Original Article

Does Low Birth Weight Vary Geospatially in Singapore?

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Abstract

Introduction: Low birth weight (LBW, <2500 g) is an important risk factor for perinatal mortality and morbidity. We performed the first geospatial study of LBW in Singapore, with focus on the public sector and analysis of the national planning areas. Materials and Methods: A dataset of 24,615 singleton deliveries from 2012 to 2014 was obtained from the largest maternity hospital in Singapore. Maternal residences were identified with 28 planning areas according to postal code. Multiple logistic regression was used to examine associations between LBW rates and planning areas. Moran's I statistic was used to test for geospatial clustering of LBW rates among planning areas. Results: The LBW rate across planning areas ranged from 5.3 to 11.5 per 100 live births (median, 8.4). High LBW rates were associated with: 1) a lower individual socioeconomic status, 2) non-compliance to antenatal visits, and 3) biological factors such as maternal hypertension, low body mass index and Indian race. Moran's statistic indicated no geospatial clustering of LBW rates among the 28 planning areas ($P = 0.12$). LBW rates were moderately correlated with the Socioeconomic Disadvantage Index (r = 0.58) but uncorrelated with distance travelled to hospital (r = -0.08). Conclusion: There was no evidence of clustering of LBW rates among planning areas in Singapore that would indicate inequitable distribution of health resources among planning areas. The 2 areas showing the highest rates of LBW infants were Outram and Bukit Merah. We recommend targeted health interventions and outreach programmes to encourage antenatal visits in these areas.

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Key words: Moran's statistic, Planning areas, Socioeconomic Disadvantage Index

Introduction

Low birth weight (LBW) is defined as birth weight <2500 g and is associated with perinatal mortality, morbidity, chronic disease in later life (e.g. cardiovascular disease, diabetes), and learning and behavioural problems.[1-5] The causes for LBW are complex and likely an interaction between the biological determinants of mother and the fetus, parent's socioeconomic status and effectiveness of medical care during the perinatal period.[6] There has been growing interest in measuring spatial variations of birth outcomes. This is because the living environment has been shown to influence birth outcomes through environmental pollution,[7] hospital accessibility,[8-9] socioeconomic status, psychosocial stress and maternal health behaviour.[10] Outreach programmes and case management for high-risk communities have led to improvements in birth outcomes internationally.[11-12]

In Singapore, geospatial analytics has been increasingly utilised to provide geographical insights and solutions to public health problems. For example, the study of spatial variation in out-of-hospital cardiac arrests led to the optimisation of ambulance response time.[13-14] Residents in public rental housing were found to have higher readmission

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risk and can be targeted to reduce unnecessary utilisation of hospital services.[15] An index of area-level socioeconomic status has been derived by Earnest et al specifically for health service research,[16] and has been shown to be associated with visual impairment in Singapore.[17]

This is the first study to assess variations in the rates of LBW rates in the public sector across planning areas in Singapore, as well as to identify individual and regional risk factors associated with LBW rates.

Materials and Methods

Obstetric data on all deliveries (n = 34,711) in KK Women's and Children's Hospital (KKH) for the years 2012 to 2014 was obtained from the Obstetric Information System (OIS). From this data, we excluded: 1) deliveries of multiple births (n = 1294), 2) deliveries for which there were missing data (n = 8535), and 3) deliveries in planning areas with less than 100 births counted over the 3-year study period (n = 267) in order to reduce sampling variability in LBW prevalence. The study cohort comprised 24,615 singleton births.

Maternal residences were geo-referenced to national planning areas based on postal codes. There are a total of 55 planning areas in Singapore, as demarcated in the Urban Redevelopment Authority's Master Plan 2008 (URA MP08).[18] Each planning area has a population of about 150,000 and is served by a town centre and several neighbourhood commercial and recreational facilities. The data extracted on deliveries at KKH represented maternal postal codes spanning 28 planning areas.

