

Geographic Distribution of Maternal and Neonatal Mortality and Inequalities in Obstetric Emergency Care Supply in Ecuador, 2006–2024

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Abstract

Background. Maternal and neonatal mortality remain sensitive indicators of health-system performance worldwide. Brazil's national space-time analysis of emergency obstetric and neonatal care (EmCOC) access demonstrated the value of combining mortality trends with facility-level supply data, but relied on binary bed-presence indicators, a single-year facility census, and explicitly could not incorporate near-miss morbidity indicators. This study applies an enhanced version of that analytic approach to Ecuador, combining mortality, severe maternal morbidity, and multi-year, multi-dimensional obstetric supply data. Because a live-birth registry was unavailable, all rates use total population as the denominator and are therefore not directly comparable to international Maternal Mortality Ratio or Neonatal Mortality Rate statistics, which are conventionally expressed per live birth; this deviation is treated as a primary limitation throughout (Section 2.2, Section 4.6).

Methods. Ecological, space-time study. General mortality microdata (INEC, 2019–2024) were harmonized to identify maternal (ICD-10 O00–O99) and neonatal (age 0–27 days) deaths. Age-standardized rates (direct method, WHO standard) with 95% confidence intervals (Dobson et al. method) were calculated for all 24 provinces, combined into a composite maternal-neonatal index (mean of standardized z-scores). Spatial autocorrelation was assessed using global and local Moran's I (LISA), with False Discovery Rate correction for multiple testing. Obstetric supply was reconstructed from three sources: obstetric and neonatal/NICU hospital bed counts (2023, with a 2006–2023 historical panel for trend context, spanning two survey redesigns), obstetrician/midwife workforce counts (2021), and severe maternal morbidity discharges (ICD-10 O10–O16, O44–O46, O85–O92, O98–O99) from hospital discharge records across eight available years (2008–2023, with data-quality gaps in 2015 and 2021). A standardized mismatch index identified provinces with the greatest gap between combined mortality burden and combined supply.

Results. Between 2019 and 2024, Ecuador recorded 1,038 maternal deaths and 10,480 neonatal deaths. Unlike chronic disease and suicide mortality previously analyzed with an identical pipeline in this country, maternal, neonatal, and combined mortality showed no statistically significant provincial spatial autocorrelation (Moran's I = -0.146 , -0.070 , and -0.212 respectively; all $p > 0.05$), and only one province (Esmeraldas) survived False Discovery Rate correction in the local cluster analysis. A cantonal sensitivity analysis ($n=208$ mainland cantons), however, found significant clustering of neonatal mortality specifically ($I=0.068$, $p=0.043$), with Santa Rosa (El Oro) surviving FDR correction as a High-High cluster — directly confirming that the provincial null result reflects a modifiable areal unit (scale) effect rather than a true absence of geographic structure. Provincial obstetric bed supply was zero in 7 of 24 provinces in 2023, while obstetrician/midwife supply was present in all 24; the cantonal breakdown revealed a starker pattern masked by provincial averaging — 37 of 221 cantons (16.7%) had simultaneously zero obstetric beds and zero obstetricians/midwives. Morona Santiago (province level) and Río Verde, Esmeraldas (canton level, the single worst case nationally) combined high mortality burden with a complete absence of obstetric infrastructure. National obstetric bed capacity grew from 2,864 (2006) to 3,809 (2019) before a 2022 survey redesign that separated obstetrics from general gynecology, precluding direct comparison

with later years. Severe maternal morbidity discharges roughly doubled between 2008–2010 (~18,000/year) and 2018–2023 (~32,000–40,000/year).

Conclusions. Maternal and neonatal mortality in Ecuador show no detectable province-level geographic clustering, in contrast to other causes of death in the same country, but a directly tested cantonal-level sensitivity analysis confirms that this reflects a scale (modifiable areal unit) effect rather than a true absence of geographic structure, at least for neonatal mortality. Independent of the spatial-scale question, obstetric infrastructure gaps are concrete and geographically specific at both levels, and — particularly where workforce is present but bed capacity is absent, as in Morona Santiago province and, more starkly, in over a sixth of all cantons nationally — provide a directly actionable target for infrastructure investment distinct from workforce deployment.

Keywords: maternal mortality; neonatal mortality; obstetric care; spatial analysis; health inequalities; Ecuador.

1. Introduction

1.1 Global and regional burden of maternal and neonatal mortality

Maternal mortality remains one of the most sensitive indicators of health-system quality and equity. The most recent inter-agency estimates (WHO, UNICEF, UNFPA, the World Bank Group, and UNDESA) report approximately 260,000 maternal deaths worldwide in 2023 — roughly 712 deaths every day — representing a 40% reduction since 2000, though the pace of decline remains insufficient to meet the Sustainable Development Goal target of fewer than 70 deaths per 100,000 live births by 2030 [1]. Progress has been highly uneven: Sub-Saharan Africa alone accounted for 70% of global maternal deaths in 2023, and disparities persist even within regions and countries that have achieved substantial aggregate reductions [1]. Obstetric hemorrhage, hypertensive disorders, and sepsis together account for more than half of maternal deaths worldwide [30], and a recent global analysis emphasizes that further progress increasingly depends on addressing within-country geographic and health-system determinants rather than national averages alone [31]. Neonatal mortality has declined more slowly than mortality among older children: globally, deaths among children aged 1–59 months fell 58% between 2000 and the most recent estimates, compared with a 44% decline in neonatal deaths, so that newborns now account for nearly half of all under-five deaths [21]. The Countdown to 2030 initiative for reproductive, maternal, newborn, and child health has likewise emphasized that tracking subnational coverage and quality gaps, not only national trends, is essential to sustaining progress [33].

A parallel literature has emphasized that mortality alone captures only the most extreme end of a continuum of obstetric risk. In 2009, the WHO Working Group on Maternal Mortality and Morbidity Classifications formalized the concept of maternal "near-miss" — a woman who survives a life-threatening complication of pregnancy, childbirth, or the postpartum period — as a complementary surveillance indicator to mortality, given that near-miss events are more frequent and therefore more statistically stable for monitoring quality of obstetric care, particularly in smaller populations [2,3]. An earlier WHO systematic review had already established wide variation in near-miss prevalence depending on the identification criteria used [24], and a more recent systematic review and meta-analysis estimated a pooled global prevalence of 2.45% for severe maternal morbidity and 1.68% for near-miss specifically [23]. The classic "three delays" framework — delay in deciding to seek care, delay in reaching a facility, and delay in receiving adequate care once there — remains the dominant lens for understanding how geographic and health-system factors translate into preventable maternal deaths [20,29], and directly motivates this study's joint focus on mortality and facility-level obstetric supply.

1.2 Geographic approaches to emergency obstetric and neonatal care access

Emergency obstetric and neonatal care (EmCOC) is conventionally benchmarked against WHO/UNFPA/UNICEF signal-function standards for basic and comprehensive obstetric care facilities [28], and global analyses have shown that the scale, scope, and quality of childbirth care — not merely its nominal availability — varies enormously across and within countries [32]. A influential national-level study in Brazil combined space-time mortality trend analysis (2000–2015) with a two-step floating catchment area (2SFCA) accessibility index built from a single-year (2015) census of 951 hospitals, explicitly modeling gravity-based interaction between population demand and obstetric/neonatal bed supply within a 120-kilometer catchment, following Lancet Commission on Global Surgery benchmarks

for emergency-care travel time [4,5,6]. That study identified extensive rural areas without obstetric or neonatal intensive care coverage and highlighted municipalities combining historically high mortality trends with low accessibility, concentrated in Brazil's North, Northeast, and lower-income states [4]. The authors explicitly noted, as limitations for future work, that bed presence/absence was used as a probabilistic rather than direct proxy for care quality, that facility geolocation was available for only a single year despite a 15-year mortality series, and that near-miss indicators — which the maternal morbidity literature considers a more statistically robust complement to mortality [2,3] — could not be incorporated [4]. WHO's intrapartum care guidelines further emphasize that the quality of care actually delivered at a facility, not only its formal capacity, determines whether proximity to a hospital translates into a positive outcome [34], reinforcing the Brazilian study's own caution about treating bed presence as a proxy for care quality.

