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A Comparative Study of Regional Trends in Fertility: Examples from Nepal

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Abstract
Nepal has undergone a dramatic demographic transition, evolving from high fertility to below-replacement levels. However, significant regional, socio-economic, and gender disparities persist across its geographical landscape. This study conducts a detailed mathematical modeling and elasticity analysis, based on Nepal Census 2021 fertility data. Parity Progression Ratios (PPR) were computed across birth orders to evaluate childbearing trajectories and stopping behaviors. In order to quantify structural responsiveness, Elasticity was estimated. It was seen that Total Fertility Rate (TFR) estimates derived from the PPR framework yielded higher values than census estimates in six out of seven provinces, except Madhesh, where the Census TFR (2.850) exceeded the PPR estimate (2.419). Cohort analysis showed lower parity progression among women aged 20–35 (completed TFR of 1.65) compared to those aged 35–49 (completed TFR of 2.72). Regarding marriage timing, the expected age at first marriage was 18.98 years for females and 22.24 years for males. While 41.08% of female, first marriages occurred before age 18 nationally—peaking at 52.21% in Madhesh Province—only 15.39% of male marriages occurred before 18. Elasticity of PPR transitioned from inelastic ($|E| < 1$) at parity one to highly elastic ($|E| > 1$) at parity two and above, with the highest sensitivity observed in the Kathmandu Valley. However, Madhesh and Karnali provinces exhibited $|E| < 1$.Hence it could be concluded that, Nepal's overall fertility decline is primarily driven by urban parity stopping after two children and delayed marriage, whereas rural, lowland, and mountain provinces maintain higher parity progression and earlier marriage patterns.

Keywords: Parity progression ratio, Birth order, Total fertility rate, Marital fertility, Age at first marriage, Elasticity, Cumulative distributive function.

1. INTRODUCTION

Fertility, defined in demography as the natural capacity of women to give birth to offspring, stands as a fundamental component of population dynamics that directly influences the size, structure, and composition of a population alongside mortality and migration. A woman's fertility level is traditionally measured using the Total Fertility Rate (TFR), which denotes the average number of live births she would have if she lived through her childbearing years between ages 15 and 49 [5]. Over recent decades, Nepal has undergone a dramatic demographic transition, evolving from a high-fertility regime to a level below replacement fertility. According to Nepal's National Statistics Office, the national TFR was recorded at approximately 5.74 children per woman in 1961, rising slightly to 6.33 in 1976 and peaking at 6.39 in 1981 during a period of sustained high fertility [10]. Following the 1980s, fertility began a steady decline: dropping to 5.6 in 1991, decreasing sharply to 3.25 in 2001, and reaching 2.52 by 2011 [10]. Presently, Nepal's TFR stands at 1.94 children per woman [10]. This figure falls below the standard population replacement threshold of approximately 2.1, fulfilling the nation's Sustainable Development Goal target and signaling smaller average family sizes and decelerated population growth [10].

Understanding these shifting demographic trends requires examining broader socioeconomic development, changing social and cultural norms, rapid urbanization, expanding female education, and the scaling of maternal health and family planning services. Data from the 2021 Census reveals significant regional, ecological, and socioeconomic disparities in fertility across the country [10]. Rural areas maintain a higher TFR of 2.4 compared to 2.0 in urban centers, while across ecological zones, TFR is highest in the Mountain region (2.4), followed by the Tarai (2.20) and the Hill region (1.64) [10]. At the provincial level, Bagmati Province reports the lowest TFR in the country at 1.37-a trend driven by high urban concentration, elevated educational levels, delayed age at marriage, and greater female labor force participation [10]. Conversely, Madhesh Province exhibits the highest TFR at 2.85, reflecting earlier marriage practices, cultural preferences for larger families, and lower relative socioeconomic development [10]. Furthermore, birth rates peak among young women aged 20-24 (149 births per 1,000 women) before declining in older cohorts, while an inverse relationship exists between household wealth and fertility: households in the lowest income group record a TFR of 2.70, whereas the highest wealth group records a TFR of 1.55 [10].

