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Examination For Independent Predictors Of Seasonality Of Birth Across Forty-Nine Low- And Middle-Income Countries: Analyses Of The United States Agency For International Development Demographic And Health Survey Data

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Examination for independent predictors of seasonality of birth across forty-nine low- and middle-income countries: *analyses of the United States Agency for International Development Demographic and Health Survey Data*

A Thesis Submitted to the Yale University School of Medicine in Partial
Fulfillment of the Requirements for the Degree of Doctor of Medicine

Jehanzeb Kayani, MPH

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Abstract

Although seasonal patterns in the distribution of live births have been well described across distinct populations for centuries, little is known about determinants of birth seasonality, particularly among low- and middle-income countries. Knowledge of determinants of birth seasonality may assist in the timely implementation and distribution of maternal and child health resources that may morbidity and mortality. In this study we examined for maternal and household sociodemographic determinants of birth seasonality in a sample of 3,260,238 live births across 49 nations that are included in the United States Agency for International Development Demographic and Health Survey Program. Our findings demonstrate that birth seasonality is independently associated with maternal and household sociodemographic characteristics including maternal age at birth, maternal body mass index, maternal education, and household wealth. Additionally, we demonstrate that temperature at time of conception is an independent predictor of birth seasonality. We also document trends in the directionality and magnitude of independent predictors of birth seasonality between the Northern and Southern Hemispheres as well as across maternal religious affiliations. The knowledge of seasonal trends in births along with its sociodemographic predictors offers meaningful insights that can be directed towards public health resources that have the potential to improve maternal and child health outcomes and more targeted public health campaigns in low- and middle-income countries.

Acknowledgments

I would like to extend my tremendous gratitude to Dr. Saad Omer, who not only serves as my thesis advisor, but has also served as my mentor for the past three years. Dr. Omer was the first to present the opportunity to engage in such meaningful work and I have benefited greatly from his support, guidance, and mentorship over the years. Dr. Omer has fundamentally shaped my early journey towards being a clinician-investigator and epidemiologist; no words can do justice towards the gratitude I owe to him. I also would like to thank Dr. Erin James, a former post-doctoral fellow in the Omer Research Group who guided me through and supervised the initial phases of this work. Her mentorship was critical to getting this project up and running and allowing for me to continue this work as a part of my thesis.

I also would like to thank my mother who serves as the inspiration for the physician, scientist, and human being that I always will hope to emulate. My mother was always there for me, no matter the time of day, as a resource to bounce ideas off and I greatly benefited from her guidance. I also must thank my mother, father, and younger brother for always being there for me and supporting me during these past few years. Lastly, I could not thank my fiancé enough for being there to lift me up during the times I wanted to fall. Ultimately, my achievements and successes are a testament to the sacrifices, guidance, and inspiration of my mother, father, and maternal grandparents; nothing I ever achieve will ever surpass the privilege of being their son and grandson.

Introduction

Patterns of seasonality in birth are well recognized across species, including among human primates.[1-5] Seasonal patterns in reproduction are considered to arise consequent to climatic changes which require adaptation in activity and behaviors towards maximizing chances of survival.[5-8] Organisms must vary their procreative behaviors in response to climactic changes as a means to maximize the fitness and survival of their offspring and ensure the continuation of respective gene pools.[9-10]

Seasonal patterns of births in humans have been described as early as the 1800s, and have since been analyzed across populations as well as geographic zones.[11-15] Multiple influences have been proposed as relevant to the seasonality in birth patterns including social factors such as seasonal variations in marriages, cultural holidays, seasonality of agricultural produce and hence food security; parental socio-demographic characteristics (marital status, age at marriage, education, etc.), environmental variables (regional rainfall, temperature, and photoperiod) and physiologic factors such as sperm quality that can affect fecundity and fertility also merit consideration.[12-14,18-21] The eventual mechanisms that impact birth seasonality are likely to involve a complex interplay of environmental, biological, and socio-cultural influences.[12-14,18-21]

Although seasonal variations in births have been well described, much of the existing literature focuses on reporting of these patterns; efforts aimed at examining predictors of seasonality in birth are limited in number and almost entirely restricted to high income countries including those in Europe, North

America, and East Asia.[12-15,21-25] For example, Lam and colleagues(1994) documented that births in Northern Europe increase substantially in the calendar months between March-May while decreasing in the period from October-November.[14] Birth seasonality in the United States has also been examined with trends noting that the most births occur in the Summer to early Fall (July-September) with a trough seen in the Spring (March-May).[14] A study in Finland that examined all births in the archipelago of Aland across an almost three century period between 1653-1950 showed bimodal peaks in the number of births between March-April and again between September-October.[26] Didikioglu and colleagues (2020) published work utilizing population-based data from the UK Biobank that demonstrated annual births peak between April-May across the United Kingdom.[27] Studies in Japan also demonstrate a bimodal distribution of first births with peaks in the winter (December-February) and another peak in late summer to early fall (August-September).[28] Bobak and colleagues (2001) reported large magnitude seasonal variations of births across sociodemographic strata from the Czech Republic; a more pronounced seasonality was observed among births to older mothers, to those who were more educated, and for higher order births.[19] Most recently, a 2022 study documented changes in the seasonality of births across more than two-hundred years of follow-up in a small agricultural community in Poland where the dominant birth pattern has gradually shifted towards midyear from January-February peak months to June towards the end of the twentieth century.[29]

Additionally, most of the published literature that has assessed birth seasonality has examined trends only within the equatorial regions. For example, in 1992, Werschler and colleagues showed discordant variations in seasonal birth patterns between Canada and the Northern United States, with birth peaks in April-May and a trough in December-January in the former and a peak in August-September with a trough in April-May in the latter.[30] Furthermore, studies examining data from Australia have shown significant differences in birth seasonality between the Northern and Southern states of Australia whereby February-March peaks are seen in the more northern areas and September-October peaks in the southern regions of the country.[31] Moreover, Lam and colleagues (1996) documented strong regional seasonal patterns in births in the United States with a substantial increase in births in March-April followed by a pronounced decline in April-May that was only seen in the southern United States.[15]

Although there exists a growing body of evidence that examines seasonal variations in births across multiple populations and countries, much of this work has been restricted to aggregate data that exist within individual nations, particularly those of high-income countries (HICs), including those of Northern Europe, North America, and Australia. Among the studies that do compare birth seasonality across nations, the majority focus on comparing trends between HICs that share similar socioeconomic structures and cultural and social infrastructures. Only a handful of investigations have focused on birth seasonality and its determinants within and across lower middle-income countries (LMIC), including those in Africa and Asia.[12,14,23]

Over the next several decades, much of the population growth on the planet is estimated to occur across LMICs that populate across Africa, Asia, South America, while the population size in the HICs of Europe and North America are projected to remain relatively stable.[32] The differences in estimates of population growth between HIC and LMIC is thought to be due to the *demographic transition*, in which there is a shift from high birth rates and high infant mortality to low birth rates and low death rates as nations develop socioeconomically.[32,33] A greater understanding of predictors of birth seasonality across LMIC can help shape global maternal and child health campaigns that seek to improve health outcomes in mothers and their infants through, on one hand, reducing unplanned and unintended conceptions, and on the other, prioritizing resources towards ensuring safe births. The knowledge of patterns and predictors in birth seasonality can be critical to the distribution of resources and implementation of programs that seek to reduce maternal and child morbidity and mortality, including obstetric and perinatal care services and immunization campaigns, allowing us to ultimately improve health outcomes across much of the globe.

Statement of Purpose

Utilizing an extensive dataset comprised of random samples of women in in their respective nations and these women’s respective birth, we analyzed changes in birth seasonality over time and assessed for independent sociodemographic predictors of birth seasonality in over 3,000,000 live births across 49 LMICs over a period that spans 40-years from 1970-2010. We also have examined birth seasonality across the Northern and Southern Hemispheres, by average regional temperatures around the month of conception, and by maternal religious affiliations. Our hypothesis is that both patterns and predictors of birth seasonality in the LMICs will differ between the Northern and Southern Hemispheres, even after adjustment for temperature at the month of conception. We believe that knowledge of such differences in peak birth patterns can assist regional and national health authorities in the allocation of the finite public health resources that are available to the LMIC's for effective implementation of strategies towards improving maternal and child health globally.

Methods

The Demographic and Health Survey (DHS) Program is a program funded by the United States Agency for International Development (USAID) that conducts national surveys across more than 80 countries in Africa, Asia, and South America.[34-37]

The DHS surveys are designed to be nationally representative samples that capture demographic and health metrics across LMIC's with overarching goals to "improve the collection, analysis, and dissemination of population, health and nutrition date and to facilitate use of these data for planning, policy-making, and program management…".[34,35] The DHS questionnaires and surveys are designed to be similar across countries and therefore contain manuals that provide unified instruction for field staff, field team leaders, and other survey staff within each host country.[34,35] Countries are provided with these standardized questionnaires but given the autonomy to follow the questionnaire absolutely, add questions of interest, or remove questions that may have limited relevance within a specific nation.[34,35] The DHS surveys thus allow for collection of standardized data across countries, creating opportunities for statistical comparisons of data across nations.

Detailed information of the DHS program is available online.[34,35] The program was first instituted in 1984 to capture population health metrics as a continuation to the World Fertility Survey (WFS) and the Contraceptive Prevalence Survey (CPS) projects and includes data on marriage, fertility, mortality, family planning, reproductive health, child health, nutrition, and HIV/AIDS.[35-37] Countries that take part in DHS are those who receive financial assistance from USAID although there are several non-USAID supported nations that participate in the program with assistance from other organizations including UNICEF, UNFPA, and the World Bank.[35-37] The DHS program has been updated continuously overtime and is implemented in overlapping five-year phases (DHS-I 1984-1990, DHS-II 1989-1993, DHS-III 1992-1998, DHS-IV 1997-2003 [MEASURE DHS], DHS-V 2003-2008 [MEASURE DHS+], DHS-VI [MEASURE DHS Phase III], DHS-7 [2013-2018], and DHS-8 2018-2023].[38] The DHS surveys are roughly conducted every 5 years to allow for comparisons to be made over time.[37] Since the DHS programs inception almost forty years ago, more than 300 DHS surveys have been conducted across almost 90 unique countries.[34,35]

The DHS surveys are nationally representative samples, but only reflect the intended populations after adjustment for weighting.[38-40] DHS samples are conducted via a two-stage probabilistic sampling design in which data are stratified and clustered in two stages with stratification occurring at the level of census area and household.[39,40] Data are ultimately stratified by the type of residence (urban-rural) and administrative/geographical regions. The first stage involves selecting several primary sampling units (PSUs) or *clusters*, that are selected from within a sampling frame independent of each stratum. The sampling frame consists of an entire list of enumeration areas (EAs) that are developed based on census data from each nation.[39,40] After the DHS has selected a random sample of these clusters from the primary EAs, the second stage of stratification occurs through which the DHS selects a random sample of households within each cluster from a list that delineates all households within the region. In this step the DHS also calculates the representative sample weights that are then applied across the survey data allowing for all subpopulation groups to be equally represented.[38-40] Therefore, **samples from the DHS are designed to be representative at the national level, residence level (urban-rural), and at the regional level** (departments, states, provinces, etc.). [38-40]

DHS Survey Data

All DHS surveys include at least two overall questionnaires, one being the Women's Questionnaire, and the other the Household Questionnaire. Additional surveys questionnaires include the Biomarker Questionnaire and the Man's

Questionnaire, which are administered and implemented at each individual country's discretion. The Woman's Questionnaire serves as the central piece of the DHS questionnaire and surveys women of reproductive age (15-49) and their young children (0-59 months).[41,42] It includes sections pertaining to 1) Background characteristics (age, education, religion, etc.), 2) Reproduction, 3) Contraception, 4) Pregnancy and postnatal care, 5) Childhood immunization, 6) Child health and nutrition, 7) Marriage and sexual activity, 8) Fertility preferences, 9) Husband's background and woman's work, 10) HIV/AIDS, and 11) Other health issues.[42] The Household Questionnaire is given to any individual age 15 or older living in a selected household and contains information on all members and visitors of a given household.[42] This survey serves to provide information on the background characteristics (age, sex, education, and relationship to head of the household) of each member of the household and to identify women (along with data pertaining to their children under the age of five) who are eligible for individual interviews. Thus, any household and subsequent women deemed eligible for interview through the Women's Questionnaire are first identified via household interview. Therefore, the overall flow of data from a DHS survey goes from households within larger geographic clusters, to household members within each household, to interviewed women who represent a subset of all household members, and to these women's children between ages of 0-59 months.[42] Data for each survey participant may be collected across more than one participant (e.g., a woman may be included in the Household Questionnaire and additionally in the Woman's Questionnaire).[40,42]

