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# Social and geographical inequalities in prenatal care coverage in Colombia: a multilevel analysis of individual heterogeneity and discriminatory accuracy (MAIHDA)

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## ABSTRACT

**Background** Access to adequate antenatal care (ANC) is crucial for improving maternal and neonatal health outcomes. Despite high national ANC coverage, Colombia still faces regional and socioeconomic disparities. This study aims to estimate geographical and intersectional inequalities in ANC coverage and evaluate the contribution of social determinants to these disparities.

**Methods** We conducted a cross-sectional observational study using data from live birth certificates of singleton pregnancies in Colombia during 2022. Multilevel analysis of individual heterogeneity and discriminatory accuracy was performed using logistic regression models. Two approaches were applied: (1) geographical, with departments as the second level and (2) intersectional, with strata as the second level, defined by the combination of health insurance, area of residency, ethnicity and maternal age. The variance partition coefficients (VPCs) from the random-intercept versions of the models were used as the disparity measure. Random slopes were included to allow for variations in the effects of ethnicity and insurance across departments.

**Results** A total of 552 284 singleton pregnancies were analysed. National ANC coverage was 95.96%. However, 15 of the 33 departments and 24 of the 36 intersectional strata reported ANC coverage below the national average. For the geographical analysis, the VPC dropped from 24.45% to 10.02%, after accounting for population compositional effects. For the intersectional analysis, the VPC dropped from 39.43% to 3.64%, after adjusting for the additive effects of the individual characteristics used to define the strata. Ethnicity and health insurance were the most significant determinants of both geographical and intersectional heterogeneity. The effect of both factors varied significantly across departments.

**Conclusions** Colombia faces significant geographical and intersectional inequalities, primarily driven by inequities in ethnicity and health insurance coverage. Policies targeting these social determinants are needed to ensure equitable access to maternal health services.

### WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Despite Colombia achieving high national antenatal care (ANC) coverage, significant regional and socioeconomic disparities persist. Previous studies have documented these inequalities, but traditional approaches often fail to capture the complex interplay between geographical and intersectional factors influencing ANC coverage.

### WHAT THIS STUDY ADDS

⇒ We integrated geographical and intersectional sociodemographic dimensions to quantify ANC coverage inequalities using multilevel analysis of individual heterogeneity and discriminatory accuracy, with the variance partition coefficient as a novel measure of inequality. Our analysis reveals substantial disparities driven by both dimensions, with ethnic and health insurance coverage gaps varying considerably across departments. While ethnicity was the main determinant of geographical heterogeneity, healthcare insurance was identified as the most significant determinant of intersectional heterogeneity.

### HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Our results provide policy-makers and healthcare providers with a more nuanced understanding of ANC inequalities, supporting the design of targeted, context-specific interventions. Additionally, this study underscores the importance of incorporating intersectional multilevel approaches in future health equity research, enabling more precise and actionable policy recommendations that can also be applied to studying other health outcomes.

## INTRODUCTION

Maternal mortality rates have declined worldwide by more than a third between 2000 and 2020. However, this reduction was just 2.8% over the same period in the Latin American and Caribbean region.[1] Many common

causes of maternal and newborn mortality, such as pre-eclampsia, haemorrhage and low birth weight, are potentially preventable and treated through adequate antenatal care (ANC) programmes.[2] Evidence indicates that at least one ANC visit is associated with a 1.04 percentage point (pp) decrease in the likelihood of neonatal mortality, a 1.07 pp in the likelihood of infant mortality[3] and a reduced incidence of both low birth weight[4] and uterine rupture.[5] Moreover, a lack of nutritional counselling during the antenatal period increases the risk of hypertensive disorders in pregnancy.[6] Consequently, ANC is an essential component of healthcare services[7] and should be assessed to monitor maternal health.[8]

ANC indicators are usually measured in women aged 15–49 who had a live birth.[9] According to the WHO report, 83% of pregnant women who gave birth to live infants between 2007 and 2014 received ANC at least once.[10] However, this drops to approximately 77% when looking specifically at pregnant women in the least developed countries.[2] The absence of ANC is a robust indicator of healthcare exclusion, particularly in settings where structural and geographical barriers persist. In Colombia, 97% of pregnant women attended ANC at least once in 2016.[11] However, this percentage is unequally distributed across geographical departments and is notably lower among the poorest regions in the country, including the departments of Vaupés (66%), Chocó (78.8%) and Guainía (89.4 %)[12 13]

Regional inequalities in ANC coverage might be explained by differences in the sociodemographic composition of the population, including socioeconomic status, urban residence, maternal age and education.[14–16] In Colombia, ethnic composition[13] and health insurance affiliation disparities in ANC coverage[7] have been studied, but these studies have assumed the effect is the same across the overall study population. In addition, a previous study from 2001 to 2010 showed that regions affected by armed conflict during pregnancy reduced the probability of women engaging with ANC services by around 2 pp, with larger reductions in rural areas.[17] Thus, various sources of geographical heterogeneity can be decomposed to better understand and ultimately inform efforts to address the root causes of inequalities across populations by 'providing the right intervention to the right population'.[18 19]

Traditionally, absolute or relative social inequalities in ANC coverage in relation to sociodemographic characteristics have been quantified using conventional logistic regression.[3 10 15 20 21] Limited attention has been given to the potential intersections of these factors,[22] and when addressed, such considerations are often confined to the inclusion of a single two-way interaction term. More recently, intersectionality theory has been increasingly applied in quantitative research on health inequalities.[23 24] Specifically, multilevel analysis of individual heterogeneity and discriminatory accuracy (MAIHDA) has been used for examining whether individual outcomes are shaped by intersectional strata derived from various combinations of social characteristics.[25–27] Some social epidemiologists now regard intersectional MAIHDA as a new gold standard for quantitative intersectional analysis of inequities.[18 28 29]