In Ecuador, spatial approaches to perinatal health have been applied at the cantonal (municipal) level: a LISA-based analysis of infant mortality from 2010 to 2019 identified high-high clusters concentrated in the central highlands, with neonatal deaths accounting for 60% of infant mortality by 2019 [7]. A separate population-based study of early neonatal mortality (before 24 hours of life) found that Apgar score, gestational age, and the altitude at which care was delivered were significant predictors, using a multilevel model with altitude as a random effect [8]. However, no prior Ecuadorian study has, to our knowledge, jointly modeled province-level maternal and neonatal mortality alongside a multi-dimensional, multi-year characterization of obstetric bed, neonatal/NICU bed, and obstetric workforce supply in a single integrated framework.

1.3 Study rationale and what this study adds

Ecuador's health system is structurally fragmented across the Ministry of Public Health, the Ecuadorian Social Security Institute, and a substantial private sector, a fragmentation documented to affect coordination and equity of access across multiple clinical domains [16,17]; obstetric emergency care, which depends on rapid coordination between primary, secondary, and tertiary levels of this fragmented system, is plausibly sensitive to the same structural constraints.

This study extends the Brazilian EmCOC framework [4] in three specific, data-driven ways, motivated directly by the limitations that prior work identified. First, rather than a binary bed-presence indicator, this study uses continuous bed counts across three specialized categories (obstetric, neonatal, neonatal intensive care), combined with obstetrician/midwife workforce counts — allowing infrastructure gaps to be distinguished from workforce gaps, which a presence/absence indicator cannot do. Second, rather than a single-year (2015) facility census set against a 15-year mortality series, this study reconstructs a 12-point historical panel of obstetric bed capacity spanning 2006–2023 (with documented data-availability gaps in 2011–2014 and 2016–2017), providing trend context alongside the 2019–2024 mortality window. Third, this study incorporates severe maternal morbidity as a near-miss proxy, directly addressing the gap the Brazilian study flagged as future work, using hospital discharge diagnoses restricted to internationally recognized severe-complication ICD-10 categories (hypertensive disorders, hemorrhage, and puerperal sepsis/complications) rather than the full obstetric chapter, which is dominated by uncomplicated deliveries.

This study is also the third in a series applying an identical spatial-epidemiological pipeline — encompassing WHO age-standardization, Moran's I/LISA with False Discovery Rate correction, and standardized composite mismatch indices — to different causes of death in Ecuador. Prior applications to chronic kidney disease and suicide mortality found, respectively, strong and moderate positive spatial autocorrelation; whether maternal and neonatal mortality follow a similar geographic logic, or instead reflect facility- and individual-level determinants that do not aggregate into province-level spatial patterns, is an empirical question this study is positioned to answer directly.

1.4 Objectives

This study has four specific objectives:

1. To characterize the provincial geographic distribution of maternal and neonatal mortality in Ecuador (2019–2024), applying formal spatial autocorrelation methods with multiple-testing correction.
2. To construct a 12-point historical panel (2006–2023) of obstetric and neonatal bed capacity to contextualize current supply within longer-run infrastructure trends.
3. To characterize severe maternal morbidity (near-miss) using hospital discharge records across available years (2008–2023) as a statistically more stable complement to mortality.
4. To construct a composite index of mismatch between maternal-neonatal mortality burden and obstetric bed/workforce supply, identifying provinces with the greatest gap and distinguishing infrastructure-specific from workforce-specific deficits.

2. Methods

2.1 Design

Ecological, space-time study. The unit of analysis is the province ($n=24$; $n=23$ mainland provinces for spatial autocorrelation models, excluding the insular province of Galápagos, which shares no land border with any other unit). The mortality component covers 2019–2024. The obstetric bed panel spans 2006–2023 across 12 available survey years. The workforce component uses the 2021 edition of Ecuador's national health-resources survey. The severe maternal morbidity component uses hospital discharge records for 2008–2010, 2018–2020, and 2022–2023 (2015 and 2021 excluded; Section 2.6).

2.2 Data sources

Source	Institution	Period used	Use
General Mortality Statistical Registry (microdata)	INEC	2019–2024	Numerator for maternal (O00–O99) and neonatal (0–27 days) mortality [18]
Population Estimates and Projections, 2024 Revision	INEC	2019–2024	Population denominator (proxy; live births unavailable) [18]
Hospital Bed Census (ECH)	INEC	2006–2010, 2015, 2018–2023	Obstetric and neonatal/NICU bed supply [18]
Hospital Discharge Registry (EEH)	INEC	2008–2010, 2018–2020, 2022–2023	Severe maternal morbidity (near-miss proxy) [18]
Resources and Health Activities Survey (RAS)	INEC	2018 and 2021	Obstetrician/midwife workforce supply [19]
Administrative geometry (provinces/cantons)	Open-access repository (GitHub)	—	Spatial analysis

A structural limitation stated at the outset: no live-birth registry was available in the data sources accessed for this study. Consequently, maternal and neonatal rates are calculated using total population as the denominator (identical convention to two companion analyses using this data infrastructure for other causes of death), rather than the international standard of live births. This is a deviation from the standard Maternal Mortality Ratio and Neonatal Mortality Rate definitions and is treated as a primary limitation (Section 4.6), not a minor caveat.

2.3 Case definition

Maternal deaths were defined as an underlying cause classified under ICD-10 Chapter XV (O00–O99, pregnancy, childbirth, and the puerperium). Neonatal deaths were defined as deaths occurring 0–27 days after birth, identified from the age and age-unit fields of the mortality microdata (which record age in hours, days, months, or years, with inconsistent coding schemes across survey years requiring harmonization; Section 2.4). Of 573,667 general deaths registered between 2019 and 2024, 1,038 (0.18%) met the maternal definition and 10,480 (1.83%) met the neonatal definition.

2.4 Data harmonization

The age-unit variable (`cod_edad`) used two incompatible coding schemes across survey years: a numeric code (2019: 1=hours, 2=days, 3=months, 4=years) and a text label (2020–2024: "Horas", "Días", "Meses", "Años", subject to character-encoding corruption requiring repair). Both schemes were harmonized to a common classification before identifying neonatal deaths (age unit "hours", or age unit "days" with a value ≤ 27). Provincial and cantonal geographic codes were harmonized using the same DPA crosswalk approach validated in companion analyses of this data infrastructure, resolving inconsistent province coding (text versus numeric DPA code) across survey years.

2.5 Rate calculation

Crude and age-standardized rates (direct method, WHO World Standard Population [9]) per 100,000 population were calculated for each province, using the 2019–2024 period total. 95% confidence intervals were calculated using the Poisson-based delta method of Dobson et al. [10]. This method produces a degenerate (zero-width) interval when a province has zero observed events in every age stratum, since the underlying variance estimator scales with observed counts; for the single province in this dataset with all-zero maternal strata (Galápagos), the upper 95% bound is instead reported using the exact Poisson (Garwood) limit for zero events, converted to a rate, to avoid the false impression of a known-zero true rate (Table 1, footnote). A composite maternal-neonatal index was constructed as the mean of the standardized z-scores of the maternal and neonatal age-standardized rates, giving equal weight to both outcomes.

2.6 Severe maternal morbidity (near-miss proxy)

Hospital discharge records were filtered to a restricted set of ICD-10 codes representing internationally recognized severe maternal complications: hypertensive disorders of pregnancy (O10–O16), antepartum hemorrhage and placental complications (O44–O46), and puerperal sepsis and other severe puerperal complications (O85–O92, O98–O99) [2,3,24]. An initial extraction using the full obstetric chapter (O00–O99) was discarded after finding that 26.7% of all hospital discharges in a single test year fell in this range, reflecting the inclusion of uncomplicated deliveries (e.g., code O80, spontaneous vertex delivery) rather

than morbidity; the restricted definition reduced this to 3.4%, consistent with a morbidity rather than care-volume indicator.