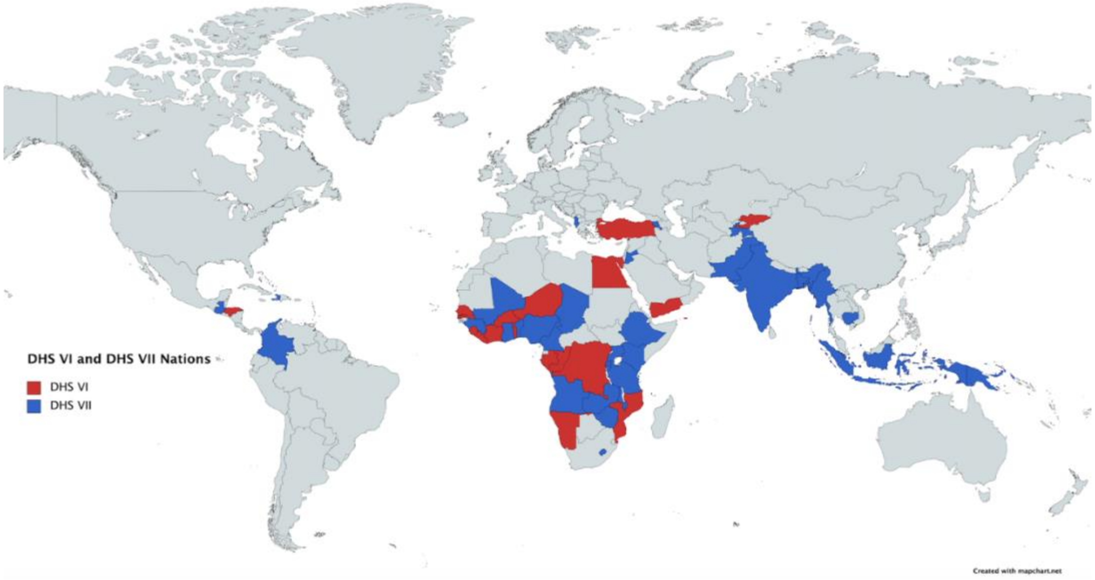
In the DHS dataset, data from each questionnaire are stored in *recode* files that were developed as standardized files and that allow access to data across nations to be cross analyzed. The Individual (Women's) Recode (IR) file contains all data that were obtained in the Woman's Questionnaire along with several datapoints from the Household Questionnaire, with the unit of analysis being the individual woman who is interviewed.[42] The Births Recode (BR) file contains information on the full live birth history of each women interviewed along with data on pregnancy, postnatal care, and immunization and health data for children under 59 months of age.[42] The unit of analysis for the BR file is at the level of each individual live birth and therefore was deemed most appropriate for use of this analysis. The DHS BR files also contain information that represents demographic characteristics of each survey participant including age, sex, ethnicity, religious identification, education, and household wealth.

To obtain the data of interest, first a request for access to DHS data from all 85 countries that are captured by the DHS was submitted. After acceptance (supplementary document 1), the BR files from each nation's most recent DHS survey were downloaded and examined with a total of 4,120,917 identified across all countries (Figure 1). We next identified the nations with data from DHS Phase VI (2008-2013) or DHS Phase 7 (2013-2018), with the most recent data downloaded (i.e., if a country had both Phase 7 and Phase VI, the Phase 7 data would be utilized, otherwise Phase VI data were utilized). The DHS questionnaires and BR files from 58 countries were identified from either DHS Phase VI or DHS Phase 7 contributing data for a total of 3,610,208 live births across the contributing nations. Data from the remaining 27 countries had been accrued from Phase-V and earlier; because these older versions of surveys had differed in content, these countries were excluded from the analytic dataset. Table 1 details the included countries, and the number of births from each country's most recent DHS Phase survey within the DHS system.

Creation of Analytic Dataset

On examination, 8 countries (Afghanistan, Angola, Colombia, Indonesia, Papa New Guinea, Philippines, Yemen, and Zambia) were determined to have incomplete data pertaining to demographic variables of interest (age, sex, marital status, ethnicity, religious identification, education, and household wealth) while an additional nation was identified to not have a BR file (South Africa). The final analytic dataset included data from 49 LMICs (Albania, Armenia, Bangladesh, Benin, Burkina Faso, Burundi, Cambodia, Cameroon, Chad, Comoros, Congo, Democratic Republic of Congo, Cote d'Ivoire, Dominican Republic, Egypt, Ethiopia, Gabon, Gambia, Ghana, Guatemala, Guinea, Haiti, Honduras, India, Jordan, Kenya, Kyrgyz Republic, Lesotho, Liberia, Malawi, Maldives, Mali, Mozambique, Myanmar, Namibia, Nepal, Niger, Nigeria, Pakistan, Rwanda, Senegal, Sierra Leone, Tajikistan, Tanzania, Timor-Leste, Togo, Turkey, Uganda, and Zimbabwe). The DHS BR files for each of the 49 countries with complete DHS Phase VI or DHS Phase 7 data were downloaded (Figure 1).

Figure 1- Geographic map detailing DHS Phase VI and 7 countries-
geographic map was generated and downloaded from https://www.mapchart.net



Climate data records pertaining to country wide mean monthly temperature between years 1901-2018 was obtained and downloaded from the University of East Anglia Climactic Research Unit (CRU) (data downloaded from: https://crudata.uea.ac.uk/cru/data/hrg/cru_ts_4.03/crucy.1905151143.v4.03/new_countries/tmp/). The CRU was founded in 1972 and has established itself as one of the world's leading centers for studying climate change.[43,44] The CRU houses numerous datasets that contain global temperature records, which are used to assess the course of climate change over time. The methods through which the CRU obtains its temperature recordings have been previously described elsewhere.[43,44]

The monthly climate data for each of the included countries from years 1901-2018 was downloaded from the CRU. The CRU temperature data for each country was merged with each respective DHS BR file by matching monthly and yearly temperature with a constructed variable in the BR file that corresponded to the month and year at *time of conception* (subtracting 9 months from the documented month and year of live birth). Temperature data pertaining to the month and year at the time of conception for each live birth was plotted and visually examined across seasons.

Inclusion criteria at the level of country were (1) nations must be a part of the DHS survey database and (2) have data from a recent DHS Phase-VI or Phase-7 Survey along with a BR file with data for every live birth (up to twenty births) per woman interviewed. Additionally, the included countries must have nationwide climate data housed within the CRU database at the University of East Anglia. Exclusion criteria at the level of a nation included countries that did not participate in the DHS Survey, that did not have survey data from Phases VI or 7, and countries for which climate data were not available within CRU.

Within each country's respective BR files, birth seasonality was first examined by visual inspection of the trends in the total number of live births per month and by season. **Seasons were defined using the meteorological nomenclature:** the Winter season extended from December to February, Spring from March to May, Summer from June to August, and the Fall season from September to November.[45]

Data Analysis:

Patterns in the seasonality of birth were examined in relation to identified maternal and household sociodemographic characteristics that included: maternal age at each live birth, maternal education, birth order, decade of live birth, maternal body mass index (BMI) at the time of survey, type of residence (urban vs. rural), wealth index, and maternal religious identification as documented in the survey. Maternal age at birth was divided into four categories (less than 18 years, 18 to 24 years, 24-30 years, and 30 years and older). Maternal education was categorized across four groups that referenced mothers' highest education received and included below primary or no education, primary education (completion of grade school), secondary education (completion of high school), and higher education (some level of undergraduate, graduate, and/or professional education). Birth order was categorized across four levels that included 1st birth, 2nd birth, 3rd birth, and 4th birth or higher. Decade of birth was categorized across five groups that included the 1970s (birth between 1970-1979), 1980s (birth between 1980-1989), 1990s (birth between 1990-1999), 2000s (birth between 2000-2010), and 2010s (birth between 2010-2018). Information on the sex of liveborn was also available. Maternal BMI at the time of survey (in kg/m^2) was organized into four groups that included underweight (BMI <18.5), normal weight (BMI 18.5-24), overweight (BMI 24-29.9), and obese (BMI ≥30). Wealth index is a measure created and utilized by DHS that reflects household wealth by encompassing household assets and is designated across five groups that include poorest, poorer, middle, richer, and richest. It is intended to be a relative measure through which comparisons can be made across surveys.[39,40] Maternal religious identification was grouped into four categories that included Hindu, Muslim, Christian, and Other (non-Hindu, non-Muslim, non-Christian).

New variables representing the Northern Hemisphere and Southern Hemisphere were constructed to reflect births that occurred in the LMICs located to the north and the south of the equator respectively. Countries identified as belonging to the Northern Hemisphere included Albania, Armenia, Bangladesh, Benin, Burkina Faso, Cambodia, Cameroon, Chad, Comoros, Congo, Democratic Republic of Congo, Cote d'Ivoire, Dominican Republic, Egypt, Ethiopia, Gabon, Gambia, Ghana, Guatemala, Guinea, Haiti, Honduras, India, Jordan, Kenya, Kyrgyz Republic, Liberia, Malawi, Maldives, Mali, Myanmar, Nepal, Niger, Nigeria, Pakistan, Senegal, Sierra Leone, Tajikistan, Tanzania, Togo, Turkey, Uganda, and Zimbabwe, whereas those in the Southern Hemisphere included Burundi, Lesotho, Malawi, Mozambique, Namibia, Rwanda, and Timor-Leste. Additionally, new variables that represented household residence above and below the sea level were constructed based on data that reflected altitude in meters. Values greater than 0 meters were coded as *above sea level* and those at or below 0 meters were considered *at or below sea level*.

The distribution of live births across months and seasons across the entire dataset including 49 nations and over 3 million live births was estimated using weighted birth frequencies. A series of bivariate analyses examined the cross-sectional association between each demographic characteristic defined above and monthly and seasonal distributions of live births. Data distributions were analyzed for the selection of appropriate statistical test. We compared categorical variables using the chi-square test and continuous variables utilizing the Wilcoxon rank sum test. Chi Squared Goodness of Fit Tests were conducted to assess for monthly and seasonal variations in the distribution of births under the null hypothesis that the distribution of births is the same across the four seasons and twelve months independently.

Weighted multivariable logistic regression models were created to assess for the independent effect of demographic characteristics including maternal age, birth order, maternal education, household wealth, maternal BMI, urban/rural residence, temperature at the time of conception, and decade of birth on live birth seasonality. Regression models adjusting for survey design were developed with a binary outcome with 1=three-month period with the greatest number of births (March-May) and 0= three-month period with the fewest number of births (October-December). Similar analytic design has previously been reported in a study by Bobak and colleagues (2001) that examined birth seasonality and predictors of birth seasonality in Northern Europe.[19] Referent categories for the categorical co-variables included in the regression model consisted of sub-groups with the largest relative sample size (maternal age: 18-24 years, birth order: 1st birth order, maternal education: no completed education, maternal BMI at time of survey: normal weight, household wealth index: middle wealth index, decade of birth: 2000s, type of residence: rural area). Adjusted predicted probability models were conducted after fitting the regression models to obtain predicted probability estimates of birth within the specified periods. Given evidence of an interaction between the temperature at the time of conception and equatorial hemispherical region after the creation of an interaction term in a logistic regression model, separate analytic models were developed to examine predictors of seasonality of livebirth respectively in the Northern and Southern Hemisphere. Therefore, results are reported independently for each hemisphere. Moreover, subset analyses were developed to further examine trends in birth seasonality within religious groups with results presented separately for each group (Hindu, Christian, Muslim, Other). Seasonality of live births over time was also assessed by examining trends in the births per month and season across the decade of birth.

Continuous data are presented as mean (± standard deviation), and categorical data are presented as numbers (percentage). The magnitude of association is presented as adjusted odds ratios (aORs) and their 95% confidence intervals (95% CIs). A two-sided p value of <0.05 was deemed to denote statistical significance; p values are reported up to three decimal places. Data analyses were conducted using Stata statistical software (Stata Corp version 16.1, College Station, Texas).

Student Contributions

All aspects of study design, methodology, and analyses were conducted by the candidate independently, with oversight and guidance from the thesis advisor and the principal investigator for this project.

Ethics Statement

Ethical approval was not required for this study.