Therefore, the purpose of this study was to provide a more accurate understanding of ANC coverage inequalities in Colombia through both geographical and intersectional MAIHDA lenses. This is a novel methodological approach for analysing health inequalities. Our specific aims were: (1) to estimate geographical and intersectional inequalities in ANC coverage; (2) to determine the explanatory power of the individual social determinants in explaining the geographical and intersectional inequalities and (3) to identify which geographical areas experienced the widest disparities in ANC coverage by ethnic group and healthcare insurance affiliation. Analysing the data through these distinct lenses provides policy-makers and healthcare providers with complementary insights into territorial and social inequities in ANC coverage. Together, these approaches enhance the precision of public health strategies, enabling the design of targeted interventions to address specific population needs and ultimately contribute to a more equitable health system.[18 19]

## METHODS

### Study population and design

This is a national cross-sectional study, based on information taken from live birth certificates of all births that occurred between 1 January 2022 and 31 December 2022 in Colombia. The information is from a publicly and fully anonymised database provided by the National Administrative Department of Statistics (DANE), available at www.dane.gov.co.[30] The DANE carries out a review, codification and quality control process before data is released. Vital statistics data currently estimate that 97% of all births in Colombia are officially registered,[31] a figure that has been used in previous studies.[27 32] The study population comprises mothers between 15 and 49 years old with singleton pregnancies.[33] Observations with missing data on the study variables were excluded and a complete case analysis was performed.

### Study variables

The outcome variable was ANC coverage, which refers to whether a pregnant woman receives at least one ANC visit during their pregnancy, which was defined as 'attendee' if in the affirmative or 'non-attendee' otherwise. The main exposure variables were the geopolitical-administrative division of residency, also known as departments, and intersectional sociodemographic strata. The social determinants used to explain departmental inequalities included departmental indicators of violence and poverty, while health insurance and ethnicity were considered the main individual sociodemographic factors of interest. Maternal age and the urbanicity of the area of residence were also included as covariates.

Colombia is divided into 33 geopolitical-administrative divisions: a capital district, Bogotá and 32 departments, which are governed from their respective administrative division capital cities and have their own public health administration that guides the formulation of public health policies. Violence levels were determined by departmental homicide rates, categorised as 'high' for rates ≥41.68 per 100 000 inhabitants, or 'low' otherwise, corresponding to the lower limit of the top quartile of the distribution provided by the National Institute of Legal Medicine and Forensic Sciences in 2022.[34] Similarly, multidimensional poverty indicators[35] provided by the DANE were included,[36] with values of ≥26 considered 'high' or 'low' otherwise. Intersectional strata were created by combining the three categories of social security, the three categories of ethnicity, the two categories of urbanisation and the two categories of maternal age (ie, 3×3×2×2=36).

The mother's health insurance variable comprises the four coverage categories of the General Health Social Security System: (1) Contributive healthcare plan, covering those who are employed, self-employed or pensioners with incomes equal to or higher than minimum wage; (2) Special or Exempt healthcare plan, covering teachers, the Armed Forces, the National Police, public universities and those working in Colombia's national oil company; (3) Subsidised healthcare plan which covers those who are unable to pay and not covered by any contributory affiliates and (4) Unaffiliated, including those below a poverty threshold. First-degree relatives and spouses/steady partners can also be affiliated as beneficiaries in the first three plans. The majority of Colombians are affiliated with either the contributory or subsidised healthcare plans.[37] Given the small proportion of individuals covered by special insurance (n=7752; 1.42% of the study population), this category was combined with the contributory insurance group for analytical purposes.

Ethnicity was recorded by asking parents their child's classification according to the culture, people or physical traits. We formed three categories of ethnicity: (1) Indigenous; (2) Afro-Colombian including Romani, Raizal and Palenquero and (3) whites and mestizos (of mixed heritage, typically with some European ancestry) reported as 'non-ethnic population' which we categorised as 'mestizos'. These ethnicities are those officially recognised by the DANE in Colombia. A maternal age of 35 years is typically considered a cut-off, above which the risk of adverse perinatal outcomes increases, many of which can potentially be detected during ANC.[38] Therefore, the maternal age variable was dichotomised as <35 or ≥35. Residential area refers to whether the women were living in rural or city contexts and was divided into: (1) urban area and (2) rural area which includes towns located in the rural area of a municipality or a departmental township.

## Statistical analysis

All statistical analyses were performed using Stata V.14 (Stata Corp). We begin by describing the study population, reporting the median number of ANC visits along with the minimum and maximum values, as well as the number and percentage of women in each category of the individual-level variables. We analysed social inequalities based on MAIHDA logistic regression models. In our geographic analysis, individuals (level 1) are considered nested within the 33 geopolitical departments (level 2). This approach highlights territorial disparities potentially linked to differences in health system performance or local context. In our intersectional analysis, individuals (level 1) are nested within the 36 intersectional strata. This analysis identifies high-risk subgroups or incongruent health patterns by mapping social disadvantage. To increase transparency, we provide a fully annotated Stata do-file as online supplemental annex 1 to enable the replication of our analyses.

### Geographical analysis

For the geographical analysis, we first included a departmental random intercept effect to capture the variation in the propensity for ANC coverage across departments. We refer to this model as the 'null' geographical model or model 1. We then quantified the magnitude of geographical inequalities based on the general contextual effect: the proportion of the variation in propensity to attend ANC that is explained by the department of residence. Based on previous studies, we considered inequalities as absent if the variance partition coefficient ($VPC_{null}$) was between 0% and 1%, small if between 1% and 5%, moderate between 5% and 10%, large between 10% and 20% and very large >20%.[27 32 39] Therefore, a $VPC_{null}$ greater than 5 was considered as strong evidence of inequalities.