Discharge records were available for 2008, 2009, 2010, 2015, 2018, 2019, 2020, 2021, 2022, and 2023. Of these, 2015 and 2021 were excluded from the severe-morbidity series after discovering that their `cau_cie10` field contained free-text diagnosis descriptions rather than ICD-10 codes, with only coarser chapter- and category-level groupings available (e.g., a combined "O30–O48" category spanning both the target complications and non-target conditions); exact code-level classification was therefore not possible for these two years, and they are reported as data-availability gaps rather than zero morbidity.

2.7 Historical obstetric bed panel (2006–2023)

Hospital bed census microdata were consolidated across all years located in the source archive: 2006, 2007, 2008, 2009, 2010 (DBF format), 2015 and 2018–2023 (CSV format) — a 12-point panel with documented gaps in 2011–2014 and 2016–2017 reflecting genuine data-availability limits in the source rather than a processing artifact. A material definitional break occurs in 2022: survey years 2006–2021 report a single combined "gynecology-obstetrics" bed variable, while the 2022–2023 redesign separates "obstetrics" from "gynecology" into distinct fields. For the primary 2023 cross-sectional supply analysis, the obstetrics-specific variable is used as it more precisely reflects emergency delivery capacity; for the 2006–2021 trend panel, the combined variable is used as the only available option, and the two series are not treated as directly comparable levels (only within-series trends are interpreted). Neonatal and neonatal intensive care unit (NICU) beds were tracked from 2018 onward only.

2.8 Obstetric workforce supply

Obstetrician/midwife counts (variable `k201` in Ecuador's national Resources and Health Activities Survey, RAS) were extracted for the 2021 edition, aggregated to the provincial level and expressed per 100,000 population.

2.9 Spatial analysis

- **Spatial weights matrix:** Queen contiguity [11], built on a geometric layer reconstructed by dissolving cantonal polygons, as validated in companion analyses of this administrative geometry.
- **Global autocorrelation:** Moran's *I* statistic [12], significance assessed via 999 permutations, applied separately to maternal, neonatal, and combined indices.
- **Local clusters:** LISA (Anselin [13]), classified into High-High (HH), Low-Low (LL), High-Low (HL), and Low-High (LH), significant at $p \leq 0.05$, with False Discovery Rate correction (Benjamini-Hochberg [14]) applied given 23 simultaneous provincial tests per outcome.

2.10 Composite mismatch index

A standardized mismatch index was constructed as the difference between the combined maternal-neonatal mortality z-score and a composite supply z-score — the equally weighted average of standardized obstetric-bed and obstetrician/midwife rates per 100,000 population (2023 and 2021 respectively). This index is a direct algebraic transformation of standardized rates and involves no Bayesian smoothing; empirical Bayesian smoothing is applied separately and only to the cantonal rates themselves (Section 2.11), prior to their use in the cantonal version of this index, to avoid conflating the two distinct methodological steps.

2.11 Cantonal sensitivity analysis

This analysis was motivated by the modifiable areal unit problem (MAUP) — the well-documented tendency for spatial statistics to depend on the scale and boundary definitions of the areal units analyzed [22] — as a candidate explanation for the null provincial results (Section 3.3). Given that Ecuador's mortality microdata records only province, not canton, of usual residence, the canton of civil-registry registration (`cant_insc`) was used as a residence proxy — the same approach validated in companion analyses of this data infrastructure — resolving canton codes for 89.3% of maternal and 87.6% of neonatal deaths (the remainder had ambiguous or unresolvable canton names and were excluded from the cantonal analysis only). Cantonal rates were smoothed using the global empirical Bayesian estimator of Marshall [15] (see also Clayton and Kaldor [26]): each canton's raw rate was shrunk toward the national mean rate (the prior), with the shrinkage weight for each canton determined by its population size relative to the ratio of the national mean rate to the between-canton variance in raw rates, following the standard global (as opposed to local, neighborhood-based) formulation. Cantons with zero observed events were not treated differently in the prior specification; their shrinkage weight is simply low given their typically small population, pulling their smoothed rate toward the national mean rather than to zero. Cantonal obstetric bed and obstetrician/midwife counts were aggregated from the same source facility-level microdata used for the provincial analysis (the hospital bed census records all sectors — public, private for-profit, private non-profit, social security, military, and municipal — so a canton's zero-bed status reflects the full census, not exclusion of any sector), using the canton-of-service-location field. Moran's I and LISA were recomputed on the cantonal geometry (Queen contiguity dissolved from the same validated administrative layer used in companion analyses), with cantonal LISA p-values computed from 9,999 permutations (versus 999 for the primary provincial analysis) to obtain adequate resolution for False Discovery Rate correction across 208 simultaneous tests. A Kulldorff-type spatial scan statistic [27], which some companion and Ecuadorian studies have used as an alternative cluster-detection method, was not applied here; LISA was retained for consistency with the provincial analysis. As a further robustness check, the cantonal mismatch index (Section 2.10) was recomputed under an alternative supply-weighting scheme (70% obstetric beds / 30% obstetricians, reflecting beds as the more acute constraint for emergency delivery) and compared with the primary equal-weighting scheme by Spearman rank correlation.

2.12 Software

Python 3.12; `pandas`, `geopandas`, `libpysal`, and `esda` for the spatial analyses [35]; `dbfread` for legacy DBF-format bed census files; `statsmodels` for the False Discovery Rate correction. Analysis code is available from the corresponding author upon reasonable request and will be deposited in a public repository (GitHub/Zenodo) prior to publication.

3. Results

3.1 General description

Between 2019 and 2024, Ecuador recorded 1,038 maternal deaths (average 173/year) and 10,480 neonatal deaths (average 1,747/year). Guayas concentrated the largest absolute numbers of both (294 maternal, 3,147 neonatal deaths), consistent with its status as the country's most populous province. All rates reported below are population-based (total population denominator; Section 2.2), not the live-birth-

based Maternal Mortality Ratio or Neonatal Mortality Rate conventionally used internationally; for brevity, subsequent mentions use "rate" without repeating this qualifier.

3.2 Geographic distribution of maternal and neonatal mortality

Age-standardized maternal mortality ranged from 0.00 per 100,000 (Galápagos, zero observed deaths) to 2.35 (Morona Santiago). Age-standardized neonatal mortality ranged from 4.81 (Galápagos) to 13.46 (El Oro). No consistent coast-highland-Amazon gradient was visually or statistically apparent (Table 1, **Figure 1**) unlike the patterns previously identified in this country for chronic kidney disease (a pronounced coastal cluster) and suicide (a highland-associated gradient) using an identical analytic pipeline.

Table 1. Maternal mortality, neonatal mortality, combined index, obstetric bed supply, obstetrician/midwife supply, and mismatch index by province (ordered by combined maternal-neonatal index, 2019–2024)