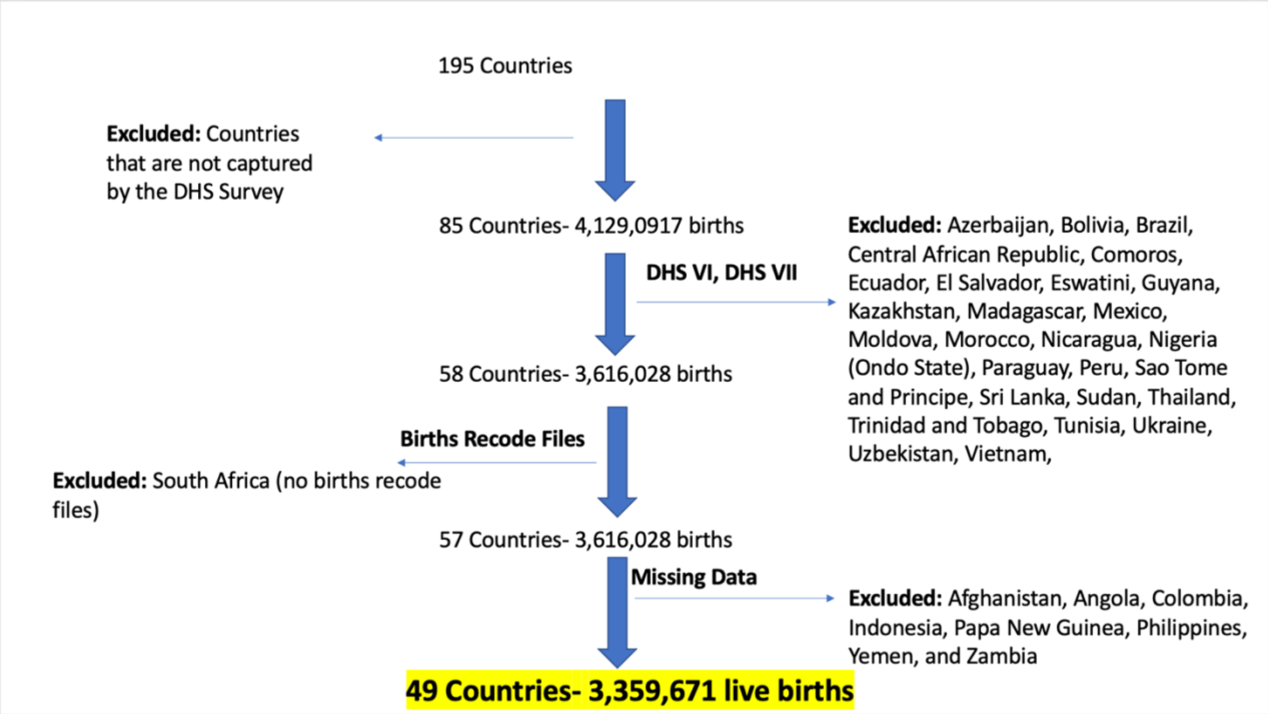
Human subject research

This study does not meet requirements for human subject’s research as the DHS data are de-identified.

Results

Figure 2 provides an overview of the eligible population sample of 3,359,671 live births.

Figure 2- Flow chart detailing countries and live births in the eligible population sample



Details on sample size, study phase and year of survey completion for the individual countries included in the analytic sample are presented in Table 1.

Table 1- DHS Phase and Sample Size for Respective Countries

Country	Year	DHS Phase	Sample Size (Number of live births)
Albania	2017-2018	DHS-7	16,128
Armenia	2015-2016	DHS-7	8,771
Bangladesh	2014	DHS-7	43,772
Benin	2017-2018	DHS-7	45,853
Burkina Faso	2010	DHS-VI	56,178
Burundi	2016-2017	DHS-7	45,419
Cambodia	2014	DHS-7	33,290
Cameroon	2018	DHS-7	33,988
Chad	2014-2015	DHS-7	137,978
Comoros	2012	DHS-VI	11,497
Congo	2011-2012	DHS-VI	31,948
Congo Democratic Republic	2013-2014	DHS-VI	59,276
Cote d'Ivoire	2011-2012	DHS-VI	28,221
Dominican Republic	2013	DHS-VI	18,167
Egypt	2015	DHS-VI	118,532
Ethiopia	2016	DHS-7	41,392
Gabon	2012	DHS-VI	23,109
Gambia	2013	DHS-VI	53,202
Ghana	2014	DHS-7	46,236
Guatemala	2014-2015	DHS-7	110,796
Guinea	2018	DHS-7	28,887
Haiti	2016-2017	DHS-7	27,809
Honduras	2011-2012	DHS-VI	49,263
India	2015-2016	DHS-7	1,315,617
Jordan	2017-2018	DHS-7	47,040
Kenya	2014	DHS-7	83,591
Kyrgyz Republic	2012	DHS-VI	16,180
Lesotho	2014	DHS-7	23,420
Liberia	2013	DHS-VI	30,804
Malawi	2015-2016	DHS-7	68,074

Maldives	2016-2017	DHS-7	13,922
Mali	2018	DHS-7	33,379
Mozambique	2011	DHS-VI	37,984
Myanmar	2015-2016	DHS-7	22,989
Namibia	2013	DHS-VI	18,090
Nepal	2016	DHS-7	26,028
Niger	2012	DHS-VI	44,183
Nigeria	2018	DHS-7	127,545
Pakistan	2017-2018	DHS-7	50,495
Rwanda	2014-2015	DHS-7	30,058
Senegal	2010-2011	DHS-VI	42,510
Sierra Leone	2013	DHS-VI	47,392
Tajikistan	2017	DHS-7	21,985
Tanzania	2015-2016	DHS-7	37,169
Timor-Leste	2016	DHS-7	28,682
Togo	2013-2014	DHS-VI	26,264
Turkey	2013	DHS-VI	17,871
Uganda	2016	DHS-7	57,906
Zimbabwe	2015	DHS-7	20,791
Total			**3,359,671**

After accounting for survey design, the analytic dataset included 3,260,238 live births. The maternal and household demographic characteristics for the analytic population sample are presented in Table 2.

Table 2- Household and maternal demographic characteristics in the population sample accounting for survey design.

	Number (percentage)
Maternal Age	
<18	291,510 (8.94%)
18-24	1,334,157 (40.92%)
24-30	1,039,450 (31.88%)
30+	595,121 (18.25%)
Birth Order	
1st	1,044,445 (32.04%)

2nd	833,276 (25.56%)
3rd	539,211 (16.54%)
4th+	843,306 (25.87%)
Maternal Education	
No Education	1,406,749 (43.15%)
Primary Education	827,822 (25.39%)
Secondary Education	863,026 (26.47%)
Higher Education	162,542 (4.99%)
BMI	
Underweight	425,211 (16.80%)
Normal	1,281,662 (50.64%)
Overweight	527,898 (20.86%)
Obese	290,794 (11.49%)
Wealth Index	
Poorest	753,972 (22.57%)
Poorer	703,725 (21.59%)
Middle	668,395 (20.50%)
Richer	624,528 (19.16%)
Richest	527,618 (16.18%)
Type of Residence	
Rural	2,231,557 (68.45%)
Urban	1,028,680 (31.55%)
Religion	
Hindu	1,029,063 (37.0%)
Christian	732,527 (26.34%)
Muslim	721,856 (25.95%)
Other	291,113 (10.72%)
Total	**N=3,260,238**

The average maternal age at time of birth was 24.36 years (SD 5.73) with 291,510 (8.94%) of births occurring in mothers under the age of 18; 1,334,157 (40.96%) in mothers between the ages of 18 to 24; 1,039,450 (31.90%) in mothers between the ages of 24 to 30; and 591,121 (18.21%) in mothers 30 years of age and older. Nearly a third (n=1,044,445, 32.04%) were first order births, 833,276 (25.56%) second order births, 539,211 (16.54%) third order births, and 843,306 (25.87%) fourth order or higher births. Maternal BMI across all live births was distributed as follows: 425,211 (16.80%) underweight, 1,281,662 (50.64%) normal weight, 533,251 (16.36%) overweight, and 290,794 (11.49%) obese.

A plurality (n=1,406,749, or 43.15%) of live births were to mothers who had not completed any level of education, 827,822 (25.39%) to mothers who finished primary schooling, 863,026 (26.47%) to mothers who had completed secondary schooling, and 162,542 (4.99%) to mothers who had at least started some level of higher education. The distribution of household wealth index among all births was as follows: poorest (735, 972, 22.57%), poorer (703,725, 21.59%), middle (668,395, 20.50%), richer (624,528, 19.16%), and richest (527,618, 16.18%).

Almost 90% of live births occurred in the Northern Hemisphere (2,932,303, 89.94%) with the remaining nearing 10% occurring in the Southern Hemisphere (327,935, 10.06%). Approximately 40% of the births in the dataset occurred in India (1,289,652, 39.56%) with no other single country contributing more than 10% of the total live births. Over 2/3 of the births were to mothers residing in rural areas (2,231,557, 68.45%), with the remaining 1/3 in urban areas (1,028,680, 31.55%). The breakdown of religious affiliation of the mothers was as follows: Hindu (1,029,063, 37.0%), Christian (732,527, 26.34%) Muslim (721,856, 25.95%), and Other Religion (298,113, 10.72%).

Maternal demographic information across regions in the Northern and Southern Hemispheres is further presented in Table 3. Significant differences in the distribution of maternal and household demographics were evident between the two hemispheres.

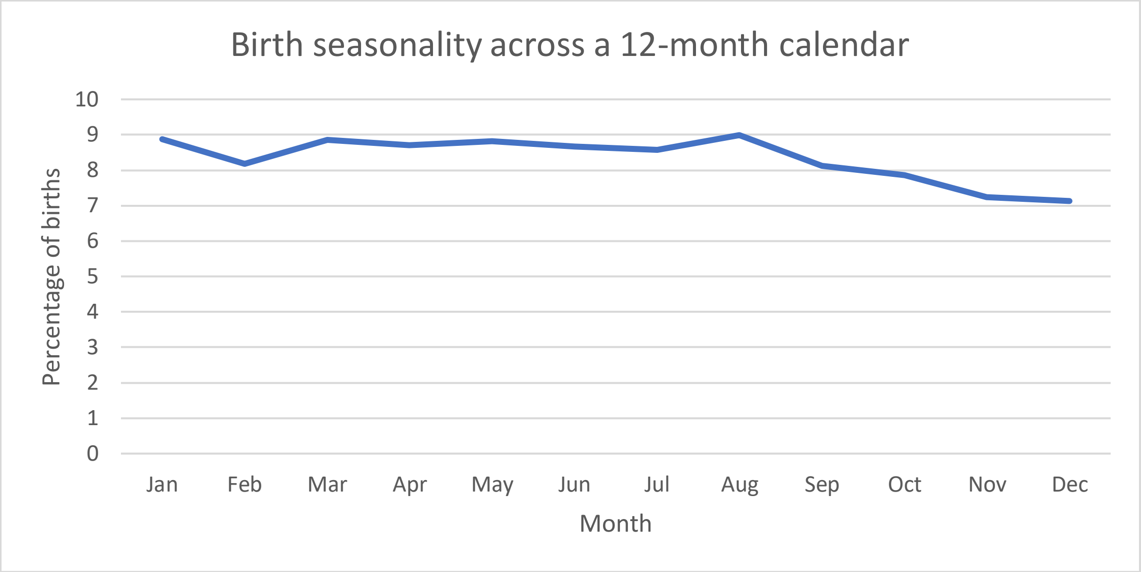
Table 3- Maternal and household characteristics across the Northern and Southern Hemispheres

	Northern Hemisphere	Southern Hemisphere	
	Number (%)	**Number (%)**	**p-value**
Maternal Age			**<0.001**
<18	269,020 (9.17%)	22,490 (6.86%)	
18-24	1,213,812 (41.39%)	120,433 (36.70%)	
24-30	935,708 (31.91%)	103,742 (31.63%)	
30+	513,763 (17.52%)	81,359 (24.81%)	
Birth Order			**<0.001**
1st	949,975 (32.36%)	95,460 (29.11%)	
2nd	758,487 (25.87%)	74,789 (22.81%)	
3rd	484,077 (16.51%)	55,113 (16.81%)	
4th+	740,753 (25.26%)	103,553 (31.27%)	
Maternal Education			**<0.001**
No Education	1,320,602 (45.04%)	86,147 (26.27%)	
Primary Education	668,905 (22.81%)	158,917 (48.46%)	
Secondary Education	793,566 (27.06%)	69,460 (21.18%)	
Higher Education	149,131 (5.09%)	13,412 (4.09%)	
BMI			**<0.001**
Underweight	398,945 (17.27%)	26,266 (11.92%)	
Normal	1,149,611 (49.75%)	132,051 (59.92%)	

Overweight	491,927 (21.29%)	41,324 (18.75%)	
Obese	270,071 (11.69%)	20,773 (9.40%)	
Wealth Index			**<0.001**
Poorest	664,687 (22.67)	71,285 (21.74%)	
Poorer	636,348 (21.70%)	67,3777 (20.55%)	
Middle	601,762 (20.52%)	66,633 (20.32%)	
Richer	558,705 (19.05%)	65,824 (20.07%)	
Richest	470,801 (16.06%)	56,816 (17.33%)	
Type of Residence			**<0.001**
Rural	1,071,644 (65.24%)	256,167 (78.12%)	
Urban	571,008 (34.76%)	71,767 (21.88%)	
Religion			**<0.001**
Hindu	1,029,034 (40.89%)	29 (0.01%)	
Christian	653,155 (25.95%)	79,372 (29.99%)	
Muslim	605,059 (24.04%)	116,797 (44.13%)	
Other	229,624 (9.12%)	68,489 (25.88%)	
Total	**2,932,303 (89.94%)**	**327,935 (10.06%)**	