We then fitted a series of partially adjusted models which included a single sociodemographic factor at a time: maternal age, ethnicity, health insurance affiliation and area of residency. Subgroups typically considered as the most advantaged were considered the reference category. The goal here was to establish the extent to which geographical inequalities in ANC coverage can be explained by the geographic variation identified within each individual sociodemographic factor. That is, to isolate the contextual effect from the compositional effect of the population.[40] To quantify this, we calculated the proportional change in variance ($PCV_{partial}$), calculated as:

$$PCV = \frac{\sigma^2_{u(null)} - \sigma^2_{u(adjusted)}}{\sigma^2_{u(null)}}$$

where $\sigma^2_{u(\text{null})}$ and $\sigma^2_{u(\text{adjusted})}$ denote the between-departments variance from the null and the partially or fully adjusted models, respectively. A higher PCV indicates a greater contribution of the included variables in explaining the observed differences between geographical departments.

Next, we fitted a fully adjusted model which included all four individual factors simultaneously. The $PCV_{full\text{-}individual}$ was then calculated again to establish the joint explanatory power of these factors on ANC coverage inequalities. PCVs were obtained after adjusting for the scaling artefacts that arise when adding level 1 variables to logistic regressions. We then added the geopolitical department homicide and poverty rates to the model to measure the specific contextual effects of these two factors,[41] calculating the PCV once more. The proportional $PCV_{full\text{-}contextual}$ was also calculated to quantify the proportion of geographical variance attributed to these contextual variables after accounting for the compositional effect of the population. To this end, we used the fully adjusted individual-level model as the reference, rather than the null model.

Finally, we allowed for the relationships between ANC coverage and both ethnicity and insurance to vary across the geopolitical departments using an adjusted random slope model and accounting for individual level covariates. The goal here was to explore whether inequalities associated with ethnicity and insurance affiliation played out similarly or differently from place to place. We performed likelihood ratio (LR) tests to establish whether the resulting geographic variation in ethnic and insurance inequalities was statistically significant. Then, we plotted department-specific differences in the adjusted predictions between each category and the reference to visualise the variation in the attributable prevalence of ANC coverage across departments. This allowed us to answer the questions: In which departments are ethnic and insurance inequalities most pronounced, and, in which departments are they the lowest? Department-specific differences of zero indicate that the inequalities in that department align with the national pattern of inequality. Positive values represent greater inequalities than the national average, while negative values reflect lower inequalities.

### Intersectional analysis

Similarly, intersectional MAIHDA was performed using the intersectional strata as the cluster variable to investigate potential intersectional inequalities. Alongside the geographical analysis, first a null model was run and $VPC_{intersectional}$ calculated.[25] Next, four intermediate or partially adjusted models were fitted, including each individual risk factor one by one. Here, the $PCV_{partial}$ statistics quantify the extent to which overall intersectional inequalities are explained by each factor in turn. Instead of using a reference category, intersectional-MAIHDA compares observed risks to expected risks based on additive main effects, identifying subgroups with unexpectedly high or low risks and, therefore, warranting further attention.

Finally, we entered all individual variables into the model to determine the extent to which intersectional inequalities are attributable to interactions between the individual sociodemographic factors that define the strata versus their purely additive effects. Specifically, the $PCV_{full}$ measures the percentage of intersectional variability attributable to the additive main effects of the four individual characteristics while $1–PCV_{full}$ measures the percentage of intersectional variability attributable to interaction effects between the four individual characteristics.[25]

Analogous to our approach to geographical analysis, we predicted the intersectional-specific probabilities of ANC coverage. We also studied the predicted random intersectional effects from our full model as these measure the intersectional-specific interaction effects. That is, the degree to which the intersectional predicted probability of ANC coverage is above or below that expected under the assumption of additive main effects. An advantageous feature of these predictions is that they are empirical Bayes predictions which exhibit shrinkage. The predictions are shrunk towards zero as an inverse function of intersection size. This protects against overinterpreting the otherwise erratic predictions that would be associated with very small strata.[25]

## RESULTS

There were 573 625 life births in Colombia in 2022. Our analyses were conducted using data from 552 284 single pregnancies, as shown in online supplemental figure S1. The median number of ANC visits was 6 (range: 0–25), 95.96% of women (95% CI: 95.91% to 96.01%) attended at least one ANC. The description of the study population is shown in online supplemental table S1. Most participants in the study were under 35 years old, identified as mestizo, had subsidised health insurance and resided in urban areas. Observed and predicted proportion of ANC coverage and population characteristics across geopolitical divisions is shown in online supplemental table S2.

### Geographical analysis

Figure 1 shows left to right patterning of ANC coverage rate across geopolitical departments, except for Chocó, which appears on the left despite low coverage. The rate ranged from 54.83% in Vichada to 98.17% in Caldas, with a median of 96.23% (IQR: 93.10%–97.42%). 15 of the 33 departments had ANC coverage rates below the national average.

Results from the geographical-MAIHDA models are presented in table 1. The $VPC_{null}$ for ANC coverage was 24.45%. The $PCV_{partial}$ was highest for maternal ethnicity, followed by health insurance and area of residency, being the lowest for maternal age. The differences between geopolitical divisions in the composition of the population regarding the study variables accounted for nearly 70% of the geographical variation on ANC coverage. Departmental homicide and poverty rates accounted for 15.60% of this geographic variation in ANC coverage rates, having adjusted for the compositional differences in the population.