The 'OG Labour, Delivery and Infant Record' is an electronic, structured record that is completed by a midwife or doctor for each delivery in KKH. From these records, we obtained individual variables previously shown to influence adverse birth outcomes.[19] Child variables were gestational age, gender, birth order (1, 2-4, >5) and congenital malformations; maternal variables were race (Chinese, Indian, Malay, Others), age (<20, 20-35, >35), marital status (single, married, divorced), resident status (citizen, permanent residents, non-residents, foreign residents), hospital bed class (A1, B1, B2+, B2, C), number of antenatal visits (<7 non-compliant, ≥7 compliant), body mass index (BMI) (<18.5, ≥18.5) and medical risk factors (hypertension, diabetes mellitus, anaemia and antepartum haemorrhage).

Both child congenital malformations and maternal medical risk factors were derived using International Classification of Diseases (ICD)-9 and ICD-10 codes. The discharge bed classes A1 and B1 correspond to private-paying patients while B2+, B2 and C correspond to subsidised-paying patients; hence, bed class was used as a surrogate marker of the individual's socioeconomic status. According to United Kingdom guidelines, a minimum of 7 antenatal visits is considered adequate for a parous woman with an uncomplicated pregnancy.[20] Based on this standard, women (both nulliparous and multiparous) who undergo at least 7 antenatal visits are classified as antenatal-care compliant.

The study looked at 3 regional characteristics of LBW rates: 1) Socioeconomic Disadvantage Index (SEDI), 2) travel distance between the planning area and KKH and, 3) Moran's I spatial autocorrelation among planning areas.

SEDI, derived by Ernest et al, is a single composite index that measures the socioeconomic status of planning areas in Singapore.[16] It incorporates areal factors (e.g. household and personal income, housing, education and occupation) from the Singapore Census of Population 2010 indicative of socioeconomic status. A high SEDI score indicates relatively poor socioeconomic status.

The travel distance between each planning area and KKH was calculated as an average of 3 driving distances (produced by the web mapping and route planning service, Google Maps) and the information was requested at different times of day—namely 0800 hr, 1200 hr and 1600 hr. This took into consideration that Google Maps suggests different routes based on the shortest travelling time at the particular time of day that the information is requested.

Statistical analysis was performed using SAS version 9.4 for Windows (SAS, Inc., Cary, NC, USA). Observed LBW rates were calculated for each planning area—using number of LBW births as the numerator and number of live births as the denominator. The association between individual potential risk factors and LBW was tested using univariate logistic regression model. Multivariable logistic regression analysis was performed using the stepwise variable selection approach with statistical significance set at $P \leq 0.05$. Ten variables—child gestational age, gender, birth order and congenital abnormalities; maternal age, race, hospital bed class, number of antenatal visits, BMI and hypertension—were included in the final regression model. The Pearson correlation coefficient was used to assess association between adjusted LBW rates and regional factors, i.e., SEDI and travel distance to KKH.

Moran's I statistic, a spatial autocorrelation statistic, takes into account the longitude and latitude of each planning area and measures the degree of dependency among observed LBW rates across planning areas. The null hypothesis is a random distribution of LBW rates among planning areas. The Moran statistic is used to evaluate whether a pattern expressed is clustered, dispersed or random. For example, on a checkerboard, the red and black squares are perfectly dispersed, so Moran's I would be -1. If all red squares were on one side of the board and all black squares on the other, Moran's I would be close to +1.[21]

This study received ethics approval from the SingHealth Centralised Institutional Review Board (CIRB) (Ref: 2016/2344) on 12 May 2016.

Results

Mean birth weight and gestational age were 3081 g (range: 420-5410 g) and 37.9 weeks (range: 23-42 weeks), respectively, in this singleton cohort study (n = 24,615). The median number of births in each planning area was 767 (range: 144-2138). Planning areas with the highest number of births were Woodlands (2138), followed by Sengkang (2125) and Yishun (1784).

Association of LBW with Individual Characteristics

The overall LBW rate was 8.3 per 100 live births. LBW rates differed markedly by child and maternal characteristics (Table 1). As expected, LBW rates were higher among premature babies (56.9 per 100 live births), female babies (9.19 per 100 live births), first-order babies (9.41 per 100 live births) and babies with congenital abnormalities (12.0 per 100 live births).