Fertility holds unique significance in demographic research because, unlike mortality which occurs only once in an individual's lifetime, fertility is a repeatable event throughout a woman's reproductive period. Because of this repeated nature, fertility provides more detailed information about family formation, reproductive behavior, and broader social patterns in a population. In many societies, childbearing is closely associated with marriage, though social customs surrounding non-marital births vary across cultures and time. In developing countries, cultural stigma often leads to the concealment or underreporting of childbearing outside marriage, creating gaps in demographic data [6, 3]. Data quality is further compromised by memory recall errors, omission of deceased infants, and gender bias that results in the systematic underreporting of female child deaths [6, 3]. Additionally, in countries like Nepal, many births continue to occur at home, particularly in remote and rural areas with limited access to health facilities. Due to a lack of awareness, physical distance from registration offices, and administrative difficulties, many families do not officially register these events, leaving numerous births and deaths unrecorded in official statistics [6, 3].

These administrative data gaps are exacerbated by inefficient Civil Registration and Vital Statistics (CRVS) systems across developing nations, particularly in South Asia [5, 6]. Although the CRVS system is critical for recording vital events such as births, deaths, marriages, and migration, geographic barriers in remote mountain regions make timely registration difficult [5, 6]. Institutional and administrative challenges-including bureaucratic hurdles, poor inter-agency coordination, shortage of trained staff, limited technological tools, and a lack of immediate personal incentives-discourage citizens from reporting vital events [5, 6, 7]. Because population projections and planning rely on accurate fertility, mortality, and migration data, incomplete registration leads to inaccurate demographic estimates [5, 6]. To address these missing records and reporting errors, researchers rely on mathematical and statistical modeling [5, 6, 7]. These models allow demographers to obtain reliable demographic estimates, providing policymakers and planners with the evidence needed to design effective policies for health, education, employment, and population management [5, 6, 7].

These demographic and structural challenges are further enriched by examining neighboring regional dynamics, particularly given Nepal's adjoining borders and cultural similarities with India [15]. Both countries exhibit parallel demographic transitions, with India also experiencing a sharp decline in fertility driven by the widespread adoption of the two-child family norm. Key drivers of this shift include a rising age at marriage, improved family planning access, lower child mortality, higher female education, urbanization, and changing socioeconomic aspirations. Despite these changes, marriage in India remains highly stable, universal (over 98 percent of women are married by age 35), and deeply influential in shaping fertility behavior [15]. Childbearing takes place almost entirely within marriage, and most marriages remain arranged by families under the influence of caste, kinship, and community norms [15]. Although age at marriage has risen and delayed marriage is emerging among educated urban women, divorce, separation, and cohabitation remain rare [15]. Understanding how enduring social institutions interact with rapid fertility decline provides essential context for analyzing demographic trajectories across the region [15].

2. Materials and Methods

Data: National Population and Housing Census 2021, Nepal was used for the study [10,11].

Methodology:

a. Parity Progression Ratio (PPR)

The Parity Progression Ratio (PPR) serves as an essential demographic measure specifically designed to analyze the sequential progression of women from one birth order to the next higher birth order. Fundamentally, this metric evaluates the statistical probability that a woman who has already attained a particular number of children will subsequently transition to give birth to another child. In demographic accounting, a woman's parity is defined as the total cumulative number of live births she has successfully experienced. Consequently, the single-step parity progression ratio transitioning from parity i to parity $i+1$ represents the precise proportion of women who, having experienced at least i live births, proceed further to have at least one additional birth [4,13]. PPR is calculated in following manner [13,14].