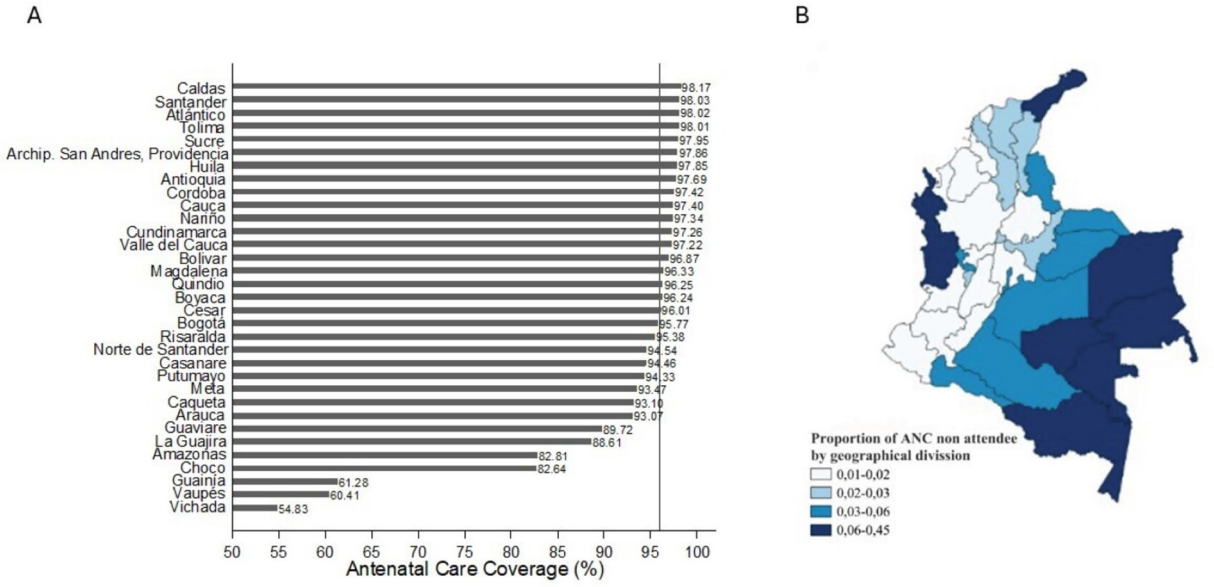


**Figure 1** Distribution of the observed proportion of antenatal care (ANC) in Colombia, 2022. (A) ANC coverage; the vertical line represents the national average coverage. (B) Proportion of non-attendees by geographical department; lighter colours indicate departments with higher coverage, while darker colours indicate lower coverage.

The random intercept model indicated lower odds of ANC coverage among individuals from specific ethnic groups, those with non-contributive affiliation, residents of non-urban areas and women aged >35 years compared with their respective reference categories. The random slope analysis revealed that the national patterns of ethnic inequalities (LR=2051.77, df=5, p<0.001) and health insurance inequalities (LR=1302.90, df=5, p<0.001) vary across departments.

Figure 2 illustrates the differences in predicted ANC coverage rates between each ethnic group and health insurance category compared with their respective reference categories in each department, while holding all other individual-level covariates in the model constant. The ethnic coverage gaps for Indigenous women varied substantially across departments (median: −4.63 pp; range: −24.27 to 8.51 pp) and far more so than was the case for Afro-Colombians (median: 0.20 pp; range: −0.66 to 12.71 pp), respectively. ANC coverage was over 10 pp lower among Indigenous women compared with Mestizos in six departments. The insurance affiliation coverage gaps were wider for those unaffiliated to any healthcare insurance than for those with subsidised insurance compared with the reference category (median −13.69 pp (range: −51.21 to −6.52 pp) and median −1.83 pp (−7.30 to −0.34 pp), respectively). The coverage was 10 pp lower among unaffiliated people compared with those with contributive insurance in 26 of the 33 departments.

### Intersectional analysis

The observed and predicted ANC coverage rates across the 36 intersectional strata are presented in table 2 . The median of ANC coverage across strata was 89.56% (IQR: 1.06%–97.18%). Stratum 25 (>35/indigenous/urban/contributive) showed the highest coverage rate at 100%, while stratum 12 (<35/indigenous/rural/not affiliated) showed the lowest coverage rate at just 54.07%. 24 out of the 36 strata showed ANC coverage rates below the national average.

Among those <35 and residing in urban areas, the absolute risk differences (RD) in ANC between contributive affiliation and not being affiliated was 1.47-fold higher among Indigenous women (stratum 7: 93.79% vs stratum 9: 68.85%, RD: 24.94%) than among Mestizos (stratum 1: 99.33% vs stratum 3: 82.39%, RD: 16.94%). Likewise, the RD in ANC between Indigenous and Mestizos was 2.50-fold higher among unaffiliated (strata 3 vs 9) than among those with contributive insurance (1 vs 7). The disadvantageous effect of belonging to an indigenous ethnicity nearly disappears among those over 35 years old and those residing in urban areas, as shown when comparing strata 25 and 19 (99.04% vs 99.54%).

Results from the intersectional models are presented in table 3. The $VPC_{null}$ was 39.43% and so the intersection inequalities with respect to age, ethnicity, health insurance and area of residency are large, accounting for 40% of the variation in the propensity to receive ANC. Some 94.19% of this variance between intersectional strata was explained by the additive effects of these four factors. Therefore, just 5.81% was attributed to unmodelled two-way and higher-way interaction effects between these variables. Health insurance contributed the most to intersectional heterogeneity as evidenced by generating the highest PCV among the four partial models, followed by ethnicity. Observed ANC coverage in six strata (3, 6, 10, 21, 28, 29) was significantly above and in seven strata (1, 2, 5, 9, 12, 19, 30) significantly below the expected coverage based on the additive main effect of the strata-defining variables as presented in online supplemental