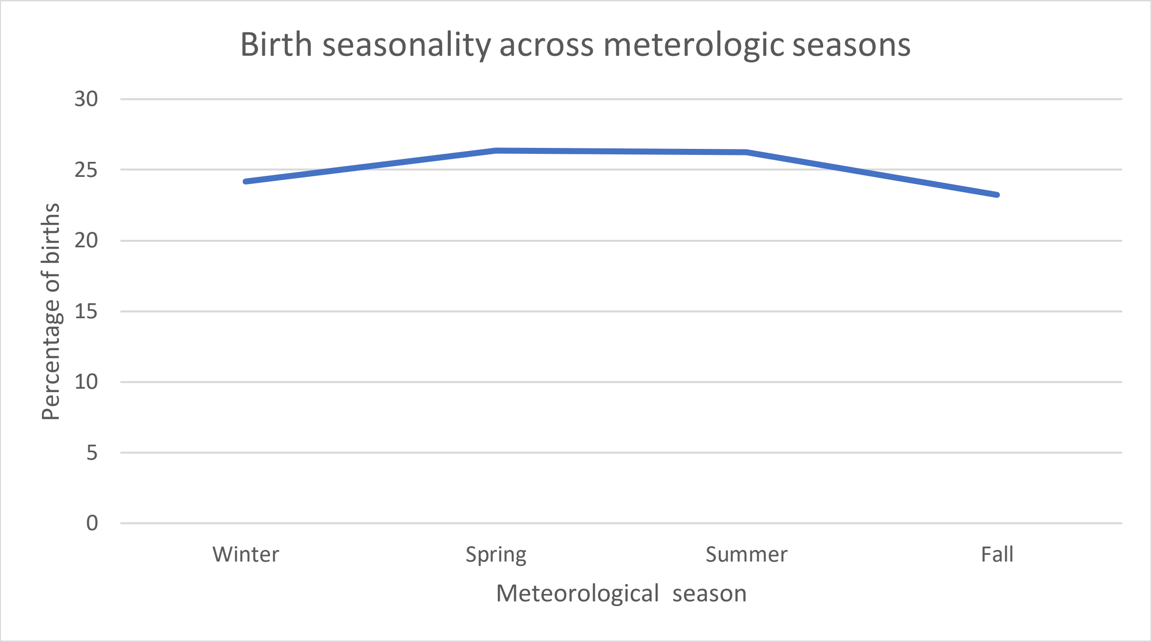
Bivariate analyses examined if the distribution of live births across the months and the seasons differed from the expected frequencies (0.25 for each season and 0.083 for each month). The distribution of live births across the twelve calendar months for the entire analytic population differed significantly (p<0.001, Figure 3) as follows: January (289,664, 8.88%), February (266,275, 8.17%), March (288,449, 8.85%), April (283,809, 8.71%) May (287,206, 8.81%), June (282,621, 8.67%), July (279,339, 8.57%), August (293,231, 8.99%) September (264,756, 8.12%), October (256,348, 7.86%), November (236,156, 7.24%) December (232,333, 7.13%).

Figure 3- Birth Seasonality Across Twelve Month Calendar



Similarly, analysis of the distribution of births across seasons demonstrated significant differences (p <0.001) in the distribution of live births across the meteorologic seasons (Figure 4): Winter (788,273, 24.18%), Spring (859,514, 26.36%), Summer (855,191, 26.23%), and Fall (757,259, 23.23%). Across the entire dataset, the peak three-month birth period extended from March-May where 26.36% (n=859,514) of births occurred. This peak birth time-period aligned with the meteorologic Spring season in the Northern Hemisphere and meteorologic Fall season in the Southern Hemisphere. Conversely, the trough three-month period extended from October-December and included 21.97% (n=724,837) of all b.

Figure 4- Birth Seasonality Across Meteorologic Seasons



Weighted bivariate analyses were conducted to examine the association between seasonality of birth and household and maternal characteristics. Weighted logistic regression models were conducted to assess for the association between household and maternal demographic factors with birth seasonality. Variables that were considered of plausible relevance (maternal age, BMI, education, wealth index) or deemed relevant to our hypothesis (regional average monthly temperatures at time of conception) were included as covariates in the multivariable analyses.

Table 4 details the crude or unadjusted (uOR) and adjusted odds ratio's (aOR's) and 95% CIs for the association of individual covariates with the probability of live birth in the peak three-month period with the greatest number of births (March-May) versus the three-month period (October-December) with the fewest number of births for the entire sample population. Maternal age, maternal education, maternal BMI at time of survey, order of birth, and household wealth index were independently associated with seasonality of birth.

Table 4- Predictors of Live Birth in the Peak Season - *results of unadjusted and multivariable logistic regression analyses.*

	Crude Odds Ratio	95% Confidence Interval	Adjusted Odds Ratio	95% Confidence Interval
Maternal Age				
<18	0.918	(0.903, 0.934) *	0.736	(0.714, 0.758) *
18-24	Ref		ref	
24-30	1.035	(1.025, 1.045) *	1.190	(1.167, 1.215) *
30+	1.083	(1.070, 1.175) *	1.308	(1.273, 1.343) *
Birth Order				
1st	Ref		ref	
2nd	0.976	(0.966, 0.985) *	0.942	(0.923, 0.961) *
3rd	0.992	(0.980, 1.003)	0.849	(0.829, 0.871) *
4th+	1.017	(1.006, 1.028) *	0.747	(0.727, 0.767) *
Maternal Education				
No Education	Ref		ref	
Primary Education	0.948	(0.938, 0.959) *	1.014	(0.991, 1.036)
Secondary Education	0.865	(0.855, 0.875) *	1.129	(1.093, 1.166) *
Higher Education	0.868	(0.849, 0.888) *	1.329	(1.258, 1.406) *
BMI				
Underweight	1.009	(0.995, 1.024)	0.959	(0.932, 0.987) *
Normal	Ref		ref	
Overweight	0.936	(0.923, 0.949) *	0.966	(0.946, 0.987) *
Obese	0.919	(0.902, 0.936) *	0.975	(0.952, 1.00) *
Wealth Index				
Poorest	1.056	(1.043, 1.069) *	1.109	(1.078, 1.140) *
Poorer	1.033	(1.021, 1.046) *	1.034	(1.009, 1.061) *
Middle	Ref		ref	
Richer	0.978	(0.965, 0.992) *	0.964	(0.938, 0.991) *

Richest	0.909	(0.896, 0.923) *	0.915	(0.885, 0.945) *
Temperature (◦C)	1.283	(1.276, 1.289) *	1.116	(1.110, 1.121) *
Decade of Birth				
1970s	1.049	(0.905, 1.217)	1.222	(1.000, 1.492)
1980s	1.033	(1.011, 1.055) *	1.185	(1.144, 1.228) *
1990s	1.040	(1.029, 1.052) *	1.113	(1.091, 1.136) *
2000s	ref		ref	
2010s	0.971	(0.960, 0.982) *	0.969	(0.950, 0.988) *
Type of Residence				
Rural	ref		ref	
Urban	0.925	(0.910, 0.941) *	0.942	(0.917, 0.969) *

** Signifies statistical significance.*

Compared to births to women between the ages of 18 to 24, births to women under 18 years of age were at approximately 25% reduced odds (aOR =0.736, 95% CI: 0.714-0.758 p<0.001) of occurring in the peak birth period. Conversely, births to mothers aged 24 to 30 at birth were nearly 20% more likely to occur in the peak birth period (aOR=1.190, 95% CI: 1.167-1.215, p<0.001). Similarly, births to mothers older than 30 years of age were 30% more likely to occur in the peak birth period (aOR=1.308, 95% CI 1.273-1.343, p<0.001).

A relationship between the birth order and the season of birth was noted. Compared to 1st order births, each successive birth order was associated with reduced odds of live births occurring in the peak period relative to the period with the fewest births (aOR's for 2nd, 3rd and 4th or higher order births respectively were: 0.942, 95% CI: 0.923-0.961, p<0.001; 0.849, 95% CI: 0.829-0.871, p<0.001; and 0.747, 95% CI: 0.727-0.767, p<0.001).

Maternal BMI was independently related to the seasonality of live birth. Compared to births to mothers of normal BMI, those to mothers who were underweight and overweight were less likely to occur in the peak birth period relative to the period with the fewest births. Births to women who were underweight had 4% lesser odds of occurring in the peak period (aOR=0.959, 95% CI: 0.932-0.987, p<0.001), whereas births to overweight women were nearly 3% less likely to occur in the peak period (aOR=0.966, 95% CI: 0.946-0.987, p<0.001) relative to the period with the fewest births.

Socio-economic status of the population was associated with seasonality of birth. Births to women who belonged in the richer and the richest household wealth index were significantly less likely to occur in the peak three-month period (aOR=0.964, 95% CI: 0.938-0.991, p=0.010, and aOR= 0.915, 95% CI: 0.885-0.945, p<0.001 respectively) compared to households in the middle bracket of wealth index (referent group). Alternatively, births to women in the poorer and the poorest households were significantly more likely to occur in the peak three-month birth period (aOR=1.034, 95% CI: 1.009-1.061, p<0.001 and aOR=1.109, 95% CI: 1.078-1.140, p<0.001 respectively).

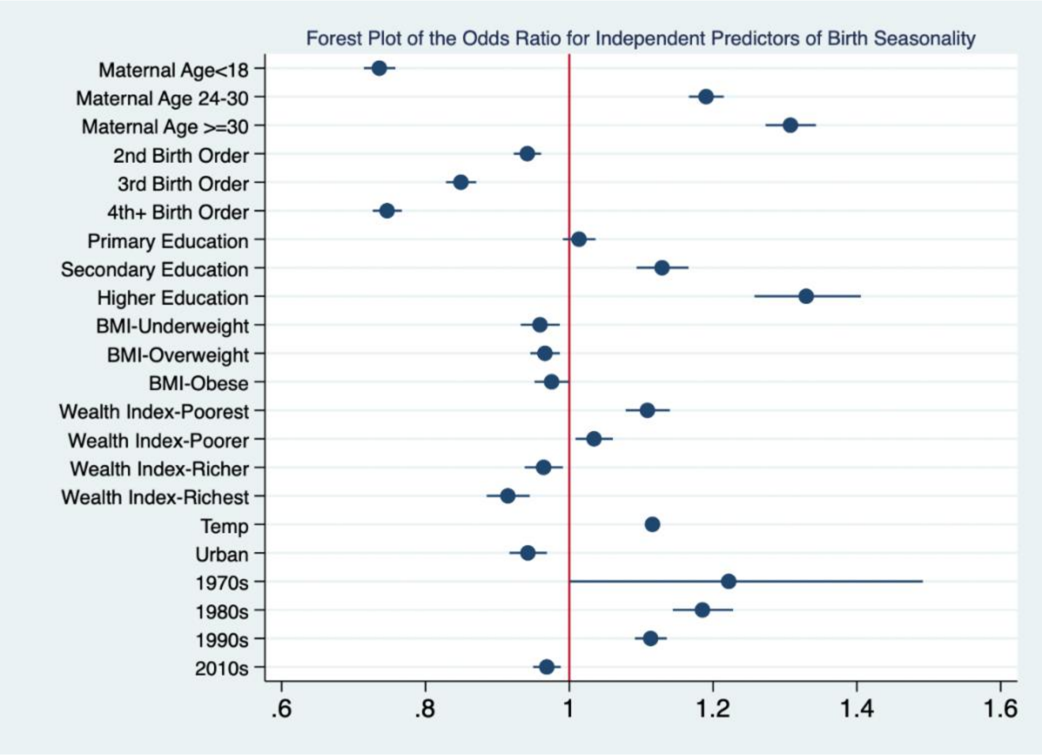
The level of maternal education was independently related to seasonality of birth. Compared to births to mothers without any formal education, progressively increasing maternal educational accomplishment was associated with an increasing likelihood of births occurring in the peak period. Births to mothers who had completed secondary education had 10% greater odds of occurring in the peak birth period (aOR= 1.129, 95% CI: 1.093-1.166, p<0.001) whereas births to mothers who had started some level of higher education had greater than 30% increased odds of occurring in the peak birth period (aOR=1.329, 95% CI: 1.258-1.406, p<0.001) compared to births to mothers without any education.