W_i = *number of women at parity i.*

$P_i = \sum_{a=i}^{l} W_a$ = *number of women at parity i or greater*

B_i = *number of births of parity I* = P_i *(for all i>0)*

$$PPR_{(i,i+1)} = \frac{B_{i+1}}{B_i} \quad \dots (1)$$

$$PPR_{(o,i)} = \frac{P_i}{P_0} = \prod_{a=0}^{i-1} PPR_{(a,a+1)} \quad \dots (2)$$

$$TFR = \frac{B}{W} = \frac{\sum_{i=1}^{l} B_i}{W} = \sum_{i=1}^{l} PPR_{(0,i)} \quad \dots (3)$$

b. Elasticity of Parity Progression Ratio

It is computed in following manner:

$$E = \frac{\left(\frac{dy}{y}\right)}{\left(\frac{dx}{x}\right)} = \left(\frac{dy}{dx}\right) \cdot \left(\frac{x}{y}\right) \dots (4)$$

In this equation, y represents the fitted quadratic polynomial equation explaining PPR (as presented in Table 4), and x denotes the specific parity order. The differential derivative term $\frac{dy}{dx}$ indicates the change in PPR relative to a single unit change in parity, thereby measuring the sensitivity of PPR to parity shifts. Ultimately, this elasticity equation expresses the relative proportional change in PPR with respect to a relative proportional change in parity x.

c. Age-Specific Probability of First Marriage

The age-specific probability of first marriage calculates the proportion of total marriages that occur within a specific age bracket, illustrating how first marriages are distributed across different ages [13].

Mathematical Formulas

For females:

$$P_f(x) = \frac{MF_x}{\sum MF_x} \quad \dots (5)$$

For males:

$$P_m(x) = \frac{MM_x}{\sum MM_x} \dots (6)$$

Where:

- $P_f(x)$ = Probability of marriage for females in age group x
- $P_m(x)$ = Probability of marriage for males in age group x
- MF_x = Number of married females in age group x
- MM_x = Number of married males in age group x
- $\sum M\,F_x$ = Total number of married females
- $\sum M\,M_x$ = Total number of married males

3. Result and Discussion

The regional trends in PPR are explained in Table 1 and figure 1 given below. It can be seen that PPR decline steadily with increasing parity across all seven provinces and the Kathmandu Valley, indicating a common pattern of reduced birth progression at higher birth orders. Despite this overall trend, considerable regional variation is evident. The progression from childlessness to the first birth remains consistently high, ranging from 0.8561 in the Kathmandu Valley to 0.8877 in Sudur Paschim. Thereafter, progression ratios decrease markedly, reflecting a strong tendency to limit childbearing after two births. The Kathmandu Valley records the lowest progression ratios at each parity level, with values declining from 0.5210 at parity one to 0.1242 at parity two, representing a reduction of more than 76% and indicating a strong tendency to limit childbearing beyond the second birth. In contrast, Madhesh and Karnali maintain comparatively higher progression ratios at later parities. At parity two, the progression ratio reaches 0.4600 in Madhesh and 0.4182 in Karnali. Beyond parity three, progression ratios approach zero in all regions, indicating that progression to higher-order births has become increasingly uncommon.

Table 1: PPR Female in seven provinces of Nepal and Kathmandu Valley, Census 2021

Provi	Koshi	Madhesh	Bagmati	Gandaki	Lumbini	Karnali	Sudur Paschim	Kathmandu Valley
0	0.8847	0.885	0.8715	0.8764	0.8762	0.8863	0.8877	0.8561
1	0.6135	0.7289	0.583	0.6207	0.6472	0.6979	0.6837	0.521
2	0.2595	0.46	0.2084	0.2374	0.3135	0.4182	0.388	0.1242
3	0.1021	0.2145	0.0781	0.0808	0.1375	0.2223	0.1927	0.0297
4	0.0402	0.0839	0.0305	0.0282	0.0578	0.107	0.0858	0.0079
5	0.0162	0.0311	0.0123	0.01	0.0235	0.0484	0.0355	0.0024
6	0.0064	0.0108	0.0049	0.0035	0.0093	0.0208	0.0139	0.0008
7	0.0026	0.0037	0.0019	0.0012	0.0036	0.0086	0.0053	0.0003
8	0.0008	0.001	0.0006	0.0004	0.0011	0.0029	0.0016	0.0001

Figure 1: PPR Female in seven provinces of Nepal and Kathmandu Valley, Census 2021