At both ends of the age spectrum, teenage mothers (13.8 per 100 live births) and mothers with advanced maternal age (9.49 per 100 live births) tended to have higher LBW rates. The Indian race had higher LBW rates (9.87 per 100 live births), compared to the Malays (9.55 per 100 live births) and Chinese (7.64 per 100 live births). Mothers in the subsidised-paying class (12.5 per 100 live births) had higher LBW rates compared to mothers in private-paying class (5.56 per 100 live births). Mothers who attended <7 antenatal visits (15.8 per 100 live births) had higher LBW rates compared to those who attended ≥7 antenatal visits (6.44 per 100 live births). Mothers who were underweight (i.e. BMI less than 18.5) had a higher LBW rate (12.4 per 100 live births). Mothers with hypertension in pregnancy (41.3 per 100 live births) were at risk of having babies with LBW.

Resident status, marital status and maternal medical conditions such as diabetes mellitus, antepartum haemorrhage and anaemia were not significantly associated with LBW after adjusting for potential confounders in this study (Table 2).

Regional Variation in Observed and Adjusted LBW Rates

Observed LBW rate across planning areas ranged from 5.3 to 11.5 per 100 live births (median, 8.4; interquartile range, 7.3-9.0). After controlling for the identified risk factors, adjusted LBW rates across planning areas ranged from 5.7 to 10.4 per 100 live births (median 8.2; interquartile range: 7.8-8.9) (Table 3). Outram and Bukit Merah exhibited the highest LBW rates, while Queenstown and Serangoon exhibited the lowest LBW rates.

Table 1. Demographics and Patient Characteristics of Singleton Birth Cohort (n = 24,615) and Observed LBW Rates

Characteristic	Cohort %	LBW Rate
Newborn Characteristics		
Gestational age		
Preterm (<37 weeks)	7.89	56.9
Term (37 – 40 weeks)	91.35	4.19
Postdates (>40 weeks)	0.77	1.06
Gender		
Female	48.3	9.19
Male	51.7	7.50
Birth order		
≤1	46.05	9.41
2 – 4	51.95	7.28
≥5	2.00	10.4
Congenital malformations	16.43	12.0
Maternal Characteristics		
Race		
Chinese	43.8	7.64
Malays	26.5	9.55
Indians	13.0	9.87
Others	16.8	6.98
Age		
<20 years	19.3	13.8
20 – 34 years	77.9	7.84
≥35 years	19.3	9.49
Residency status		
Resident	87.8	8.49
Non-resident	12.2	7.17
Marital status		
Married	92.1	8.05
Single	2.66	15.9
Divorced	0.51	9.52
Others	4.73	9.27
Hospital bed class		
Private (class A, B1)	59.9	5.56
Subsidised (class B2, C)	40.1	12.5
No. of antenatal visits		
Compliant (≥7 visits)	79.8	6.44
Non-compliant (<7 visits)	20.2	15.8
BMI less than 18.5	8.56	12.4
Hypertension	1.78	41.3
Diabetes mellitus	7.78	7.99
Antepartum haemorrhage	3.15	20.9
Anaemia	5.87	11.1
Overall		8.32

BMI: Body mass index; LBW: Low birth weight

Table 2. Logistic Regression Analysis Summary on Association of LBW rates with Newborn and Maternal Characteristics