Monthly average temperatures at the time of conception were independently predictive of seasonality of live birth. A 1-unit Celsius increase in temperature was associated with over 10% increased odds of birth within the peak birth period (aOR=1.116, 95% CI: 1.110-1.121, p<0.001).

The decade of birth was also observed to be independently associated with birth seasonality as there was a decreased trend in the odds of births within the peak three-month period across each subsequent decade. Births in the 1970s had over 20% increased odds of occurring in the peak three-month period relative to births in the 2000s (aOR=1.222, 95% CI: 1.001-1.492, p=0.049) while births in the 1980s had less than 20% increased odds (aOR=1.185, 95% CI: 1.144-1.228, p<0.001), those in the 1990s had around a 10% increased odds (aOR=1.113, 95% CI: 1.091-1.136, p<0.001), and those in the 2010s had over 3% decreased odds (aOR=0.960, 95% CI: 0.950-0.988, p=0.002).

Figure 5 provides a visual overview of adjusted OR's (and 95% CI's) for the association of the examined covariates with the probability of birth in the peak period.

Figure 5- Forest Plot Depicting Associations of Examined Covariates with the Probability of Births Occurring in the Peak Period *- results of multivariable logistic regression analysis.*



Sensitivity Analyses:

a) **Analyses Examining Seasonality in Live Births by Regional Hemispheres.**

On analyses stratified by geographical regions in relation to the equator, shifts in the magnitude of association of independent predictors of birth seasonality were apparent; results are presented in Table 5a and 5b and further detailed in Figures 5a and 5b. Regardless of the Hemisphere, births to mothers of older age had an increased odds of occurring within the peak three-month period; the magnitude of this difference however was more prominent in the Northern Hemisphere where births to mothers under the age of 18 had 30%

reduced odds of occurring in the peak period (aOR= 0.713, 95% CI: 0.690-0.737, p<0.001) whereas in the Southern Hemisphere, births to this age group had almost 10% lesser odds of occurring in peak periods (aOR=0.912, 95% CI: 0.854-0.975, p<0.001). Moreover, in the Northern Hemisphere births to mothers between 24-30 years of age had almost a 20% (aOR=1.193, 95% CI: 1.164-1.222, p<0.001**)** increased odds while those to mothers at least 30 years of age had close to a 30% (aOR=1.282, 95% CI: 1.242-1.323, p<0.001) increased odds of occurring in the peak period compared to mothers between the ages of 18 to 24. Similar trends were noted in the Southern Hemisphere with births to mothers 24-30 years of age having a 20% greater likelihood (aOR=1.203, 95% CI 1.153-1.254, p<0.001) and those to mothers 30 years and older had over 1.3 times greater odds (aOR=1.348, 95% CI 1.274-1.426, p<0.001) of occurring in the peak birth period relative to births among mothers between 18 to 24 years of age.

Additionally, a significant negative association between births within peak period and birth order was seen across both the Northern and Southern hemispheres. Compared to 1st order births, the odds of birth within the peak period among 2nd order births were 6% lower (aOR=0.942, 95% CI: 0.920-0.964, p<0.001), among 3rd order births almost 15% lower (aOR=0.844, 95% CI: 0.819-0.869, p<0.001), and among 4th order and greater births over 25% lower (aOR=0.738, 95% CI: 0.714-0.762, p<0.001) in the Northern Hemisphere. Similar patterns were seen in the Southern Hemisphere where relative to 1st order births, the odds of birth within the peak period were 15% lower among 3rd order births (aOR=0.852, 95% CI: 0.809-0.897, p<0.001) and almost 25% lower among 4th order births (aOR=0.756, 95% CI: 0.713-0.802, p<0.001).

Discrepant trends were observed in the relationship of maternal education with seasonality of birth between the two hemispheres. The odds of birth within the peak period increased with increasing maternal education in the Northern hemisphere but decreased in the Southern hemisphere. Compared to births to mothers who had not received any formal education, births to mothers who had completed primary education had a 5% greater likelihood of occurring in the peak period (aOR=1.056, 95% CI: 1.029-1.085, p<0.001). In the Northern Hemisphere, the likelihood of births occurring in the peak period was 30% and 50% greater among births to mothers who had completed secondary education or had at least started higher education (aOR=1.280, 95% CI: 1.229-1.334, p<0.001 and aOR=1.562, 95% CI: 1.462-1.669, p<0.001 respectively) compared to births occurring to mothers without any formal education. In contrast, a reversed trend was notable in the Southern hemisphere where the odds of births within the peak period decreased across increasing maternal education categories compared to births to mothers who did not complete any level of education. The odds of birth occurring within the peak three-month period were 20%, almost 40% and 60% lower respectively among mothers who had completed primary education (aOR=0.787, 95% CI: 0.752-0.802, p<0.001), completed secondary education(aOR=0.620, 95% CI: 0.585-0.658, p<0.001) or had some level of higher education (aOR=0.416, 95% CI: 0.260-0.482, p<0.001) compared to births to mothers who did not receive any formal education.

Temperature at time of conception was independently associated with birth within the peak three-month period in both the hemispheres. Discrepant trends were however observed in the directionality of this association. In the Northern Hemisphere a 1-unit Celsius increase in temperature was associated with a 20% increase (aOR=1.239, 95% CI: 1.229-1.250, p<0.001) in the odds of birth within the peak period, whereas in the Southern Hemisphere a 1-unit Celsius increase in temperature was associated with a 5% decrease (aOR=0.951, 95% CI: 0.938-0.963, p<0.001) in the odds of birth within the peak period.

Decade of birth was independently associated with birth seasonality and this trend was most apparent in the Northern Hemisphere wherein lessening odds of birth within peak periods were observed over the decades from the 1970s to the 2010s. Relative to births in the 2000s, births in the 1970s had over 1.4 times greater odds (aOR=1.451, 95% CI: 1.165-1.808, p=0.001) of occurring in the peak period while those in the 1980s had approximately 1.2 times greater odds (aOR=1.229, 95% CI: 1.180-1.279, p<0.001). Those in the 1990s had 1.18 times greater odds (aOR=1.179, 95% CI: 1.152-1.206, 95% CI: 1.152-1.206, p<0.001), and conversely births in the 2010s had close to 0.95 times odds (aOR=0.940, 95% CI: 0.918-0.964, p<0.001). In the Southern hemisphere, compared to births in the 2000s, those in the 1980s were significantly more likely to occur in the peak period (aOR=1.141, 95% CI: 1.048-1.241, p=0.002).

Table 5a- Predictors of Live Birth in the Peak Season in the Northern Hemisphere - *results of multivariable logistic regression analyses stratified by geographical region in relation to the equator.*

	Adjusted Odds Ratio	95% Confidence Interval
Maternal Age		
<18	0.713	(0.690, 0.737) *
18-24	Ref	
24-30	1.193	(1.164, 1.222) *
30+	1.282	(1.242, 1.323) *
Birth Order		
1st	ref	
2nd	0.942	(0.920, 0.964) *
3rd	0.844	(0.819, 0.869) *
4th+	0.738	(0.714, 0.762) *
Maternal Education		
No Education	ref	
Primary Education	1.056	(1.029, 1.085) *
Secondary Education	1.280	(1.229, 1.334) *
Higher Education	1.562	(1.462, 1.669) *
BMI		
Underweight	0.959	(0.926, 0.993) *
Normal	ref	
Overweight	1.052	(1.026, 1.080) *
Obese	1.149	(1.114, 1.185) *
Wealth Index		
Poorest	1.176	(1.136, 1.217) *
Poorer	1.066	(1.035, 1.100) *
Middle	ref	
Richer	0.928	(0.897, 0.961) *
Richest	0.813	(0.780, 0.847) *

Temperature	1.239	(1.229, 1.250) *
Decade of Birth		
1970s	1.451	(1.165, 1.808) *
1980s	1.229	(1.180, 1.279) *
1990s	1.179	(1.152, 1.206) *
2000s	ref	
2010s	0.940	(0.918, 0.964) *
Type of Residence		
Rural	ref	
Urban	1.009	(0.974, 01.046)

** Signifies statistical significance.*

Figure 5a- Forest Plot Depicting Odds Ratios from Multivariable Logistic Regression Models - *analyses restricted to the Northern Hemisphere*

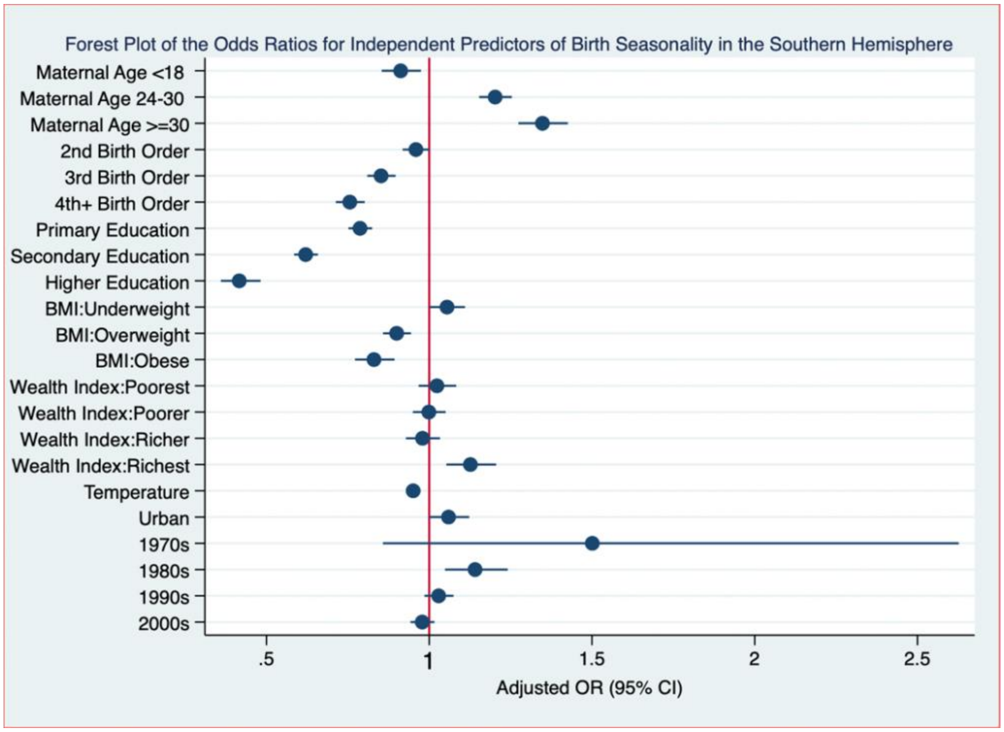
Table 5b- Predictors of Live Birth in the Peak Season in the Southern Hemisphere - *results of multivariable logistic regression analyses stratified by geographical region in relation to the equator.*

	Adjusted Odds Ratio	**95% Confidence Interval**
Maternal Age		
<18	ref	
18-24	**0.912**	**(0.854, 0.975)**
24-30	**1.203**	**(1.153, 1.254)**
30+	**1.348**	**(1.274, 1.426)**
Birth Order		
1st	ref	
2nd	0.959	(0.918, 1.002)
3rd	**0.852**	**(0.809, 0.897)**
4th+	**0.756**	**(0.713, 0.802)**
Maternal Education		
No Education	ref	
Primary Education	**0.787**	**(0.752, 0.802)**
Secondary Education	**0.620**	**(0.585, 0.658)**
Higher Education	**0.416**	**(0.360, 0.482)**
BMI		
Underweight	**1.055**	**(1.002, 1.110)**
Normal	ref	
Overweight	**0.900**	**(0.858, 0.944)**
Obese	**0.830**	**(0.772, 0.893)**
Wealth Index		
Poorest	**1.024**	**(0.968, 1.083)**
Poorer	0.999	(0.950, 1.050)
Middle	ref	
Richer	0.979	(0.929, 1.033)
Richest	**1.126**	**(1.053, 1.206)**
Temperature	**0.951**	**(0.938, 0.963)**

Decade of Birth		
1970s	1.501	(0.858, 2.627)
1980s	**1.141**	**(1.048, 1.241)**
1990s	1.029	(0.985, 1.075)
2000s	ref	
2010s	0.978	(0.942, 1.016)
Type of Residence		
Rural	**ref**	
Urban	1.059	(1.00, 1.123)

** Signifies statistical significance.*

Figure 5b- Forest Plot Depicting Odds Ratios from Multivariable Logistic Regression Models - *analyses restricted to the Southern Hemisphere*



b) Analyses Examining Seasonality of Live Birth in Relation to Religious Affiliation of the Studied Populations

Tables 6-9 detail results of multivariable logistic regression analyses examining the relationship of birth seasonality stratified by the specified religious affiliation of the population.

Among births to followers of Hindu religion, maternal age, birth order, maternal education, and temperature at time of conception were independently and significantly associated with birth occurring within the peak three-month period.

