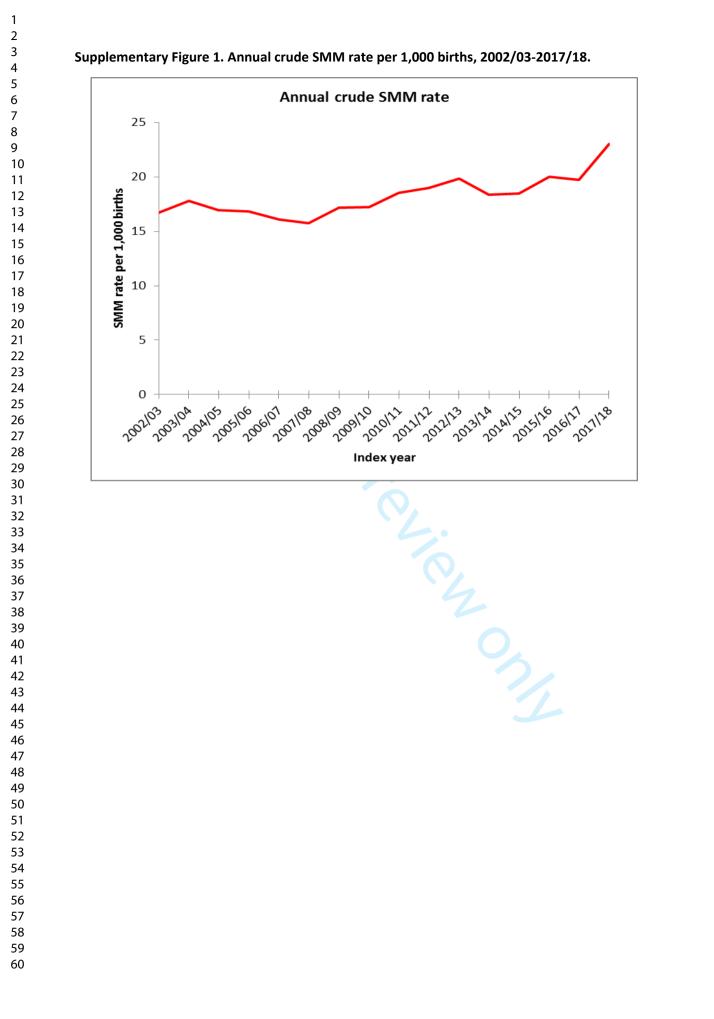
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Number of years since arrived in Ontario. See: <u>https://datadictionary.ices.on.ca/Application</u> <u>s/DataDictionary/Library.aspx?Library=CIC</u>

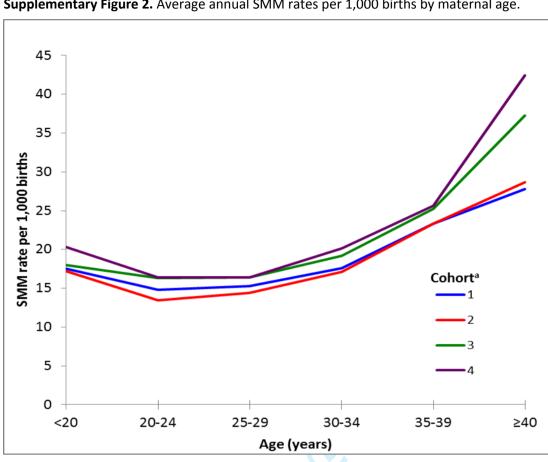
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4. *Canadian Classification of Health Interventions*. Ottawa: Canadian Institute for Health Information;2012.





Supplementary Figure 2. Average annual SMM rates per 1,000 births by maternal age.

^acohort 1: 1 April 2002 to 31 March 2006; cohort 2: 1 April 2006 to 31 March 2010; cohort 3: 1 April 2010 to 31 March 2014; cohort 4: 1 April 2014 to 31 March 2018

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Average SMM rate per 1,000 deliveries by 4-year cohort

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BMJ Open Supplementary table 1. Four-year average SMM rates per 1,000 births by age and by material deprivation, and rate change over study period.

		SMM rates	by cohort ^a		SMM rate change, cohort	$4 vs 1^a \qquad \stackrel{4}{\circ}$
Variable	1	2	3	4	Rate difference (95% CI)	Rate ratio (95% d)
Overall study population	17.10	16.55	18.94	19.82	2.72 (1.96, 3.49)***	1.16 (1.11, 1.21) ^O
Maternal age (years)						obe
<20	17.54	17.22	17.97	20.34	2.80 (-0.43, 6.04)	1.15 (0.98, 1.37) 🛛
20-24	14.80	13.47	16.32	16.40	1.60 (-0.15, 3.35)	1.11 (0.99, 1.24).
25-29	15.26	14.40	16.37	16.42	1.15 (-0.77, 2.39)	1.08 (0.99, 1.16)反
30-34	17.58	17.10	19.21	20.16	2.58 (1.18, 3.97)*	1.15 (1.06, 1.23) 🛓
35-39	23.31	23.35	25.23	25.67	2.36 (-0.16, 4.88)	1.10 (0.99, 1.22)ຊັ້
≥40	27.78	28.68	37.30	42.48	14.69 (7.96, 21.43)*	1.53 (1.24 <i>,</i> 1.89) 🚆
Material deprivation						mo
Quintile 1 (least)	16.05	16.58	19.36	18.41	2.36 (2.31, 2.41)***	1.15 (1.14 <i>,</i> 1.15) <mark></mark> ***
Quintile 2	16.36	15.97	16.17	18.52	2.16 (2.11, 2.22)***	1.13 (1.13, 1.14)
Quintile 3	17.46	15.73	18.34	18.99	1.54 (1.48, 1.59)***	1.09 (1.08, 1.09)
Quintile 4	16.49	16.37	19.19	20.18	3.69 (3.63, 3.74)***	1.22 (1.22, 1.23)
Quintile 5 (most)	18.14	17.32	20.78	22.32	4.19 (4.13, 4.24)***	1.23 (1.22 <i>,</i> 1.23) 🔄

 Quintile 5 (most)
 18.14
 17.32
 20.78
 22.32
 4.19 (4.13, 4.24)***
 1.23 (1.22, 1.23)***

 ^acohort 1: 1 April 2002 to 31 March 2006; cohort 2: 1 April 2006 to 31 March 2010; cohort 3: 1 April 2010 to 31 March 2018
 *p<0.05, **p<0.01, ***p<0.001</td>

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	Item No.	STROBE items	Location in manuscript where items are reported	RECORD items	Location in manuscript where items are reported
Title and abstra	ct			r 20	1
	1	(a) Indicate the study's design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found	Title page (p.1)	RECORD 1.1: The type of cata used should be specified in the tige or abstract. When possible, the name of the databases used should be included. RECORD 1.2: If applicable the geographic region and time frame within which the study took place should be reported in the title or abstract. RECORD 1.3: If linkage between databases was conducted for the study, this should be clearly stated in the title or abstract.	Title page, abstract (p. 1-3)
Introduction				лана стана стан Грани стана стан	
Background rationale	2	Explain the scientific background and rationale for the investigation being reported	Background p.4-5	April 18, 2024	
Objectives	3	State specific objectives, including any prespecified hypotheses	Background p.4-5	24 by gues	
Methods				<u> </u>	
Study Design	4	Present key elements of study design early in the paper	Methods p.5-9	otected	
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Methods: <i>Study</i> population and data sources, Main outcome, p. 5-6	d by copyright	

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Participants	6	(a) Cohort study - Give the	Cohort study, no	RECORD 6.1: The methods of study	Methods: Study
i articipants	0	eligibility criteria, and the	matching:	population selection (such as codes or	population and
		sources and methods of selection	matering.	algorithms used to identify subjects)	data sources,
		of participants. Describe methods	Methods: Study	should be listed in detail. If this is not	Main outcome,
		of follow-up	population and data	possible, an explanation should be	Exposures and
		<i>Case-control study</i> - Give the	sources, Main	provided.	covariates p. 5-8
		eligibility criteria, and the	outcome, Exposures		Supplementary
		sources and methods of case	and covariates p. 5-	RECORD 6.2: Any validation studies	Appendix 1
		ascertainment and control	8; Appendix 1	of the codes or algorithms used to select	
		selection. Give the rationale for		the population should be referenced. If	
		the choice of cases and controls		validation was conducted for this study	
		<i>Cross-sectional study</i> - Give the		and not published elsewhere detailed	
		eligibility criteria, and the		methods and results should F e provided.	
		sources and methods of selection			
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		or participants		linkage of databases, consider use of a	
		(b) Cohort study - For matched		flow diagram or other graphical display	
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		modifiers. Give diagnostic	outcome, Exposures	effect modifiers should be provided. If	Main outcome,
		criteria, if applicable.	and covariates p. 5-	these cannot be reported, an explanation	Exposures and
			8; Supplementary	should be provided $\vec{\delta}$	<i>covariates</i> p. 5-8
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Snelgrove JW et d	al. Neighbo	urhood material deprivation and severe	e maternal morbidity: A p	opulation-based cohort study in Ontario, Canada
		Describe comparability of assessment methods if there is more than one group	<i>and covariates</i> p. 5- 8; Supplementary Appendix 1	020-046174 0
Bias	9	Describe any efforts to address potential sources of bias	Methods: <i>Exposures</i> and covariates p. 7- 8; Interpretation: <i>Strengths/ limitations</i> p.11-12	6 October 2021
Study size	10	Explain how the study size was arrived at	Methods: <i>Study</i> <i>population and data</i> <i>sources,</i> p. 5-6; Figure 1	Downloaded
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why	Methods: Statistical analysis, p. 8-9	from http://bmjop
Statistical methods	12	 (a) Describe all statistical methods, including those used to control for confounding (b) Describe any methods used to examine subgroups and interactions (c) Explain how missing data were addressed (d) Cohort study - If applicable, explain how loss to follow-up was addressed <i>Case-control study</i> - If applicable, explain how matching of cases and controls was addressed <i>Cross-sectional study</i> - If applicable, describe analytical methods taking account of 	Methods: <i>Statistical</i> <i>analysis</i> , p. 8-9, Results, p.9-11.	en.bmj.com/ on April 18, 2024 by guest. Protected by copyright

		sampling strategy (e) Describe any sensitivity analyses		0-046174 or	
Data access and cleaning methods				RECORD 12.1: Authors should describe the extent to which the investigators had access to the database population used to create the study population.	Methods: <i>Study</i> <i>population and</i> <i>data sources</i> , p. 5- 6; Supplementary Appendix 1; Author contributions, p. 20
Linkage			or revie	RECORD 12.3: State whether the study included person-level, institutional- level, or other data linkage across two or more databases. The methods of linkage and methods of linkage quality evaluation should be provided.	Methods: <i>Study</i> population and data sources, Main outcome, Exposures and covariates p. 5-8; Supplementary Appendix 1
Results				2	
Participants	13	 (a) Report the numbers of individuals at each stage of the study (<i>e.g.</i>, numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed) (b) Give reasons for non- participation at each stage. (c) Consider use of a flow diagram 	Results p.10; Table 1; Figure 1	RECORD 13.1: Describe indetail the selection of the persons included in the study (<i>i.e.</i> , study population selection) including filtering based on data quality, data availability and linkage. The selection of included persons can be described in the text and by r by means of the study flow diagram.	Methods: <i>Study</i> <i>population and</i> <i>data sources,</i> <i>Main outcome,</i> <i>Exposures and</i> <i>covariates</i> p. 5-8; Results p.10; Table 1; Figure 1; Supplementary Appendix 1
Descriptive data	14	(a) Give characteristics of study participants (<i>e.g.</i> , demographic, clinical, social) and information	Results p.10; Table 1	y copyright	

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		on exposures and potential confounders (b) Indicate the number of participants with missing data for each variable of interest (c) <i>Cohort study</i> - summarise follow-up time (<i>e.g.</i> , average and total amount)			-046174 on 6 October 2021	
Outcome data	15	Cohort study - Report numbers of outcome events or summary measures over time Case-control study - Report numbers in each exposure category, or summary measures of exposure Cross-sectional study - Report numbers of outcome events or summary measures	Results p.10; Figure 1; Table 1		. Downloaded from http://bmjopen.l	
Main results	16	 (a) Give unadjusted estimates and, if applicable, confounder- adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included (b) Report category boundaries when continuous variables were categorized (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period 	Results p.10; Table 1-3; Supplementary Figure 1	201	bmj.com/ on April 18, 2024 by guest. Protected by copyright	
Other analyses	17	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses For peer review only - htt	Results p.10-11		y copyright.	

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Key results	18	Summarise key results with reference to study objectives	Interpretation, <i>Main</i> <i>findings</i> p.11	61 74 or	
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Interpretation, <i>Strengths/limitations</i> p.11-12	RECORD 19.1: Discuss theo implications of using data that were not created or collected to answer the specific research question(s). Include discussion of misclassification bias, unmeasured confounding, no bias, and changing eligibility over time, as they pertain to the study being reported.	Interpretation, Strengths/limitation ns p.11-12
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	Discussion, <i>Main</i> findings p. 11, Strengths / Limitations p. 11-12	ded from http://bmjopen.	
Generalisability	21	Discuss the generalisability (external validity) of the study results	Discussion, Interpretation p.11- 12	mj.com/ o	
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Funding	22	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	Funding, p. 21-22	pril 18, 2024 by g	
Accessibility of protocol, raw data, and programming code				RECORD 22.1: Authors should provide information on how to access any supplemental information such as the study protocol, raw data, or a programming code.	p. 21; Supplementary Appendix 1

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*Reference: Benchimol EI, Smeeth L, Guttmann A, Harron K, Moher D, Petersen I, Sørensen HT, von Elm E, Langan SM, the RECORD Working

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 Committee. The REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) Statement. PLoS Medicine 2015; in press. on 6 October 2021. Downloaded from http://bmjopen.bmj.com/ on April 18, 2024 by guest. Protected by copyright.

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Neighbourhood material deprivation and severe maternal morbidity: A population-based cohort study in Ontario, Canada.