Variable	Unadjusted OR (95% CI)	*P* Value	Omnibus *P* Value	Adjusted OR* (95% CI)	*P* Value	Omnibus *P* Value
Newborn Characteristics						
Gestational age						
Term	Reference		<0.0001	Reference		<0.0001
Preterm	30.21 (27.03, 33.76)	<0.0001		25.4 (22.5, 28.7)	<0.0001	
Postdate	0.30 (0.09, 1.07)	<0.0001		0.28 (0.08, 0.97)	0.0442	
Gender						
Male	Reference			Reference		
Female	1.25 (1.14, 1.37)	<0.0001		1.56 (1.4, 1.74)	<0.0001	
Birth order						
2 – 4	Reference		<0.0001	Reference		<0.0001
1	1.32 (1.21, 1.45)	0.3162		1.53 (1.37, 1.72)	<0.0001	
≥5	1.49 (1.10, 2.00)	0.0869		1.01 (0.7, 1.45)	0.9745	
Congenital malformations	1.66 (1.49, 1.85)	<0.0001		1.27 (1.11, 1.45)	0.0005	
Maternal Characteristics						
Race						
Chinese	Reference		<0.0001	Reference		<0.0001
Indian	1.33 (1.16, 1.52)	0.0004		1.46 (1.24, 1.72)	<0.0001	
Malay	1.28 (1.15, 1.42)	0.0005		1.06 (0.92, 1.21)	0.4455	
Others	0.91 (0.79, 1.04)	<0.0001		0.87 (0.73, 1.02)	0.0855	
Age						
20 – 34 years	Reference		<0.0001	Reference		0.0053
<20 years	1.89 (1.51, 2.37)	<0.0001		0.98 (0.74, 1.3)	0.8953	
≥35 years	1.23 (1.10, 1.38)	0.1534		1.26 (1.1, 1.45)	0.0012	
Residency status						
Resident	Reference			Reference		
Non-resident	0.83 (0.72, 0.97)	0.0154		1.08 (0.89 – 1.31)	0.4249	
Marital status						
Married	Reference		<0.0001	Reference		0.4874
Single	2.17 (1.75, 2.69)	<0.0001		1.21 (0.91 – 1.62)	0.1941	
Divorced	1.25 (0.69, 2.24)	0.7659		1.27 (0.66 – 2.45)	0.4684	
Others	1.17 (0.96, 1.44)	0.2374		1.08 (0.84 – 1.38)	0.5538	
Hospital bed class						
Private	Reference			Reference		
Subsidised	2.42 (2.21, 2.65)	<0.0001		1.8 (1.6, 2.02)	<0.0001	
No. of antenatal visits						
Compliant (≥7 visits)	Reference			Reference		
Non-compliant (<7 visits)	2.73 (2.48, 3.00)	<0.0001		1.39 (1.23, 1.58)	<0.0001	
BMI						
>18.5	Reference			Reference		
≤18.5	1.63 (1.42, 1.88)	<0.0001		2.06 (1.75, 2.44)	<0.0001	
Hypertension	8.42 (6.92, 10.24)	<0.0001		2.93 (2.23, 3.85)	<0.0001	
Diabetes mellitus	0.95 (0.80, 1.13)	0.5973		1.00 (0.81 – 1.22)	0.9663	
Antepartum haemorrhage	3.08 (2.58, 3.69)	<0.0001		1.26 (0.99 – 1.60)	0.0587	
Anaemia	1.41 (1.19, 1.67)	<0.0001		0.92 (0.75 – 1.14)	0.4658	

CI: Confidence interval; OR: Odds ratio; LBW: Low birth weight

*Adjusted for gestational age, child gender, birth order, congenital malformations, maternal race, age, hospital bed class, compliance to antenatal visits, BMI, and hypertension, using stepwise selection approach.

Table 3. Regional Characteristics of the Singleton Birth Cohort (n = 24,615)

Planning Area	n	Observed LBW Rate	Adjusted LBW Rate*	Socioeconomic Disadvantage Index (SEDI)†	Distance Travelled (km)
Ang Mo Kio	1055	10.24	8.87 (7.78, 10.10)	107.9	8.4
Bedok	1562	8.13	8.27 (7.20, 9.45)	102	12.6
Bishan	285	10.88	8.96 (7.93, 10.10)	92.8	7.3
Bukit Batok	633	6.48	6.88 (5.95, 7.95)	100.6	11.9
Bukit Merah	762	11.29	10.37 (9.15, 11.71)	110.1	6.2
Bukit Panjang	959	6.57	7.49 (6.53, 8.60)	100.9	13.1
Bukit Timah	144	6.94	5.67 (4.85, 6.63)	79.8	9.5
Choa Chu Kang	943	8.80	7.87 (6.84, 9.02)	97.6	16.8
Clementi	310	6.77	7.91 (6.88, 9.08)	100.3	12.3
Geylang	771	9.99	9.11 (8.00, 10.35)	109.3	7.6
Hougang	1184	8.61	8.74 (7.67, 9.94)	102.8	8.9
Jurong East	341	7.62	8.10 (7.08, 9.26)	99.9	15.2
Jurong West	1510	7.28	8.30 (7.28, 9.46)	101.6	19.9
Kallang	715	8.11	8.68 (7.61, 9.87)	110.1	3.7
Marine Parade	223	8.97	9.36 (8.11, 10.77)	94.5	7.7
Novena	261	9.58	7.86 (6.81, 9.07)	96.3	3.1
Outram	156	11.54	10.08 (8.83, 11.48)	120.1	5
Pasir Ris	791	7.21	7.81 (6.83, 8.91)	90.7	18.7
Punggol	1676	8.11	7.64 (6.71, 8.69)	-‡	17.6
Queenstown	433	5.31	7.87 (6.82, 9.06)	106.9	10.3
Rochor	144	9.03	7.18 (6.18, 8.33)	111	1.7
Sembawang	561	8.56	8.91 (7.82, 10.12)	100.8	23
Sengkang	2125	8.38	8.07 (7.08, 9.17)	100.2	15.3
Serangoon	435	6.44	6.83 (5.89, 7.92)	94.2	7.9
Tampines	1733	8.83	8.86 (7.81, 10.02)	99.8	17.1
Toa Payoh	981	7.95	8.26 (7.23, 9.42)	107.2	6.3
Woodlands	2138	8.79	8.89 (7.80, 10.13)	102.7	19.4
Yishun	1784	7.90	8.18 (7.14, 9.37)	105.6	17.3