Province	Maternal deaths	Maternal rate (x100k)	95% CI (maternal)	Neonatal deaths	Neonatal rate (x100k)	95% CI (neonatal)	Combined index (z)	Obstetric beds (2023)	Obstetricians (2021)	Mismatch index (z)
Morona Santiago	27	2.35	1.43–3.26	189	12.36	10.60–14.12	1.82	0	24	2.25
El Oro	52	1.11	0.81–1.41	554	13.46	12.34–14.58	0.85	7	81	1.15
Sucumbios	15	1.16	0.57–1.75	183	13.08	11.19–14.98	0.82	1	60	0.02
Cotopaxi	32	1.03	0.67–1.39	322	12.53	11.16–13.90	0.58	10	58	0.57
Guayas	294	1.03	0.91–1.15	3147	11.98	11.56–12.40	0.47	90	438	0.66
Bolivar	17	1.36	0.71–2.01	114	9.99	8.16–11.83	0.39	0	24	0.84
Los Rios	83	1.40	1.09–1.70	518	9.12	8.34–9.91	0.25	40	136	-0.36
Napo	16	1.84	0.93–2.76	66	6.90	5.24–8.57	0.24	1	28	-0.05
Chimborazo	33	1.13	0.74–1.52	260	10.12	8.89–11.35	0.20	11	38	0.42
Santa Elena	33	1.28	0.84–1.72	227	9.26	8.05–10.46	0.17	13	72	-0.49
Pichincha	96	0.45	0.36–0.54	1912	13.03	12.45–13.61	0.13	319	238	-1.25
Pastaza	12	1.66	0.72–2.61	59	7.13	5.31–8.95	0.11	3	11	0.16
Carchi	7	0.63	0.16–1.10	109	11.16	9.07–13.26	-0.07	0	47	-0.58
Canar	18	1.36	0.73–1.99	111	7.46	6.07–8.84	-0.11	0	11	0.80
Esmeraldas	64	1.79	1.35–2.23	213	5.39	4.67–6.11	-0.12	0	170	-0.77
Imbabura	19	0.62	0.34–0.89	271	10.56	9.31–11.82	-0.21	10	49	-0.09
Manabi	94	0.85	0.67–1.02	883	9.46	8.84–10.09	-0.21	13	88	0.50
Orellana	13	1.17	0.53–1.81	105	7.76	6.27–9.24	-0.24	2	33	-0.39
Azuay	31	0.60	0.39–0.81	471	10.07	9.16–10.98	-0.32	18	9	0.35
Loja	27	0.89	0.55–1.23	240	8.58	7.50–9.67	-0.34	11	15	0.20
Santo Domingo de los Tsachilas	24	0.76	0.45–1.06	242	7.54	6.59–8.49	-0.68	26	36	-1.00
Tungurahua	27	0.76	0.47–1.04	226	7.50	6.52–8.48	-0.69	32	42	-1.14
Zamora Chinchipe	4	0.49	0.01–0.96	51	6.99	5.07–8.91	-1.05	0	14	-0.63
Galápagos*	0	0.00	0.00–2.10*	7	4.81	1.25–8.38	-1.96	0	2	-1.18

Source: authors' elaboration based on INEC (deaths, population, hospital bed census, and RAS workforce survey). Rates per 100,000 population (population-based proxy; live births unavailable, Section 2.2). Combined index = $\text{mean}[z(\text{maternal rate}), z(\text{neonatal rate})]$. Obstetric beds from the 2023 obstetrics-specific variable. Mismatch index = $\text{combined index} - \text{mean}[z(\text{obstetric beds}/100\text{k}), z(\text{obstetricians}/100\text{k})]$; positive = above-average burden with below-average supply. * Galápagos had zero observed maternal deaths in every age stratum, for which the Dobson et al. delta-method variance is degenerate (zero); the upper 95% bound reported instead uses the exact Poisson (Garwood) limit for zero events (3.69 deaths) converted to a rate, following standard practice for age-standardized rates based on all-zero strata.

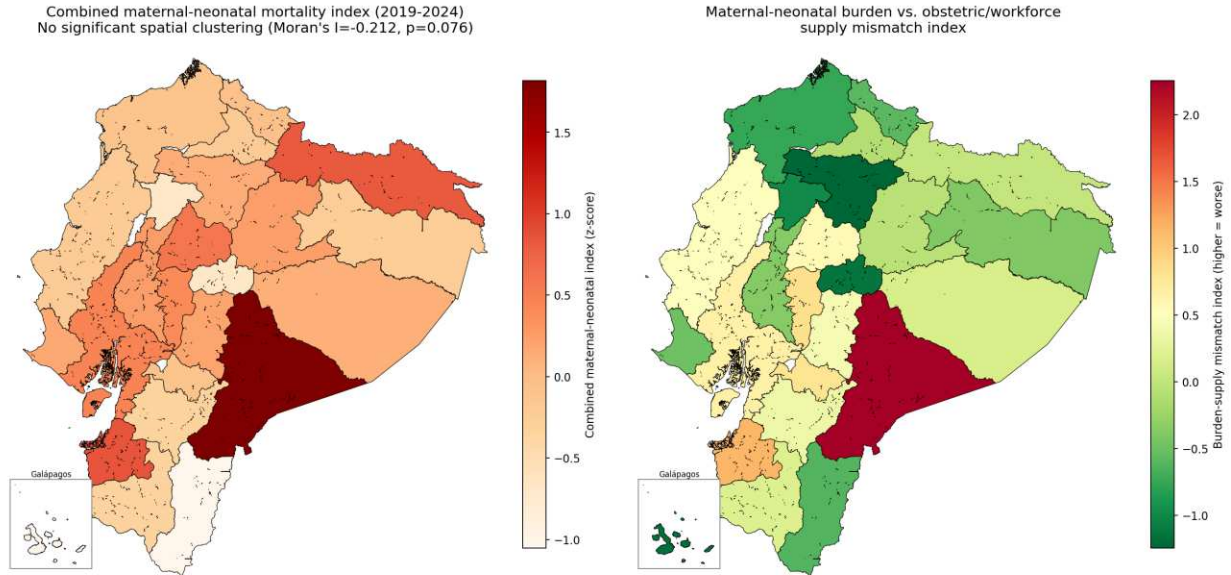


Figure 1. Combined maternal-neonatal mortality index (left) and burden-supply mismatch index (right) by province, Ecuador, 2019–2024.

3.3 Spatial autocorrelation

Global Moran's I was negative and not statistically significant for all three outcomes: maternal mortality ($I=-0.146$, $p=0.225$, $z=-0.84$), neonatal mortality ($I=-0.070$, $p=0.454$, $z=-0.21$), and the combined index ($I=-0.212$, $p=0.076$, $z=-1.41$). This contrasts sharply with the same pipeline's findings for chronic kidney disease ($I=0.476$, $p=0.001$) and suicide ($I=0.218$, $p=0.023$) mortality in this country. A non-significant global Moran's I indicates that spatial autocorrelation was not detected at the provincial level with the available data and sample size ($n=23$); it does not, on its own, establish that no geographic pattern exists — a distinction this study examines directly via the cantonal sensitivity analysis in Section 3.8.

LISA: For maternal mortality, 4 of 23 provinces were nominally significant ($p \leq 0.05$) — Pastaza (High-High, $p=0.035$), Esmeraldas (High-Low, $p=0.002$), Tungurahua (Low-High, $p=0.008$), and Loja (Low-Low, $p=0.040$) — but only Esmeraldas survived False Discovery Rate correction ($p_{FDR}=0.046$). For neonatal mortality, no province reached nominal significance. For the combined index, 2 provinces were nominally significant (Morona Santiago, High-Low, $p=0.037$; Tungurahua, Low-High, $p=0.025$), and none survived FDR correction. The heterogeneous, non-adjacent mix of HH/LL/HL/LH classifications among the few nominally significant provinces (rather than a spatially coherent block) is itself consistent with the absence of true underlying clustering (**Figure 2**).

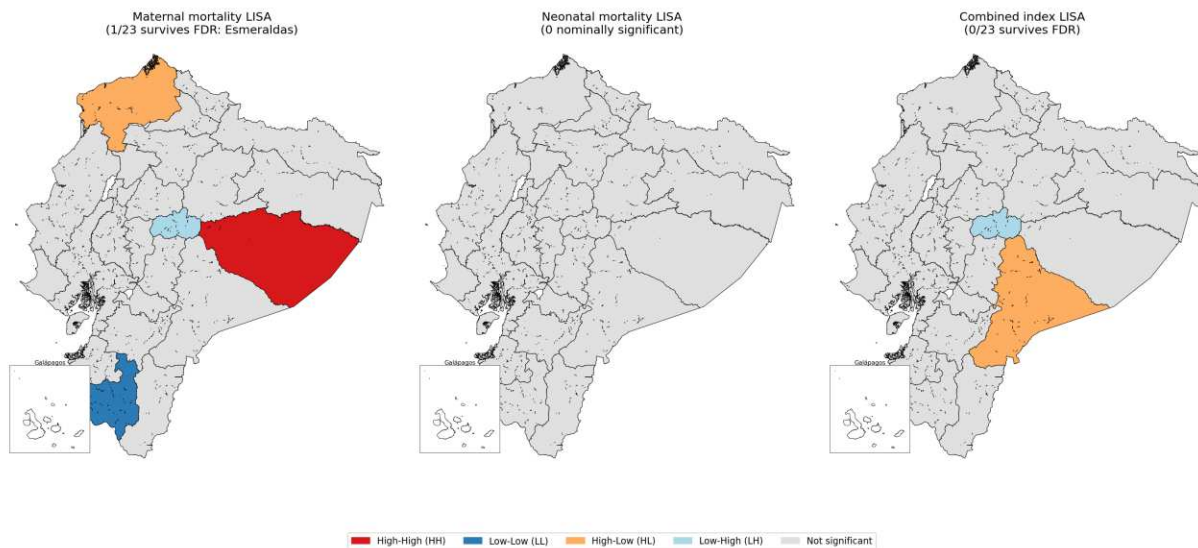


Figure 2. Local spatial clusters (LISA) for maternal mortality, neonatal mortality, and the combined index, by province, Ecuador, 2019–2024. Only Esmeraldas (maternal, High-Low) survives False Discovery Rate correction; the near-absence of significant, spatially coherent clusters is itself the key result.