**Table 1** Null and full level individual and geographical MAIHDA models for antenatal care coverage in Colombia

| Characteristic | Null | Maternal age | Ethnicity | Health insurance | Area of residency | Full individual | Full individual and geographic |
|---|---|---|---|---|---|---|---|
| **Individual-level characteristics** | | | | | | | |
| Maternal age, years | | | | | | | |
| <35 | | Reference | | | | Reference | |
| ≥35 | | 1.23 (1.18–1.29) | | | | 0.95 (0.90–0.99) | 0.95 (0.90–0.99) |
| Ethnicity | | | | | | | |
| Mestizos | | | Reference | | | Reference | |
| Indigenous | | | 0.13 (0.12–0.14) | | | 0.16 (0.15–0.17) | 0.16 (0.15–0.17) |
| Rom/Raizal/ Palenque/ Afrocolombian | | | 0.88 (0.81–0.96) | | | 0.82 (0.75–0.89) | 0.82 (0.75–0.89) |
| Heath insurance | | | | | | | |
| Contributive | | | | Reference | | Reference | |
| Subsidise | | | | 0.17 (0.16–0.18) | | 0.21 (0.20–0.23) | 0.21 (0.20–0.23) |
| Non affilated | | | | 0.04 (0.03–0.04) | | 0.04 (0.03–0.04) | 0.04 (0.03–0.04) |
| Area of residency | | | | | | | |
| Urban | | | | | Reference | Reference | |
| Non urban | | | | | 0.41 (0.40–0.43) | 0.60 (0.58–0.62) | 0.60 (0.58–0.62) |
| **Second level characteristics** | | | | | | | |
| Homicide rate | | | | | | | |
| Low | | | | | | | Reference |
| High | | | | | | | 0.93 (0.60–1.46) |
| Poverty | | | | | | | |
| Low | | | | | | | Reference |
| High | | | | | | | 0.58 (0.38–0.90) |
| Second level variance | 1.07 (0.66–1.73) | 1.06 (0.66–1.73) | 0.44 (0.27 to 0.71) | 0.85 (0.52–1.38) | 0.96 (0.59–1.55) | 0.37 (0.23–0.60) | 0.32 (0.20–0.52) |
| VPC % | 24.45 (16.62–34.44) | 24.44 (16.61–34.43) | 11.70 (7.52–17.74) | 20.50 (13.70–29.51) | 22.51 (15.17–32.06) | 10.02 (6.41–15.36) | 8.60 (5.46–13.28) |
| PCV % | – | 0.14 | 54.47 | 32.63 | 10.99 | 69.83 | 15.60 |
| BIC | 31399.60 | 31318.66 | 25728.71 | 2616.06 | 28376.94 | 8023.99 | 8032.07 |

BIC, Bayesian information criterion; MAIHDA, multilevel analysis of individual heterogeneity and discriminatory accuracy; PCV, proportional change in variance; VPC, variance partition coefficient.

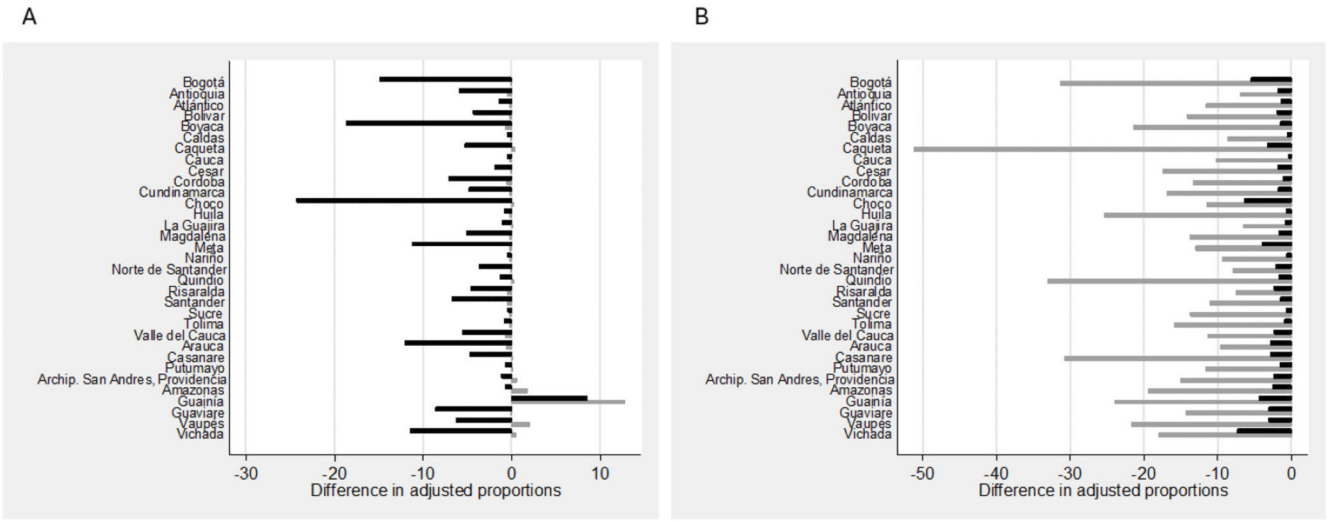


**Figure 2** Risk differences of antenatal care coverage based on MAIHDA predicted proportions in Colombia, 2022: (A) Ethnic groups compared with Mestizos (black bar: Indigenous, grey bar: Afro-Colombians) and (B) Health insurance categories compared with contributive (black bar: subsidised, grey bar: non-affiliated). MAIHDA, multilevel analysis of individual heterogeneity and discriminatory accuracy.

figure S2. In other words, the observed coverage rates in approximately one-third of the studied strata significantly deviated from what would be expected based on a simpler additive risk factors analysis.

## DISCUSSION

Our analysis using MAIHDA and the VPC as a novel measure of inequality reveals very large inequalities driven by both geographical and intersectional sociodemographic dimensions. Geographical differences persisted even after adjusting for individual-level sociodemographic factors, with ethnicity composition differences emerging as the primary predictor of the geographical heterogeneity. However, the exact influence of ethnicity varied significantly across departments, reflecting a contextual heterogeneity of its effect: ethnic coverage gaps were much larger in some departments than others. Similarly, the national coverage gaps observed between different types of health insurance also varied considerably across departments. Additionally, our findings highlight marked disparities across intersectional strata, with healthcare insurance identified as the most significant determinant of intersectional heterogeneity, underscoring its pivotal role in perpetuating inequities in ANC access.