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Journal:	BMJ Open
Manuscript ID	bmjopen-2020-046174.R1
Article Type:	Original research
Date Submitted by the Author:	17-Apr-2021
Complete List of Authors:	Snelgrove, John; Sinai Health System, Obstetrics & Gynaecology; University of Toronto, Obstetrics & Gynaecology Lam, Melody; ICES Western Watson, Tristan; Institute for Clinical Evaluative Sciences, Richard, Lucie; Institute for Clinical Evaluative Sciences, N/A Fell, DB; CHEO Research Institute, Ottawa, Ontario, Canada; University of Ottawa, School of Epidemiology and Public Health Murphy, Kellie; Sinai Health System, Obstetrics & Gynaecology; University of Toronto, Obstetrics & Gynaecology Rosella, Laura; University of Toronto, Dalla Lana School of Public Health
Primary Subject Heading :	Obstetrics and gynaecology
Secondary Subject Heading:	Epidemiology
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4 5		
6 7	2	Neighbourhood material deprivation and severe maternal morbidity:
, 8 9	3	A population-based cohort study in Ontario, Canada
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11 12	4	
13	5	John W. Snelgrove, MD, MSc ^{1,2 *}
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2 3 4 5	26	ABSTRACT
6 7	27	Objectives: Rates of age-associated severe maternal morbidity (SMM) have increased in
8 9 10	28	Canada, and an association with neighbourhood income is well established. Our aim was to
11 12	29	examine SMM trends according to neighbourhood material deprivation quintile, and to
13 14 15	30	assess whether neighbourhood deprivation effects are moderated by maternal age.
16 17 18	31	Design, setting, participants: A population-based retrospective cohort study using linked
19 20	32	administrative databases in Ontario, Canada. We included primiparous women with a live
21 22 23 24	33	birth or stillbirth at ≥20 weeks gestational age.
25 26	34	Primary outcome: SMM from pregnancy onset to 42 days postpartum. We calculated SMM
27 28 29	35	rate differences (RD) and rate ratios (RR) by neighbourhood material deprivation quintile for
30 31	36	each of four 4-year cohorts from 1 April 2002 to 31 March 2018. Log-binomial multivariable
32 33 34	37	regression adjusted for maternal age, demographic, and pregnancy-related variables.
35 36 37	38	Results: There were 1,048,845 primiparous births during the study period. The overall rate
38 39	39	of SMM was 18.0 per 1,000 births. SMM rates were elevated for women living in areas with
40 41 42	40	high material deprivation. In the final 4-year cohort, the RD between women living in high
43 44	41	versus low deprivation neighbourhoods was 3.91 SMM cases per 1,000 births (95% CI: 2.12,
45 46 47	42	5.70). This was higher than the difference observed during the first 4-year cohort (RD 2.09,
47 48 49	43	95% CI: 0.62, 3.56). SMM remained associated with neighbourhood material deprivation
50 51	44	following multivariable adjustment in the pooled sample (RR 1.16, 95% CI: 1.11, 1,21). There
52 53 54 55	45	was no evidence of interaction with maternal age.
56 57	46	Conclusion: SMM rate increases were more pronounced for primiparous women living in
58 59 60	47	neighbourhoods with high material deprivation compared to those living in low deprivation

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3	48	areas. This raises concerns of a widening social gap in maternal health disparities and
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6	49	highlights an opportunity to focus risk reduction efforts toward disadvantaged women
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8 9	50	during pregnancy and postpartum.
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15	52	Keywords: severe maternal morbidity; maternal mortality; maternal health; pregnancy;
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17 18	53	perinatal epidemiology; social epidemiology; social inequalities; deprivation
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24	55	Strengths and Limitations of this Study
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27	56	 Data were from population linked administrative and health registries that capture
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29 30	57	all hospital births in Ontario, Canada 🔨
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33 34	58	 Neighbourhood material deprivation was measured using the Ontario
35	59	Marginalization Index, a comprehensive area-level measure based on Census data
36	29	Warginalization index, a comprehensive area-level measure based on census data
37 38	60	developed using theoretical frameworks on marginalization and deprivation
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41	61	Limiting our study to primiparous women enabled the evaluation of population SMM
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44	62	trends and reduced confounding from previous births
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46 47	63	• It was not possible to control for all covariates associated with SMM, including body
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49	64	mass index, co-morbidities, and the use of assisted reproductive technology
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66 INTRODUCTION

Each year, approximately 4,000 Canadian women survive a maternal "near-miss"—a life-threatening event associated with pregnancy.[1] To characterize maternal near-misses in a standardized way, the World Health Organization proposed the concept of severe maternal morbidity (SMM), a composite of conditions that represent end-organ dysfunction or states of heightened maternal mortality risk associated with pregnancy, birth, or the postpartum period.[2, 3] Advances in the recognition and management of SMM have resulted in low maternal mortality rates in economically developed nations. Women living in high income countries are now more likely to survive a life-threatening pregnancy condition and, correspondingly, the rates of SMM are 100-fold higher than the rates of maternal mortality in Canada.[1] However, recent trends in Canada and other high income countries show an increase in SMM rates coinciding with advancing maternal age and corresponding increases in pre-existing co-morbidities and the use of assisted reproductive technology.[4-9] The literature also shows persistent though complex associations between SMM and the social determinants of health. Low occupational class, Black ethnicity, [10] and non-private health insurance[11] are all associated with higher risk of SMM in the US. Canadian women who experience SMM are more likely to come from a low-income background, and to originate from an African or Caribbean country. [4, 6, 12] A systematic review found evidence for effects of material dimensions of inequality on SMM risk, though it pointed out the need for further work on other dimensions and in elucidating effect mechanisms.[13] Women of advanced maternal age may be more likely to come from more advantaged socioeconomic backgrounds and to have planned pregnancies.[14-16] This suggests the possibility for effect modification, whereby the negative effects of advanced maternal age

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may be attenuated for women who come from more advantaged backgrounds, and exacerbated for women from disadvantaged backgrounds. The effects of maternal age and neighbourhood-level material deprivation may therefore interact, with the highest SMM risk among older women living in neighbourhoods with higher deprivation. In this study, our first objective was to evaluate trends in SMM rates among primiparous women in Ontario by neighbourhood material deprivation guintile between 1 April 2002 and 31 March 2018. Our second objective was to determine if maternal age moderates the effect of neighbourhood material deprivation. We hypothesized that SMM rates would increase disproportionately over time among women living in neighbourhoods with high

material deprivation. We further hypothesized that the highest risk of SMM would be among women of advanced maternal age living in neighbourhoods with the highest material ere deprivation.

METHODS

This population-based retrospective cohort study used linked administrative datasets for Ontario, held at ICES, which is an independent non-profit research institute whose legal status under Ontario's health information privacy law allows it to collect and analyze health care and demographic data, without consent, for health system evaluation and improvement. The use of data in this project was authorized under section 45 of Ontario's Personal Health Information Protection Act, which does not require review by a Research Ethics Board. We followed the RECORD guidelines (REporting of studies Conducted using Observational Routinely-collected Data) for reporting this study.[17]

Patient and public involvement

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111 There was no direct patient or public involvement in this study.

112 Study population and data sources

The Canadian Institute for Health Information Discharge Abstract Database (DAD) was used 113 to capture all hospital admissions for birth and link to newborn records using the ICES-114 115 derived MOMBABY dataset. We included primiparous women aged 10-55 years who had a hospital birth in Ontario and were enrolled in the province's universal health insurance 116 program (OHIP). We identified the first live birth or stillbirth delivery at a gestational age of 117 \geq 20 weeks. We used gestational age at birth to calculate pregnancy onset. Women were 118 119 included if the onset of their first pregnancy was on or after 1 April 2002 and the 120 corresponding birth occurred on or before 17 February 2018-allowing 42 days of 121 postpartum follow-up through the study end date of 31 March 2018. Women who had a previous birth within 14 years prior to the index date were excluded. We linked these data 122 with the Registered Persons Database (RPDB), DAD, and OHIP Claims Database to identify 123 124 exposures and outcomes of interest. To identify women who had recently immigrated to Ontario, we used the Ontario portion of the federal Immigration, Refugees and Citizenship 125 126 Canada (IRCC) Permanent Resident Database. For neighbourhood material deprivation, we used the 2001 and 2006 Canadian Census, and Ontario Marginalization Index (ON-127 128 MARG).[18] These datasets were linked using unique encoded identifiers and analyzed at 129 ICES and are shown in **Appendix 1**.

130 Main outcome

The main outcome was a composite of medical conditions and interventions that comprise
 SMM. Cases of SMM were identified using diagnosis and procedural codes (International

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133	Statistical Classification of Diseases and Related Health Problems, 10 th revision [ICD-10] and
134	Canadian Classification of Health Interventions, respectively) within the DAD database.[15,
135	19-21] The DAD data have been validated and shown to accurately reflect the information in
136	medical records.[21, 22] The composite SMM outcome included: 1) causes of direct
137	obstetric death and conditions related to these (antepartum, intrapartum, and postpartum
138	hemorrhage; hypertensive disorders of pregnancy and eclampsia; puerperal sepsis; uterine
139	rupture; obstetric embolus); 2) severe organ system dysfunction (cardiac arrest, failure, or
140	arrhythmia; renal or hepatic failure; coagulation defect; thromboembolism; respiratory
141	failure; coma or non-eclamptic seizure; psychosis); 3) procedures or interventions
142	accompanying life-threatening conditions or health states (cesarean or postpartum
143	hysterectomy; pelvic vessel ligation; surgical repair of bowel, bladder, or urethra;
144	endotracheal or tracheostomy ventilation; dialysis; blood transfusion in the context of
145	severe blood loss); and 4) deaths that were ill-defined or sudden, as these could not reliably
146	be classified as non-obstetric deaths. Appendix 1 shows the list of SMM indicators for this
147	study. We specified a binary SMM outcome variable for the presence of one or more
148	indicators occurring from the onset of pregnancy up to and including 42 days after birth.
149	Exposures and covariates
150	Our main exposure of interest was neighbourhood material deprivation quintile from the
151	Ontario Marginalization Index (ON-MARG). ON-MARG is the Ontario-specific version of the
152	Canadian marginalization index (CAN-MARG).[23] The index was developed based on
153	theoretical frameworks of marginalization and deprivation, and derived empirically using

154 principal component analysis of Canadian Census variables.[18, 23]The material deprivation

dimension is comprised of the following Census measures, each expressed as a proportion:

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156	population aged ≥20 without secondary school graduation, single parent families,
157	households receiving government transfer payments, population aged ≥15 who are
158	unemployed, population living below the low income cut-off (adjusted for community size,
159	household size, and inflation).[18] The geographical unit of aggregation is Dissemination
160	Areas, which average 400-700 people and cover the entirety of Canadian territory.[24] ON-
161	MARG can be operationalized as a standardized interval scale based on factor loadings from
162	the principal component analysis, or as quintiles each representing 20% of Dissemination
163	Areas.[18, 23] We modelled this exposure as quintiles, with quintile 1 representing
164	neighbourhoods with the lowest material deprivation, and quintile 5 representing
165	neighbourhoods with the highest deprivation.[18, 23] ON-MARG has been used to
166	demonstrate inequalities in various health measures and is stable over time.[25-27] We
167	used the 2001 material deprivation index for births between years 2002-2003, and the 2006
168	index for years 2004-2018. The change from mandatory Census reporting to the voluntary
169	National Household Survey and resulting data quality concerns meant that the 2011 index
170	was comprised from alternate data sources.[28] We used the 2006 version for all years after
171	2004 to avoid operationalizing this variable differently between study years.
172	We included maternal age at birth, categorized in 5-year bands. We adjusted for rural
173	setting using the 2004 and 2008 Rurality Index of Ontario (RIO).[29] We used the 2004 RIO
174	index for pregnancies between years 2002 and 2006, and the 2008 index for years 2007 to
175	2018. We adjusted for number of years since immigration using data from the IRCC.
176	Additional demographic and pregnancy related variables included delivery mode and
177	multiple gestations. For multiple gestation pregnancies, delivery mode was specified based
178	on highest level of intervention: unassisted vaginal birth of all fetuses (lowest), assisted

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vaginal birth of one or more fetuses, assisted vaginal breech birth of one or more fetuses,
and caesarean birth of one or more fetuses (highest). We examined SMM rates by
gestational age at birth, induction of labour, and the use of epidural analgesia, however
these variables were not adjusted-for in the multivariable models.

183 Statistical analysis

We summarized baseline characteristics and SMM rates overall for the study population. Due to low birth counts for ages 10-14 years, we collapsed these into an age <20 years group for analysis. We plotted SMM rates by year for the whole study population, and then to evaluate changes over time, we divided the population into four, 4-year cohorts based on pregnancy onset: 1 April 2002 to 31 March 2006 (cohort 1); 1 April 2006 to 31 March 2010 (cohort 2); 1 April 2010 to 31 March 2014 (cohort 3); and 1 April 2014 to 31 March 2018 (cohort 4). To address our first objective, we calculated average annual SMM rates for each 4-year cohort by neighbourhood material deprivation quintile. Within each cohort, we estimated unadjusted absolute rate differences (RD) and rate ratios (RR) with 95% confidence intervals (CI) comparing women in quintile 5 (highest deprivation) with women in quintile 1 (lowest deprivation). Our second objective was to evaluate the effect of neighbourhood material deprivation,

adjusting for covariates and testing for interaction with maternal age for the overall study
population. We constructed multivariable log-binomial regression models. We initially fit a
model with neighbourhood material deprivation, adjusting only for year of pregnancy onset
(model 1). We then added maternal age (model 2), followed by demographic and
pregnancy-related covariates, immigration status, and rurality (model 3). We tested for

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	201	interaction between material deprivation and maternal age using a cross product term. We
	202	did not adjust for stillbirth or gestational age at birth, as these are variables are considered
	203	colliders rather than true confounders of outcomes associated with SMM.[30] We did not
)	204	include induction of labour or epidural analgesia, as these interventions are associated with
<u>2</u> 5 L	205	clinical decisions surrounding birth rather than SMM risk factors. We excluded women with
5	206	missing information for neighbourhood material deprivation from the multivariable analysis,
7 3	207	as these women represented less than 2 percent of the study population (n=17,130).
,)		
<u>)</u>	208	We performed two additional analyses evaluating SMM rate trends (RD and RR) over the
} 	209	study period, comparing the 4-year average annual rates during cohort 4 to cohort 1
,) ,	210	separately by maternal age and by neighbourhood material deprivation quintile. We also
3	211	examined the 4-year average rates of SMM excluding cases defined by HIV disease. This was
) <u>)</u>	212	done in reference to recently proposed changes to the Canadian SMM composite indicator
6 	213	excluding chronic, asymptomatic HIV disease.[12, 31] Statistical analyses were performed
5	214	using SAS (version 7.15, SAS Institute Inc., Cary, NC) and STATA (version 13, StataCorp.,
3	215	College Station, TX).
) <u>?</u> }	216	RESULTS
 ; ;	217	There were 2,143,045 hospital-based births in Ontario between 1 April 2002 and 17
3	218	February 2018, of which 1,048,845 were primiparous births and included in the study
)	219	(Figure 1). The overall SMM rate across the study period was 18.0 per 1,000 births, and
<u>)</u> }	220	increased from 16.7 per 1,000 births in 2002-03 (95% CI: 15.6, 17.9) to 23.0 per 1,000 births
 ;	221	in 2017-18 (95% CI: 21.2, 25.0, Supplementary Figure 1). Baseline characteristics and SMM
) 7 3	222	case number and rate for each characteristic are presented in Table 1. SMM rates were
)		

higher at the extremes of maternal age, and among women living in neighbourhoods withthe highest material deprivation.

Table 2 presents SMM rates by material deprivation guintile for the pooled study sample (2002-2018) and each of the four 4-year cohorts. The RD was 2.09 cases per 1,000 births (95% CI: 0.62, 3.56), corresponding with a RR of 1.13 (95% CI: 1.04, 1.23) comparing women in quintile 5 with women in quintile 1 during the first 4-year cohort. This increased to a RD of 3.91 cases per 1,000 births (95% CI: 2.12, 5.70) and RR of 1.21 (95% CI: 1.11, 1.32) in the final 4-year cohort of the study period. Average annual SMM rates increased between cohort 1 and cohort 4 for women aged 30-34, and \geq 40 years (Supplementary Table 1, **Supplementary Figure 2**). For the latter group, the absolute increase was 14.69 cases per 1,000 births (95% CI: 7.96-21.43, Supplementary Table 1). SMM rates increased over time for women in each quintile of neighbourhood deprivation, and this increase was most pronounced for women in the highest quintile of neighbourhood deprivation (RD 4.19 cases per 1,000 births 95% CI: 4.13-4.24, Supplementary Table 1). In the multivariable regression analysis for the overall study population, women living in neighbourhoods with the highest material deprivation had higher rates of SMM compared to those in neighbourhoods with the lowest after adjusting for pregnancy year (RR: 1.11, 95% CI: 1.06, 1.16, Table 3). Full adjustment for age, demographics, pregnancy-related

variables, and rurality had minimal effect on the association between material deprivation

and SMM persisted in the fully adjusted model, with higher risk for women <20 and ≥30

⁵ 244 years of age. We did not find evidence of statistical interaction between maternal age and

neighbourhood material deprivation quintile.

and SMM rates (adjusted RR: 1.16, 95% CI: 1.11, 1.21, Table 3). The association between age

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DISCUSSION

Main findings

This study demonstrated an association between neighbourhood material deprivation and severe maternal morbidity among primiparous women in Ontario from 2002-2018. Rates of SMM increased across all material deprivation guintiles, and we found some evidence that women in the highest deprivation quintile experienced a higher magnitude SMM rate increase over the 16-year study period compared with women in the lowest deprivation quintile. This finding suggests a possible widening of the gap between women living in the most and least deprived neighbourhoods.