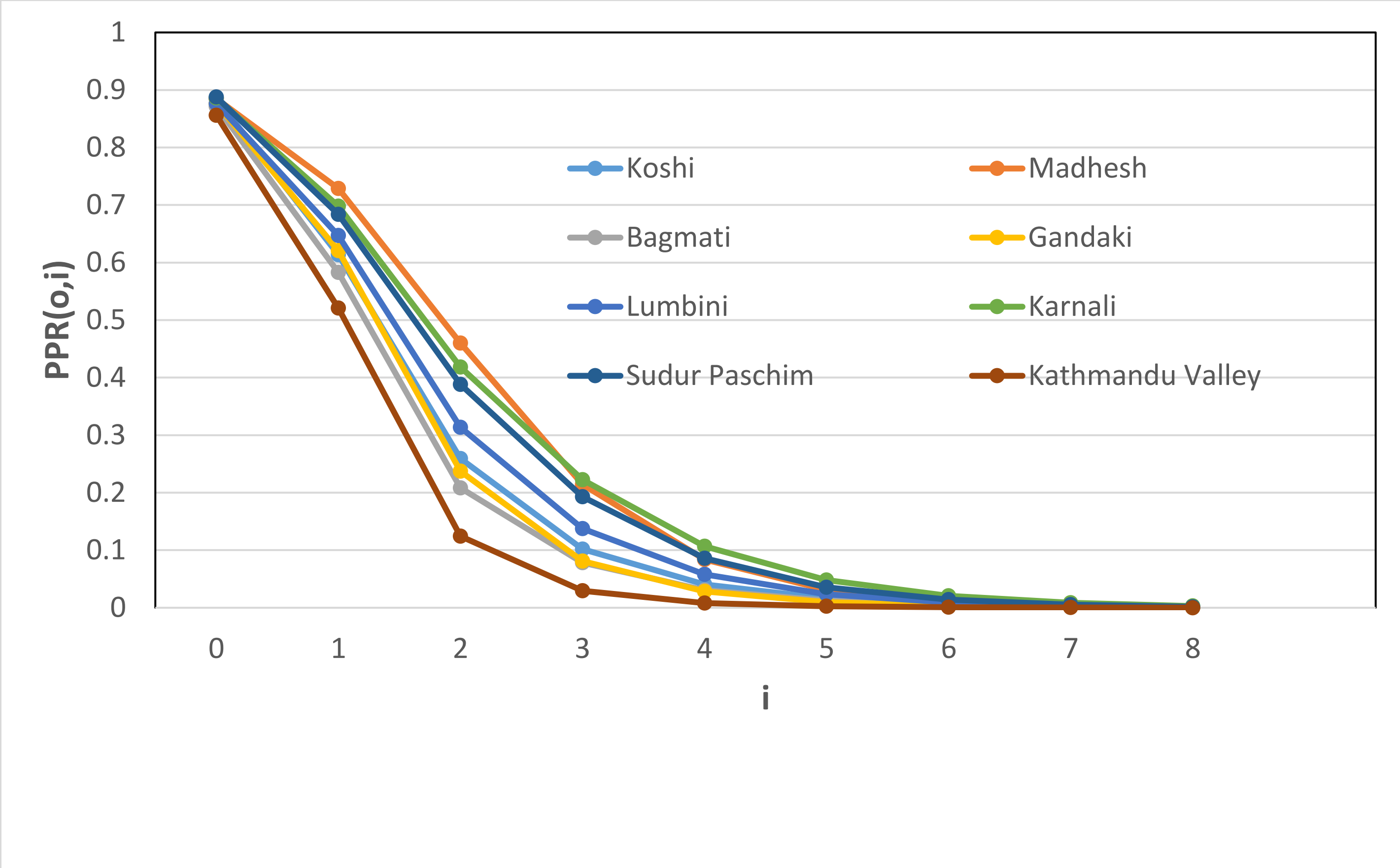


Table 2: TFR by PPR and Census in different places of Nepal, 2021

Sr. No.	Region	$PPR(0,i)$ TFR	Census TFR	$y = PPR(0,i)$	R^2
1	Koshi	1.926	1.81	$y = 0.026i^2 - 0.307i + 0.855$	0.971
2	Madhesh	2.419	2.85	$y = 0.022i^2 - 0.289i + 0.926$	0.987
3	Bagmati	1.791	1.37	$y = 0.027i^2 - 0.309i + 0.828$	0.9588
4	Gandaki	1.859	1.54	$y = 0.027i^2 - 0.314i + 0.851$	0.964
5	Lumbini	2.070	1.84	$y = 0.025i^2 - 0.299i + 0.869$	0.981
6	Karnali	2.412	2.19	$y = 0.021i^2 - 0.279i + 0.904$	0.992
7	Sudur Paschim	2.294	1.88	$y = 0.023i^2 - 0.289i + 0.899$	0.990
8	Kathmandu Valley Combine	1.542		$y = 0.028i^2 - 0.3121i + 0.784$	0.9301

Table 2 compares the TFR estimated using the PPR method with the corresponding 2021 Census estimates across the seven provinces of Nepal and the Kathmandu Valley. The table also presents the fitted quadratic polynomial equations and their coefficients of determination (R^2). The PPR-based estimates indicate above-replacement fertility in Madhesh (2.419), Karnali (2.412), and Sudur Paschim (2.294), whereas Koshi (1.926), Gandaki (1.859), Bagmati (1.791), the Kathmandu Valley (1.542), and Lumbini (2.070) record fertility at or below the replacement level. In six of the seven provinces, the PPR-based TFR is higher than the corresponding Census estimate. Madhesh is the only province where the Census TFR (2.850) exceeds the PPR estimate (2.419). This difference may be associated with the high prevalence of early marriage and cross-border population mobility during the census enumeration period. The fitted quadratic models show an excellent fit across all regions, with R^2 values ranging from 0.9301 in the Kathmandu Valley to 0.9920 in Karnali, indicating that the models adequately represent the observed parity progression patterns.

Table 3: PPR of female aged 20-35 seven provinces of Nepal and Kathmandu Valley, 2021

prov / i	Koshi 20-35	Madhesh (20-35)	Bagmati 20-35)	Gandaki 20-35)	Lumbini 20-35)	Karnali 20-35)	Sudur Paschim (20-35)	Kathmandu Valley (20-35)