3.4 Historical obstetric bed panel (2006–2023)

National combined gynecology-obstetrics bed capacity increased from 2,864 (2006) to a peak of 3,809 (2019), a 33% increase over 13 years, before declining to 3,369 (2021) — still within the pre-redesign measurement scheme (**Figure 3**). Following the 2022 survey redesign that separated obstetrics from general gynecology, the obstetrics-specific count was 550 (2022) and 607 (2023); these figures are not directly comparable to the pre-2022 combined series and should not be read as an abrupt 85% capacity loss, but as a change in what is being measured (Section 2.7). Neonatal and NICU bed tracking began only in 2018 (1,440 neonatal beds nationally that year).

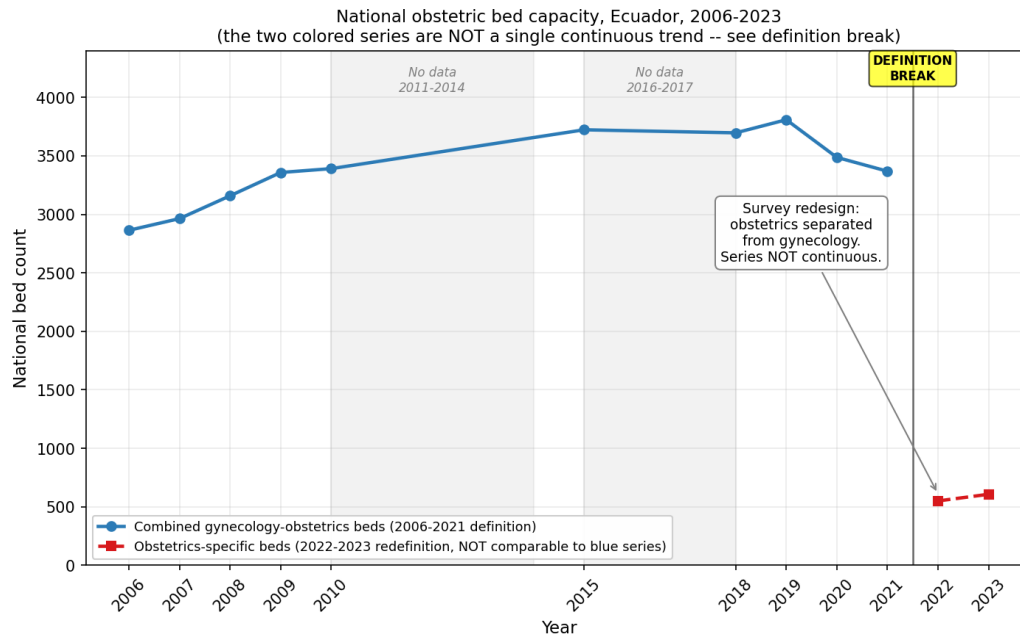


Figure 3. National obstetric bed capacity, Ecuador, 2006–2023. Shaded bands mark years without available data (2011–2014, 2016–2017). The 2022 discontinuity reflects a survey redefinition, not a real capacity collapse (Section 2.7).

3.5 Severe maternal morbidity (near-miss proxy)

Severe maternal morbidity discharges (restricted ICD-10 definition) were 18,310 (2008), 17,528 (2009), and 18,458 (2010), followed by a marked increase to 33,802 (2018), 40,429 (2019), 32,320 (2020), 33,238 (2022), and 31,549 (2023) — roughly a doubling between the earliest and most recent available years (**Figure 4**). This shift could reflect genuine increases in obstetric complications, improved hospital-based detection and coding of complications over time, expanded hospital-based delivery coverage, or some combination; the discrete, gapped nature of the available years (2015 and 2021 excluded; Section 2.6) precludes a formal trend test, and this pattern is presented descriptively rather than as evidence of a specific mechanism.

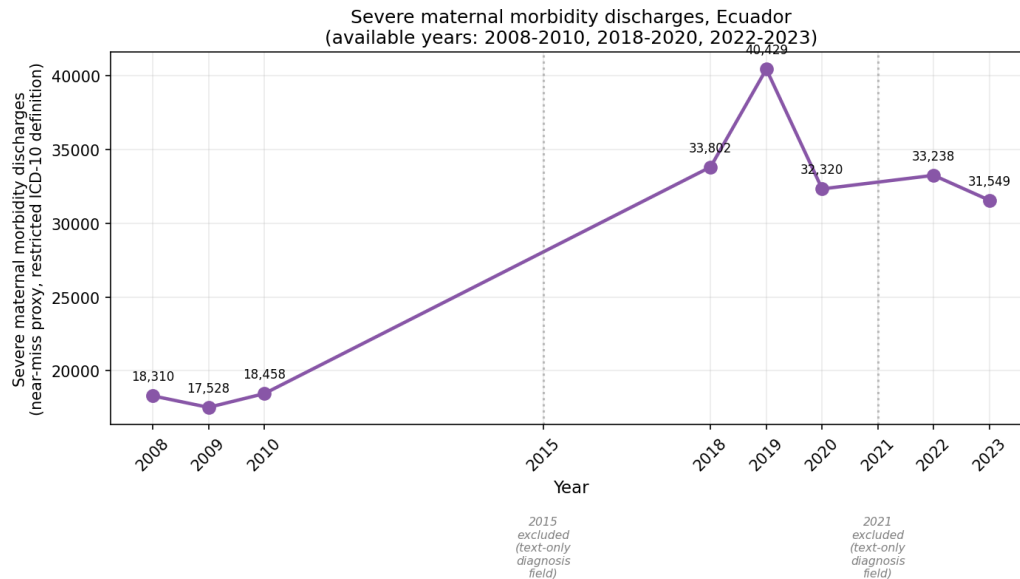


Figure 4. Severe maternal morbidity (near-miss proxy) hospital discharges, Ecuador, by available year. 2015 and 2021 are excluded due to a text-only diagnosis field in those specific source files (Section 2.6).

3.6 Obstetric bed and workforce supply (2023/2021)

Seven of 24 provinces had zero obstetric beds in 2023: Morona Santiago, Bolívar, Carchi, Cañar, Esmeraldas, Zamora Chinchipe, and Galápagos. In contrast, obstetrician/midwife workforce (RAS 2021) was present in all 24 provinces, ranging from 2 (Galápagos) to 438 (Guayas). This asymmetry — zero-bed provinces without corresponding zero-workforce provinces — indicates that, unlike the psychiatric workforce gaps identified in a companion analysis of mental health services in this country, the obstetric care gap in Ecuador is predominantly one of hospital infrastructure, not absolute absence of trained personnel (Figure 5).