Births to mothers between 24-30 years of age had nearly 60% decreased odds (aOR=0.372, 95% CI: 0.140-0.986, p=0.047) of occurring in the peak period compared to births to mothers 18-24 years of age.

Birth order was significantly associated with birth seasonality with higher order births having greater odds of occurring in the peak period relative to first order births. 2nd order births had over a 7-fold increased odds (aOR=7.056, 95% CI: 1.584-31.429, p=0.01), 3rd order births over a 3-fold increased odds (aOR=3.482, 95% CI: 1.025-11.833, p=0.046), and 4th order births also over a 7-fold increased odds (aOR=7.015, 95% CI: 1.766-27.862, p=0.006) of occurring in the peak birth period relative to first order births.

Compared to births to mothers who had not completed any formal education, births to Hindu mothers who had completed primary or secondary education were less likely to occur during the peak period; this relationship was of statistical significance only among births to women who had completed secondary education (aOR=0.215, 95% CI= 0.063-0.742, p<0.001). Interestingly, the trend was reversed for those receiving higher education, albeit the relationship was not of statistical significance.

An inverse association was observed between the average regional temperature at time of conception and birth seasonality such that each 1 unit increase in the regional temperature at the time of conception was associated with 21% reduced likelihood for birth occurring during the peak period (aOR=0.788, 95% CI: 0.658-0.961, p<0.001).

Maternal BMI, household wealth index, type of residence or decade of birth were unrelated to birth seasonality in Hindu mothers. Results of the multivariable logistic regression model for mothers of Hindu religion are further outlined in Table 6.

Table 6- Predictors of Live Birth in the Peak Season to Hindu Mothers - *results of multivariable logistic regression analyses stratified by religion.*

	Adjusted Odds Ratio	**95% Confidence Interval**
Maternal Age		
<18	0.678	(0.114, 4.025)
18-24	ref	
24-30	0.372	(0.140, 0.986) *
30+	0.352	(0.111, 1.113)
Birth Order		
1st	ref	
2nd	7.056	(1.584, 31.429) *
3rd	3.482	(1.025, 11.833) *
4th+	7.015	(1.766, 27.862) *
Maternal Education		

No Education	Ref	
Primary Education	0.591	(0.173, 2.018)
Secondary Education	0.215	(0.063, 0.742) *
Higher Education	1.262	(0.291, 5.475)
BMI		
Underweight	2.496	(0.902, 6.907)
Normal	Ref	
Overweight	0.790	(0.377, 1.655)
Obese	0.641	(0.146, 2.804)
Wealth Index		
Poorest	0.843	(0.292, 2.431)
Poorer	0.668	(0.263, 1.698)
Middle	Ref	
Richer	1.864	(0.615, 5.651)
Richest	2.678	(0.718, 9.980)
Temperature ◦C	0.789	(0.658, 0.961) *
Decade of Birth		
1970s	-	-
1980s	1.748	(0.360, 8.483)
1990s	2.268	(0.856, 6.006)
2000s	Ref	
2010s	1.573	(0.561, 4.414)
Type of Residence		
Rural	Ref	
Urban	1.012	(0.377, 2.714)

** Signifies statistical significance.*

Among births to Christian mothers, maternal age, birth order, maternal education, maternal BMI, household wealth index, and temperature at time of conception were independently associated with birth within the peak three-month period. Compared to births in mothers between ages 18-24 years, births to mothers under the age of 18 were significantly less likely to occur in the peak period (aOR=0.815, 95% CI: 0.774-0.858, p<0.001). Conversely, births to mothers between ages 24-30 years and to those 30 years and older were significantly more likely to occur in the peak period (aOR=1.122, 95% CI: 1.082-1.164, p<0.001 and aOR=1.232, 95% CI: 1.174-1.291, p<0.001, respectively) compared to mothers between the ages of 18-24.

In contrast to the trend seen in births to Hindu mothers, higher order births amongst Christian mothers were less likely to occur in the peak three-month period relative to first order births (aOR's for 2nd, 3rd and 4th order or higher births respectively were: 0.934, 95% CI: 0.900-0.970, p<0.001, 0.862, 95% CI: 0.825-0.902, p<0.001 and 0.768, 95% CI: 0.732-0.806, p<0.001).

Births to Christian mothers of normal BMI were more likely to occur during the peak season compared to births to the underweight (aOR=0.930, 95% CI: 0.887-0.975, p<0.001), overweight (aOR=0.891, 95% CI: 0.858-0.924, p<0.001) and the obese (aOR=0.864, 95% CI: 0.825-0.906, p<0.001) mothers.

Amongst births to Christian mothers, maternal education was significantly associated with seasonality of birth with greater education associating with a lessening likelihood for birth occurring in the peak season. Relative to births to women without a formal education, births to mothers with primary, secondary, and higher education were increasingly less likely to occur in the peak season (aOR 0.843, 95% CI: 0.810-0.878, p<0.001; aOR=0.768, 95% CI: 0.731-0.805, p<0.001; and aOR=0.719, 95% CI: 0.655-0.788, p<0.001 respectively).

Additionally, births mothers belonging to households of poorest wealth index had 8% increased odds (aOR=1.079, 95% CI: 1.028-1.131, p=0.002) of occurring in the peak period compared to births to mothers of middle wealth income; a converse trend was noted with increasing wealth index of mothers wherein the likelihood of birth in the peak period was 5% lower for births to o mothers of households in the richer wealth index (aOR=0.949, 95% CI: 0.907-0.933, p=0.025) compared to births to households in the middle wealth index.

An association between temperature at time of conception and birth seasonality was notable with trends that were opposite in directionality to that seen for the Hindu population (Table 6). Each 1 unit increase in regional temperature at the time of conception was associated with 3% increase in the odds of birth during the peak period (aOR=1.032, 95% CI: 1.023-1.041, p<0.001).

The type of residence or decade of birth were unrelated to birth seasonality in Christian mothers. Results of the multivariable logistic regression model for births to Christian mothers are detailed in Table 7.

Table 7- Predictors of Live Birth in the Peak Season to Christian Mothers - *results of multivariable logistic regression analyses stratified by religion.*

	Adjusted Odds Ratio	**95% Confidence Interval**
Maternal Age		
<18	0.815	(0.774, 0.858) *
18-24	ref	
24-30	1.122	(1.082, 1.164) *
30+	1.232	(1.174, 1.291) *

Birth Order		
1st	ref	
2nd	0.934	(0.900, 0.970) *
3rd	0.862	(0.825, 0.902) *
4th+	0.768	(0.732, 0.806) *
Maternal Education		
No Education	ref	
Primary Education	0.843	(0.810, 0.878) *
Secondary Education	0.768	(0.731, 0.805) *
Higher Education	0.719	(0.655, 0.788) *
BMI		
Underweight	0.930	(0.887, 0.975) *
Normal	Ref	
Overweight	0.891	(0.858, 0.924) *
Obese	0.864	(0.825, 0.906) *
Wealth Index		
Poorest	1.079	(1.028, 1.131) *
Poorer	0.967	(0.926, 1.009)
Middle	ref	
Richer	0.949	(0.907, 0.993) *
Richest	0.965	(0.916, 1.017)
Temperature ◦C	1.032	(1.023, 1.041) *
Decade of Birth		
1970s	0.979	(0.692, 1.384)
1980s	1.046	(0.981, 1.115)
1990s	1.013	(0.978, 1.048)
2000s	ref	
2010s	0.973	(0.941, 1.005)
Type of Residence		
Rural	ref	
Urban	0.977	(0.938, 1.017)

** Signifies statistical significance.*

Among births to Muslim mothers, maternal age, birth order, maternal BMI, education, household wealth index, temperature at time of conception and decade of birth were each independently associated with birth seasonality. Compared to mothers between the ages of 18-24 years (referent), births to mothers under the age of 18 were significantly less likely to occur in the peak period (aOR=0.736, 95% CI: 0.704-0.769, $p<0.001$). Conversely births to mothers of increasing age was associated with increasing likelihood for birth occurring in the peak period (adjusted associations for maternal ages at birth of between 24-30 years and 30 years and older were aOR=1.234, 95% CI: 1.197-1.273, $p<0.001$, and aOR=1.352, 95% CI: 1.298-1.407, $p<0.001$, respectively). The trends in the associations between maternal age and seasonality of birth observed in births to Muslim mothers were similar to those in Christian mothers and contrasted with those observed for the Hindu mothers.

Similar to the trends that were observed in births to Christian mothers, and in contrast to those seen for births to Hindu mothers, higher order births amongst Muslim mothers were increasingly less likely to occur in the peak three-month period relative to first order births (aOR's for 2nd, 3rd and 4th or higher order births respectively were: aOR=0.930, 95% CI: 0.903-0.959, $p<0.001$; aOR=0.831, 95% CI: 0.801-0.861, $p<0.001$; and aOR=0.731, 95% CI: 0.707-0.768, $p<0.001$).

Similar to observations seen in births to Christian mothers, those to Muslim mothers who were overweight were significantly less likely to occur during the peak period relative to births to mothers of normal BMI (aOR=0.967, 95% CI: 0.938-0.997, p=0.032).

As was noted for births to Christian mothers, increasing maternal education was significantly associated with seasonality of birth with greater education associated with lessening likelihood for birth occurring in the peak season; compared to mothers without any completed formal education, odds for births occurring in the peak period for mothers with completed secondary education and higher education respectively were: aOR=0.891, 95% CI: 0.856-0.926, p<0.001; and aOR=0.892, 95% CI: 0.832-0.955, p<0.001.

Relationship between household wealth index and likelihood for birth occurring in the peak period was observed, and again, the trends were similar to those noted for the Christian mothers. Births that occurred in Muslim households in the poorest wealth index category had a 6% increased likelihood for occurring during the peak period compared to births to households in the middle wealth index (aOR=1.065, 95% CI: 1.021-1.112, p=0.003).

An association between temperature at time of conception and birth seasonality was notable with trends that were similar to seen for the Christian population (Table 7), and opposite in directionality to seen for the Hindu population (Table 6). Each 1 unit increase in regional temperature at the time of conception was associated with 15% increased odds (aOR=1.151, 95% CI: 1.142-1.160, p<0.001) of birth during the peak period.

The type of residence or decade of birth were unrelated to birth seasonality in births to Muslim mothers. Results of the multivariable logistic regression model examining predictors for the odds of birth in the peak season for Muslim mothers are detailed in Table 8.

Table 8- Predictors of Live Birth in the Peak Season to Muslim Mothers- *results of multivariable logistic regression analyses stratified by religion.*

	Adjusted Odds Ratio	**95% Confidence Interval3**
Maternal Age		
<18	0.815	(0.774, 0.858) *
18-24	ref	
24-30	1.122	(1.082, 1.164) *
30+	1.232	(1.174, 1.291) *
Birth Order		
1st	ref	
2nd	0.934	(0.900, 0.970) *
3rd	0.862	(0.825, 0.902) *
4th+	0.768	(0.732, 0.806) *
Maternal Education		
No Education	ref	
Primary Education	0.843	(0.810, 0.878) *
Secondary Education	0.768	(0.731, 0.805) *
Higher Education	0.719	(0.655, 0.788) *
BMI		
Underweight	0.930	(0.887, 0.975) *
Normal	ref	
Overweight	0.891	(0.858, 0.924) *
Obese	0.864	(0.825, 0.906) *

Wealth Index		
Poorest	1.079	(1.028, 1.131) *
Poorer	0.967	(0.926, 1.009) *
Middle	ref	
Richer	0.949	(0.907, 0.993) *
Richest	0.965	(0.916, 1.017)
Temperature	1.032	(1.023, 1.041) *
Decade of Birth		
1970s	0.979	(0.692, 1.384)
1980s	1.046	(0.981, 1.115)
1990s	1.013	(0.978, 1.048)
2000s	ref	
2010s	0.973	(0.941, 1.005)
Type of Residence		
Rural	ref	
Urban	0.977	(0.938, 1.017)

** Signifies statistical significance*

Among births to mothers who were neither Hindu, Christian nor Muslim (of Other religious affiliation), maternal age, birth order, maternal education, maternal BMI, household wealth index, temperature at time of conception as well as decade of birth were each independently associated with birth seasonality.

Similar to the results seen for the Christian and Muslim mothers, births to mothers of other religious affiliation who were under the age of 18 were significantly less likely to occur in the peak period (aOR=0.781, 95% CI: 0.718-0.850, $p<0.001$). Conversely births to mothers between 24-30 years and to those 30 years of age or older were increasingly more likely to occur during the peak period (aORs were 1.278, 95% CI: 1.198-1.362, p<0.001 and 1.414, 95% CI: 1.302-1.536, p<0.001, respectively compared to mothers between the ages of 18-24). Moreover, similar to the trends noted for Christian and Muslim mothers, higher order births were significantly less likely to occur in the peak three-month period relative to first order births with 2nd order births having a 10% reduced odds (aOR=0.904, 95% CI: 0.848-0.914, p<0.001), 3rd order births an almost 15% reduced odds (aOR=0.849, 95% CI: 0.788-0.914, p<0.001), and 4th order births approximately 25% reduced odds (aOR=0.735, 95% CI: 0.677-0.797, p<0.001) of occurring in the peak period.