LBW: Low birth weight

*Adjusted for gestational age, child gender, birth order, congenital malformations, maternal race, age, hospital bed class, compliance to antenatal visits, body mass index and hypertension using stepwise selection approach.

†SEDI was derived from Earnest et al's study. Higher SEDI scores indicate areas with higher socioeconomic disadvantage.

‡Punggol was not included in the abovementioned study, hence no SEDI index score was available.

Association of Adjusted LBW Rates and Regional Characteristics

The *P* value for Moran's I statistic was *P* = 0.12, inferring randomly distributed LBW rates across planning areas. The mean SEDI was 101.7 (range: 79.8-120.1). Planning areas with the highest SEDI values were Outram (120.1), Rochor (111.0) and Bukit Merah (110.1) (Table 3). SEDI was moderately positively correlated with adjusted LBW rates, r = 0.58 (*P* value = 0.001). The mean travelling distance from planning area to KKH was 11.6 km (range 1.7-23.0 km). Regions located the furthest distance from KKH are Sembawang (23.0 km), followed by Jurong West (19.9 km) and Woodlands (19.4 km) (Table 3). There was no linear correlation between travelling distance to hospital with adjusted LBW rates, r = -0.08 (*P* value = 0.70).

Discussion

This study found that LBW rates varied twofold across planning areas in Singapore. The distribution of LBW rates is reflective of multiple identified risk factors that are either inherent in mother or child (firstborn, preterm gestational age, female gender child, congenital abnormalities, Indian race, age), associated with socioeconomic status (bed class, SEDI) or clinical risk factors (antenatal visit compliance,

low BMI, hypertension) (Fig. 1). After adjustment for these risk factors, marked variation in LBW rates persisted, demonstrating that a significant extent of LBW risk remains unexplained and is linked to place of maternal residence and perinatal health care delivery.

Although individual risk factors play a significant role in LBW rates, the role of maternal race or individual socioeconomic status in LBW rates across planning areas may be mitigated by the public housing system in Singapore. Known as the Housing and Development Board (HDB), this system began in the 1960s and at presently, houses 82% of residents across all planning areas.[22] HDB prevents racial enclaves by introducing ethnic quotas for HDB blocks based on the ethnic makeup of Singapore. It similarly prevented the grouping of income segments by offering different flat types (i.e. 2- to 5-room flats, executive flats) to cater to different household size and budget within a precinct. The relative spatial homogenisation of different ethnic groups and income brackets across planning areas contributes to reducing variation in LBW rates across planning areas in Singapore.

