Supplementary Material

Spatiotemporal patterns and surveillance artifacts in maternal mortality in the United States: A population-based study

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Supplementary Table 1. Maternal characteristics in the United States in 1999-2002 and 2018-2021, in states with a low vs high maternal mortality ratio (MMR) in 2018-2021, and in California and Texas in 2018-2021 (NH denotes non-Hispanic; Hypertension and diabetes refer to chronic hypertension and pre-existing diabetes). Low MMR states include 19 states with a maternal mortality ratio of <20 per 100,000 live births in 2018-2021 and high MMR states include 20 states with a maternal mortality ratio ≥26 per 100,000 live births in 2018-2021.

Maternal characteristics	United States 1999-2002		United States 2018-2021		Low MMR states 2018-2021		High MMR states 2018-2021		California 2018-2021		Texas 2018-2021	
	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
All	16,065,890	100·0	14,817,191	100·0	5,155,788	100·0	6,386,379	100·0	1,742,266	100·0	1,498,007	100·0
Age: <20 years	1,849,146	11·5	663,726	4·48	179,310	3·48	360,152	5·64	58,856	3·27	93,974	6·27
20-24	4,043,468	25·2	2,744,596	18·5	809,213	15·7	1,377,046	21·6	257,152	14·8	322,606	21·5
25-29	4,284,455	26·7	4,225,979	28·5	1,417,885	27·5	1,895,721	29·7	447,428	25·7	435,237	29·1
30-34	3,715,594	23·1	4,365,017	29·5	1,640,129	31·8	1,717,370	26·9	546,742	31·4	399,235	26·7
35-39	1,792,001	11·2	2,295,622	15·5	902,470	17·5	848,835	13·3	343,210	19·7	201,750	13·5
40-44	361,704	2·25	484,435	3·27	190,743	3·70	175,276	2·74	80,635	4·63	42,277	2·82
≥45	19,522	0·12	37,816	0·26	16,038	0·31	11,979	0·19	8,243	0·47	2,928	0·20
Race: NH White	9,334,152	58·1	7,603,413	51·3	2,629,248	51·0	3,097,025	48·5	475,603	27·3	494,008	33·0
NH Black	2,361,579	14·7	2,147,804	14·5	467,367	9·06	1,231,019	19·3	87,391	5·02	188,484	12·6
Hispanic	3,308,700	20·6	3,525,306	23·8	1,347,315	26·1	1,605,118	25·1	805,639	46·2	712,157	47·5
AIAN	166,078	1·03	110,479	0·75	21,081	0·41	69,617	1·09	5,576	0·32	2,658	0·18
Asian	754,885	4·70	912,448	6·16	440,747	8·55	238,344	3·73	250,518	14·4	78,268	5·22
Other	140,496	0·87	517,741	3·49	250,030	4·85	145,256	2·27	117,539	6·75	22,432	1·50
Plurality: Single	15,556,769	96·8	14,334,147	96·7	4,987,505	96·7	6,179,563	96·8	1,689,609	97·0	1,451,966	96·9
Twin	479,603	2·99	470,425	3·17	164,048	3·18	201,348	3·15	51,448	2·95	44,769	2·99
Triplet+	29,518	0·18	12,619	0·09	4,235	0·08	5,468	0·09	1,209	0·07	1,272	0·08
Hypertension: Yes	123,851	0·77	352,543	2·38	104,269	2·02	159,679	2·50	23,168	1·33	24,038	1·60
No	15,752,360	98·0	14,449,214	97·5	5,046,562	97·9	6,220,602	97·4	1,718,284	98·6	1,472,481	98·3
Unknown	189,679	1·18	15,434	0·10	4,957	0·10	6,098	0·10	814	0·05	1,488	0·10
Diabetes: Yes	478,971	2·98	1,246,726	8·41	437,882	8·49	489,394	7·66	148,048	8·50	102,789	6·86
No	15,397,240	95·8	13,555,031	91·5	4,712,949	91·4	5,890,887	92·2	1,593,404	91·5	1,393,730	93·0
Unknown	189,679	1·18	15,434	0·10	4,957	0·10	6,098	0·10	814	0·05	1,488	0·10

Supplementary Table 2. Cause-specific maternal mortality ratio (MMR) due to "pregnancies with abortive outcome"*, United States, and specific regions, 1999-2002 and 2018-2021. MMRs and MMR differences expressed per 100,000 live births.