0	0.855	0.8679	0.8178	0.8429	0.848	0.885	0.8684	0.7758
1	0.469	0.6519	0.4144	0.4658	0.5133	0.6187	0.5622	0.3306
2	0.132	0.3397	0.0947	0.1003	0.1687	0.2619	0.2196	0.0486
3	0.035	0.1229	0.0237	0.0201	0.0511	0.0936	0.0733	0.0084
4	0.009	0.0349	0.0063	0.0044	0.0149	0.0298	0.0217	0.0017
5	0.003	0.0095	0.0018	0.0011	0.0043	0.0094	0.006	0.0004
6	0.001	0.0022	0.0005	0.0003	0.0011	0.0028	0.0015	0.0001
7	0.000	0.0005	0.0001	0.0001	0.0002	0.0008	0.0004	0
8	0	0	0	0	0	0.0001	0	0

It is clear form table 3 that the age-specific $PPR_{(o,i)}$ for birth orders (i = 0–8) among women aged 20–35 years across the seven provinces of Nepal and the Kathmandu Valley, based on the 2021 Census. Progression to the first birth is highest in Karnali (0.8850), Sudur Paschim (0.8684), and Madhesh (0.8679), but comparatively lower in Bagmati (0.8178) and the Kathmandu Valley (0.7758), indicating delayed entry into motherhood in more urbanized areas. The regional gap widens at the second birth, where the progression ratio reaches 0.6519 in Madhesh and 0.6187 in Karnali but declines to 0.4144 in Bagmati and 0.3306 in the Kathmandu Valley. A similar pattern is observed at the third birth, with progression remaining relatively high in Madhesh (0.3397), Karnali (0.2619), and Sudur Paschim (0.2196), while falling to 0.0947 in Bagmati and only 0.0486 in the Kathmandu Valley. Progression to higher-order births ($i \geq 3$) decreases sharply in all regions. The cumulative PPR indicates that completed fertility by age 35 is highest in Madhesh (2.0295 births per woman), followed by Karnali (1.9021) and Sudur Paschim (1.7531), whereas Bagmati (1.3593) and the Kathmandu Valley (1.1656) record the lowest levels. These findings suggest that urban and hill regions are experiencing a faster shift towards one- and two-child families, while the lowland and mountain provinces continue to exhibit higher parity progression.