The SEDI is a characterisation of the socioeconomic status in each planning area. This index is the only regional factor to have a moderate correlation with adjusted LBW (r =0.58). Living in a disadvantaged neighbourhood influences birth outcomes through: 1) psychosocial and, 2) materialist pathway.[10] Psychosocial stress can result in adverse pregnancy outcomes directly through neuroendocrine and immunological processes; or indirectly through maternal health behavioural changes, such as increased smoking, reduced prenatal care and poor dietary intake. The materialist pathway looks at the provision of public services and infrastructure that facilitate women's access to medical care and their ability to make healthy lifestyle choices. Planning areas in Singapore are relatively self-sufficient; residents have accessibility to neighbourhood resources (e.g. recreation facilities, food stores, medical clinics and schools) and social support (e.g. community centres and places of worship).[22] However, there are still measurable differences in SEDIs across planning areas that influence LBW rates.

We further investigated the correlation of travel distance (from home) to LBW rates. One hypothesis might be that longer travel distance may become a physical barrier or disincentive to women to attend their routine antenatal visits, which we have already shown to be a significant risk factor. Although KKH is located centrally, a large proportion of women delivering at KKH come from planning areas outside

Planning Area	n	Observed LBW Rates	Gestational Age Preterm	Child Gender Female	Birth Order 1	Congenital Malformations	Race		Maternal Age More than 35	Hospital Bed Class Class B2/ C	Antenatal Visits Non-Compliant	BMI <18.5	Hypertension	SEDI
							Indian	Malay						
Ang Mo Kio	1055	10.24	8.25	46.54	48.53	15.36	13.46	16.4	23.41	43.32	18.58	9.76	2.37	107.9
Bedok	1562	8.13	7.36	46.8	47.31	15.69	13.76	27.91	19.91	41.42	21.45	9.99	1.66	102
Bishan	285	10.88	9.82	48.59	51.23	15.79	14.04	10.88	25.26	25.96	22.46	8.42	1.75	92.8
Bukit Batok	633	6.48	5.21	46.29	49.92	15.48	12.48	27.96	19.75	39.97	17.38	6.95	2.05	100.6
Bukit Merah	762	11.29	11.15	47.77	46.06	17.45	13.65	21.52	25.98	42.65	26.77	9.19	1.05	110.1
Bukit Panjang	959	6.57	6.67	47.76	45.88	18.25	9.49	33.79	17.52	39.1	18.77	8.13	1.88	100.9
Bukit Timah	144	6.94	4.17	52.08	49.31	14.58	4.17	2.08	28.47	9.72	20.83	18.06	1.39	79.8
Choa Chu Kang	943	8.80	7.53	47.93	45.6	14.74	10.71	32.56	19.19	40.62	21.1	8.27	1.7	97.6
Clementi	310	6.77	6.77	51.29	51.29	14.19	12.9	19.68	24.19	30.97	24.19	13.87	0.65	100.3
Geylang	771	9.99	8.17	51.75	48.38	17.25	14.4	22.7	19.2	49.03	23.09	8.17	2.2	109.3
Hougang	1184	8.61	8.19	49.49	47.13	16.22	15.96	18.58	19.93	40.2	19.76	10.73	2.03	102.8
Jurong East	341	7.62	7.92	43.99	42.23	13.49	13.78	28.74	20.82	43.11	24.05	7.33	0.29	99.9
Jurong West	1510	7.28	8.01	47.55	41.59	15.96	9.8	28.15	19.93	41.66	20.79	7.02	2.32	101.6
Kallang	715	8.11	8.11	48.39	45.31	16.5	24.06	13.29	21.54	36.78	20.56	8.95	2.24	110.1
Marine Parade	223	8.97	9.87	47.98	41.7	17.04	9.87	24.66	29.15	38.57	27.8	8.07	1.35	94.5
Novena	261	9.58	7.28	47.89	41	18.01	21.84	16.86	26.05	34.1	24.14	8.05	1.92	96.3
Outram	156	11.54	10.26	48.72	46.79	16.67	7.05	26.92	17.95	52.56	26.92	10.26	1.28	120.1
Pasir Ris	791	7.21	7.71	50.44	43.49	13.91	11.5	34.01	22.38	32.49	19.85	7.08	0.76	90.7
Punggol	1676	8.11	6.98	48.81	49.94	15.75	12.29	27.68	14.86	31.5	14.92	9.84	1.61	.
Queenstown	433	5.31	6.93	50.58	51.5	17.55	12.24	19.4	16.17	37.88	22.86	9.47	0.69	106.9
Rochor	144	9.03	6.25	52.78	43.75	15.97	30.56	6.94	18.75	28.47	14.58	5.56	2.08	111
Sembawang	561	8.56	9.63	45.99	42.07	15.86	11.94	24.42	23.17	39.22	17.83	6.77	2.67	100.8
Sengkang	2125	8.38	7.81	49.86	46.64	16.52	15.72	25.79	16.47	33.41	14.82	8.38	1.84	100.2
Serangoon	435	6.44	5.29	47.36	49.89	17.47	15.4	8.74	25.06	30.11	16.78	8.74	2.07	94.2
Tampines	1733	8.83	9.29	45.76	46.22	17.31	12.93	34.68	18.7	37.28	20.72	6.75	1.62	99.8
Toa Payoh	981	7.95	7.65	45.16	44.75	18.04	10.4	12.84	18.14	50.87	21.3	8.26	1.22	107.2
Woodlands	2138	8.79	8.51	50.19	41.81	16.79	11.09	38.26	17.4	48.32	23.01	7.95	2.25	102.7
Yishun	1784	7.90	7.29	48.93	46.3	17.71	10.65	32.79	16.03	48.04	20.91	8.52	1.68	105.6