Region/ Period	Maternal deaths due to pregnancies with abortive outcome			
	No.	MMR	MMR difference	MMR ratio (95% CI)
United States				
1999-02	128	0·80	-	1·00 (ref)
2018-21	130	0·88	0·08	1·10 (0·86, 1·41)
Low MMR states				
1999-02	33	0·55	-	1·00 (ref)
2018-21	31	0·60	0·05	1·10 (0·67, 1·79)
High MMR states				
1999-02	56	0·87	-	1·00 (ref)
2018-21	75	1·17	0·30	1·35 (0·96, 1·91)
California				
1999-02	13	0·62	-	1·00 (ref)
2018-21	18	1·03	0·41	1·67 (0·82, 3·42)
Texas				
1999-02	†	†	-	1·00
2018-21	20	1·34	†	† (1·07, 5·50)

* Pregnancies with abortive outcome (International Classification of Diseases codes O00-O07), which includes ectopic pregnancy, hydatidiform mole, other abnormal products of conception, spontaneous abortion, medical abortion, other abortion, unspecified abortion and failed attempted abortion.
† Cells suppressed as cell count <10.

Supplementary Table 3a. Pearson correlation coefficients, 95% confidence intervals (CI) and associated P values expressing the relationships between overall and cause-specific maternal mortality ratios (MMR) in each state in 1999-2002, 2018-2021 and the change in MMRs between the two periods, United States.

Index		Maternal mortality ratio in 1999-2002			Maternal mortality ratio in 2018-2021		
		Overall	From selected obstetric causes	From less-specific causes	Overall	From selected obstetric causes	From less-specific causes
MMR in 1999-2002							
Overall	Correlation (r)	1·00	0·73	0·61	0·47	0·37	0·23
	95% CI	-	0·57, 0·84	0·40, 0·76	0·23, 0·66	0·11, 0·59	-0·05, 0·47
	P value	-	<0·0001	<0·0001	0·0005	0·006	0·11
From selected obstetric causes	Correlation (r)	0·73	1·00	0·25	0·34	0·14	0·22
	95% CI	0·57, 0·84	-	-0·03, 0·49	0·08, 0·57	-0·14, 0·40	-0·06, 0·47
	P value	<0·0001	-	0·08	0·01	0·34	0·12
From less-specific causes	Correlation (r)	0·61	0·25	1·00	0·25	0·30	0·18
	95% CI	0·40, 0·76	-0·03, 0·49	-	-0·03, 0·49	0·03, 0·53	-0·10, 0·44
	P value	<0·0001	0·08	-	0·08	0·03	0·19
MMR in 2018-2021							
Overall	Correlation (r)	0·47	0·37	0·23	1·00	0·37	0·83
	95% CI	0·23, 0·66	0·11, 0·59	-0·05, 0·47	-	0·10, 0·58	0·72, 0·90
	P value	0·0005	0·006	0·11	-	0·008	<0·0001
From selected obstetric causes	Correlation (r)	0·34	0·14	0·22	0·37	1·00	0·06
	95% CI	0·08, 0·57	-0·14, 0·40	-0·06, 0·47	0·10, 0·58	-	-0·21, 0·33
	P value	0·01	0·34	0·12	0·008	-	0·65
From less-specific causes	Correlation (r)	0·25	0·30	0·18	0·83	0·06	1·00
	95% CI	-0·03, 0·49	0·03, 0·53	-0·10, 0·44	0·72, 0·90	-0·21, 0·33	-
	P value	0·08	0·03	0·19	<0·0001	0·65	-
MMR change: 2018-21 vs 1999-02							
Overall	Correlation (r)	-0·05	-0·03	-0·07	0·86	0·20	0·81
	95% CI	-0·32, 0·23	-0·31, 0·24	-0·34, 0·21	0·76, 0·92	-0·08, 0·45	0·69, 0·89
	P value	0·75	0·81	0·62	<0·0001	0·16	<0·0001
From selected obstetric causes	Correlation (r)	-0·31	-0·70	0·02	-0·01	0·61	-0·13
	95% CI	-0·54, -0·04	-0·82, -0·52	-0·26, 0·29	-0·28, 0·27	0·41, 0·76	-0·39, 0·15
	P value	0·02	<0·0001	0·89	0·95	<0·0001	0·36
From less-specific causes	Correlation (r)	0·05	0·15	-0·10	0·77	-0·02	0·96
	95% CI	-0·23, 0·32	-0·13, 0·41	-0·37, 0·18	0·63, 0·86	-0·29, 0·26	0.93-0.97
	P value	0·71	0·28	0·48	<0·0001	0·88	<0·0001

Supplementary Table 3b. Pearson correlation coefficients, 95% confidence intervals (CI). and associated P values expressing the relationships between overall and cause-specific maternal mortality ratios (MMR) in each state in 1999-2002, 2018-2021 and the change in MMRs between the two periods, United States.