ANC coverage in Colombia was around 96% during 2022, slightly lower than that reported in 2016.[11] However, departmental coverage proportions vary considerably around this national average. So much so that they account for 24.45% of the variation in the individual propensity for women to receive ANC. The influence of population composition or regional characteristics on ANC coverage inequalities remains largely unexplored, with few studies addressing this issue, most of which are from African contexts.[15 42–44] Our results show that 30% of departmental inequalities remain unexplained after considering the variation in the sociodemographic composition of the population which comprised ethnicity, maternal age, health insurance and rurality. Differences in ANC coverage may also be influenced by unmeasured individual-level factors, such as obstetric risk classification or educational level.

A previous study assessing whether mothers completed a minimum of four ANC visits found that the Amazon and Orinoco regions had a higher risk of non-attendance compared with the Andean region.[15] Although we evaluated ANC coverage for at least one visit, our findings confirm persistent inequalities, as departments in these regions continue to show the lowest ANC coverage rates. Another study reported 83% ANC coverage in the Pacific region.[45] However, within this region, coverage across departments was heterogeneous, with Chocó in the lowest quintile of ANC coverage distribution. In Colombia, regional disparities have been linked to lower economic status, geographical isolation[15] and hostile environments.[17] In our analysis, departmental poverty and violence rates explained 15% of the variability between departments, but the VPC of the fully adjusted model remained moderate. Other unmeasured contextual factors—such as healthcare infrastructure or regional health policies—may also contribute to ANC coverage differences.

It is important to consider that cases in which there are large contextual effects, as observed in our study, could result in imprecise estimates of the specific contextual effect, increasing the likelihood of concluding that there is no specific effect of the contextual variable when, in fact, it does exist.[41] Nonetheless, our results are consistent with a study[46] in Mali, in which wealthier areas were associated with higher ANC attendance, and with another in Colombia in which higher household income also correlated with completing four or more visits.[15]

Table 2 Observed and predicted proportion of antenatal care coverage according to intersectional strata in Colombia, 2022

| Strata | Age | Ethnicity | Area of residency | Health insurance | Size | Observed coverage | Predicted coverage |
|---|---|---|---|---|---|---|---|
| 12 | <35 | Indigenous | Rural | Not affiliated | 1204 | 54.07 | 54.16 |
| 33 | ≥35 | Afro-Colombian | Urban | Not affiliated | 19 | 57.89 | 62.90 |
| 30 | ≥35 | Indigenous | Rural | Not affiliated | 130 | 66.15 | 66.82 |
| 9 | <35 | Indigenous | Urban | Not affiliated | 787 | 68.74 | 68.85 |
| 29 | ≥35 | Indigenous | Rural | Subsidised | 2471 | 72.36 | 72.39 |
| 27 | ≥35 | Indigenous | Urban | Not affiliated | 81 | 72.84 | 73.72 |
| 11 | <35 | Indigenous | Rural | Subsidised | 16639 | 77.99 | 78.00 |
| 24 | ≥35 | Mestizos | Rural | Not affiliated | 359 | 80.22 | 80.37 |
| 6 | <35 | Mestizos | Rural | Not affiliated | 5825 | 81.89 | 81.90 |
| 3 | <35 | Mestizos | Urban | Not affiliated | 25518 | 82.39 | 82.39 |
| 36 | ≥35 | Afro-Colombian | Rural | Not affiliated | 9 | 77.78 | 82.89 |
| 26 | ≥35 | Indigenous | Urban | Subsidised | 496 | 84.07 | 84.16 |
| 21 | ≥35 | Mestizos | Urban | not affiliated | 1506 | 84.20 | 84.22 |
| 18 | <35 | Afro-Colombian | Rural | Not affiliated | 137 | 83.94 | 84.24 |
| 10 | <35 | Indigenous | Rural | Contributive | 615 | 84.55 | 84.62 |
| 28 | ≥35 | Indigenous | Rural | Contributive | 135 | 85.19 | 85.46 |
| 15 | <35 | Afro-Colombian | Urban | Not affiliated | 329 | 85.41 | 85.52 |
| 8 | <35 | Indigenous | Urban | Subsidised | 4215 | 86.88 | 86.89 |
| 35 | ≥35 | Afro-Colombian | Rural | Subsidised | 451 | 92.24 | 92.25 |
| 17 | <35 | Afro-Colombian | Rural | Subsidised | 4073 | 93.30 | 93.30 |
| 7 | <35 | Indigenous | Urban | Contributive | 500 | 93.80 | 93.79 |
| 32 | ≥35 | Afro-Colombian | Urban | Subsidised | 1060 | 95.38 | 95.36 |
| 23 | ≥35 | Mestizos | Rural | Subsidised | 8306 | 95.64 | 95.64 |
| 14 | <35 | Afro-Colombian | Urban | Subsidised | 10523 | 95.70 | 95.69 |
| 34 | ≥35 | Afro-Colombian | Rural | Contributive | 80 | 96.25 | 95.90 |
| 5 | <35 | Mestizos | Rural | Subsidised | 76741 | 96.49 | 96.49 |
| 20 | ≥35 | Mestizos | Urban | Subsidised | 15797 | 97.10 | 97.10 |
| 2 | <35 | Mestizos | Urban | Subsidised | 166076 | 97.26 | 97.26 |
| 16 | <35 | Afro-Colombian | Rural | Contributive | 528 | 98.30 | 98.17 |
| 13 | <35 | Afro-Colombian | Urban | Contributive | 3224 | 98.57 | 98.55 |
| 4 | <35 | Mestizos | Rural | Contributive | 16822 | 98.60 | 98.59 |
| 22 | ≥35 | Mestizos | Rural | Contributive | 2497 | 98.80 | 98.76 |
| 25 | ≥35 | Indigenous | Urban | Contributive | 101 | 100.00 | 99.04 |
| 1 | <35 | Mestizos | Urban | Contributive | 151866 | 99.33 | 99.33 |
| 31 | ≥35 | Afro-Colombian | Urban | Contributive | 703 | 99.72 | 99.53 |
| 19 | ≥35 | Mestizos | Urban | Contributive | 32461 | 99.55 | 99.54 |

The strata are ordered in ascending order according to the percentage of prenatal care coverage.