Strengths/limitations

The current study was a population-based analysis of all primiparous hospital births at ≥ 20 weeks' gestational age in Ontario. Hospital births account for over 98% of births in the province. We used a measure of neighbourhood marginalization that includes income along with other measures of material resources, and that is stable across time and different health outcomes. [23, 25] Our study nonetheless had some limitations. We were unable to account for births prior to 20 weeks' gestation or births that occurred outside of the province. Our measure of SMM was based on validated perinatal health data for Canada.[15, 21] A revision of the Canadian SMM composite was recently developed which resolves issues surrounding the inclusion of some pre-eclampsia and HELLP syndrome measures, as well as the exclusion of HIV infection—a condition that is unlikely to represent SMM when asymptomatic [12, 31]. We elected to use the former SMM composite for comparison with previous literature, recognizing this may complicate direct comparison

with recent Canadian studies [4, 6, 12, 31]. The proportion of women with SMM defined by HIV disease was around 2 percent for each of the 4-year cohorts, and thus we do not believe these cases substantively altered the results of this study. Information on immigrants arriving prior to 1985 is not captured in the IRCC Permanent Resident Database, and the database does not identify immigrants who landed in other provinces and subsequently moved to Ontario. Although we used a measure of neighbourhood material deprivation developed for Ontario using Canadian Census elements, [28] the ON-MARG index does not include individual-level indicators of marginalization or socioeconomic status. Important social determinants may differ among individuals living in areas characterized by similar measures of neighbourhood deprivation, and it is not possible to elucidate the causal pathways that link social disadvantage to poor health outcomes without incorporating such factors.[32, 33] Finally, pre-pregnancy co-morbidities, obesity, and the use of assisted reproductive technology, contribute to higher SMM rates and may partially explain SMM trends.[8, 9, 34] We were unable to account for these factors. Obstetric comorbidity indices have been developed for risk prediction and adjustment in clinical research. [35, 36] We did not use an obstetric comorbidity index in our adjusted analysis as some index indicators represent SMM outcomes themselves, or are mediators of SMM outcomes. In addition, our aim was to examine population SMM trends rather than individual clinical risk factors. Interpretation

The present study contributes to our understanding of the association between neighbourhood marginalization and SMM and provides preliminary evidence of a possible widening of this health disparity over time in Ontario. The association between neighbourhood-level measures of inequality and risk of SMM has been demonstrated

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previously in several high-income countries.[6, 9, 11, 13, 37-41] Notably in Canada, Aoyama 291 and colleagues reported a rise in SMM linked to the relative increase in maternal age and 292 293 found a significant association between SMM and neighbourhood income guintile.[4]. Our 294 study confirms this finding using a measure that encompasses income along with additional 295 measures of neighbourhood material deprivation. Moreover, we extend the current 296 understanding of this association by providing evidence for a possible disproportionate rise 297 in SMM risk experienced by women living in marginalized neighbourhoods over time. We 298 interpret this last finding with caution, as our study showed significant rate differences by 299 neighbourhood marginalization only during the first and final 4-year cohorts of the 16-year 300 study period. SMM risks have been demonstrated among other social determinants of health; for example, lower occupational class, Black ethnicity, [10] and non-private health 301 insurance[11] are associated with higher risk of SMM in the US. Interaction between 302 303 socioeconomic indicators—including ethnicity, education, and poverty—likely contribute to 304 the social gradient of risk such that the protective effects afforded by higher education and 305 income do not fully ameliorate racial disparities in SMM.[38] Our study showed an 306 association between neighbourhood deprivation and SMM suggesting the effects of 307 marginalization persist even in the context of universal healthcare. This is a consistent 308 finding across countries that have similar publicly funded healthcare systems. [41-43] The 309 factors contributing to social inequality are myriad; ethnicity and country of origin, rurality 310 and access to care, income, material resources, education, and psychosocial supports all 311 have worrisome associations with maternal reproductive health risks.[6, 10-12, 38, 41-47] 312 How these factors contribute to widening health gaps, and what interventions may

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2 3	313	attenuate their effects will be imperative lines of inquiry going forward as the global
4	313	attenuate their effects will be imperative lines of inquiry going forward as the global
5 6	314	challenge to lower SMM continues.
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8 9	315	Conclusion
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13	316	Ontario women living in areas with higher neighbourhood material deprivation experienced
14 15	317	the highest risk of SMM, and this association was not fully explained by maternal age.
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17	318	Additionally, women living in high-deprivation neighbourhoods may have experienced a
18 19		
20	319	disproportionate increase in the risk of SMM over time. Future work must focus on
21 22	320	addressing the widening social gap in maternal health disparities.
23	520	dual essing the widening social gap in maternal nearth dispartites.
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TABLES

Table 1. Baseline characteristics of the study population, 2002-2018. N=1,048,845 births.

	Number of		Number of	SMM rate per
Variable	births	Percent	SMM cases	1,000 births
Overall study population	1,048,845	100	18,880	18.00
Maternal age at birth, years				
10-14	1,330	0.1	35	26.32
15-19	72,579	6.9	1,291	17.79
20-24	178,074	17.0	2,684	15.07
25-29	342,003	32.6	5,324	15.57
30-34	305,898	29.2	5,653	18.48
35-39	123,698	11.8	3,017	24.39
≥40	25,263	2.4	876	34.68
Gestational age at birth, weeks				
20-23	2,751	0.3	147	53.44
24-27	4,158	0.4	306	73.59
28-33	17,688	1.7	1,104	62.42
34-36	59,040	5.6	1,966	33.30
37-41	961,322	91.7	15,278	15.89
≥42	3,886	0.4	79	20.33
Induced labour	275,262	26.2	5,836	21.20
Epidural	655,107	62.5	10,713	16.35
Delivery mode				
Vaginal unassisted	579,814	55.3	6,386	11.01
Vaginal assisted	156,383	14.9	2,724	17.42
Vaginal breech	2,328	0.2	95	40.81
Caesarean	310,320	29.6	9,675	31.18
Multiple gestations	20,850	2.0	1,137	54.53
Stillbirth	3,645	0.3	199	54.60
Rurality				
Urban	993,282	94.7	17,814	17.93
Rural	55,563	5.3	1,066	19.19
Immigration Status				
Non-immigrant / before 1985	739,252	70.5	13,222	17.89
Immigrated >10 years	62,381	5.9	1,165	18.68
Immigrated 5-10 years	62,090	5.9	1,249	20.12
Immigrated <5 years	185,122	17.7	3,244	17.52
Neighbourhood marginalization				
Material deprivation				
Quintile 1 (least deprived)	237,877	22.7	4,183	17.58
Quintile 2	186,550	17.8	3,112	16.68
Quintile 3	189,575	18.1	3,327	17.55

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2 3		Quintile 4	191,376	18.2	3,423	17.89
4 5		Quintile 5 (most deprived)	226,337	21.6	4,397	19.43
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Table 2. Four-year average SMM rates per 1,000 births for neighbourhood material

deprivation quintiles, by pooled sample (2002-2018) and by study period cohort.

	SMM rate Q1	s by materio	al deprivatio	on quintile	Q5	<i>Q5 vs Q1</i> Rate difference (95%	
Cohort ^a	(least)	Q2	Q3	Q4	(most)	CI)	Rate ratio (95% C
Pooled	17.58	16.68	17.55	17.89	19.43	1.84 (1.82,1.87)***	1.10 (1.10-1.11)*
1	16.05	16.36	17.46	16.49	18.14	2.09 (0.62, 3.56)**	1.13 (1.04, 1.23)*
2	16.58	15.97	15.73	16.37	17.32	0.75 (-0.70, 2.20)	1.05 (0.96, 1.14)
3	19.36	16.17	18.34	19.19	20.78	1.41 (-0.20, 3.02)	1.07 (0.99, 1.16)
4	18.41	18.52	18.99	20.18	22.32	3.91 (2.12, 5.70)***	1.21 (1.11, 1.32)*
						2006 to 31 March 2010 1 March 2018	; cohort 3:
341 *p<	0.05 <i>,</i> **p<0.	01 <i>,</i> ***p<0.(001				
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Table 3. Neighbourhood material deprivation and risk of SMM: Adjusted multivariable

347 models, RR (95% Cl). N=1,031,715 births.

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)		Variable	Model 1 ^a	Model 2 ^b	Model	
10 11		Maternal age (years)				
12		<20		1.05 (0.99, 1.12)	1.20 (1.13, 1.28)	
13		20-24		0.95 (0.90, 0.99)	1.01 (0.96, 1.06)	
14		25-29		1 (ref)	1 (ref)	
15		30-34		1.19 (1.14, 1.23)	1.10 (1.06, 1.15)	
16 17		35-39		1.56 (1.49, 1.63)	1.34 (1.28, 1.40)	
18		≥40		2.21 (2.06, 2.37)	1.73 (1.61, 1.86)	
19		Material deprivation		2.21 (2.00, 2.37)	1.75 (1.01, 1.00)	
20		Quintile 1 (least)	1 (ref)	1 (ref)	1 (ref)	
21			0.95 (0.91, 0.99)	0.97 (0.93, 1.02)	0.97 (0.92, 1.01)	
22 23		Quintile 2				
24		Quintile 3	1.00 (0.96, 1.05)	1.04 (0.99, 1.08)	1.03 (0.98, 1.07)	
25		Quintile 4	1.02 (0.98, 1.07)	1.07 (1.02, 1.12)	1.06 (1.01, 1.11)	
26		Quintile 5 (most)	1.11 (1.06, 1.16)	1.17 (1.12, 1.22)	1.16 (1.11, 1.21)	
27		^a adjusted for pregnancy ye	ear 💦			
28		^b adjusted for pregnancy ye	ear, age			
29 30		^c adjusted for pregnancy year, age, delivery mode, multiple				
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7	358	Figure 1. Study inclusion / exclusion flow chart, primiparous births.
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14	360	SUPPLEMENTARY MATERIAL CAPTIONS
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16	361	Supplementary Appendix 1. Data sources for the project.
17	301	Supplementary Appendix 1. Data sources for the project.
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19 20	362	Supplementary Figure 1. Annual crude SMM rate per 1,000 births, 2002-2018.
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23	363	Supplementary Figure 2. Average annual SMM rates per 1,000 births by maternal age.
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26	364	Supplementary Table 1. Four-year average SMM rates per 1,000 births by age and by
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75 Acknowledgements

The authors would like to thank Josie Chundamala, Scientific Grant Editor funded by the Department of Obstetrics and Gynecology at Mount Sinai Hospital, for assistance editing and preparing this manuscript for submission.

379 Declaration of competing interests

380 The authors declare no conflicts of interest.

381 Author contributions

JWS, DF, KEM, and LCR contributed to the overall conception of the study. JWS, ML, LR, DF,
 and LCR contributed to study design and protocol. TW had full access to data used in the
 study. JWS, TW, and LCR take responsibility for the integrity of the data analysis. JWS wrote
 the manuscript. All authors made substantial contributions to the data analysis
 interpretation, and manuscript editing and revising for this project. All authors approve the

387 final submitted version and agree to be accountable for all aspects of the work.

388 Ethical approval

ICES is a prescribed entity under section 45 of Ontario's Personal Health Information
 Protection Act. Section 45 authorizes ICES to collect personal health information, without
 consent, for the purpose of analysis or compiling statistical information with respect to the
 management of, evaluation or monitoring of, the allocation of resources to or planning for
 all or part of the health system. Projects conducted under section 45, by definition, do not
 require review by a Research Ethics Board. This project was conducted under section 45,
 and approved by ICES' Privacy and Legal Office.

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3 4 5	396	Patient consent for publication
6 7 8	397	None required.
9 10 11 12	398	Data availability statement
13 14	399	The dataset from this study is held securely in coded form at ICES. While data sharing
15 16 17	400	agreements prohibit ICES from making the dataset publicly available, access may be granted
18 19	401	to those who meet pre-specified criteria for confidential access, available at
20 21 22	402	www.ices.on.ca/DAS. The full dataset creation plan and underlying analytic code are
23 24	403	available from the authors upon request, understanding that the computer programs may
25 26 27	404	rely upon coding templates or macros that are unique to ICES and are therefore either
28 29 30	405	inaccessible or may require modification.
31 32 33	406	Funding
34 35	407	John Snelgrove received funding for this project through an internal grant from the
36 37 38 39 40 41 42 43 44 45	408	Department of Obstetrics & Gynaecology, University of Toronto, and Department of
	409	Obstetrics & Gynaecology, Mount Sinai Hospital (grant number N/A). This study was
	410	supported by ICES, which is funded by an annual grant from the Ontario Ministry of Health
	411	and Long-Term Care (grant number N/A). This study was completed at the ICES University of
46 47 48	412	Toronto site and ICES Western site—where core funding is provided by the Academic
48 49 50	413	Medical Organization of Southwestern Ontario, the Schulich School of Medicine and
51 52 53	414	Dentistry, Western University, and the Lawson Health Research Institute. Parts of this
54 55	415	material are based on data and information compiled and provided by the Canadian
56 57 58	416	Institute for Health Information, and by Immigration, Refugees and Citizenship Canada
55 56	417	(IRCC). The analyses, conclusions, opinions and statements expressed herein are solely 22

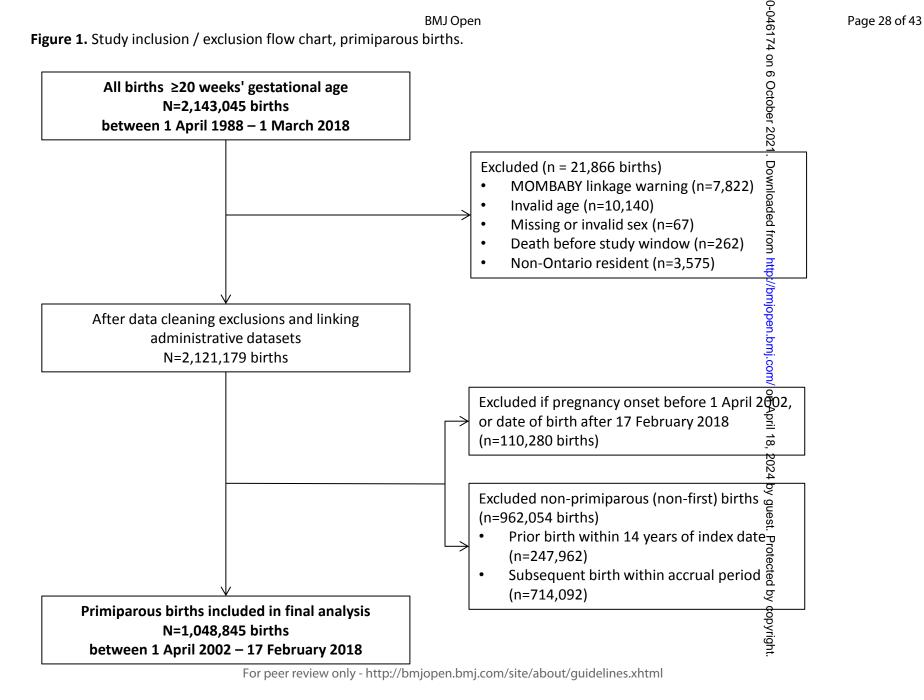
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3 4	418	those of the authors and do not reflect those of the funding or data sources; no
5 6	419	endorsement is intended or should be inferred.
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Supplementary Appendix 1. Data sources for project

Discharge Abstract Database (DAD)

The DAD is compiled by the Canadian Institute for Health Information and contains administrative, clinical (diagnoses and procedures/interventions), demographic, and administrative information for all admissions to acute care hospitals, rehab, chronic, and day surgery institutions in Ontario. At ICES, consecutive DAD records are linked together to form 'episodes of care' among the hospitals to which patients have been transferred after their initial admission.