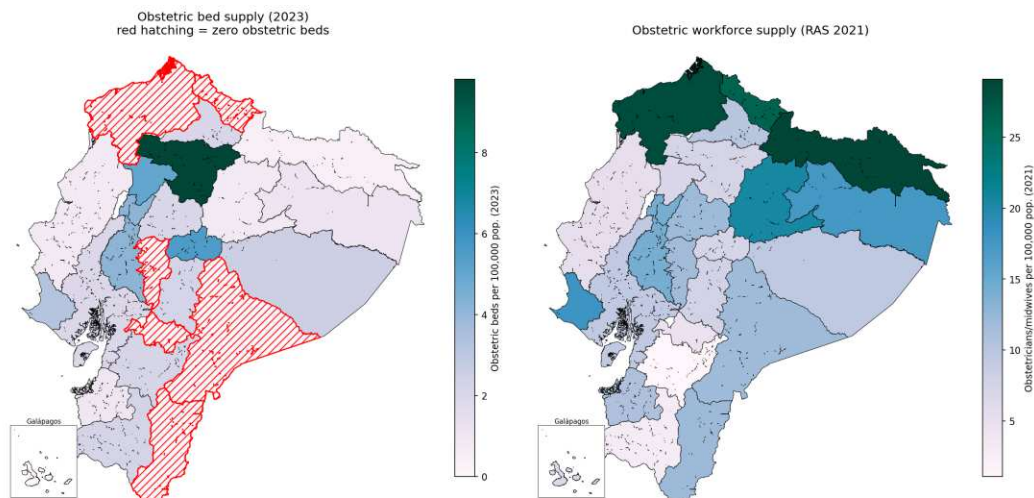


Figure 5. Obstetric bed supply per 100,000 population, 2023 (left; red hatching = zero obstetric beds) and obstetrician/midwife supply per 100,000 population, 2021 (right), by province, Ecuador.

3.7 Burden-supply mismatch

Morona Santiago showed the country's most severe mismatch (index=+2.25): the highest combined maternal-neonatal mortality index (+1.82) combined with zero obstetric beds, despite a workforce supply (24 obstetricians/midwives, 11.83 per 100,000) above the national median. El Oro (+1.15) and Bolívar (+0.84) followed, the latter also with zero obstetric beds. At the opposite end, Pichincha showed the most favorable mismatch score (−1.25), reflecting the country's largest absolute obstetric bed count (319) concentrated in its capital, Quito (**Figure 6**).

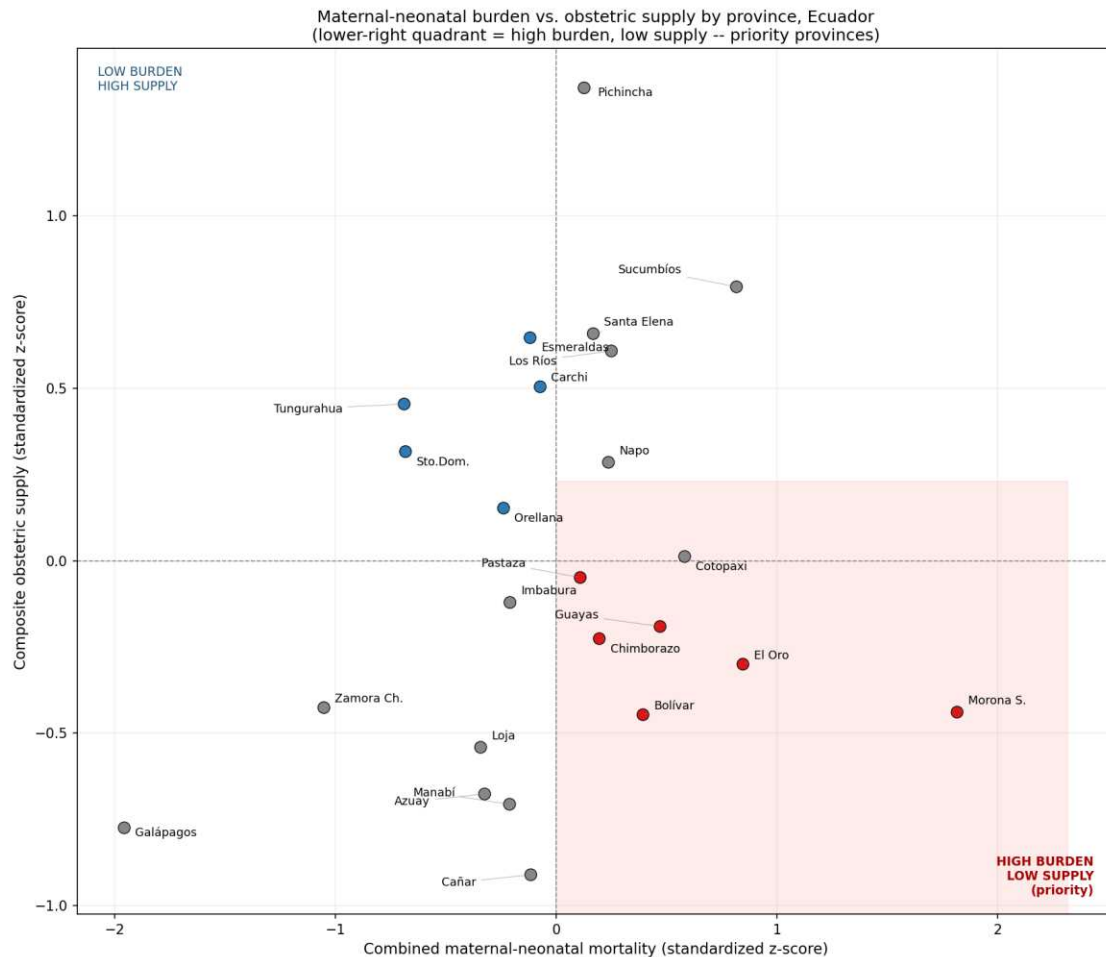


Figure 6. Combined maternal-neonatal mortality burden versus composite obstetric supply by province, Ecuador, expressed as standardized z-scores. The lower-right quadrant (red points) identifies provinces combining above-average burden with below-average supply.

3.8 Cantonal sensitivity analysis

Repeating the analysis at the cantonal level (n=208 mainland cantons with resolved data and valid spatial neighbors) produced a materially different result for neonatal mortality specifically. Unlike the null provincial finding, the cantonal global Moran's I for neonatal mortality was positive and statistically significant ($I=0.068$, $p=0.043$, $z=2.00$), and Santa Rosa (El Oro) survived False Discovery Rate correction as a High-High cluster ($p_{FDR}=0.021$) — the first statistically robust, spatially confirmed cluster identified anywhere in this study. For the combined maternal-neonatal index, 2 of 208 cantons survived FDR

correction: Santa Rosa (High-High) and Lomas de Sargentillo, Guayas (Low-Low). Maternal mortality alone remained non-significant at the cantonal level after FDR correction (0/208), though with more nominally significant cantons (32) than at the provincial level (**Figure 7**).

This finding directly confirms, rather than merely motivates by citation, the modifiable areal unit problem (MAUP) hypothesis raised in Section 4.2: a real, spatially coherent cluster of neonatal mortality exists in Ecuador, but it is only detectable at the cantonal resolution and is diluted to statistical non-significance when aggregated to the province level. This is consistent with the cantonal-level clustering of infant mortality in the central highlands reported by a companion Ecuadorian study using a different time window [7], though the specific cluster location identified here (El Oro, on the southern coast) differs, suggesting that more than one geographically distinct cantonal-level process may be at work.