Legend:
High Risk — Low Risk

Fig.1. The number of deliveries and observed LBW rates in each planning area are shown. Risk factors (represented in percentage) are shaded red if they contribute to the planning areas having a higher LBW rate or they are shaded blue if they contribute to the planning areas having a lower LBW rates. BMI: Body mass index; LBW: Low birth weight; SEDI: Socioeconomic Disadvantage Index.

the central area, for example, Sengkang, Woodlands and Yishun (Fig. 2), which correspond to the areas with newer public housing developments that are home to many young families and couples. Despite having to travel a longer distance to KKH, these women do not have higher rates of LBW (r = -0.08). In Singapore, the car ownership rate is about 11%, and most people commute by public transport. The public transport system consists of the Mass Rapid Transit (MRT) and Light Rail Transit (LRT) rail systems (9 lines), a system of bus routes throughout the island, as well as taxis and private hire cars such as Uber and Grab. The impact of variation in travelling distance to hospitals is largely mitigated by the efficient public transport system.

Outram and Bukit Merah were identified as planning areas with the highest LBW rates; associated risk factors were lower socioeconomic status and non-compliance to antenatal visits. For these areas, we recommend a targeted social and health interventions, as well as outreach programmes and case management for pregnant women to encourage antenatal visits. We investigated the hypothesis that planning areas with high LBW rates were clustered together geographically, as such clustering may indicate preferential, inadequate or inequitable access or distribution of health services resources among planning areas. However, we found no statistical evidence of clustering (Moran's I statistic, *P* value = 0.12).

Strength and Limitations

The strength of this study is that it included a large and representative sample of deliveries from the public sector hospitals to which government healthcare resources are directed towards. Based on the annual Registration of Births and Deaths report 2014, 60% of women delivered in private sector hospital. Of the 40% of women who delivered in public sector hospitals, two-thirds of the deliveries were in KKH.[23]

Currently, there is no data on the geographical distribution of patients who delivered in other hospitals. Hence, for each planning area, the proportion of patients who delivered in KKH is unknown. Women from residences in core central areas like Newton, Tanglin and River Valley were relatively less represented in the data from KKH. The abovementioned planning areas correspond to the higher socioeconomically advantaged regions in Ernest et al's study,[16] and pregnant women in these planning areas likely booked in private hospitals. These deliveries may not be relevant to our study that focused on deliveries in the public sector.