MOMBABY

The ICES MOMBABY Database is an ICES-derived cohort that links the DAD inpatient admission records of delivering mothers and their newborns. From 2002 onward, this linkage is performed deterministically using a maternal-newborn chart matching number. Prior to 2002, mothers were linked to their children by matching on the institutions they were admitted, their postal codes, and their admission/discharge dates.

Registered Persons Database (RPDB)

The RPDB provides basic demographic information (age, sex, location of residence, date of birth, and date of death for deceased individuals) for those issued an Ontario health insurance number. The RPDB also indicates the time periods for which an individual was eligible to receive publicly funded health insurance benefits and the best known

Ontario Health Insurance Plan (OHIP)

The OHIP claims database contains information on inpatient and outpatient services provided to Ontario residents eligible for the province's publicly funded health insurance system by fee-for-service health care practitioners (primarily physicians) and "shadow billings" for those paid through non-fee-for-service payment plans. The main data elements include patient and physician identifiers (encrypted), code for service provided, date of service, associated diagnosis, and fee paid.

Immigration, Refugees, and Citizenship Canada's (IRCC) Permanent Resident Database

The Ontario portion of the IRCC Permanent Resident Database includes immigration application records for people who initially applied to land in Ontario since 1985. The dataset contains permanent residents' demographic information such as country of citizenship, level of education, mother tongue, and landing date. New immigrants who are currently residing in Ontario but originally landed in another province are not captured in this dataset.

Ontario Marginalization Index (ONMARG)

ONMARG is a geographically (census) based index developed to quantify the degree of marginalization occurring across the province of Ontario. It is comprised of four major dimensions thought to underlie the construct of marginalization: residential instability, material deprivation, dependency, and ethnic concentration. The dataset contains census divisions (CD), census tracts (CT), census subdivisions (CSD), consolidated municipal service manager areas (CMSM), public health units (PHU), local health integration networks (LHIN), sub-LHINs, and dissemination areas (DA).

These datasets were linked using unique encoded identifiers and analyzed at ICES.

The dataset from this study is held securely in coded form at ICES. While data sharing agreements prohibit ICES from making the dataset publicly available, access may be granted to those who meet pre-specified criteria for confidential access, available at www.ices.on.ca/DAS. The full dataset creation plan and underlying analytic code are available from the authors upon request, understanding that the computer programs may rely upon coding templates or macros that are unique to ICES and are therefore either inaccessible or may require modification.

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Concept	Data Sources	Code Type	Window	Notes (including Dataset references
Inclusion Criteria				
Hospital birth (live or stillbirth) at gestational age ≥20 weeks	DAD, MOMBABY	ICD-10 main patient service code for "Obstetrical birth"	Accrual window: 1 April 2002 – 17 Feb 2018	Canadian Institute for Health Information Discharge Abstract Database (DAD, linked to newborn record in MOMBABY dataset) See: <u>https://datadictionary.ices.on.ca/Ap ations/DataDictionary/Library.aspx3 ary=MOMBABY</u>
Exclusion Criteria			-	
Missing or invalid IKN	RPDB	0	Index date	Registered Persons Database See: <u>https://datadictionary.ices.on.ca//</u> <u>lications/DataDictionary/Library.as</u> ?Library=RPDB
MOMBABY linkage warning	MOMBABY	C	Index date	
Missing or invalid age (<10 or >55)	RPDB		Index date	
Missing or invalid sex	RPDB		Index date	
Death before the index date	RPDB		Index date	
Non-Ontario residents / invalid OHIP number	RPDB		Index date	
Any births with an index date occurring outside of the accrual period	MOMBABY		Accrual window	Pregnancy onset before 1 April 2002
Any births occurring after accrual end date	MOMBABY		Accrual window	Births after 17 February 2018
Not first birth	MOMBABY		14 years prior to index date	Prior record in MOMBABY within pa 14 years of index date
Not first birth in accrual period	MOMBABY		Accrual window	Subsequent records in MOMBABY

5 6	Outcome				
7	Concept	Data	Code Type	Window	Notes
8		Sources			(including Dataset references)
9	Severe maternal	DAD	ICD 10	Start of lookback	Patient considered to have outcome IF ANY
10 11	morbidity (SMM)		ССІ	period ("pregnancy onset" = index date	code in ANY of the following:
12				 gestational age 	1) Obstetric/ ill-defined or sudden death
13				at birth) to end of	2) Hypertensive heart/renal disease
14				observation	3) Eclampsia
15				window (42 days	4) Cerebral venous thrombosis
16				following index	5) Complications of anaesthesia – non-
17				date)	cardiac
18					6) Complications of anaesthesia – cardiac
19					7) Cardiac diseases (cardiac arrest,
20					infarction, failure, pulmonary edema)
21 22					8) Placental abruption c/ coagulation defect
22					9) Antepartum hemorrhage c/ coagulation
23 24					defect
24					10) Intrapartum hemorrhage c/ coagulation
26					defect
27					11) Uterine rupture – before labour
28					12) Uterine rupture – during labour
29					13) Obstetric shock (including septic shock)
30					14) Septecemia during labour
31					15) Puerperal sepsis
32					16) Pulmonary embolism
33					17) Obstetric embolism
34					18) Cardiomyopathy
35					19) Acute renal failure
36					20) HIV disease 21) Cerebrovascular disease
37					22) Acute respiratory distress syndrome
38					23) Acute abdomen
39					24) Hepatic failure
40					25) Acute psychosis
41 42					26) Cerebral edema, coma
42 43					27) Disseminated intravascular coagulation
43					28) Sickle cell anemia crisis
45					29) Status asthmaticus
46					30) Status epilepticus
47					31) Assisted ventilation (endotracheal tube
48					or tracheostomy)
49					32) Caesarean hysterectomy
50					33) Postpartum hysterectomy
51					34) Dialysis
52					35) Evacuation of incisional hematoma
53					36) Surgical repair of bladder, urethra,
54					intestine
55					37) Intrapartum hemorrhage with no
56					coagulation defect AND blood transfusion
57					38) Postpartum hemorrhage AND blood
58				Page 3	
59					

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		transfusion 39) Placenta previa AND blood transfusion 40) Embolization/ ligation/ suturing AND postpartum hemorrhage See: Joseph KS et al, 2009, ¹ Joseph KS et al, 2010, ² ICD-10CA, 2009, ³ and CCHI, 2012. ⁴

Study exposures, covariates

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Notes

7 Concept Data **Code Type** Window 8 Sources (including Dataset references) 9 RPDB Age Index date 10 Index year DAD Index date 11 Material deprivation ONMARG Index date Ontario Marginalization Index, Material 12 index Deprivation, in quintiles. 13 14 Use version of ONMARG closest to year of 15 index date: 16 2001 for 2002-2003 17 2006 for 2004-2018 18 See: 19 https://datadictionary.ices.on.ca/Application 20 s/DataDictionary/Library.aspx?Library=ONM 21 ARG 22 23 RPDB Index date Ontario Census area profile: income quintile. Income quintile 24 Census 25 Use Census closest to year of index date: 26 2001 for 2002-2003 27 2006 for 2004-2018 28 See: 29 https://datadictionary.ices.on.ca/Application 30 s/DataDictionary/Library.aspx?Library=CENS 31 US 32 33 RPDB Rurality Index date Rurality Index for Ontario (RIO). 34 Use version of RIO closest to year of index 35 date: 36 RIO2004 for 2002-2006 37 RIO2008 for 2007-2018 38 39 Gestational age at MOMBABY Index date birth 40 41 Induction of labour DAD CCI code Within index Canadian Classification of Health 42 hospitalization Interventions (CCI) 43 44 Epidural DAD CCI code Within index Canadian Classification of Health 45 OHIP OHIP fee code Interventions (CCI); Ontario Health Insurance 46 hospitalization 47 Plan Claims Database (OHIP) 48 Delivery mode DAD CCI code Within index 49 hospitalization 50 51 52 53 Multiple gestations MOMBABY Within index 54 hospitalization 55 Stillbirth MOMBABY Within index 56 hospitalization 57 Immigration status IRCC Index date Immigration, Refugees and Citizenship 58 Page 5 59 For peer review only - http://bmjopen.bmj.com/site/about/guidelines.xhtml 60

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	Canada (IRCC)'s Permanent Resident Database
	Number of years since arrived in Ontario. See: <u>https://datadictionary.ices.on.ca/Application</u> <u>s/DataDictionary/Library.aspx?Library=CIC</u>

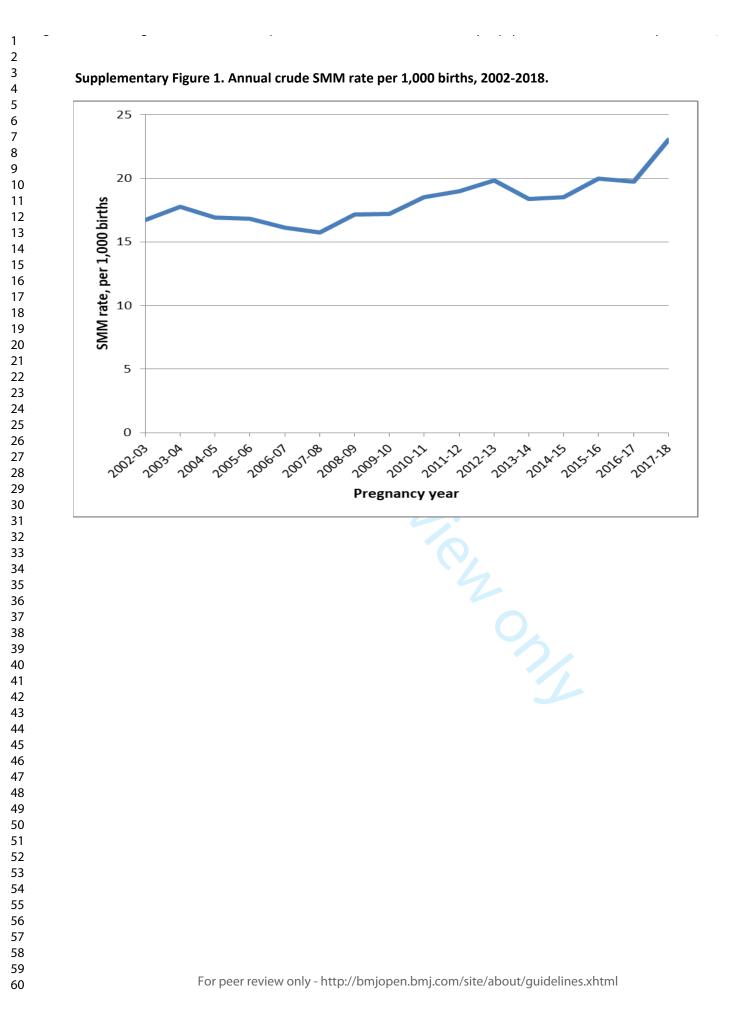
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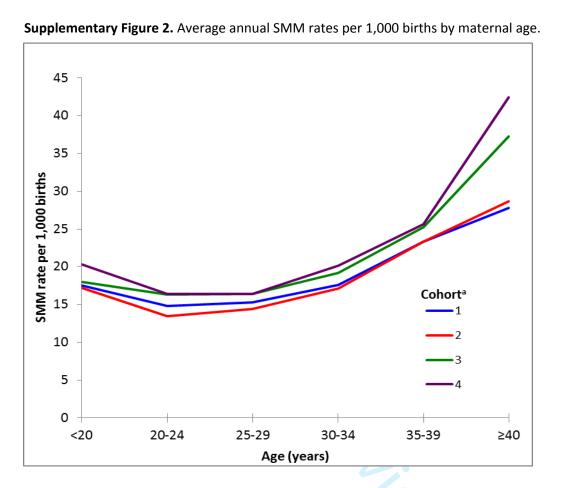
 Joseph KS, Fahey J, Canadian Perinatal Surveillance S. Validation of perinatal data in the Discharge Abstract Database of the Canadian Institute for Health Information. *Chronic Diseases in Canada*. 2009;29:96-100.
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^acohort 1: 1 April 2002 to 31 March 2006; cohort 2: 1 April 2006 to 31 March 2010; cohort 3: 1 April 2010 to 31 March 2014; cohort 4: 1 April 2014 to 31 March 2018

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		SMM rate	s by cohort ^a		SMM rate change, cohort	$4 vs 1^{\alpha}$
Variable	1	2	3	4	Rate difference (95% CI)	Rate ratio 🗍 95% CI)
Overall study population	17.10	16.55	18.94	19.82	2.72 (1.96, 3.49)***	1.16 (1.11 [⊃] 1.21)***
Maternal age (years)						Q
<20	17.54	17.22	17.97	20.34	2.80 (-0.43, 6.04)	1.15 (0.98 🛱 .37)
20-24	14.80	13.47	16.32	16.40	1.60 (-0.15, 3.35)	1.11 (0.99 J.24)
25-29	15.26	14.40	16.37	16.42	1.15 (-0.77, 2.39)	1.08 (0.9981.16)
30-34	17.58	17.10	19.21	20.16	2.58 (1.18, 3.97)*	1.15 (1.06 <mark>d</mark> 1.23)*
35-39	23.31	23.35	25.23	25.67	2.36 (-0.16, 4.88)	1.10 (0.99≸1.22)
≥40	27.78	28.68	37.30	42.48	14.69 (7.96, 21.43)*	1.53 (1.24 👼 1.89)*
Material deprivation						ded
Quintile 1 (least)	16.05	16.58	19.36	18.41	2.36 (2.31, 2.41)***	1.15 (1.14 <u>ਰ</u> ੋ1.15)***
Quintile 2	16.36	15.97	16.17	18.52	2.16 (2.11, 2.22)***	1.13 (1.13 $\stackrel{\exists}{_1}$ 1.14)***
Quintile 3	17.46	15.73	18.34	18.99	1.54 (1.48, 1.59)***	1.09 (1.08 🔁 1.09)***
Quintile 4	16.49	16.37	19.19	20.18	3.69 (3.63, 3.74)***	1.22 (1.22
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^acohort 1: 1 April 2002 to 31 March 2006; cohort 2: 1 April 2006 to 31 March 2010; cohort 3: 1 April 2010 to 31 March 2014; cohort 4: 1 . April 18, 202 April 2014 to 31 March 2018

*p<0.05, **p<0.01, ***p<0.001

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BMJ Open Snelgrove JW et al. Neighbourhood material deprivation and severe maternal morbidity: A population-based cohort study in Ontario, Canada

	Item No.	STROBE items	Location in manuscript where items are reported	RECORD items	Location in manuscript where items ar reported
Title and abstra	nct		1	r 20	1
	1	(a) Indicate the study's design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found	Title page (p.1)	RECORD 1.1: The type of data used should be specified in the tipe or abstract. When possible, the name of the databases used should be included. RECORD 1.2: If applicable the geographic region and time frame within which the study took place should be reported in the title or abstract. RECORD 1.3: If linkage between databases was conducted for the study, this should be clearly stated on the title or abstract.	Title page, abstract (p. 1-3)
Introduction				→ >	
Background rationale	2	Explain the scientific background and rationale for the investigation being reported	Background p.4-5	pril 18, 202	
Objectives	3	State specific objectives, including any prespecified hypotheses	Background p.4-5	2024 by guest	
Methods	·				
Study Design	4	Present key elements of study design early in the paper	Methods p.5-9	otected	
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Methods: <i>Study</i> population and data sources, Main outcome, p. 5-6	d by copyright.	