In contrast to previous results, we found no association between departmental homicide rates and ANC utilisation. However, results are not directly comparable: these reports found that pregnant women who had experienced intimate partner violence were less likely to use ANC services,[47] and that conflict incidents such as explosions, bombardments or clashes[48] were associated negatively with the utilisation of routine health services, such as outpatient consultations and ANC.

It has also been suggested that a higher proportion of ethnic minorities reside in regions with lower rates of ANC,[15] as ethnicity as a determinant has been associated with lower ANC utilisation.[49 50] Indeed, over half (54.47%) of geographical inequalities were explained by the variation in their ethnic composition, suggesting that this variable is a significant factor in explaining between-departmental heterogeneity. Besides the fact that Afro-Colombians, and especially indigenous ethnicities,

**Table 3** Null, intermediate and full intersectional MAIHDA models for antenatal care coverage in Colombian

| Characteristic | Null | Intermediate maternal age | Intermediate ethnicity | Intermediate insurance | Intermediate area of residency | Full |
|---|---|---|---|---|---|---|
| Maternal age, years | | | | | | |
| <35 | | Reference | | | | Reference |
| ≥35 | | 1.11 (0.42–2.94) | | | | 1.03 (0.80–1.34) |
| Ethnicity | | | | | | |
| Meztizo | | | Reference | | | Reference |
| Indigenous | | | 0.19 (0.07–0.52) | | | 0.18 (0.13–0.25) |
| Rom/Raizal/Palenque/Afrocolombian | | | 0.69 (0.25–1.91) | | | 0.68 (0.49–0.94) |
| Health insurance | | | | | | |
| Contributive | | | | Reference | | Reference |
| Subsidise | | | | 0.24 (0.11–0.52) | | 0.28 (0.20–0.38) |
| Non-affilated | | | | 0.06 (0.03–0.13) | | 0.07 (0.05–0.10) |
| Area of residency | | | | | | |
| Urban | | | | | Reference | Reference |
| Non-urban | | | | | 0.52 (0.20–1.34) | 0.57 (0.44–0.74) |
| Second level variance | 2.141 (1.31–3.51) | 2.14 (1.31–3.50) | 1.53 (0.92 to 2.55) | 0.85 (0.52–1.39) | 2.04 (1.25–3.35) | 0.124 (0.0665–0.233) |
| VPC % | 39.43 (28.43–51.61) | 39.42 (28.43–51.60) | 31.75 (21.78 to 43.72) | 20.55 (13.59–29.84) | 38.31 (27.48–50.43) | 3.64 (1.98–6.60) |
| PCV % | – | 0.01 | 28.53 | 60.27 | 4.60 | 94.19 |
| BIC | 468.8668 | 472.4054 | 466.6183 | 443.9877 | 470.6545 | 407.7994 |

BIC, Bayesian information criterion; MAIHDA, multilevel analysis of individual heterogeneity and discriminatory accuracy; PCV, proportional change in variance; VPC, variance partition coefficient.

were associated with a lower ANC coverage, these national ethnic gaps varied between departments as shown by the random slope model. Thus, the proportion of ANC coverage for Indigenous women was not just lower, on average, compared with their mestizo counterparts, but the magnitude of this gap varied substantially from department to department. Colombia boasts remarkable cultural diversity, enriched by more than 100 indigenous groups spread across various regions of the country. For instance, the Misak reside in Cauca, the Tikuna in the Amazon, the Wayuu in the Caribbean, the Emberá in the Pacific and the Sikuani in Meta. Each group has its own language, traditions and unique social organisation, which may help explain the varying effects of indigenous ethnicity across different departments.

In line with other studies, having health insurance was associated with a higher coverage of ANC.[51–53] Our study also supports its contribution to geographical disparities, being the second most important predictor after ethnicity (PCV=32.634%). In most departments, the attributable risk of not using ANC was 10pp higher among those not affiliated, but the magnitude varies from −7 pp to −51 pp, suggesting the presence of disparities of different magnitudes across departments. Overall, the random slope analysis reveals that ANC coverage disparities based on ethnicity and insurance status do not manifest uniformly across departments. This indicates that targeted policy responses must consider local context rather than implementing one-size-fits-all national interventions.

Likewise, the intersectional approach showed that health insurance followed by ethnicity accounted the most in between strata heterogeneity (PCV=60.27% and 28.53%, respectively). Our study reveals large intersectional disparities as the VPC of this dimension was nearly 40%. Despite the country's high ANC coverage, two-thirds of our 36 intersectional strata did not reach this national level. The between strata heterogeneity was almost fully explained by the additive effect of the variables that comprise the strata, and only 5% of the between strata variation was due to potential interaction of effects.[25] Nevertheless, six strata still showed ANC coverage rates significantly different from those implied by the additive effects of their defining characteristics. Together, this suggests that while interaction effects in general play a minor role in predicting ANC utilisation, they still matter for specific strata.

Understanding how intersectional strata protects or increases individual risk is essential for public health. A recent study in the USA suggested that both race/ethnicity and insurance type intersect to create different patterns of ANC access, with black patients experiencing disparities that vary depending on their type of insurance coverage.[54] In our study, most strata comprising Indigenous and unaffiliated had the lowest ANC coverage (9, 12, 30 and 27), independent of maternal age and rurality. Most strata, including mestizos and contributive insurance (1, 4, 19 and 22), showed higher coverage. However, being older than 35, from an urban area of residency and having a contributive affiliation all reduce the disadvantage associated with Indigenous and Afro-Colombian ethnicity. This demonstrates that in the presence of multiple protective factors, the detrimental effect of an exposure may be offset.