Table 4: PPR female aged 35-49 seven provinces of Nepal, 2021

Prov i	Koshi 35-49	Madhesh 35-49	Bagmati 35-49	Gandaki 35-49	Lumbini 35-49	Karnal 35-49	Sudur Paschim 35-49	Kathmandu Valley 35-49
0	0.9475	0.9543	0.9426	0.943	0.9504	0.9602	0.9595	0.9394
1	0.8132	0.8932	0.7725	0.8293	0.8655	0.9147	0.8984	0.7052
2	0.4183	0.6638	0.3295	0.4037	0.522	0.7073	0.6391	0.1958
3	0.1835	0.3573	0.1353	0.1531	0.2581	0.4408	0.3631	0.0498
4	0.0777	0.1572	0.0557	0.0566	0.1168	0.2337	0.1757	0.0137
5	0.0326	0.0631	0.0232	0.021	0.0498	0.1116	0.0766	0.0043
6	0.0133	0.0233	0.0094	0.0077	0.0204	0.0497	0.0311	0.0014
7	0.0054	0.0084	0.0037	0.0029	0.0081	0.0211	0.012	0.0006
8	0.0018	0.0024	0.0011	0.0008	0.0025	0.0073	0	0.0001

It can be observed from table 4 that the $PPR_{(o,i)}$ for birth orders (i = 0–8) among women aged 35–49 years across the seven provinces of Nepal and the Kathmandu Valley. The results show a steady decline in parity progression as birth order increases in all regions. Progression to the first birth is nearly universal, with values ranging from 0.9394 to 0.9602. Regional differences become more pronounced at higher birth orders. Madhesh Province records high progression ratios at the second and third births (0.8932 and 0.6638, respectively), while Karnali exhibits the highest progression to higher-order births, with values of 0.7073 at parity two, 0.4408 at parity three, and 0.2337 at parity four. Sudur Paschim and Lumbini also maintain relatively high progression to larger family sizes. In contrast, Bagmati, Gandaki, and particularly the Kathmandu Valley show the lowest progression ratios across most birth orders. In the Kathmandu Valley, the progression ratio declines sharply to 0.1958 at parity two and 0.0498 at parity three. Compared with women aged 20–35 years, those aged 35–49 years exhibit consistently higher PPR values at all birth orders, reflecting their longer exposure to childbearing. The cumulative PPR indicates that achieved fertility by age 49 is highest in Karnali (3.4464 births per woman), followed by Sudur Paschim (3.1555) and Madhesh (3.1230), while Bagmati (2.2730) and the Kathmandu Valley (1.9103) record the lowest levels. These results represent near-completed lifetime fertility and reflect fertility patterns before the recent decline in national fertility.