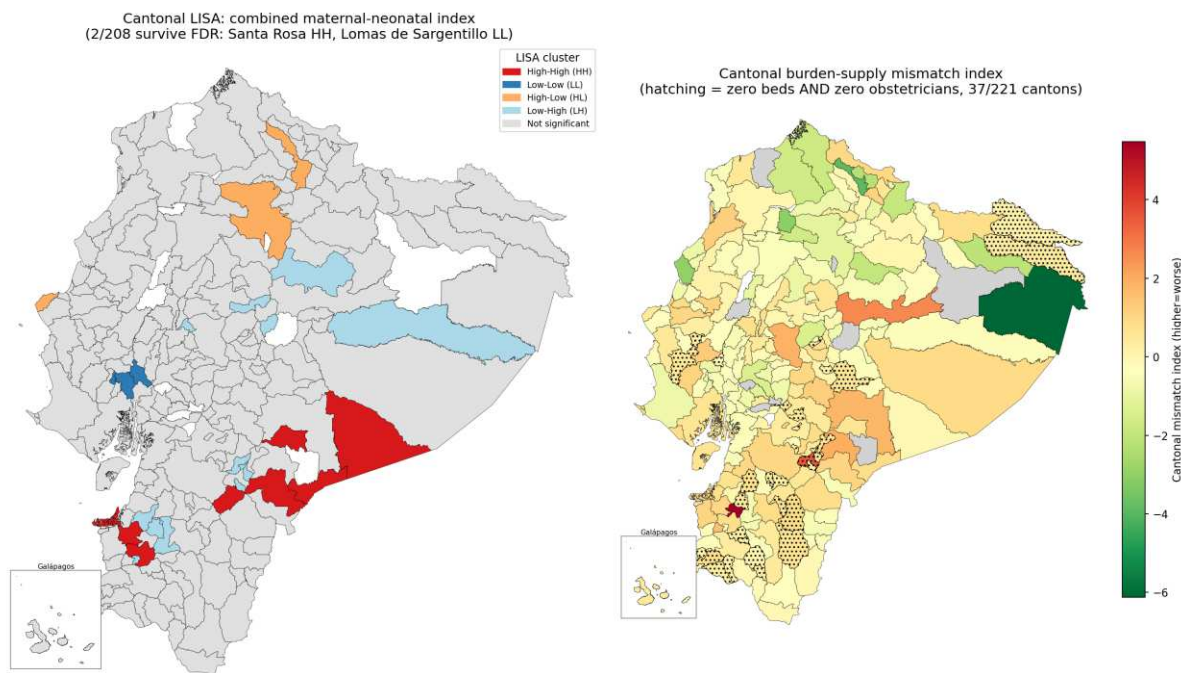


Figure 7. Cantonal-level LISA clusters for the combined maternal-neonatal index (left; Santa Rosa and Lomas de Sargentillo survive FDR correction) and cantonal burden-supply mismatch index (right; hatching = cantons with zero obstetric beds AND zero obstetricians/midwives, 37 of 221 cantons), Ecuador.

Cantonal supply reveals a "double desert" pattern masked at the provincial level. While provincial-level analysis (Section 3.6) found obstetrician/midwife workforce present in all 24 provinces, the cantonal breakdown shows that 37 of 221 cantons (16.7%) have simultaneously zero obstetric beds and zero obstetricians/midwives — a genuine double desert that provincial aggregation conceals, because a single well-staffed provincial-capital canton can offset an entire province's average even when most of its constituent cantons have no service of any kind. The cantonal mismatch index identifies Río Verde (Esmeraldas) as the single worst case nationally (mismatch=+6.69: the highest smoothed combined mortality index in the country combined with zero beds and zero obstetricians), followed by Atahualpa (El Oro) and Gualaceo (Azuay). This ranking is robust to the specific supply-weighting scheme used: recomputing the index with a 70% beds / 30% obstetricians weighting (rather than the primary equal

weighting) left Río Verde, Atahualpa, and Gualaceo in the same top three positions, with a Spearman rank correlation of 0.968 between the two schemes across all 208 cantons. At the opposite extreme, some of the most favorable cantonal mismatch scores occur in large, sparsely populated Amazonian cantons (e.g., Aguarico, Orellana), where low absolute mortality counts and comparatively higher per-capita staffing combine — a result that should be interpreted cautiously given these cantons' vast geographic area and low population density, which per-capita supply ratios do not adjust for.

4. Discussion

4.1 Synthesis of main findings

This study finds no statistically significant *province*-level spatial clustering of maternal or neonatal mortality in Ecuador (2019–2024) — a genuinely different result from chronic kidney disease and suicide mortality previously analyzed with an identical pipeline in this country. However, a cantonal sensitivity analysis directly confirms that this provincial null result is a scale (modifiable areal unit) effect rather than a true absence of geographic structure: neonatal mortality shows significant, FDR-corrected clustering at the cantonal level (Santa Rosa, El Oro). Independent of spatial scale, the supply-side findings are unambiguous and directly actionable at both levels: seven provinces have zero obstetric beds, and — more granularly — 37 of 221 cantons (16.7%) have neither obstetric beds nor obstetricians/midwives, with Morona Santiago (province) and Río Verde, Esmeraldas (canton) representing the starkest cases of high mortality burden coinciding with a complete absence of obstetric infrastructure.

4.2 Why is there no detectable spatial clustering at the provincial level?

Three explanations merit consideration, consistent with the broader literature and with this research program's own comparative findings across causes of death. First, a companion Ecuadorian study using LISA at the cantonal (municipal) level found significant high-high clusters of infant mortality concentrated in the central highlands [7] — a finer spatial resolution than the province level. This raised the modifiable areal unit problem (MAUP) as a candidate explanation: true clustering might exist at the cantonal level and be diluted when aggregated to only 23–24 provincial units. This study tested that hypothesis directly (Section 3.8) using the same canton-of-registration residence proxy validated in companion analyses of other causes of death in this country, and found confirmatory evidence: neonatal mortality showed significant global clustering at the cantonal level ($I=0.068$, $p=0.043$) that was entirely absent at the province level ($I=-0.070$, $p=0.454$), with one canton (Santa Rosa, El Oro) surviving strict FDR correction. This is not a citation of an external precedent but a direct within-study demonstration that the null provincial result reflects a genuine scale (MAUP) effect rather than a true absence of geographic structure in neonatal mortality.

Second, maternal and neonatal mortality are individually rare events (province-level annual counts in the low single-to-double digits for several provinces), and a companion Ecuadorian study of early neonatal mortality found that individual-level clinical factors — Apgar score, gestational age, birth weight — were the dominant predictors, with altitude entering only as a random effect on the model intercept rather than as a primary geographic driver [8]. This is consistent with maternal-neonatal mortality being determined substantially by facility-level quality of intrapartum and neonatal care and individual clinical risk factors, alongside the more localized (cantonal-scale) geographic structure identified in Section 3.8,

rather than by the broader environmental, cultural, or health-system-density gradients that appear to structure chronic disease and suicide mortality at the provincial scale in this country.

Third, Ecuadorian narrative and descriptive literature on maternal mortality consistently identifies the Amazon region (Morona Santiago, Orellana, Sucumbíos) as having persistently elevated maternal mortality across nearly two decades (2008–2022), attributed to rurality, geographic dispersion, and ethnic and socioeconomic vulnerability. This qualitative consensus is compatible with this study's finding that Morona Santiago has the country's highest provincial combined mortality index, even though the formal province-level spatial statistic does not detect this as part of a significant contiguous cluster — the descriptive pattern and the formal spatial test are not necessarily in conflict, since a single extreme province without similarly extreme immediate neighbors will not register as a significant LISA cluster even if its individual situation is genuinely severe, and since the cantonal analysis (Section 3.8) identifies its own, geographically distinct significant cluster (El Oro) rather than one centered on the Amazon.

4.3 Infrastructure versus workforce: a different policy problem than mental health

The pattern identified here — obstetric beds absent in seven provinces despite obstetrician/midwife presence in all 24 — is structurally distinct from the psychiatric workforce deserts identified in a companion analysis of Ecuador's mental health system, where entire provinces lacked both personnel and infrastructure. For obstetric care, the binding constraint at the *provincial* level in Morona Santiago, Bolívar, and Cañar is hospital bed capacity, since obstetrician/midwife workforce is present in each; this study's cantonal analysis (Section 3.8) directly confirms the same infrastructure-specific pattern for at least a subset of cantons nationally (37 double-desert cantons notwithstanding), but was not disaggregated separately by province, so the Bolívar- and Cañar-specific claim rests on provincial aggregates alone and should be treated as somewhat less certain than the directly cantonal-verified Morona Santiago/Río Verde finding. Where the pattern holds, it represents a capital-infrastructure investment problem (renovating or licensing inpatient obstetric units) rather than a workforce-training or recruitment problem. This distinction matters for policy: expanding telemedicine or provider incentive programs — effective levers for workforce gaps — would not resolve a bed-capacity constraint, whereas targeted infrastructure investment in these specific provinces would directly address the gap this study identifies.