In contrast to trends noted in Christian and Muslim mothers, in mothers of Other religious affiliation, births to underweight mothers were significantly more likely to occur during the peak period (aOR=1.086, 95% CI: 1.006-1.172, p=0.034). However, similar to observations in the Christian and Muslim population, maternal obesity was associated with a significantly reduced likelihood of births occurring during the peak period (aOR=0.903, 95% CI: 0.826-0.988, p=0.025) compared to mothers of normal BMI.

As was noted for births to Christian and Muslim mothers, increasingly maternal education was significantly associated with seasonality of birth with greater education associating with lessening likelihood for birth occurring in the peak season (aOR's for births in the peak period to mothers with completed primary, secondary and higher education relative to those who did not complete formal education respectively were: aOR=0.560, 95% CI: 0.522-

0.601, p<0.001; aOR=0.527, 95% CI: 0.482-0.577 p<0.001; and aOR=0.333, 95% CI: 0.255-0.435, p<0.001 respectively).

Additionally, the relationship of seasonality of birth with household wealth was similar to that observed for the Christian and the Muslim populations; births occurring in households belonging to the richer wealth index had about 10% reduced odds of occurring during the peak period (aOR=0.896, 95% CI: 0.822-0.978, p=0.013) compared to the events in the middle wealth index population.

Temperature at time of conception was independently associated with birth within the peak three-month period with directionality of association that was aligned with observations noted in the Hindu population, and that contrasted with observations in Christian and Muslim mothers. In the population of mothers of Other religious affiliation, each 1 unit increase in the regional temperature around time of conception was associated with an almost 25% decrease in the odds of birth during the peak period (aOR=0.772, 95% CI: 0.758-0.786, p<0.001).

Unlike the Hindu, the Christian and Muslim populations, births to mothers of other religious affiliation occurring in the 1980's were 31% more likely to happen during the peak period compared to births in the 2000's (aOR 1.306, 95% CI 1.174-1.453).

Results of the multivariable logistic regression model examining predictors for the odds of birth in the peak season for mothers of other religious affiliation are detailed in Table 9.

Table 9- Predictors of Live Birth in the Peak Season to Mothers of Other Religious Affiliation- *results of multivariable logistic regression analyses stratified by religion.*

	Adjusted Odds Ratio	95% Confidence Interval3
Maternal Age		
<18	0.781	(0.718, 0.850) *
18-24	ref	
24-30	1.278	(1.198, 1.362) *
30+	1.414	(1.302, 1.536) *
Birth Order		
1st	ref	
2nd	0.904	(0.848, 0.963) *
3rd	0.849	(0.788, 0.914) *
4th+	0.735	(0.677, 0.797) *
Maternal Education		
No Education	ref	
Primary Education	0.560	(0.522, 0.601) *
Secondary Education	0.527	(0.482, 0.577) *
Higher Education	0.333	(0.255, 0.435) *
BMI		
Underweight	1.086	(1.006, 1.172) *
Normal	ref	
Overweight	0.997	(0.933, 1.065)
Obese	0.903	(0.826, 0.988) *
Wealth Index		
Poorest	0.997	(0.919, 1.081)
Poorer	1.017	(0.939, 1.103)
Middle	ref	
Richer	0.896	(0.822, 0.978) *
Richest	0.979	(0.877, 1.093)

Temperature	0.772	(0.758, 0.786) *
Decade of Birth		
1970s	1.027	(0.578, 1.823)
1980s	1.306	(1.174, 1.453) *
1990s	1.008	(0.951, 1.069)
2000s	ref	
2010s	0.983	(0.932, 1.036)
Type of Residence		
Rural	ref	
Urban	1.414	(1.296, 1.542)

** Signifies statistical significance*

c) Temporal Trends in Seasonality of Live Births

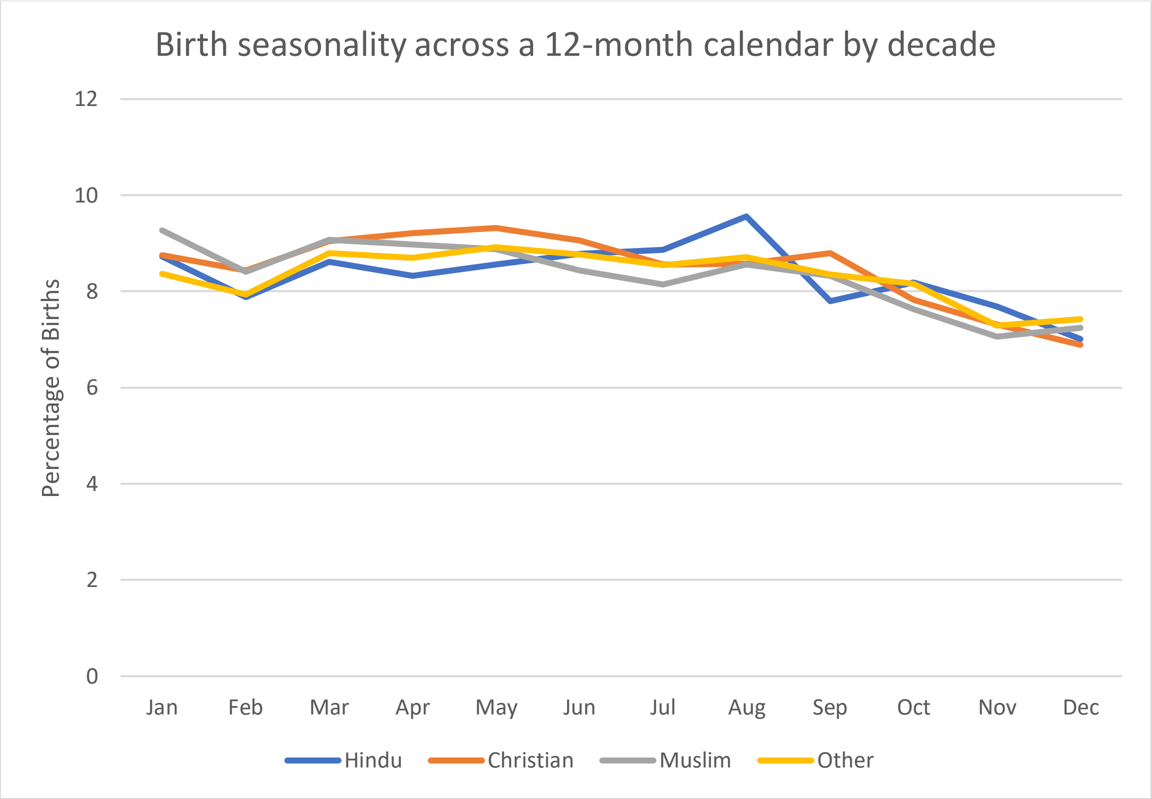
Analysis of the distribution of live births across 12 months of a calendar year across the five decades (1970s-2010s) demonstrated statistically significant differences (p<0.001). Visual inspection of the data showed changes in the peak three-month birth period throughout the decades with the period occurring through February-April (27.41%) in the 1970s, April-June (26.93%) in the 1980s, June-August (27.07%) in the 1990s, March-May (26.3%) in the 2000s, and January-March (26.84%) in the 2010s (Table 10, Figure 6).

Table 10- Percentage of births across a calendar year through each decade

Month	1970s	1980s	1990s	2000s	2010s
Jan	8.98	8.64	8.74	8.76	**9.36**
Feb	**9.36**	8.05	8.06	8.11	**8.44**
Mar	**9.06**	8.83	8.71	**8.83**	**9.04**
Apr	**8.99**	**8.9**	8.74	**8.71**	8.6

May	8.73	**8.98**	9.02	**8.76**	8.61
Jun	9.27	**9.05**	**9.03**	8.69	8.14
Jul	7.93	8.8	**8.86**	8.57	8.18
Aug	7.93	9.03	**9.18**	9.01	8.8
Sep	7.55	7.84	7.97	8.2	8.21
Oct	7.65	7.8	7.69	7.85	8.06
Nov	6.56	7.12	7.02	7.33	7.34
Dec	7.98	6.96	6.98	7.18	7.22

Figure 6: Temporal Trends in Live Birth Across Calendar Year by Decade



Discussion

In this analysis of over 3,000,000 live births across almost 50 LMICs, we have identified that birth seasonality is independently associated with maternal and household socio-demographic characteristics. We furthermore observed a relationship between average regional temperature at the time of conception with birth seasonality.

This study represents the first effort at description of patterns in birth seasonality across a large sample of LMICs that span both sides of the equator. We have shown that live births are not evenly distributed across twelve-month calendar. Notably, in an analytic dataset comprising more than 3 million births in LMICs, the overall pattern of births demonstrates pronounced peaks and troughs that occur from March to May and October to December respectively. If the births were to be evenly distributed across a calendar year, we would expect any and every three-month period to contain 25% of births across a year. However, in our analysis we identified that the peak three-month birth period that extended from March-May contained 26.36% of all births while the lowest three-month period that spanned from October-Decembers included only 21.97% of all births.

We additionally have identified statistically significant differences in birth seasonality between the Northern and Southern Hemispheres. In the Northern hemisphere, the peak birth period extended from March-May; 26.33% of all births occurred during this peak period. In contrast, the peak birth period in the Southern hemisphere fell between April-June wherein 26.80% of all births occurred. While the peak births periods differ above and below the equator, the trough period of least number of births was observed to be similar in both the hemispheres, extending from October-December in both regions, and included comparable proportion of births (22.22% of births in the Northern Hemisphere and 22.33% of births in the Southern Hemisphere). Our findings are among the first to demonstrate discrepant patterns in birth seasonality in LMIC's located in the two hemispheres.

We have additionally demonstrated that maternal age is independently associated with birth seasonality; the probability of births occurring over the three-month peak period increased across each subsequent maternal age group. This trend was seen across the entire study population as well in analyses restricted to the Northern and Southern hemispheres respectively, suggesting that maternal age may be independently associated with seasonality of birth irrespective of location relative to the equator. Moreover, we have identified birth order as a significant independent predictor of birth seasonality with trends demonstrating that subsequent births are significantly less likely to fall in the peak birth period relative to first order births; a negative linear association was evident such that the magnitude of attenuation in the likelihood of birth occurring in the peak period was progressively greater for second, third and fourth order births respectively even after controlling for other maternal and household sociodemographic characteristics. These observations of relationships between maternal age and birth order with the probability of birth occurring in the peak birth season raise possibility of other unquantified anthropological factors that may influence the timing of subsequent conceptions and thereby, births; that to some extent family planning practices may play a role in dictating when second, third, fourth (and so on) children are conceived is a plausible consideration.

The observed association between maternal education and birth seasonality is of interest wherein births to mothers with greater levels of education were more likely to fall in the peak three-month birth period, with greater magnitude of associations seen at increasing maternal education levels. On further examination however, discrepant regional trends were observed. In the Northern hemisphere, births that occurred to mothers with higher educational levels were more likely to occur in the peak period; conversely, an opposite directionality was evident for the Southern hemisphere where births to mothers with higher educational attainment had significantly lesser likelihood of occurring in the peak period. Although the overall trends may suggest that increasing maternal education may influence family planning decision-making across LMICs, results of sensitivity analyses restricted to each respective hemisphere raise questions regarding if additional socio-demographic and even ecological factors may be at play that differ in the geographical regions above and below the equator and that may be relevant to reproductive plans and outcomes.

Given that others have shown a peaking in birth rates nine months after major religious holidays,[14] we conceptualized that religious affiliation may serve as a surrogate variable for socio-cultural practices that may be relevant to reproductive decision-making. On analyses stratified by religious affiliation, we have shown some similarities as well as distinctions in the relationships between birth seasonality with demographics as well as socio-economic and regional variables. These findings suggest that socio-cultural practices that align with religious affiliation may be relevant to reproductive planning in LMIC’s.