Figure 2: PPR Female of Overall Nepal, 2021

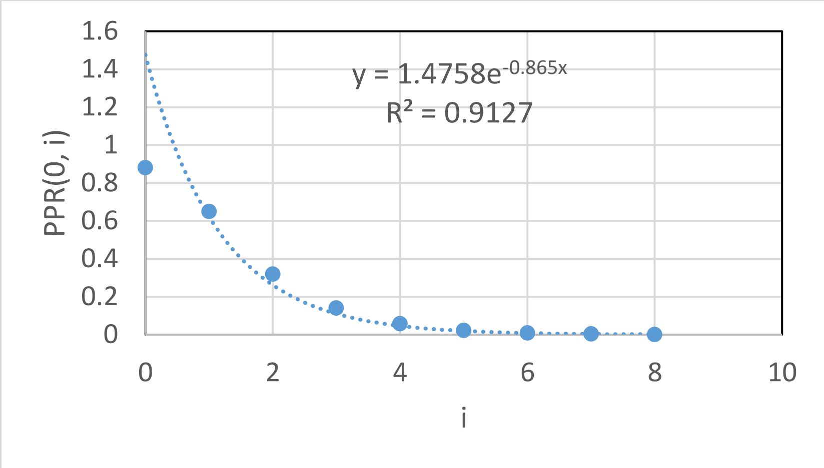


Figure 2 Illustrates the cumulative $PPR_{(o,i)}$ for females in Nepal. The results show high progression to the first and second births, with 88.01% of women progressing to the first birth and 64.91% to the second birth. Beyond the second birth, cumulative progression declines sharply, falling to 14.02% at the third birth. Progression to higher-order births declines rapidly, with only 5.74% of women progressing beyond the fourth birth and fewer than 1% reaching the sixth birth or higher.