Index		Maternal mortality ratio in 1999-2002			Maternal mortality ratio in 2018-2021		
		Overall	From selected obstetric causes	From less-specific causes	Overall	From selected obstetric causes	From less-specific causes
MMR in 1999-2002							
Chronic hypertension	Correlation (r)	0·20	0·14	0·10	-0·07	0·11	-0·11
	95% CI	-0·08, 0·45	-0·14, 0·40	-0·18, 0·37	-0·34, 0·31	-0·18, 0·37	-0·38, 0·17
	P value	0·16	0·32	0·49	0·63	0·46	0·43
Malignant neoplasms	Correlation (r)	-0·10	-0·01	-0·13	-0·12	-0·14	-0·09
	95% CI	-0·37, 0·18	-0·29, 0·27	-0·39, 0·15	-0·39, 0·16	-0·40, 0·14	-0·36, 0·19
	P value	0·48	0·94	0·38	0·39	0·31	0·52
MMR in 2018-2021							
Chronic hypertension	Correlation (r)	0·42	0·10	0·07	0·39	0·20	0·01
	95% CI	0·16, 0·62	-0·18, 0·36	-0·21, 0·34	0·13, 0·60	-0·08, 0·45	-0·27, 0·28
	P value	0·002	0·50	0·64	0·004	0·16	0·97
Malignant neoplasms	Correlation (r)	-0·15	-0·19	-0·07	0·15	-0·22	0·33
	95% CI	-0·40, 0·14	-0·45, 0·09	-0·34, 0·21	-0·13, 0·41	-0·46, 0·06	0·06, 0·55
	P value	0·31	0·17	0·63	0·30	0·13	0·02
MMR change: 2018-21 vs 1999-02							
Chronic hypertension	Correlation (r)	0·36	0·20	0·09	0·13	0·28	-0·24
	95% CI	0·10, 0·58	-0·08, 0·45	-0·19, 0·36	-0·15, 0·39	0·01, 0·52	-0·49, 0·04
	P value	0·009	0·15	0·51	0·37	0·04	0·09
Malignant neoplasms	Correlation (r)	-0·14	-0·19	-0·06	0·15	-0·21	0·33
	95% CI	-0·40, 0·14	-0·44, 0·09	-0·33, 0·21	-0·13, 0·41	-0·46, 0·07	0·06, 0·56
	P value	0·33	0·18	0·65	0·28	0·14	0·02

Supplementary Table 4. Pearson (r) and Spearman correlation coefficients (ρ) expressing the relationship between selected overall and cause-specific maternal mortality ratios (MMR), United States, 1999-2002 and 2018-2021.

Index	Overall MMR 2018-2021	Less-specific causes MMR 2018-21
Overall MMR 1999-2002 (r)	0.47, P=0.0005	
Overall MMR 1999-2002 (ρ)	0.46, P=0.0008	
Obstetric causes MMR 2018-2021 (r)	0.37, P=0.008	0.06, P=0.65
Obstetric causes MMR 2018-2021 (ρ)	0.42, P=0.002	0.13, P=0.36
Less-specific causes MMR 2018-2021 (r)	0.83, P<0.0001	
Less-specific causes MMR 2018-2021 (ρ)	0.80, P<0.0001	
Change in obstetric causes MMR (r)	-0.01, P=0.95	
Change in obstetric causes MMR (ρ)	0.01, P=0.94	
Change in less-specific causes MMR (r)	0.77, P<0.0001	
Change in less-specific causes MMR (ρ)	0.75, P<0.0001	

Supplementary Table 5. Number of maternal deaths and maternal mortality ratios (MMRs per 100,000live births) of overall maternal death, deaths due to selected obstetric causes and deaths due to less specific causes, by race/ethnicity, United States, 1999-2002 and 2018-2021 (MMR difference denotes difference in 2 MMRs per 100,000 live births, MMR ratio refers to the ratio of 2 MMRs, and 95% CI denotes 95% confidence interval).