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Participants	6	 (a) Cohort study - Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up Case-control study - Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls Cross-sectional study - Give the eligibility criteria, and the sources and methods of selection of participants (b) Cohort study - For matched studies, give matching criteria and number of exposed and unexposed Case-control study - For matched studies, give matching criteria and the number of controls per 	Cohort study, no matching: Methods: <i>Study</i> <i>population and data</i> <i>sources, Main</i> <i>outcome, Exposures</i> <i>and covariates</i> p. 5- 8; Appendix 1	RECORD 6.1: The methods of study population selection (such as codes or algorithms used to identify subjects) should be listed in detail. If this is not possible, an explanation should be provided. RECORD 6.2: Any validation studies of the codes or algorithms used to select the population should be referenced. If validation was conducted for this study and not published elsewhere detailed methods and results should be provided. RECORD 6.3: If the study involved linkage of databases, consider use of a flow diagram or other graphical display to demonstrate the data linkage process, including the number of individuals with linked data at each stage.	Methods: Study population and data sources, Main outcome, Exposures and covariates p. 5 Supplementary Appendix 1
Variables	7	case Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable.	Methods: Study population and data sources, Main outcome, Exposures and covariates p. 5- 8; Supplementary Appendix 1	RECORD 7.1: A complete Bet of codes and algorithms used to classify exposures, outcomes, confounders, and effect modifiers should be provided. If these cannot be reported, an explanation should be provided.	Methods: Stua population and data sources, Main outcome Exposures and covariates p. 5 Supplementary Appendix 1
Data sources/ measurement	8	For each variable of interest, give sources of data and details of methods of assessment (measurement).	Methods: Study population and data sources, Main outcome, Exposures p.//bmjopen.bmj.com/site,	y copyright	

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		Describe comparability of assessment methods if there is more than one group	<i>and covariates</i> p. 5- 8; Supplementary Appendix 1		0-046174 0	
Bias	9	Describe any efforts to address potential sources of bias	Methods: <i>Exposures</i> and covariates p. 7- 8; Interpretation: <i>Strengths/ limitations</i> p.11-12		n 6 October 2021	
Study size	10	Explain how the study size was arrived at	Methods: <i>Study</i> <i>population and data</i> <i>sources,</i> p. 5-6; Figure 1		. Downloaded	
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why	Methods: Statistical analysis, p. 8-9		from http://bmiop	
Statistical methods	12	 (a) Describe all statistical methods, including those used to control for confounding (b) Describe any methods used to examine subgroups and interactions (c) Explain how missing data were addressed (d) <i>Cohort study</i> - If applicable, explain how loss to follow-up was addressed <i>Case-control study</i> - If applicable, explain how matching of cases and controls was addressed <i>Cross-sectional study</i> - If applicable, describe analytical methods taking account of 	Methods: <i>Statistical</i> <i>analysis</i> , p. 8-9, Results, p.9-11.		from http://bmiopen.bmi.com/ on April 18. 2024 by quest. Protected by copyright	

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		sampling strategy (e) Describe any sensitivity analyses		020-046174 0	
Data access and cleaning methods				RECORD 12.1: Authors should describe the extent to which the investigators had access to the database population used to create the study population.	Methods: <i>Study</i> <i>population and</i> <i>data sources,</i> p. 6; Supplementa Appendix 1; Author contributions, p 20
Linkage			or revie	RECORD 12.3: State whether the study included person-level, institutional- level, or other data linkage across two or more databases. The methods of linkage and methods of linkage quality evaluation should be provided.	Methods: Study population and data sources, Main outcome, Exposures and covariates p. 5- Supplementary Appendix 1
Results		1		2	
Participants	13	 (a) Report the numbers of individuals at each stage of the study (<i>e.g.</i>, numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed) (b) Give reasons for non- participation at each stage. (c) Consider use of a flow diagram 	Results p.10; Table 1; Figure 1	RECORD 13.1: Describe indetail the selection of the persons included in the study (<i>i.e.</i> , study population selection) including filtering based on data quality, data availability and linkage. The selection of included persons can be described in the text and persons can of the study flow diagram.	Methods: Study population and data sources, Main outcome, Exposures and covariates p. 5-8 Results p.10; Table 1; Figure Supplementary Appendix 1
Descriptive data	14	(a) Give characteristics of study participants (<i>e.g.</i> , demographic, clinical, social) and information	Results p.10; Table 1	v copyright	

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		 on exposures and potential confounders (b) Indicate the number of participants with missing data for each variable of interest (c) <i>Cohort study</i> - summarise follow-up time (<i>e.g.</i>, average and total amount) 			0-046174 on 6 October 2021.	
Outcome data	15	Cohort study - Report numbers of outcome events or summary measures over time Case-control study - Report numbers in each exposure category, or summary measures of exposure Cross-sectional study - Report numbers of outcome events or summary measures	Results p.10; Figure 1; Table 1		Downloaded from http://bmjopen.l	
Main results	16	 (a) Give unadjusted estimates and, if applicable, confounder- adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included (b) Report category boundaries when continuous variables were categorized (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period 	Results p.10; Table 1-3; Supplementary Figure 1	201	hmj.com/ on April 18, 2024 by guest. Protected by copyright	
Other analyses	17	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses	Results p.10-11		y copyright.	

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Discussion				<u> </u>	
Key results	18	Summarise key results with reference to study objectives	Interpretation, <i>Main</i> <i>findings</i> p.11	6174 or	
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Interpretation, <i>Strengths/limitations</i> p.11-12	RECORD 19.1: Discuss the implications of using data that were not created or collected to answer the specific research question(sy Include discussion of misclassification bias, unmeasured confounding, no ssing data, and changing eligibility over time, as they pertain to the study being reported.	Interpretation, Strengths/limit ns p.11-12
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	Discussion, Main findings p. 11, Strengths / Limitations p. 11-12	ded from http://bmjopen.t	
Generalisability	21	Discuss the generalisability (external validity) of the study results	Discussion, Interpretation p.11- 12	mj.com/ o	
Other Informatio	n			<u> </u>	
Funding	22	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	Funding, p. 21-22	April 18, 2024 by gu	
Accessibility of protocol, raw data, and programming code				RECORD 22.1: Authors should provide information on how to access any supplemental information such as the study protocol, raw data, or programming code.	p. 21; Supplementary Appendix 1
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*Reference: Benchimol EI, Smeeth L, Guttmann A, Harron K, Moher D, Petersen I, Sørensen HT, von Elm E, Lang SM, the RECORD Working , K, , , Observatio. .s Attribution (<u>CC BY</u>) license. Committee. The REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) Statement. PLoS Medicine 201 in press. on 6 October 2021. Downloaded from http://bmjopen.bmj.com/ on April 18, 2024 by guest. Protected by copyright.

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Journal:	BMJ Open
Manuscript ID	bmjopen-2020-046174.R2
Article Type:	Original research
Date Submitted by the Author:	17-Aug-2021
Complete List of Authors:	Snelgrove, John; Sinai Health System, Obstetrics & Gynaecology; University of Toronto, Obstetrics & Gynaecology Lam, Melody; ICES Western Watson, Tristan; Institute for Clinical Evaluative Sciences, Richard, Lucie; Institute for Clinical Evaluative Sciences, N/A Fell, DB; CHEO Research Institute, Ottawa, Ontario, Canada; University of Ottawa, School of Epidemiology and Public Health Murphy, Kellie; Sinai Health System, Obstetrics & Gynaecology; University of Toronto, Obstetrics & Gynaecology Rosella, Laura; University of Toronto, Dalla Lana School of Public Health
Primary Subject Heading :	Obstetrics and gynaecology
Secondary Subject Heading:	Epidemiology
Keywords:	EPIDEMIOLOGY, OBSTETRICS, PERINATOLOGY

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3 4	1	TITLE PAGE
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6 7	2	Neighbourhood material deprivation and severe maternal morbidity:
8 9	3	A population-based cohort study in Ontario, Canada
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11 12	4	
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2 3 4 5	26	ABSTRACT
6 7	27	Objectives: Rates of age-associated severe maternal morbidity (SMM) have increased in
8 9 10	28	Canada, and an association with neighbourhood income is well established. Our aim was to
11 12	29	examine SMM trends according to neighbourhood material deprivation quintile, and to
13 14 15	30	assess whether neighbourhood deprivation effects are moderated by maternal age.
16 17 18	31	Design, setting, participants: A population-based retrospective cohort study using linked
19 20	32	administrative databases in Ontario, Canada. We included primiparous women with a live
21 22 23 24	33	birth or stillbirth at ≥20 weeks gestational age.
25 26	34	Primary outcome: SMM from pregnancy onset to 42 days postpartum. We calculated SMM
27 28 29	35	rate differences (RD) and rate ratios (RR) by neighbourhood material deprivation quintile for
30 31	36	each of four 4-year cohorts from 1 April 2002 to 31 March 2018. Log-binomial multivariable
32 33 34	37	regression adjusted for maternal age, demographic, and pregnancy-related variables.
35 36 37	38	Results: There were 1,048,845 primiparous births during the study period. The overall rate
38 39	39	of SMM was 18.0 per 1,000 births. SMM rates were elevated for women living in areas with
40 41 42	40	high material deprivation. In the final 4-year cohort, the RD between women living in high
43 44	41	versus low deprivation neighbourhoods was 3.91 SMM cases per 1,000 births (95% CI: 2.12,
45 46 47	42	5.70). This was higher than the difference observed during the first 4-year cohort (RD 2.09,
47 48 49	43	95% CI: 0.62, 3.56). SMM remained associated with neighbourhood material deprivation
50 51	44	following multivariable adjustment in the pooled sample (RR 1.16, 95% CI: 1.11, 1,21). There
52 53 54	45	was no evidence of interaction with maternal age.
55 56 57	46	Conclusion: SMM rate increases were more pronounced for primiparous women living in
58 59 60	47	neighbourhoods with high material deprivation compared to those living in low deprivation

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3	48	areas. This raises concerns of a widening social gap in maternal health disparities and
4 5		
6	49	highlights an opportunity to focus risk reduction efforts toward disadvantaged women
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8 9	50	during pregnancy and postpartum.
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14 15	52	Keywords: severe maternal morbidity; maternal mortality; maternal health; pregnancy;
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17	53	perinatal epidemiology; social epidemiology; social inequalities; deprivation
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23	55	Strengths and Limitations of this Study
24 25	55	Strengths and Emitations of this Study
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27	56	• Data were from population linked administrative and health registries that capture
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29 30	57	all hospital births in Ontario, Canada 🔨
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33	58	 Neighbourhood material deprivation was measured using the Ontario
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36	59	Marginalization Index, a comprehensive area-level measure based on Census data
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38	60	developed using theoretical frameworks on marginalization and deprivation
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40	61	• Limiting our study to primiparous women enabled the evaluation of population SMM
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43	62	trends and reduced confounding from previous births
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47	63	 It was not possible to control for all covariates associated with SMM, including body
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49 50	64	mass index, co-morbidities, and the use of assisted reproductive technology
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66 INTRODUCTION

Each year, approximately 4,000 Canadian women survive a maternal "near-miss"—a life-threatening event associated with pregnancy.[1] To characterize maternal near-misses in a standardized way, the World Health Organization proposed the concept of severe maternal morbidity (SMM), a composite of conditions that represent end-organ dysfunction or states of heightened maternal mortality risk associated with pregnancy, birth, or the postpartum period.[2, 3] Advances in the recognition and management of SMM have resulted in low maternal mortality rates in economically developed nations. Women living in high income countries are now more likely to survive a life-threatening pregnancy condition and, correspondingly, the rates of SMM are 100-fold higher than the rates of maternal mortality in Canada.[1] However, recent trends in Canada and other high income countries show an increase in SMM rates coinciding with advancing maternal age and corresponding increases in pre-existing co-morbidities and the use of assisted reproductive technology.[4-9] The literature also shows persistent though complex associations between SMM and the social determinants of health. Low occupational class, Black ethnicity, [10] and non-private health insurance[11] are all associated with higher risk of SMM in the US. Canadian women who experience SMM are more likely to come from a low-income background, and to originate from an African or Caribbean country. [4, 6, 12] A systematic review found evidence for effects of material dimensions of inequality on SMM risk, though it pointed out the need for further work on other dimensions and in elucidating effect mechanisms.[13] Women of advanced maternal age may be more likely to come from more advantaged socioeconomic backgrounds and to have planned pregnancies.[14-16] This suggests the possibility for effect modification, whereby the negative effects of advanced maternal age

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may be attenuated for women who come from more advantaged backgrounds, and exacerbated for women from disadvantaged backgrounds. The effects of maternal age and neighbourhood-level material deprivation may therefore interact, with the highest SMM risk among older women living in neighbourhoods with higher deprivation. In this study, our first objective was to evaluate trends in SMM rates among primiparous women in Ontario by neighbourhood material deprivation guintile between 1 April 2002 and 31 March 2018. Our second objective was to determine if maternal age moderates the effect of neighbourhood material deprivation. We hypothesized that SMM rates would increase disproportionately over time among women living in neighbourhoods with high material deprivation. We further hypothesized that the highest risk of SMM would be among women of advanced maternal age living in neighbourhoods with the highest material elie deprivation.

METHODS

This population-based retrospective cohort study used linked administrative datasets for Ontario, held at ICES (formerly, the Institute for Clinical Evaluative Sciences). ICES is an independent, non-profit research institute funded by an annual grant from the Ontario Ministry of Health (MOH) and the Ministry of Long-Term Care (MLTC). As a prescribed entity under Ontario's privacy legislation, ICES is authorized to collect and use health care data for the purposes of health system analysis, evaluation and decision support. Secure access to these data is governed by policies and procedures that are approved by the Information and Privacy Commissioner of Ontario. The use of data in this project was authorized under section 45 of Ontario's Personal Health Information Protection Act, which does not require

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3 4	111	review by a Research Ethics Board. We followed the RECORD guidelines (REporting of
5 6 7	112	studies Conducted using Observational Routinely-collected Data) for reporting this
8 9	113	study.[17]
10 11 12 13	114	Patient and public involvement
14 15 16	115	There was no direct patient or public involvement in this study.
17 18	116	Study population and data sources
19 20		
21 22	117	The Canadian Institute for Health Information Discharge Abstract Database (DAD) was used
23 24 25	118	to capture all hospital admissions for birth and link to newborn records using the ICES-
26 27	119	derived MOMBABY dataset. We included primiparous women aged 10-55 years who had a
28 29 20	120	hospital birth in Ontario and were enrolled in the province's universal health insurance
30 31 32	121	program (OHIP). We identified the first live birth or stillbirth delivery at a gestational age of
33 34	122	≥20 weeks. We used gestational age at birth to calculate pregnancy onset. Women were
35 36 37	123	included if the onset of their first pregnancy was on or after 1 April 2002 and the
38 39	124	corresponding birth occurred on or before 17 February 2018—allowing 42 days of
40 41 42	125	postpartum follow-up through the study end date of 31 March 2018. Women who had a
42 43 44	126	previous birth within 14 years prior to the index date were excluded. We linked these data
45 46	127	with the Registered Persons Database (RPDB), DAD, and OHIP Claims Database to identify
47 48 49	128	exposures and outcomes of interest. To identify women who had recently immigrated to
50 51	129	Ontario, we used the Ontario portion of the federal Immigration, Refugees and Citizenship
52 53 54	130	Canada (IRCC) Permanent Resident Database. For neighbourhood material deprivation, we
55 56 57 58	131	used the 2001 and 2006 Canadian Census, and Ontario Marginalization Index (ON-
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MARG).[18] These datasets were linked using unique encoded identifiers and analyzed at 132 133 ICES and are shown in Appendix 1.