4.4 Comparison with the Brazilian EmCOC framework

This study's design was directly motivated by, and extends, the Brazilian national EmCOC analysis [4]. Three extensions were achieved: continuous bed and workforce counts rather than binary presence/absence, a 12-point historical bed-supply panel (2006–2023) rather than a single-year (2015) cross-section, and a severe-morbidity (near-miss) indicator using hospital discharge diagnoses — precisely the extension the Brazilian study's authors flagged as attempted but not achieved in their own work [4]. However, this study did not implement the Brazilian study's two-step floating catchment area (2SFCA) accessibility index [5,6], which formally models gravity-based interaction between population demand and supply across facilities within a defined travel-time catchment; this study instead used simpler per-capita supply ratios at the provincial level. With only 23–24 provincial units, a full 2SFCA implementation would offer limited additional resolution over the cantonal or facility level at which it is normally applied, but a cantonal-level 2SFCA analysis — infeasible here due to the residence-data limitation noted above —

would likely be a superior next step for this specific national context, following the finer-grained precedent already set for infant mortality in Ecuador [7].

4.5 Methodological limitations

- **No live-birth denominator.** Maternal and neonatal rates use total population rather than live births, the international standard denominator. This is a first-order limitation affecting the comparability of this study's rates with international Maternal Mortality Ratio and Neonatal Mortality Rate statistics, and was necessitated by the unavailability of a live-birth registry in the data sources accessed for this study.
- **Canton-of-residence proxy, not exact residence.** The cantonal sensitivity analysis (Section 3.8) uses canton of civil-registry registration as a residence proxy, since exact canton of usual residence is not recorded in Ecuador's mortality microdata; this may over-represent cantons with high-throughput registry offices or referral hospitals, the same limitation documented in companion analyses of this data infrastructure.
- **Residual instability in cantonal rates despite empirical Bayesian smoothing.** With an average of fewer than one maternal death per canton-year nationally, Marshall's global empirical Bayesian estimator [15] shrinks extreme cantonal rates toward the national mean but cannot fully eliminate ranking instability in the smallest cantons; the cantonal maternal-mortality LISA results in particular (Section 3.8) should be read as suggestive rather than definitive for any single small canton, even after smoothing.
- **Empirical Bayesian smoothing may itself have reduced power to detect maternal LISA clusters.** By design, shrinking extreme cantonal rates toward the national mean (Section 2.11) narrows the between-canton variance, which could partly explain why 32 cantons were nominally significant for maternal mortality but none survived FDR correction (Section 3.8); this is an inherent trade-off of variance-stabilizing methods for rare events, not a flaw specific to this analysis, and the stabilized ranking is still judged to outweigh this cost for policy purposes.
- **Definitional break in the obstetric bed series (2022)** precludes treating the full 2006–2023 panel as a single comparable series; only within-era trends (2006–2021 combined variable; 2022–2023 obstetrics-specific variable) are interpretable.
- **Severe maternal morbidity data availability gaps (2015, 2021)** due to a coarser, text-based diagnosis classification in the source discharge records for those specific years, limiting the near-miss series to 8 of 10 potentially available years.
- **No 2SFCA or travel-time accessibility modeling,** unlike the Brazilian reference study [4,5,6]; per-capita provincial supply ratios do not capture cross-province referral patterns or travel time to the nearest facility, which may be especially important in Ecuador's Amazon region given documented road-access limitations.
- **Limited statistical power from only 23–24 spatial units,** restricting the precision of both the global Moran's I estimates and the local cluster tests, consistent with the same limitation documented in companion analyses of other causes of death in this country.

- **Ecological design.** As in any study of this type, associations observed at the aggregate level cannot be interpreted as individual-level causal relationships (ecological fallacy [25]).

4.6 Public policy implications

Independent of the null spatial-clustering result, this study's findings support two concrete, low-controversy actions. First, the seven provinces with zero obstetric beds — particularly Morona Santiago, where this coincides with the country's highest mortality burden and adequate workforce — constitute a defensible, infrastructure-specific priority list for targeted hospital bed licensing or construction, distinct from and complementary to workforce-focused interventions. Second, the roughly two-fold increase in severe maternal morbidity discharges between the 2008–2010 and 2018–2023 periods, even if partly attributable to improved detection, warrants dedicated surveillance attention independent of the (statistically noisier) mortality trend, consistent with the broader rationale for near-miss monitoring in the international literature [2,3].

5. Conclusions

This study finds no statistically significant province-level geographic clustering of maternal or neonatal mortality in Ecuador (2019–2024), a result that stands in clear contrast to chronic kidney disease and suicide mortality previously analyzed with an identical spatial-epidemiological pipeline in this country. A cantonal sensitivity analysis directly resolves this apparent puzzle for neonatal mortality specifically: neonatal deaths show real, FDR-corrected spatial clustering at the finer cantonal resolution (Santa Rosa, El Oro), confirming a modifiable areal unit (scale) effect for this outcome rather than a genuine absence of geographic structure; maternal mortality alone remained non-significant even at the cantonal level, and this study cannot rule out that its province- and canton-level null results instead reflect a true absence of geographic structure, low statistical power given rare events, or both. Independent of spatial scale, this study identifies concrete and geographically specific obstetric infrastructure gaps at both levels — seven provinces with zero obstetric beds, and more granularly, 37 of 221 cantons with neither obstetric beds nor obstetricians/midwives — that, in the cases of Morona Santiago (province) and Río Verde, Esmeraldas (canton), coincide with the country's highest maternal-neonatal mortality burden despite adequate or present obstetric workforce, isolating hospital bed capacity as a directly actionable policy target distinct from personnel deployment.

These findings extend a Brazilian national framework for analyzing emergency obstetric and neonatal care access by incorporating continuous supply measures, a multi-decade infrastructure panel, a near-miss morbidity indicator, and a directly tested multi-scale (provincial and cantonal) spatial analysis — precisely the kind of extension that framework's original authors identified as valuable future work. Future research combining exact canton-of-residence data, travel-time accessibility modeling, and a live-birth registry denominator would substantially strengthen the evidence base this study provides for the geographic prioritization of Ecuador's maternal and neonatal health investments, particularly at the cantonal double-desert level this study has newly identified.

Data availability statement

The mortality microdata analyzed in this study were obtained from the National Institute of Statistics and Census of Ecuador (INEC) General Mortality Statistical Registry and Population Estimates and Projections (2024 Revision), publicly available at <https://www.ecuadorencifras.gob.ec>. Hospital bed census data (Estadística de Camas Hospitalarias) and hospital discharge records (Estadística de Egresos Hospitalarios) for the 2006–2023 historical panel and the severe maternal morbidity (near-miss) analysis were likewise obtained from INEC. Obstetric and midwifery workforce data were obtained from INEC's Resources and Health Activities Survey (RAS, 2018 and 2021 editions). The processed, de-identified, aggregate datasets generated for this study (provincial and cantonal maternal and neonatal mortality rates, the consolidated obstetric bed and workforce panels, and derived spatial statistics) are available from the corresponding author upon reasonable request.

Ethics statement

This study used exclusively secondary, publicly available, aggregate and de-identified administrative data (national vital statistics, hospital bed censuses, hospital discharge records, and health workforce surveys); no individually identifiable patient information was accessed, and no direct contact with human participants occurred. In accordance with institutional and national research ethics guidelines for secondary analysis of anonymized public administrative data, ethical review and approval were not required for this study.

Author contributions

ESLM conceived and designed the study, acquired and analyzed the data, developed the software and mismatch index, produced the visualizations, drafted the original manuscript, and supervised the project. AWGV contributed to study design, methodology, formal analysis, data interpretation, visualization, and critical revision of the manuscript, and provided clinical epidemiological expertise overseeing the ICD-10 case definition for maternal and neonatal mortality and the severe maternal morbidity (near-miss) classification. ASHA contributed to methodological design, statistical validation, and critical revision of the manuscript for important intellectual content. All authors approved the final version to be published and agree to be accountable for all aspects of the work. ESLM is the corresponding author and guarantor.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

Generative artificial intelligence tools (Claude, Anthropic) were used during the preparation of this manuscript solely to assist with improving the clarity, grammar, and readability of the text. All data sources, analytical methods, statistical results, and scientific interpretations were reviewed, verified, and approved by the authors, who take full responsibility for the accuracy, integrity, and originality of the content presented.

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