An association between climate, temperature and birth seasonality has previously been recognized,[16] and our results are consistent with this observation. We accessed monthly climate data records for the countries included in our analytic dataset for time-period between 1901-2018 to examine the association between regional average temperatures around the time of conception. We identified an independent association of regional temperature approximating the time of conception with birth seasonality; increasing temperature was noted to associate with a greater likelihood of births occurring in a peak period. Interestingly, discrepant patterns in the associations between birth seasonality and temperature approximating time of conception between the Northern and Southern hemispheres were notable. In analyses restricted to data for regions above the equator, the average annual countrywide temperature at approximately the time of conception was positively associated with birth within the peak three-month period such that a 1-unit increase in temperature was independently associated with an over 20% increase in the likelihood of births in the peak period. However, in similar analyses on birth data for regions to the South of the equator, regional temperature at the time of conception was negatively associated with birth seasonality such that a 1 unit increase in temperature at the time of conception associated with 5% lesser odds of birth within the peak period. This discrepant relationship in regional temperature and peak birth may be explained by the seasonal divides in the Northern and

Southern Hemispheres where for example the period from March to the next month in the Northern Hemisphere is associated with warming temperatures while in the Southern Hemisphere the period from March to April and so on and so forth is associated with lessening temperatures. Indeed, global data suggest that on average, annual mean-temperatures in the Northern Hemisphere are warmer than in the Southern Hemisphere.[46,47] Numerous theories exist that seek to explain this global phenomenon including 1) the Northern Hemisphere contains more land which retains more heat in the summer relative to the ocean dense Southern Hemisphere, 2) the ocean transports heat northward toward and across the equator, and 3) due to greenhouse gas effects the Northern Hemisphere heats up faster due to its larger fraction of land mass.[46]

Our findings add to the growing body of evidence supporting that births are not evenly distributed across a twelve-month calendar. Previous investigations that have examined for the influence of socio-demographic factors on the seasonality of live births have highlighted the role of maternal age, maternal education, and birth order in influencing birth seasonality. Bobak and colleagues (2001) documented weaker seasonal variations in births among both younger (≤19 years old) and older women (≥35 years old) with greater seasonal variation among mothers who were between 25-34 years of age along with greater variation seen in 2nd and 3rd order births in their study examining data on all live births that occurred in the Czech Republic between 1989-1991.[19] Our findings differ from this previously published work in that we have exclusively examined birth trends in LMICs, and have noted that increasing birth seasonality across births to older mothers as well as decreasing birth seasonality across higher birth orders. Additionally, Bobak and colleagues (2001) found there was greater birth seasonality seen in mothers with higher education with those births to mothers who had completed secondary and university level education individually having 25% increased odds of occurring in the peak birth period.[19] Our findings are consistent with Bobak et al. as we too observed similar results with greater likelihood of births in peak period to mothers with greater educational attainment. Moreover, our findings that demonstrate increased seasonal variation among births to mothers with higher educational attainment and those to second time and third time mothers are also in concordance to work from Dahlberg and colleagues (2018) that examined trends in seasonal variations of births across a 70-year period in Sweden.[20] In their work Dahlberg *et al.* also noted a decline in seasonal variations in births over time with births in the 21st century showing less variation compared to those in the 20th century and overall fewer births between March-May in the 21st century as compared to prior. We have observed similar trends with decreasing odds of births occurring in the peak period across each subsequent decade of period of observation captured in our dataset. We identified changing trends in the three-month peak birth period across the decades with the period lasting between February-April in the 1970s, April-June in the 1980s, June-August in the 1990s, March-May in the 2000s, and January-March in the 2010s.

This study's strengths and weaknesses should be considered in understanding the significance of its findings. The strengths of our study include the robust sample size representative of births over a three-decade period wherein we have analyzed trends in predictors of birth seasonality in over 3 million live births across 49 LMICs. The DHS datasets are a well-established and validated survey that provides our study with robustness in terms of quality of data.[37] Moreover, the survey design of the DHS Questionnaires allows us to draw conclusions from a sample that is representative of each country's larger population. The statistical methodology utilized, our systematic approach that took into consideration relevance of regional temperatures around time of conception, that examined religious affiliation as a surrogate for socio-cultural practices and nuances, and that took into consideration geographical location of studied populations are additional strengths of this work. Conversely, while this cross-sectional study allows us to identify predictors and associations of birth seasonality, we are unable to investigate the underlying causal mechanisms that may influence birth seasonality due to the inherent cross-sectional design of the study. Additionally, we are limited in our analyses by the DHS dataset itself and are unable to investigate beyond the datapoints on which DHS collects information. For example, the observation that births to women of higher education are more likely to occur during the peak birth period between March-May raises plausibility of planning that may center around socio-cultural norms and economic considerations. We do not have information on if births were planned or unintended and are therefore unable to ascertain if trends in birth seasonality or differences in predictors of birth seasonality differ between planned versus unintended births. Another question that may warrant further investigation is if time from marriage and/or cohabitation to pregnancy (and its birth) affects the seasonality of births, however these questions cannot be answered given the data source. Moreover, our approach of examining the relevance of temperature at time of conception to birth seasonality is limited by information restricted to average monthly countrywide temperatures. Additionally, we had to assume that all gestations resulting in live birth were of nine-month duration. We thus cannot examine independent predictors of birth seasonality for preterm births, nor can we examine relevance or pattern of seasonality for pregnancy losses.

In conclusion, the results of this study make a case for enhanced awareness of patterns in birth seasonality and independent predictors of birth seasonality across LMICs. The knowledge of seasonal trends in births along with its sociodemographic predictors offers meaningful insights that can be channeled to resource allocation for maternal and child health services in LMICs. Directed efforts to provide these public health resources at the national level through nationwide health departments and via international non-governmental organizations holds the potential to improve maternal child health morbidity and mortality statistics. A better understanding of predictors of birth seasonality may also assist in the implementation of newborn and infant immunization campaigns which often occur at set intervals after birth. Furthermore, the knowledge of birth seasonality and its predictors may be influential in the allocation and deployment of family planning services towards harnessing population growth within LMICs towards alignment with available resources. Over the ensuing years and by

2050, the knowledge of patterns and predictors in birth seasonality may be critical to the distribution of resources and implementation of programs that seek to reduce maternal and child morbidity and mortality, including obstetric and perinatal care services and immunization campaigns, allowing us to ultimately improve adverse health outcomes across much of the globe.

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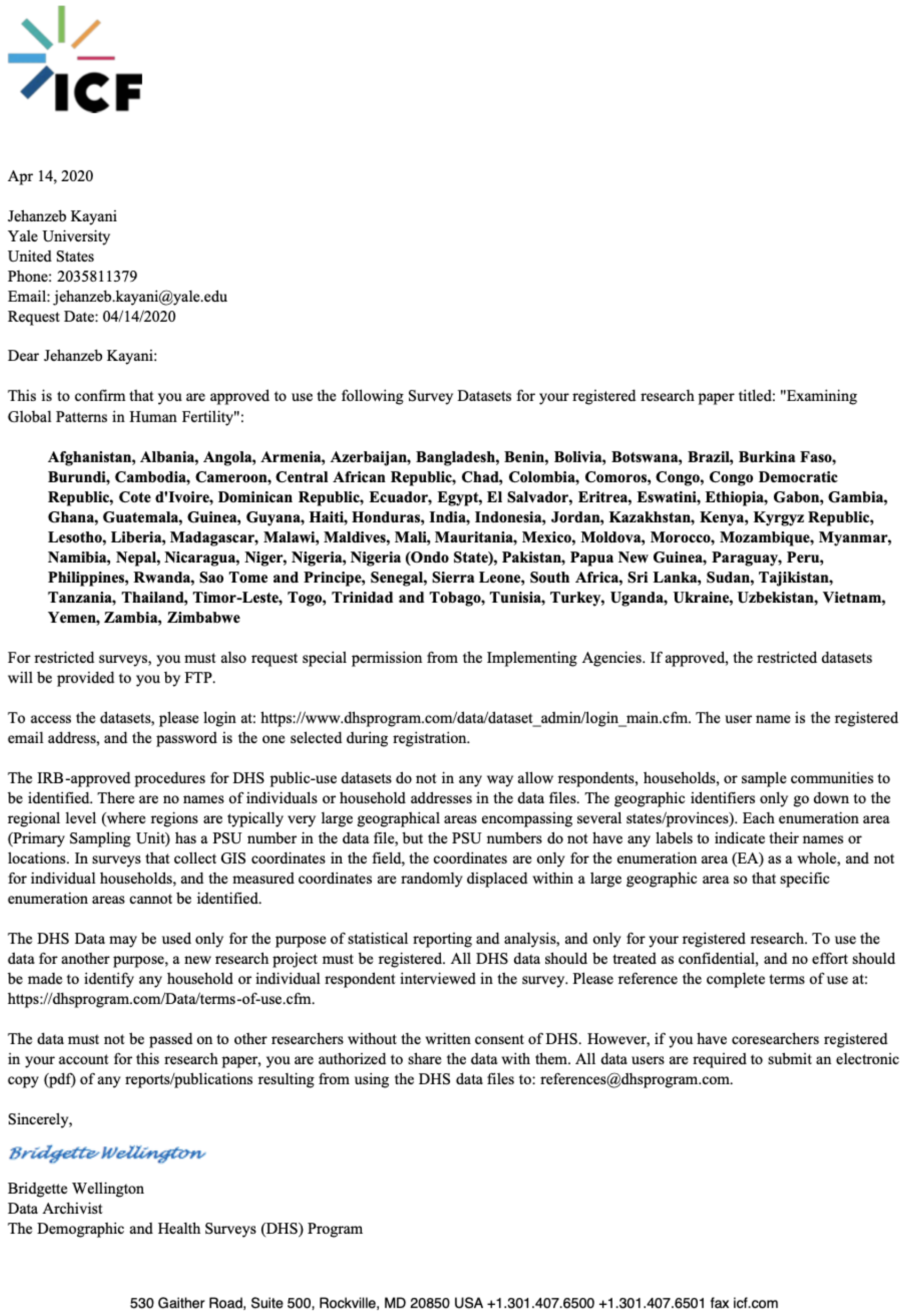
Supplementary Document 1



Apr 14, 2020

Jehanzeb Kayani
Yale University
United States
Phone: 2035811379
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Request Date: 04/14/2020

Dear Jehanzeb Kayani:

This is to confirm that you are approved to use the following Survey Datasets for your registered research paper titled: "Examining Global Patterns in Human Fertility":

> **Afghanistan, Albania, Angola, Armenia, Azerbaijan, Bangladesh, Benin, Bolivia, Botswana, Brazil, Burkina Faso, Burundi, Cambodia, Cameroon, Central African Republic, Chad, Colombia, Comoros, Congo, Congo Democratic Republic, Cote d'Ivoire, Dominican Republic, Ecuador, Egypt, El Salvador, Eritrea, Eswatini, Ethiopia, Gabon, Gambia, Ghana, Guatemala, Guinea, Guyana, Haiti, Honduras, India, Indonesia, Jordan, Kazakhstan, Kenya, Kyrgyz Republic, Lesotho, Liberia, Madagascar, Malawi, Maldives, Mali, Mauritania, Mexico, Moldova, Morocco, Mozambique, Myanmar, Namibia, Nepal, Nicaragua, Niger, Nigeria, Nigeria (Ondo State), Pakistan, Papua New Guinea, Paraguay, Peru, Philippines, Rwanda, Sao Tome and Principe, Senegal, Sierra Leone, South Africa, Sri Lanka, Sudan, Tajikistan, Tanzania, Thailand, Timor-Leste, Togo, Trinidad and Tobago, Tunisia, Turkey, Uganda, Ukraine, Uzbekistan, Vietnam, Yemen, Zambia, Zimbabwe**

For restricted surveys, you must also request special permission from the Implementing Agencies. If approved, the restricted datasets will be provided to you by FTP.

To access the datasets, please login at: https://www.dhsprogram.com/data/dataset_admin/login_main.cfm. The user name is the registered email address, and the password is the one selected during registration.

The IRB-approved procedures for DHS public-use datasets do not in any way allow respondents, households, or sample communities to be identified. There are no names of individuals or household addresses in the data files. The geographic identifiers only go down to the regional level (where regions are typically very large geographical areas encompassing several states/provinces). Each enumeration area (Primary Sampling Unit) has a PSU number in the data file, but the PSU numbers do not have any labels to indicate their names or locations. In surveys that collect GIS coordinates in the field, the coordinates are only for the enumeration area (EA) as a whole, and not for individual households, and the measured coordinates are randomly displaced within a large geographic area so that specific enumeration areas cannot be identified.

The DHS Data may be used only for the purpose of statistical reporting and analysis, and only for your registered research. To use the data for another purpose, a new research project must be registered. All DHS data should be treated as confidential, and no effort should be made to identify any household or individual respondent interviewed in the survey. Please reference the complete terms of use at: https://dhsprogram.com/Data/terms-of-use.cfm.

The data must not be passed on to other researchers without the written consent of DHS. However, if you have coresearchers registered in your account for this research paper, you are authorized to share the data with them. All data users are required to submit an electronic copy (pdf) of any reports/publications resulting from using the DHS data files to: references@dhsprogram.com.

Sincerely,

Bridgette Wellington

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