Main outcome 134

The main outcome was a composite of medical conditions and interventions that comprise 135 136 SMM. Cases of SMM were identified using diagnosis and procedural codes (International Statistical Classification of Diseases and Related Health Problems, 10th revision [ICD-10] and 137 Canadian Classification of Health Interventions, respectively) within the DAD database.[15, 138 139 19-21] The DAD data have been validated and shown to accurately reflect the information in medical records.[21, 22] The composite SMM outcome included: 1) causes of direct 140 obstetric death and conditions related to these (antepartum, intrapartum, and postpartum 141 142 hemorrhage; hypertensive disorders of pregnancy and eclampsia; puerperal sepsis; uterine rupture; obstetric embolus); 2) severe organ system dysfunction (cardiac arrest, failure, or 143 144 arrhythmia; renal or hepatic failure; coagulation defect; thromboembolism; respiratory failure; coma or non-eclamptic seizure; psychosis); 3) procedures or interventions 145 accompanying life-threatening conditions or health states (cesarean or postpartum 146 147 hysterectomy; pelvic vessel ligation; surgical repair of bowel, bladder, or urethra; endotracheal or tracheostomy ventilation; dialysis; blood transfusion in the context of 148 severe blood loss); and 4) deaths that were ill-defined or sudden, as these could not reliably 49 150 be classified as non-obstetric deaths. Appendix 1 shows the list of SMM indicators for this 151 study. We specified a binary SMM outcome variable for the presence of one or more 152 indicators occurring from the onset of pregnancy up to and including 42 days after birth. **Exposures and covariates** 153

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154	Our main exposure of interest was neighbourhood material deprivation quintile from the
155	Ontario Marginalization Index (ON-MARG). ON-MARG is the Ontario-specific version of the
156	Canadian marginalization index (CAN-MARG).[23] The index was developed based on
157	theoretical frameworks of marginalization and deprivation, and derived empirically using
158	principal component analysis of Canadian Census variables.[18, 23]The material deprivation
159	dimension is comprised of the following Census measures, each expressed as a proportion:
160	population aged \geq 20 without secondary school graduation, single parent families,
161	households receiving government transfer payments, population aged ≥15 who are
162	unemployed, population living below the low income cut-off (adjusted for community size,
163	household size, and inflation).[18] The geographical unit of aggregation is Dissemination
164	Areas, which average 400-700 people and cover the entirety of Canadian territory.[24] ON-
165	MARG can be operationalized as a standardized interval scale based on factor loadings from
166	the principal component analysis, or as quintiles each representing 20% of Dissemination
167	Areas.[18, 23] We modelled this exposure as quintiles, with quintile 1 representing
168	neighbourhoods with the lowest material deprivation, and quintile 5 representing
169	neighbourhoods with the highest deprivation.[18, 23] ON-MARG has been used to
170	demonstrate inequalities in various health measures and is stable over time.[25-27] We
171	used the 2001 material deprivation index for births between years 2002-2003, and the 2006
172	index for years 2004-2018. The change from mandatory Census reporting to the voluntary
173	National Household Survey and resulting data quality concerns meant that the 2011 index
174	was comprised from alternate data sources.[28] We used the 2006 version for all years after
175	2004 to avoid operationalizing this variable differently between study years.

> We included maternal age at birth, categorized in 5-year bands. We adjusted for rural setting using the 2004 and 2008 Rurality Index of Ontario (RIO).[29] We used the 2004 RIO index for pregnancies between years 2002 and 2006, and the 2008 index for years 2007 to 2018. We adjusted for number of years since immigration using data from the IRCC. Additional demographic and pregnancy related variables included delivery mode and multiple gestations. For multiple gestation pregnancies, delivery mode was specified based on highest level of intervention: unassisted vaginal birth of all fetuses (lowest), forceps or vacuum assisted vaginal birth of one or more fetuses, vaginal breech birth of one or more fetuses, and caesarean birth of one or more fetuses (highest). We examined SMM rates by gestational age at birth, induction of labour, and the use of epidural analgesia, however these variables were not adjusted-for in the multivariable models.

187 Statistical analysis

We summarized baseline characteristics and SMM rates overall for the study population. Due to low birth counts for ages 10-14 years, we collapsed these into an age <20 years group for analysis. We plotted SMM rates by year for the whole study population, and then to evaluate changes over time, we divided the population into four, 4-year cohorts based on pregnancy onset: 1 April 2002 to 31 March 2006 (cohort 1); 1 April 2006 to 31 March 2010 (cohort 2); 1 April 2010 to 31 March 2014 (cohort 3); and 1 April 2014 to 31 March 2018 (cohort 4). To address our first objective, we calculated average annual SMM rates for each 4-year cohort by neighbourhood material deprivation quintile. Within each cohort, we estimated unadjusted absolute rate differences (RD) and rate ratios (RR) with 95% confidence intervals (CI) comparing women in quintile 5 (highest deprivation) with women in quintile 1 (lowest deprivation).

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	199	Our second objective was to evaluate the effect of neighbourhood material deprivation,
	200	adjusting for covariates and testing for interaction with maternal age for the overall study
	201	population. We constructed multivariable log-binomial regression models. We initially fit a
)	202	model with neighbourhood material deprivation, adjusting only for year of pregnancy onset
<u>2</u> 5 L	203	(model 1). We then added maternal age (model 2), followed by demographic and
5	204	pregnancy-related covariates, immigration status, and rurality (model 3). We tested for
7 3	205	interaction between material deprivation and maternal age using a cross product term. We
)	206	did not adjust for stillbirth or gestational age at birth, as these are variables are considered
<u>)</u> 5	207	colliders rather than true confounders of outcomes associated with SMM.[30] We did not
 ; ;	208	include induction of labour or epidural analgesia, as these interventions are associated with
3	209	clinical decisions surrounding birth rather than SMM risk factors. We excluded women with
)	210	missing information for neighbourhood material deprivation from the multivariable analysis,
<u>2</u> 5	211	as these women represented less than 2 percent of the study population (n=17,130).
+ ;		
; ,	212	We performed two additional analyses evaluating SMM rate trends (RD and RR) over the
3	213	study period, comparing the 4-year average annual rates during cohort 4 to cohort 1
)	214	separately by maternal age and by neighbourhood material deprivation quintile. We also
<u>′</u> } }	215	examined the 4-year average rates of SMM excluding cases defined by HIV disease. This was
5	216	done in reference to recently proposed changes to the Canadian SMM composite indicator
7 3 3	217	excluding chronic, asymptomatic HIV disease.[12, 31] Statistical analyses were performed
)	218	using SAS (version 7.15, SAS Institute Inc., Cary, NC) and STATA (version 13, StataCorp.,
<u>)</u> 5	219	College Station, TX).
+ 5		
) 7	220	RESULTS

There were 2,143,045 hospital-based births in Ontario between 1 April 2002 and 17 February 2018, of which 1,048,845 were primiparous births and included in the study (Figure 1). The overall SMM rate across the study period was 18.0 per 1,000 births, and increased from 16.7 per 1,000 births in 2002-03 (95% CI: 15.6, 17.9) to 23.0 per 1,000 births in 2017-18 (95% CI: 21.2, 25.0, Supplementary Figure 1). Baseline characteristics and SMM case number and rate for each characteristic are presented in Table 1. SMM rates were higher at the extremes of maternal age, and among women living in neighbourhoods with the highest material deprivation.

Table 2 presents SMM rates by material deprivation quintile for the pooled study sample (2002-2018) and each of the four 4-year cohorts. The RD was 2.09 cases per 1,000 births (95% CI: 0.62, 3.56), corresponding with a RR of 1.13 (95% CI: 1.04, 1.23) comparing women in guintile 5 with women in guintile 1 during the first 4-year cohort. This increased to a RD of 3.91 cases per 1,000 births (95% CI: 2.12, 5.70) and RR of 1.21 (95% CI: 1.11, 1.32) in the final 4-year cohort of the study period. Average annual SMM rates increased between cohort 1 and cohort 4 for women aged 30-34, and \geq 40 years (Supplementary Table 1, **Supplementary Figure 2**). For the latter group, the absolute increase was 14.69 cases per 1,000 births (95% CI: 7.96-21.43, Supplementary Table 1). SMM rates increased over time for women in each quintile of neighbourhood deprivation, and this increase was most pronounced for women in the highest quintile of neighbourhood deprivation (RD 4.19 cases per 1,000 births 95% CI: 4.13-4.24, Supplementary Table 1).

In the multivariable regression analysis for the overall study population, women living in
 neighbourhoods with the highest material deprivation had higher rates of SMM compared
 to those in neighbourhoods with the lowest after adjusting for pregnancy year (RR: 1.11,

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95% CI: 1.06, 1.16, Table 3). Full adjustment for age, demographics, pregnancy-related 244 variables, and rurality had minimal effect on the association between material deprivation 245 246 and SMM rates (adjusted RR: 1.16, 95% CI: 1.11, 1.21, Table 3). The association between age 247 and SMM persisted in the fully adjusted model, with higher risk for women <20 and \geq 30 years of age. We did not find evidence of statistical interaction between maternal age and 248 neighbourhood material deprivation guintile. 249

DISCUSSION 250

Main findings 251

This study demonstrated an association between neighbourhood material deprivation and 252 severe maternal morbidity among primiparous women in Ontario from 2002-2018. Rates of 253 254 SMM increased across all material deprivation guintiles, and we found some evidence that 255 women in the highest deprivation quintile experienced a higher magnitude SMM rate increase over the 16-year study period compared with women in the lowest deprivation 256 257 quintile. This finding suggests a possible widening of the gap between women living in the 258 most and least deprived neighbourhoods.

Strengths/ limitations 259

260 The current study was a population-based analysis of all primiparous hospital births at ≥ 20 weeks' gestational age in Ontario. Hospital births account for over 98% of births in the 261 province. We used a measure of neighbourhood marginalization that includes income along 262 263 with other measures of material resources, and that is stable across time and different 264 health outcomes. [23, 25] Our study nonetheless had some limitations. We were unable to 265 account for births prior to 20 weeks' gestation or births that occurred outside of the 60

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266	province. Our measure of SMM was based on validated perinatal health data for
267	Canada.[15, 21] A revision of the Canadian SMM composite was recently developed which
268	resolves issues surrounding the inclusion of some pre-eclampsia and HELLP syndrome
269	measures, as well as the exclusion of HIV infection—a condition that is unlikely to represent
270	SMM when asymptomatic [12, 31]. We elected to use the former SMM composite for
271	comparison with previous literature, recognizing this may complicate direct comparison
272	with recent Canadian studies [4, 6, 12, 31]. The proportion of women with SMM defined by
273	HIV disease was around 2 percent for each of the 4-year cohorts, and thus we do not believe
274	these cases substantively altered the results of this study. Information on immigrants
275	arriving prior to 1985 is not captured in the IRCC Permanent Resident Database, and the
276	database does not identify immigrants who landed in other provinces and subsequently
277	moved to Ontario. Although we used a measure of neighbourhood material deprivation
278	developed for Ontario using Canadian Census elements,[28] the ON-MARG index does not
279	include individual-level indicators of marginalization or socioeconomic status. Important
280	social determinants may differ among individuals living in areas characterized by similar
281	measures of neighbourhood deprivation, and it is not possible to elucidate the causal
282	pathways that link social disadvantage to poor health outcomes without incorporating such
283	factors.[32, 33] Finally, pre-pregnancy co-morbidities, obesity, and the use of assisted
284	reproductive technology, contribute to higher SMM rates and may partially explain SMM
285	trends.[8, 9, 34] We were unable to account for these factors. Obstetric comorbidity indices
286	have been developed for risk prediction and adjustment in clinical research. [35, 36] We did
287	not use an obstetric comorbidity index in our adjusted analysis as some index indicators

3 4	288	represent SMM outcomes themselves, or are mediators of SMM outcomes. In addition, our
5 6 7	289	aim was to examine population SMM trends rather than individual clinical risk factors.
8 9 10	290	Interpretation
11 12 13	291	The present study contributes to our understanding of the association between
14 15 16	292	neighbourhood marginalization and SMM and provides preliminary evidence of a possible
17 18	293	widening of this health disparity over time in Ontario. The association between
19 20 21	294	neighbourhood-level measures of inequality and risk of SMM has been demonstrated
22 23	295	previously in several high-income countries.[6, 9, 11, 13, 37-41] Notably in Canada, Aoyama
24 25 26	296	and colleagues reported a rise in SMM linked to the relative increase in maternal age and
20 27 28	297	found a significant association between SMM and neighbourhood income quintile.[4]. Our
29 30	298	study confirms this finding using a measure that encompasses income along with additional
31 32 33	299	measures of neighbourhood material deprivation. Moreover, we extend the current
34 35	300	understanding of this association by providing evidence for a possible disproportionate rise
36 37 38	301	in SMM risk experienced by women living in marginalized neighbourhoods over time. We
39 40	302	interpret this last finding with caution, as our study showed significant rate differences by
41 42 43	303	neighbourhood marginalization only during the first and final 4-year cohorts of the 16-year
43 44 45	304	study period. SMM risks have been demonstrated among other social determinants of
46 47	305	health; for example, lower occupational class, Black ethnicity,[10] and non-private health
48 49 50	306	insurance[11] are associated with higher risk of SMM in the US. Interaction between
51 52	307	socioeconomic indicators—including ethnicity, education, and poverty—likely contribute to
53 54 55	308	the social gradient of risk such that the protective effects afforded by higher education and
56 57	309	income do not fully ameliorate racial disparities in SMM.[38] Our study showed an
58 59 60	310	association between neighbourhood deprivation and SMM suggesting the effects of 14

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311	marginalization persist even in the context of universal healthcare. This is a consistent
312	finding across countries that have similar publicly funded healthcare systems.[41-43] The
313	factors contributing to social inequality are myriad; ethnicity and country of origin, rurality
314	and access to care, income, material resources, education, and psychosocial supports all
315	have worrisome associations with maternal reproductive health risks.[6, 10-12, 38, 41-47]
316	How these factors contribute to widening health gaps, and what interventions may
317	attenuate their effects will be imperative lines of inquiry going forward as the global
318	challenge to lower SMM continues.
319	Conclusion
320	Ontario women living in areas with higher neighbourhood material deprivation experienced
321	the highest risk of SMM, and this association was not fully explained by maternal age.
322	Additionally, women living in high-deprivation neighbourhoods may have experienced a
323	disproportionate increase in the risk of SMM over time. Future work must focus on
324	addressing the widening social gap in maternal health disparities.
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TABLES

Table 1. Baseline characteristics of the study population, 2002-2018. N=1,048,845 births.

Verieble	Number of	Democrat	Number of	SMM rate per
Variable	births	Percent	SMM cases	1,000 births
Overall study population	1,048,845	100	18,880	18.00
Maternal age at birth, years				
10-14	1,330	0.1	35	26.32
15-19	72,579	6.9	1,291	17.79
20-24	178,074	17.0	2,684	15.07
25-29	342,003	32.6	5,324	15.57
30-34	305,898	29.2	5,653	18.48
35-39	123,698	11.8	3,017	24.39
≥40	25,263	2.4	876	34.68
Gestational age at birth, weeks				
20-23	2,751	0.3	147	53.44
24-27	4,158	0.4	306	73.59
28-33	17,688	1.7	1,104	62.42
34-36	59,040	5.6	1,966	33.30
37-41	961,322	91.7	15,278	15.89
≥42	3,886	0.4	79	20.33
Induced labour	275,262	26.2	5,836	21.20
Epidural	655,107	62.5	10,713	16.35
Delivery mode				
Vaginal unassisted	579,814	55.3	6,386	11.01
Vaginal assisted	156,383	14.9	2,724	17.42
Vaginal breech	2,328	0.2	95	40.81
Caesarean	310,320	29.6	9,675	31.18
Multiple gestations	20,850	2.0	1,137	54.53
Stillbirth	3,645	0.3	199	54.60
Rurality				
Urban	993,282	94.7	17,814	17.93
Rural	55,563	5.3	1,066	19.19
Immigration Status				
Non-immigrant / before 1985	739,252	70.5	13,222	17.89
Immigrated >10 years	62,381	5.9	1,165	18.68
Immigrated 5-10 years	62,090	5.9	1,249	20.12
Immigrated <5 years	185,122	17.7	3,244	17.52
Neighbourhood marginalization				
Material deprivation				
Quintile 1 (least deprived)	237,877	22.7	4,183	17.58
Quintile 2	186,550	17.8	3,112	16.68
Quintile 3	189,575	18.1	3,327	17.55

1 2 3 4 5 6	Quintile 4 Quintile 5 (most deprived) Missing	191,376 226,337 17,130	18.2 21.6 1.6	3,423 4,397 438	17.89 19.43 25.57
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Table 2. Four-year average SMM rates per 1,000 births for neighbourhood material

deprivation quintiles, by pooled sample (2002-2018) and by study period cohort.