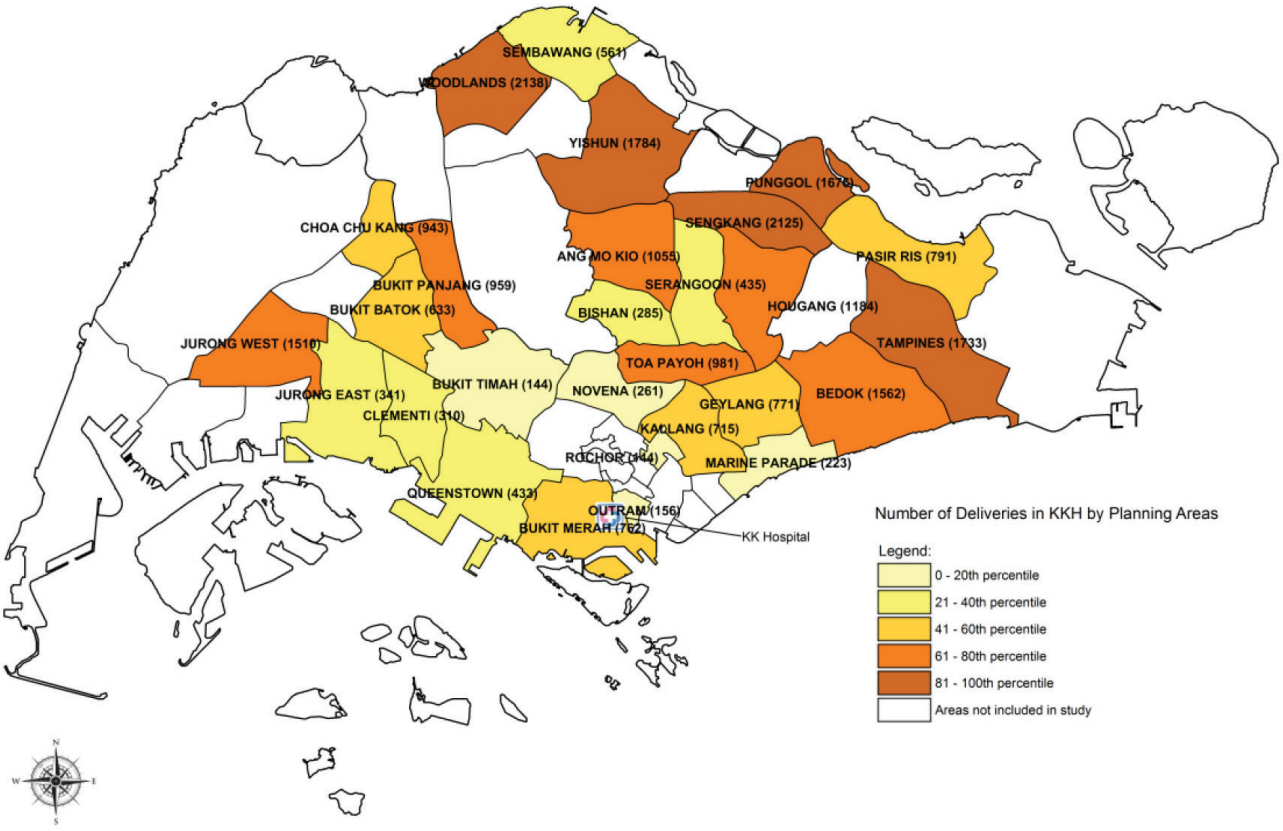

Fig. 2. Map showing the distribution of deliveries in KKH by planning areas.

A total of 8535 out of 34,711 cases were excluded due to missing data on maternal BMI and marital status—characteristics that were not reliably recorded on the OIS in KKH. Our investigation showed that these missing cases were more or less uniformly distributed across planning areas, so any impact on the study would be uniform across all planning areas and we have no reason to believe that these exclusions would have materially influenced the outcome of the study.

Lastly, our analysis of LBW rates neglected the heterogeneity within each planning area, which has an average area of 12.0 km^2. It would have been ideal to analyse LBW rates at a finer postal code level, so as to pinpoint the "highest risk" targets for intervention. Unfortunately, such data is not made available to researchers in Singapore.

Conclusion

LBW rates varied twofold across planning areas in Singapore. The distribution of LBW rates is reflective of the multiple identified risk factors in our study, like socioeconomic status and non-compliance to antenatal visits, as well as unknown risk factors that require further analyses. The 2 areas with the highest rates of LBW infants were Outram and Bukit Merah. For these areas, we recommend targeted social and health interventions, outreach programmes and case management encouraging antenatal visits. There was no statistical evidence indicating clustering relative to high or low LBW rates among planning areas that would indicate inadequate or inequitable access or distribution of health services resources among planning areas.

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