Race/ethnicity and Period	All maternal deaths				MMR from sel. obstetric causes*				MMR from less-specific causes*			
	No.	% of deaths	MMR/100,000 live births	MMR ratio (95% CI) MMR difference (95% CI)	No.	% of deaths	MMR/100,000 live births	MMR ratio (95% CI) MMR difference (95% CI)	No.	% of deaths	MMR/100,000 live births	MMR ratio (95% CI) MMR difference (95% CI)
All												
1999-2002	1,543	100·0	9·60	1·00	569	47·9	3.54	1.00	258	16.7	1.61	1.00
2018-2021	3,478	100·0	23·5	2·44 (2·30, 2·60) 13·9 (13·0, 14·8)	413	11·9	2.79	0.79 (0·69, 0·89) -0·75 (-1·14, 0·36)	1,665	47.9	11.2	7.00 (6.14, 7.98) 9·62 (9·05, 10·2)
Non-Hispanic White												
1999-2002	588	100·0	6·30	1·00	212	36·1	2.27	1.00	121	20.6	1.30	1.00
2018-2021	1,489	100·0	19·6	3·11 (2·83, 3·42) 13·3 (12·2, 14·4)	175	11·8	2.30	1.01† (0·83, 1·24) 0·03 (-0·43, 0·49)	768	51.6	10.1	7.79† (6·43, 9·44) 8·80 (8·05, 9·55)
Non-Hispanic Black												
1999-2002	575	100·0	24·3	1·00	185	32·2	7.83	1.00	93	16.2	3.94	1.00
2018-2021	1,102	100·0	51·3	2·11 (1·91, 2·33) 27·0 (23·3, 30·6)	115	10·4	5.35	0.68† (0·54, 0·86) -2·48 (-3·97, -0·98)	51646	46.8	24.0	6.10† (4.89, 7.61) 20·1 (17·9, 22·3)
Hispanic												
1999-2002	291	100·0	8·79	1·00	134	46·0	4.05	1.00	34	11.7	1.03	1.00
2018-2021	623	100·0	17·7	2·01 (1·75, 2·31) 8·86 (7·15, 10·6)	77	12·4	2.18	0.54 (0·41, 0·71) -1·86 (-2·71, -1·02)	275	44.1	7.80	7.59 (5.32, 10.8) 6·77 (5·78, 7·75)
Other												
1999-2002	89	100·0	8·38	1·00	38	42·7	3.58	1.00	10	11.2	0.94	1.00
2018-2021	264	100·0	17·1	2·04 (1·61, 2·61) 8·75 (6·03, 11·5)	46	17·4	2.99	0.83 (0·54, 1·28) -0·59 (-2·02, 0·83)	106	40.2	6.88	7.30 (3.82, 14.0) 5·93 (4·50, 7·37)

*Deaths from less-specific causes included deaths due to the following underlying causes: "Other specified pregnancy-related conditions" (ICD-10 code O26.8) and "Other maternal diseases classifiable elsewhere" (O99). Deaths from selected obstetric causes included deaths due to the following underlying causes: pre-eclampsia (O11, O14), gestational hypertension (O13), eclampsia (O15), placental disorders (O43), placenta previa (O44), placental abruption (O45), antepartum hemorrhage, not elsewhere classified (O46), obstructed labor (O64, O65, O66), uterine rupture and other obstetric trauma (O71), postpartum hemorrhage (O72), retained placenta (O73), puerperal sepsis (O85), other puerperal infections (O86) and amniotic fluid embolism (O881).

† Test for homogeneity of the MMR ratio between non-Hispanic White and non-Hispanic Black women for MMR from selected obstetric causes: P value 0·01; and from less-specific causes: P value 0·10. Period-specific patterns of maternal death due to chronic hypertension and maternal death associated with malignant neoplasms were not assessed by race/ethnicity due to the small numbers of such cases in most race/ethnicity groups.

Supplementary Table 6. Sensitivity analyses showing the change in cause-specific maternal mortality ratios (MMR) including changes in direct obstetric deaths (instead of selected obstetric deaths) and from deaths due to less-specific causes (ICD-10 codes O268 and O998 instead of O268 and O99), United States, and specific regions, 1999-2002 and 2018-2021.

Region/ Period	Cause-specific maternal mortality							
	Direct maternal deaths				Less-specific causes			
	No.	MMR/ 100,000 live births	MMR difference	MMR ratio (95% CI)	No.	MMR/ 100,000 live births	MMR difference	MMR ratio (95% CI)
United States								
1999-02	1,125	7·00	-	1·00 (ref)	75	0·47	-	1·00 (ref)
2018-21	1,002	6·76	-0·24	0·97 (0·89, 1·05)	1,083	7·31	6·84	15·7 (12·4,18·8)
Low MMR states								
1999-02	364	6·03	-	1·00 (ref)	19	0·31	-	1·00 (ref)
2018-21	279	5·41	-0·62	0·90 (0·77, 1·05)	204	3·96	3·64	12·6 (7·85, 20·1)
High MMR states								
1999-02	499	7·74	-	1·00 (ref)	45	0·70	-	1·00 (ref)
2018-21	493	7·72	-0·02	1·00 (0·88, 1·13)	625	9·79	9·09	14·0 (10·4, 19·0)
California								
1999-02	151	7·16	-	1·00 (ref)	*	*	*	1·00 (ref)
2018-21	110	6·31	-0·85	0·88 (0·69, 1·13)	31	1·78	*	* (2·92, 19·3)
Texas								
1999-02	91	6·27	-	1·00	10	0·69	-	1·00 (ref)
2018-21	89	5·94	-0·33	0·95 (0·71, 1·27)	133	8·88	1·54	12·9 (6·77, 24·5)

*Cells suppressed as cell count <10.