9		SMM rates by material deprivation quintile			Q5 vs Q1			
10		Q1				Q5	Rate difference (95%	
11 12	Cohort ^a	(least)	Q2	Q3	Q4	(most)	CI)	Rate ratio (95% CI)
13	Pooled	17.58	16.68	17.55	17.89	19.43	1.84 (1.82,1.87)***	1.10 (1.10-1.11)***
14								
15	1	16.05	16.36	17.46	16.49	18.14	2.09 (0.62, 3.56)**	1.13 (1.04, 1.23)**
16 17	2	16.58	15.97	15.73	16.37	17.32	0.75 (-0.70, 2.20)	1.05 (0.96, 1.14)
18	3	19.36	16.17	18.34	19.19	20.78	1.41 (-0.20, 3.02)	1.07 (0.99, 1.16)
19	4	18.41	18.52	18.99	20.18	22.32	3.91 (2.12, 5.70)***	1.21 (1.11, 1.32)***
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24	343 ^a coł	nort 1: 1 Ap	ril 2002 to 3	31 March 2	006; cohor	t 2: 1 April	2006 to 31 March 2010	; cohort 3:
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26	344 1 Ap	oril 2010 to	31 March 2	2014; cohoi	rt 4: 1 April	2014 to 31	March 2018	
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29	345 [*] p<(0.05 <i>,</i> **p<0.	01 ***n<0()01				
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Table 3. Neighbourhood material deprivation and risk of SMM: Adjusted multivariable

models, RR (95% CI). N=1,031,715 births.

10		Variable	Model 1ª	Model 2 ^b	Model
1		Maternal age (years)			
2		<20		1.05 (0.99, 1.12)	1.20 (1.13, 1.28)
3		20-24		0.95 (0.90, 0.99)	1.01 (0.96, 1.06)
4		25-29		1 (ref)	1 (ref)
5 6		30-34		1.19 (1.14, 1.23)	1.10 (1.06, 1.15)
7		35-39		1.56 (1.49, 1.63)	1.34 (1.28, 1.40)
8		≥40		2.21 (2.06, 2.37)	1.73 (1.61, 1.86)
9		Material deprivation			, , ,
0		Quintile 1 (least)	1 (ref)	1 (ref)	1 (ref)
1 2		Quintile 2	0.95 (0.91, 0.99)	0.97 (0.93, 1.02)	0.97 (0.92, 1.01)
3		Quintile 3	1.00 (0.96, 1.05)	1.04 (0.99, 1.08)	1.03 (0.98, 1.07)
4		Quintile 4	1.02 (0.98, 1.07)	1.07 (1.02, 1.12)	1.06 (1.01, 1.11)
5		Quintile 5 (most)	1.11 (1.06, 1.16)	1.17 (1.12, 1.22)	1.16 (1.11, 1.21)
6				1.17 (1.12, 1.22)	1.10 (1.11, 1.21)
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3	361	FIGURE CAPTIONS
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6	362	Figure 1. Study inclusion / exclusion flow chart, primiparous births.
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13	364	SUPPLEMENTARY MATERIAL CAPTIONS
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16	365	Supplementary Appendix 1. Data sources for the project.
17	303	Supplementary Appendix 1. Data sources for the project.
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20	366	Supplementary Figure 1. Annual crude SMM rate per 1,000 births, 2002-2018.
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23	367	Supplementary Figure 2. Average annual SMM rates per 1,000 births by maternal age.
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26	368	Supplementary Table 1. Four-year average SMM rates per 1,000 births by age and by
27	508	Supplementary rable 1. Four year average Sivily rates per 1,000 births by age and by
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29	369	material deprivation, and rate change over study period.
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2 3 4 5	379	Acknowledgements
6 7	380	The authors would like to thank Josie Chundamala, Scientific Grant Editor funded by the
8 9 10	381	Department of Obstetrics and Gynecology at Mount Sinai Hospital, for assistance editing
10 11 12 13	382	and preparing this manuscript for submission.
14 15 16	383	Declaration of competing interests
17 18 19	384	The authors declare no conflicts of interest.
20 21 22	385	Author contributions
23 24 25	386	JWS, DF, KEM, and LCR contributed to the overall conception of the study. JWS, ML, LR, DF,
26 27 28	387	and LCR contributed to study design and protocol. TW had full access to data used in the
29 30	388	study. JWS, TW, and LCR take responsibility for the integrity of the data analysis. JWS wrote
31 32 33	389	the manuscript. All authors made substantial contributions to the data analysis
33 34 35	390	interpretation, and manuscript editing and revising for this project. All authors approve the
36 37 38	391	final submitted version and agree to be accountable for all aspects of the work.
39 40 41	392	Ethical approval
42 43 44	393	ICES is a prescribed entity under section 45 of Ontario's Personal Health Information
45 46	394	Protection Act. Section 45 authorizes ICES to collect personal health information, without
47 48 49	395	consent, for the purpose of analysis or compiling statistical information with respect to the
50 51	396	management of, evaluation or monitoring of, the allocation of resources to or planning for
52 53 54	397	all or part of the health system. Projects conducted under section 45, by definition, do not
55 56	398	require review by a Research Ethics Board. This project was conducted under section 45,
57 58 59	399	and approved by ICES' Privacy and Legal Office.
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1 2 3	400	Patient consent for publication
4 5	400	
6 7 8	401	None required.
9 10 11	402	Data availability statement
12 13 14	403	The dataset from this study is held securely in coded form at ICES. While data sharing
15 16	404	agreements prohibit ICES from making the dataset publicly available, access may be granted
17 18 19	405	to those who meet pre-specified criteria for confidential access, available at
20 21	406	www.ices.on.ca/DAS. The full dataset creation plan and underlying analytic code are
22 23 24	407	available from the authors upon request, understanding that the computer programs may
25 26	408	rely upon coding templates or macros that are unique to ICES and are therefore either
27 28 29	409	inaccessible or may require modification.
30 31 32 33	410	Funding
34 35	411	John Snelgrove received funding for this project through an internal grant from the
36 37 38	412	Department of Obstetrics & Gynaecology, University of Toronto, and Department of
39 40	413	Obstetrics & Gynaecology, Mount Sinai Hospital. This study was supported by ICES, which is
41 42	414	funded by an annual grant from the Ontario Ministry of Health and Long-Term Care
43 44 45	415	(MOHLTC). This study was completed at the ICES University of Toronto site and ICES
46 47	416	Western site—where core funding is provided by the Academic Medical Organization of
48 49 50	417	Southwestern Ontario, the Schulich School of Medicine and Dentistry, Western University,
51 52	418	and the Lawson Health Research Institute. Parts of this material are based on data and
53 54 55	419	information compiled and provided by the Canadian Institute for Health Information, and by
56 57 58	420	Immigration, Refugees and Citizenship Canada (IRCC). The analyses, conclusions, opinions
59 60		23

2 3 4	421	and statements expressed herein are solely those of the authors and do not reflect those of
5	422	the funding or data sources; no endorsement is intended or should be inferred.
	422	the funding or data sources; no endorsement is intended or should be inferred.
59 60		24

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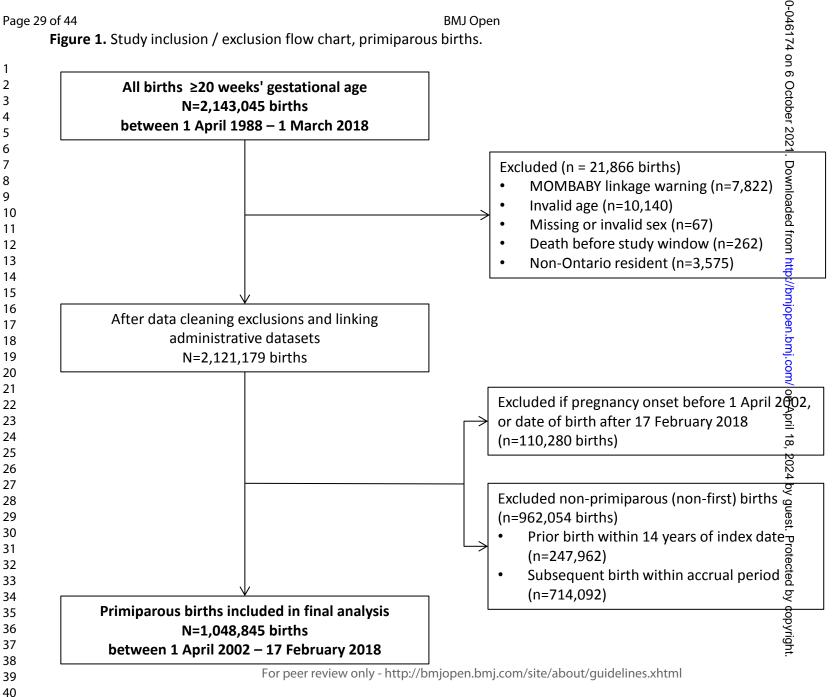
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Neighbourhood material deprivation and severe maternal morbidity: A population-based cohort study in Ontario, Canada Snelgrove JW et al.

Supplementary Appendix 1. Data sources for project

Discharge Abstract Database (DAD)

The DAD is compiled by the Canadian Institute for Health Information and contains administrative, clinical (diagnoses and procedures/interventions), demographic, and administrative information for all admissions to acute care hospitals, rehab, chronic, and day surgery institutions in Ontario. At ICES, consecutive DAD records are linked together to form 'episodes of care' among the hospitals to which patients have been transferred after their initial admission.

MOMBABY

The ICES MOMBABY Database is an ICES-derived cohort that links the DAD inpatient admission records of delivering mothers and their newborns. From 2002 onward, this linkage is performed deterministically using a maternal-newborn chart matching number. Prior to 2002, mothers were linked to their children by matching on the institutions they were admitted, their postal codes, and their admission/discharge dates.

Registered Persons Database (RPDB)

The RPDB provides basic demographic information (age, sex, location of residence, date of birth, and date of death for deceased individuals) for those issued an Ontario health insurance number. The RPDB also indicates the time periods for which an individual was eligible to receive publicly funded health insurance benefits and the best known

Ontario Health Insurance Plan (OHIP)

The OHIP claims database contains information on inpatient and outpatient services provided to Ontario residents eligible for the province's publicly funded health insurance system by fee-for-service health care practitioners (primarily physicians) and "shadow billings" for those paid through non-fee-for-service payment plans. The main data elements include patient and physician identifiers (encrypted), code for service provided, date of service, associated diagnosis, and fee paid.

Immigration, Refugees, and Citizenship Canada's (IRCC) Permanent Resident Database

The Ontario portion of the IRCC Permanent Resident Database includes immigration application records for people who initially applied to land in Ontario since 1985. The dataset contains permanent residents' demographic information such as country of citizenship, level of education, mother tongue, and landing date. New immigrants who are currently residing in Ontario but originally landed in another province are not captured in this dataset.

Ontario Marginalization Index (ONMARG)

ONMARG is a geographically (census) based index developed to quantify the degree of marginalization occurring across the province of Ontario. It is comprised of four major dimensions thought to underlie the construct of marginalization: residential instability, material deprivation, dependency, and ethnic concentration. The dataset contains census divisions (CD), census tracts (CT), census subdivisions (CSD), consolidated municipal service manager areas (CMSM), public health units (PHU), local health integration networks (LHIN), sub-LHINs, and dissemination areas (DA).

These datasets were linked using unique encoded identifiers and analyzed at ICES.

The dataset from this study is held securely in coded form at ICES. While data sharing agreements prohibit ICES from making the dataset publicly available, access may be granted to those who meet pre-specified criteria for confidential access, available at <u>www.ices.on.ca/DAS</u>. The full dataset creation plan and underlying analytic code are available from the authors upon request, understanding that the computer programs may rely upon coding templates or macros that are unique to ICES and are therefore either inaccessible or may require modification.

Concept	Data	Code Type	Window	Notes
•	Sources			(including Dataset reference
Inclusion Criteria				
Hospital birth (live or stillbirth) at gestational age ≥20 weeks	DAD, MOMBABY	ICD-10 main patient service code for "Obstetrical birth"	Accrual window: 1 April 2002 – 17 Feb 2018	Canadian Institute for Health Information Discharge Abstract Database (DAD, linked to newborr record in MOMBABY dataset) See: <u>https://datadictionary.ices.on.ca/ations/DataDictionary/Library.asp</u>
Exclusion Criteria				ary=MOMBABY
Missing or invalid IKN	RPDB	0	Index date	Registered Persons Database See: <u>https://datadictionary.ices.on.ca</u> <u>lications/DataDictionary/Library.</u> ?Library=RPDB
MOMBABY linkage warning	MOMBABY	C C	Index date	
Missing or invalid age (<10 or >55)	RPDB		Index date	
Missing or invalid sex	RPDB		Index date	
Death before the index date	RPDB		Index date	
Non-Ontario residents / invalid OHIP number	RPDB		Index date	
Any births with an index date occurring outside of the accrual period	MOMBABY		Accrual window	Pregnancy onset before 1 April 20
Any births occurring after accrual end date	MOMBABY		Accrual window	Births after 17 February 2018
Not first birth	MOMBABY		14 years prior to index date	Prior record in MOMBABY within 14 years of index date
Not first birth in accrual period	MOMBABY		Accrual window	Subsequent records in MOMBABY

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Concept	Data Sources	Code Type	Window	Notes (including Dataset references)
Severe maternal	DAD	ICD 10	Start of lookback	Patient considered to have outcome IF A
morbidity (SMM)	DAD	CCI	period ("pregnancy	code in ANY of the following:
morbially (Sivilvi)			onset" = index date	code in ANY of the following.
				1) Obstatuis/ill defined ar sudden death
			 gestational age at hirth) to and of 	1) Obstetric/ ill-defined or sudden death
			at birth) to end of	2) Hypertensive heart/renal disease
			observation	3) Eclampsia
			window (42 days	4) Cerebral venous thrombosis
			following index	5) Complications of anaesthesia – non-
			date)	cardiac
				6) Complications of anaesthesia – cardiad
				7) Cardiac diseases (cardiac arrest,
				infarction, failure, pulmonary edema)
				8) Placental abruption c/ coagulation def
				9) Antepartum hemorrhage c/ coagulatic
				defect
				10) Intrapartum hemorrhage c/ coagulat
				defect
				11) Uterine rupture – before labour
				12) Uterine rupture – during labour
				13) Obstetric shock (including septic sho
				14) Septecemia during labour
				15) Puerperal sepsis
				16) Pulmonary embolism
			Ι N.	17) Obstetric embolism
				18) Cardiomyopathy
			9	19) Acute renal failure
				20) HIV disease
				21) Cerebrovascular disease
				22) Acute respiratory distress syndrome
				23) Acute abdomen
				24) Hepatic failure
				25) Acute psychosis
				26) Cerebral edema, coma
				27) Disseminated intravascular coagulati
				28) Sickle cell anemia crisis
				29) Status asthmaticus
				30) Status epilepticus
				31) Assisted ventilation (endotracheal tu
				or tracheostomy)
				32) Caesarean hysterectomy
				33) Postpartum hysterectomy
				34) Dialysis
				35) Evacuation of incisional hematoma
				36) Surgical repair of bladder, urethra,
				intestine
				37) Intrapartum hemorrhage with no
				coagulation defect AND blood transfusion
				38) Postpartum hemorrhage AND blood

	transfusion 39) Placenta previa AND blood trans 40) Embolization/ ligation/ suturing postpartum hemorrhage
	See: Joseph KS et al, 2009, ¹ Joseph KS et a 2010, ² ICD-10CA, 2009, ³ and CCHI, 2