We illustrated how MAIHDA can be used to evaluate healthcare inequalities.[25] Our findings indicate that reducing ANC disparities requires targeted interventions based on both geographic and intersectional insights. In departments where ethnicity is the strongest predictor of low ANC access, culturally appropriate maternal healthcare programmes, such as community-based midwifery models or Indigenous-led clinics, should be prioritised. Meanwhile, in areas where health insurance status is the main determinant, policy efforts should focus on expanding insurance coverage, simplifying enrolment processes and reducing out-of-pocket costs for uninsured women. Likewise, our intersectional approach, which considers how multiple sociodemographic factors such as age, ethnicity, health insurance and urbanicity interact, showed that limiting the study of social inequalities to a single factor at a time fails to understand how the different dimensions of social position interact and compound to create unique experiences of advantage or disadvantage.[55 56] Intersectional analysis provides granular data that can uncover inequalities that broader analyses might overlook.[57 58] Our methodology aligns with the concept of precision public health which employs detailed population data to tailor interventions and address health inequalities.

Several measures of inequality have been applied, such as the Gini coefficient to measure economic inequality, and both relative and absolute measures of social inequality according to different demographic, socioeconomic or geographic characteristics,[59] such unidimensional measures may fail to capture the complexity of human experiences. A recent review[22] found only a few interventions that explicitly aimed to improve existing ethnic or racial inequalities and did not identify any intersectionality-informed strategies or interventions in global maternal health that were measured using quantitative approaches, either from the perspective of intervention design or outcome evaluation. To our knowledge, this is the first study that addresses these limitations by using MAIHDA as a strategy for analysing inequities, assuming that the effect of a health determinant can manifest as an advantage or disadvantage, or that its relevance may fluctuate depending on the context, whether geographical or intersectional, in a way that neither oversimplifies nor underestimates the challenges faced by specific subgroups.

Our approach goes beyond traditional measures of relative inequalities, such as prevalence ratios, ORs or RD, by introducing innovative metrics. Specifically, we used the VPC from a null random effects model as a summary measure of inequalities. Additionally, we employed the PCV to ascertain whether population composition explains geographical inequalities based

on partially and fully adjusted models. Through random slope models, we explored whether social inequalities are more pronounced in specific geographical areas. Finally, we offered a granular perspective on the magnitude of absolute inequalities by using weighted predicted proportions, leveraging the shrinkage properties of multilevel models to enhance precision particularly for small strata. Hence, MAIHDA can significantly enhance equity tracking for Sustainable Development Goals by providing a more granular understanding of where (geographical) and for whom (intersectional) disparities in health coverage persist. Moreover, they hold great potential for integration into national monitoring systems, to support progress tracking, guide equitable resource allocation and inform the development of targeted, equity-oriented health interventions.

Our study has several limitations. Although the use of shrunken predictions in MAIHDA offers advantages over a single-level approach, the estimation of stratum-specific prevalence and interaction effects remains uncertain for small strata, particularly among certain strata including Indigenous women. Misclassification of ethnicities cannot be entirely ruled out, as it is recorded on birth certificates based on parents' self-reported classification of their child according to cultural background, ethnic group or physical characteristics. Additionally, individuals may provide different responses regarding their ethnicity depending on the context.[60] Furthermore, due to data constraints, key socioeconomic determinants like income, education, nationality, migration status or distance to health services were not included, limiting our ability to explore potential pathways of disadvantage.

Another significant limitation is the lack of information on gestational age at first ANC visit. Similarly, other quality indicators, for example, blood pressure measurement during the first visit or the provision of basic laboratory tests, were not available in the database used for this study. This lack of information prevented us from assessing ANC adequacy and quality based on current WHO definitions.[7] However, it can be argued that the indicator of at least one ANC contact is less prone to misclassification or underreporting bias in birth-related data, particularly when detailed information on maternal risk and visit timing is unavailable

One may also argue that the inclusion of departments as a variable in the intersectional analysis could provide a greater disaggregation of strata. However, we chose to analyse geographical and intersectional disparities separately because departmental-level analysis enables targeted, context-specific insights aligned with Colombia's administrative structure, while including departments in intersectional models would result in an unmanageable number of small strata (2×3×2×3×33=1188 strata) with uncertain estimates despite statistical shrinkage. Therefore, we prioritised a balance between granularity and interpretability, ensuring that each stratum retained substantive meaning and could be meaningfully interpreted.

A small proportion of the study population (0.79%) had missing data, primarily related to the department of residence, which introduces the possibility of selection bias due to exclusion. However, using the department of occurrence instead of residence yielded similar inequality estimates, as measured by VPC (data not shown). Lastly, the inability to link records belonging to the same mother restricted our analyses to singleton pregnancies. Furthermore, the study analysed individuals residing in Colombia, where the health insurance model has distinctive characteristics; therefore, the generalisability of the findings to other healthcare systems may be limited. Future research should address these limitations, further explore disparities among multiple pregnancies, and consider the role of unmeasured contextual variables including health facility availability, staffing levels and transportation access, in shaping disparities in ANC coverage.

## CONCLUSIONS

Substantial inequalities persist across geopolitical departments and intersectional strata in Colombia, largely explained by ethnicity and whether pregnant women had health insurance coverage. Our findings highlight that the effects of ethnicity and health insurance status—particularly among indigenous populations and the uninsured—on ANC coverage vary significantly across departments and strata. However, the importance of these two factors in explaining inequalities differs depending on whether the analysis focuses on geographical or intersection inequalities. This variability underscores the need for targeted policies that consider both regional healthcare access gaps and intersectional vulnerabilities to address these disparities. If prevention resources are limited, implementing focused, context-specific strategies aimed at improving ANC coverage among the uninsured and indigenous populations could be more effective than blanket interventions. Supporting initiatives such as Indigenous-led maternal care models and mobile clinics targeting uninsured populations in rural areas represents context-sensitive strategies that may enhance access to care and address structural inequities in maternal health.

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