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Study exposures, covariates

Concept	Data Sources	Code Type	Window	Notes (including Dataset references)
Age	RPDB		Index date	(
Index year	DAD		Index date	
Material deprivation index	ONMARG		Index date	Ontario Marginalization Index, Material Deprivation, in quintiles.
				Use version of ONMARG closest to year of index date: 2001 for 2002-2003 2006 for 2004-2018 See: https://datadictionary.ices.on.ca/Applica s/DataDictionary/Library.aspx?Library=O ARG
Income quintile	RPDB Census	C	Index date	Ontario Census area profile: income quin
	Census	9		Use Census closest to year of index date: 2001 for 2002-2003 2006 for 2004-2018 See:
			2.	See: <u>https://datadictionary.ices.on.ca/Applica</u> s/DataDictionary/Library.aspx?Library=Cl US
Rurality	RPDB		Index date	Rurality Index for Ontario (RIO). Use version of RIO closest to year of inde date: RIO2004 for 2002-2006 RIO2008 for 2007-2018
Gestational age at birth	MOMBABY		Index date	21
Induction of labour	DAD	CCI code	Within index hospitalization	Canadian Classification of Health Interventions (CCI)
Epidural	DAD OHIP	CCI code OHIP fee code	Within index hospitalization	Canadian Classification of Health Interventions (CCI); Ontario Health Insura Plan Claims Database (OHIP)
Delivery mode	DAD	CCI code	Within index hospitalization	
Multiple gestations	MOMBABY		Within index hospitalization	
Stillbirth	MOMBABY		Within index hospitalization	
Immigration status	IRCC		Index date	Immigration, Refugees and Citizenship

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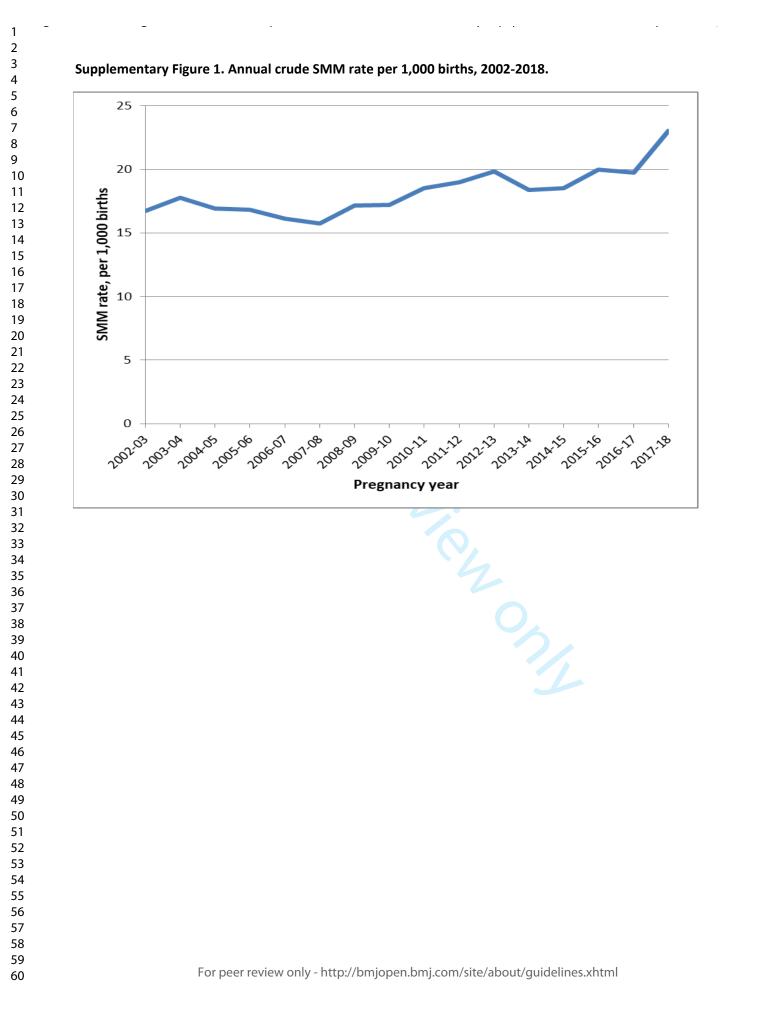
Canada (IRCC)'s Permanent Resident Database
Number of years since arrived in Ontario. See: <u>https://datadictionary.ices.on.ca/Applications/Library.aspx?Library=CIC</u>

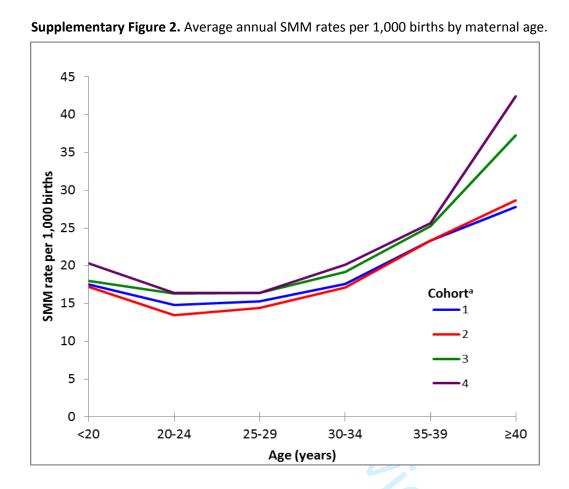
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^acohort 1: 1 April 2002 to 31 March 2006; cohort 2: 1 April 2006 to 31 March 2010; cohort 3: 1 April 2010 to 31 March 2014; cohort 4: 1 April 2014 to 31 March 2018

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BMJ Open Supplementary table 1. Four-year average SMM rates per 1,000 births by age and by material deprivation, and rate change over study period. 0-0

		SMM rates	s by cohort ^a		SMM rate change, cohort	$4 vs 1^{a}$
Variable	1	2	3	4	Rate difference (95% CI)	Rate ratio 🖁 95% CI)
Overall study population	17.10	16.55	18.94	19.82	2.72 (1.96, 3.49)***	1.16 (1.11 _o 1.21)***
Maternal age (years)						Q
<20	17.54	17.22	17.97	20.34	2.80 (-0.43, 6.04)	1.15 (0.98gat.37)
20-24	14.80	13.47	16.32	16.40	1.60 (-0.15, 3.35)	1.11 (0.99, 1.24)
25-29	15.26	14.40	16.37	16.42	1.15 (-0.77, 2.39)	1.08 (0.99🕺.16)
30-34	17.58	17.10	19.21	20.16	2.58 (1.18, 3.97)*	1.15 (1.06 ¤ 1.23)*
35-39	23.31	23.35	25.23	25.67	2.36 (-0.16, 4.88)	1.10 (0.99≸1.22)
≥40	27.78	28.68	37.30	42.48	14.69 (7.96, 21.43)*	1.53 (1.24 <u>ឆ</u> ,1.89)*
Material deprivation						ded
Quintile 1 (least)	16.05	16.58	19.36	18.41	2.36 (2.31, 2.41)***	1.15 (1.14adī 1.15)***
Quintile 2	16.36	15.97	16.17	18.52	2.16 (2.11, 2.22)***	1.13 (1.13 <mark>⊐</mark> 1.14)***
Quintile 3	17.46	15.73	18.34	18.99	1.54 (1.48, 1.59)***	1.09 (1.08 1.09)***
Quintile 4	16.49	16.37	19.19	20.18	3.69 (3.63, 3.74)***	1.22 (1.22
Quintile 5 (most)	18.14	17.32	20.78	22.32	4.19 (4.13, 4.24)***	1.23 (1.22 31.23)***

April 2010 to 31 March. ^acohort 1: 1 April 2002 to 31 March 2006; cohort 2: 1 April 2006 to 31 March 2010; cohort 3: 1 April 2010 to 31 March 2014; cohort 4: 1 April 2014 to 31 March 2018

*p<0.05, **p<0.01, ***p<0.001

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	Item No.	STROBE items	Location in manuscript where items are reported	RECORD items	Location in manuscript where items ar reported
Title and abstrac	et			r 20	1
	1	(a) Indicate the study's design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found	Title page (p.1)	RECORD 1.1: The type of data used should be specified in the title or abstract. When possible, the name of the databases used should be included. RECORD 1.2: If applicable the geographic region and time trame within which the study took place should be reported in the title or abstract. RECORD 1.3: If linkage between databases was conducted for the study, this should be clearly stated on the title or abstract.	Title page, abstract (p. 1-3)
Introduction	-				
Background rationale	2	Explain the scientific background and rationale for the investigation being reported	Background p.4-5	pril 18, 202	
Objectives	3	State specific objectives, including any prespecified hypotheses	Background p.4-5	4 by gues	
Methods					
Study Design	4	Present key elements of study design early in the paper	Methods p.5-9	otected	
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Methods: <i>Study</i> population and data sources, Main outcome, p. 5-6	l by copyright	

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Participants	6	 (a) Cohort study - Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up Case-control study - Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls Cross-sectional study - Give the eligibility criteria, and the sources and methods of selection of participants (b) Cohort study - For matched studies, give matching criteria and number of exposed and unexposed Case-control study - For matched studies, give matching criteria and the number of controls per case 	Cohort study, no matching: Methods: <i>Study</i> <i>population and data</i> <i>sources, Main</i> <i>outcome, Exposures</i> <i>and covariates</i> p. 5- 8; Appendix 1	RECORD 6.1: The methods of study population selection (such as codes or algorithms used to identify subjects) should be listed in detail. If this is not possible, an explanation should be provided. RECORD 6.2: Any validation studies of the codes or algorithms used to select the population should be referenced. If validation was conducted for this study and not published elsewhere detailed methods and results should be provided. RECORD 6.3: If the study involved linkage of databases, consider use of a flow diagram or other graphical display to demonstrate the data linkage process, including the number of individuals with linked data at each stage.	Methods: Stud population and data sources, Main outcome, Exposures and covariates p. 5 Supplementary Appendix 1
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable.	Methods: <i>Study</i> <i>population and data</i> <i>sources, Main</i> <i>outcome, Exposures</i> <i>and covariates</i> p. 5- 8; Supplementary Appendix 1	RECORD 7.1: A complete list of codes and algorithms used to classify exposures, outcomes, confounders, and effect modifiers should be provided. If these cannot be reported, an explanation should be provided.	Methods: Stud population and data sources, Main outcome, Exposures and covariates p. 5 Supplementary Appendix 1
Data sources/ measurement	8	For each variable of interest, give sources of data and details of methods of assessment (measurement).	Methods: Study population and data sources, Main outcome, Exposures tp://bmjopen.bmj.com/site,	cted by copyright.	

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Snelgrove JW et d	al. Neighbourhood material deprivation and severe	maternal morbidity: A p	opulation-based cohort study in Ontario, Canada
	assessment methods if there is	<i>and covariates</i> p. 5- 8; Supplementary Appendix 1	0.046174 0
Bias	9 Describe any efforts to address potential sources of bias	Methods: <i>Exposures</i> and covariates p. 7- 8; Interpretation: <i>Strengths/ limitations</i> p.11-12	n 6 October 2021
Study size	10 Explain how the study size was arrived at	Methods: <i>Study</i> <i>population and data</i> <i>sources</i> , p. 5-6; Figure 1	. Downloaded
Quantitative variables		Methods: <i>Statistical</i> analysis, p. 8-9	from http://bmjop
Statistical methods	methods, including those used to	Methods: <i>Statistical</i> <i>analysis</i> , p. 8-9, Results, p.9-11.	an.bmj.com/ on April 18, 2024 by guest. Protected by copyright

				-2020	
		sampling strategy (e) Describe any sensitivity analyses		046174 0	
Data access and cleaning methods				RECORD 12.1: Authors should describe the extent to which the investigators had access to the database population used to create the study population.	Methods: <i>Study</i> <i>population and</i> <i>data sources,</i> p. 6; Supplementar Appendix 1; Author contributions, p. 20
Linkage			or revie	RECORD 12.3: State whether the study included person-level, institutional- level, or other data linkage across two or more databases. The methods of linkage and methods of linkage quality evaluation should be provided.	Methods: Study population and data sources, Main outcome, Exposures and covariates p. 5-8 Supplementary Appendix 1
Results				2	
Participants	13	 (a) Report the numbers of individuals at each stage of the study (<i>e.g.</i>, numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed) (b) Give reasons for non- participation at each stage. (c) Consider use of a flow diagram 	Results p.10; Table 1; Figure 1	RECORD 13.1: Describe indetail the selection of the persons included in the study (<i>i.e.</i> , study population selection) including filtering based on data quality, data availability and linkage. The selection of included persons can be described in the text and persons can of the study flow diagram.	Methods: Study population and data sources, Main outcome, Exposures and covariates p. 5-8 Results p.10; Table 1; Figure Supplementary Appendix 1
Descriptive data	14	(a) Give characteristics of study participants (<i>e.g.</i> , demographic, clinical, social) and information	Results p.10; Table 1	y copyright	

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Outcome data	on exposures and potential confounders (b) Indicate the number of participants with missing data for each variable of interest (c) Cohort study - summarise follow-up time (e.g., average and total amount)15Cohort study - Report numbers of outcome events or summary	Results p.10; Figure 1; Table 1	020-046174 on 6 October 2021. Dow
	measures over time <i>Case-control study</i> - Report numbers in each exposure category, or summary measures of exposure <i>Cross-sectional study</i> - Report numbers of outcome events or summary measures		Downloaded from http://bmjopen.t
Main results	 16 (a) Give unadjusted estimates and, if applicable, confounder- adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included (b) Report category boundaries when continuous variables were categorized (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period 	Results p.10; Table 1-3; Supplementary Figure 1	omj.com/ on April 18, 2024 by guest. Protected by
Other analyses	17 Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses	Results p.10-11 tp://bmjopen.bmj.com/site/	/ copyright.

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Discussion					
Key results	18	Summarise key results with	Interpretation, Main	5174	
~ • • • •	10	reference to study objectives	findings p.11	<u>g</u>	.
Limitations	19	Discuss limitations of the study,	Interpretation,	RECORD 19.1: Discuss them	Interpretation,
		taking into account sources of	Strengths/limitations	implications of using data that were not	Strengths/limite
		potential bias or imprecision. Discuss both direction and	p.11-12	created or collected to answer the	<i>ns</i> p.11-12
				specific research question(s) Include discussion of misclassification bias,	
		magnitude of any potential bias		unmeasured confounding, n Ssing data,	
		U h		and changing eligibility over time, as	
		6		they pertain to the study being reported.	
Interpretation	20	Give a cautious overall	Discussion, Main		
		interpretation of results	findings p. 11,	fro	
		considering objectives,	Strengths /	from http://bmjopen.	
		limitations, multiplicity of	Limitations p. 11-12	tt:	
		analyses, results from similar			
		studies, and other relevant		jope	
		evidence			
Generalisability	21	Discuss the generalisability	Discussion,	mj.com/ o	
		(external validity) of the study	Interpretation p.11-	Öm	
		results	12	ġ	
Other Informatio			F 1: 01.00	A pr	
Funding	22	Give the source of funding and the role of the funders for the	Funding, p. 21-22		
				3, 20	
		present study and, if applicable, for the original study on which		April 18, 2024 by	
		the present article is based		by (
Accessibility of				RECORD 22.1: Authors should provide	p. 21;
protocol, raw				information on how to access any	Supplementary
data, and				supplemental information such as the	Appendix 1
programming				study protocol, raw data, or	
code				programming code.	
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