Figure 3: $\mathbf{PPR_{(o,i)}}$ of female aged 20-35 and 35-49 Nepal, 2021

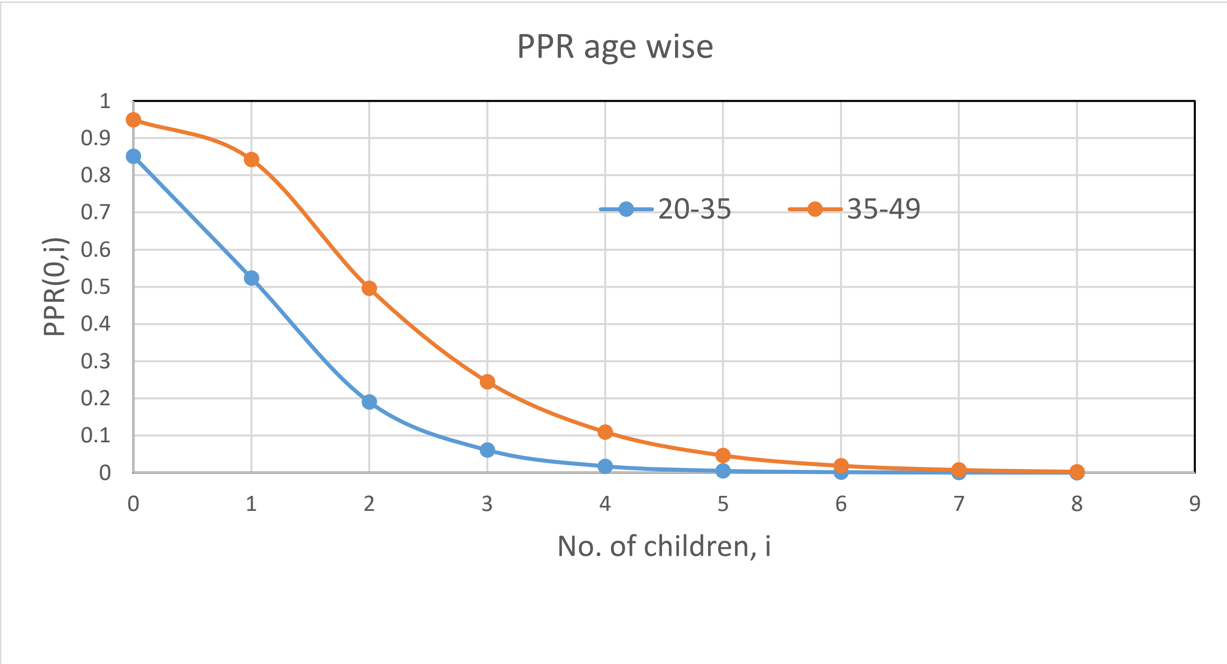


Figure 3 compares the cumulative $PPR_{(o,i)}$ of Nepalese women aged 20–35 and 35–49 years. The older age cohort consistently exhibits higher cumulative progression ratios across all birth orders than the younger cohort. Progression to the first birth declines from 94.95% among women aged 35–49 years to 85.15% among those aged 20–35 years. Similarly, progression to the second birth decreases from 84.25% to 52.39%. In both cohorts, cumulative PPR declines steadily with increasing birth order, with the most pronounced reduction occurring after the second birth. The cumulative PPR further indicates a decline in the estimated completed fertility from 2.72 children per woman in the older cohort to 1.65 children per woman in the younger cohort, reflecting lower parity progression among younger women.

Table 5 : Elasticity of PPR in the Seven Provinces of Nepal, 2021

Parity	Koshi	Madhesh	Bagmati	Gandaki	Lumbini	Karnali	Sudur Paschim	Kathmandu Valley
0	0	0	0	0	0	0	0	0
1	-0.42	-0.34	-0.44	-0.42	-0.38	-0.34	-0.36	-0.51
2	-1.97	-0.87	-1.94	-1.74	-1.27	-0.93	-1.02	-3.54
3	-7.53	-2.2	-5.7	-5.65	-3.27	-2.05	-2.39	-17.57
4	-25.5	-5.39	-12.45	-13.98	-6.98	-4.09	-5.05	-64.81
5	-79.04	-11.08	-16.88	-22.26	-11.01	-6.93	-8.88	-169.85
6	-238.67	-13.83	14.7	15.47	-1.81	-7.13	-7.71	-285.66
7	-699.44	35.56	243.45	368.23	90.63	14.4	36.11	224.97
8	-2503.76	504.02	1674.77	2402.4	707.49	166.88	360.28	6154.25

Table 5 presents the absolute elasticity of the PPR across birth orders (x = 0–8) for the seven provinces of Nepal and the Kathmandu Valley. The elasticity values are calculated from the fitted quadratic models presented in Table 2 and measure the responsiveness of parity progression to increasing birth order. At parity one, elasticity remains inelastic ($|E| < 1$) in all regions. The Kathmandu Valley records the highest value (0.51), followed by Bagmati Province (0.44). A clear shift occurs at parity two, where elasticity exceeds one in most regions, indicating greater responsiveness to higher birth orders. The Kathmandu Valley exhibits the highest elasticity (3.54), followed by Koshi (1.97), Bagmati (1.94), and Gandaki (1.74). Elasticity increases further at parities three and four. The Kathmandu Valley continues to show the highest values (17.57 and 64.81), reflecting a rapid decline in progression beyond the first and second births. Koshi also records relatively high elasticity (7.53 and 25.50). In contrast, Karnali (2.05 and 4.09) and Madhesh (2.20 and 5.39) display the lowest elasticity values, indicating continued progression to higher-order births. The very high elasticity observed at parities six and above mainly reflects the mathematical behavior of the fitted quadratic models as progression probabilities approach zero, rather than substantial demographic change.

Table 6: PPR Equations and R^2 values for seven provinces of Nepal and Kathmandu valley Women Aged 20-35 and 35-49, census 2021

S.N.	Provinces/ region	Age 20-35	R^2	Age 35-49	R^2
1	Koshi	$y = 0.0274x^2 - 0.3048x + 0.7647$	0.931	$y = 0.0256x^2 - 0.324x + 0.9935$	0.9754
2	Madhesh	$y = 0.0251x^2 - 0.3043x + 0.8739$	0.9826	$y = 0.0187x^2 - 0.2838x + 1.0577$	0.9692
3	Bagmati	$y = 0.0265x^2 - 0.2907x + 0.7133$	0.9122	$y = 0.0274x^2 - 0.3331x + 0.9635$	0.9674

4	Gandaki	$y = 0.0277x^2 - 0.3049x + 0.7507$	0.9184	$y = 0.0269x^2 - 0.3348x + 0.998$	0.9669
5	Lumbini	$y = 0.0268x^2 - 0.3028x + 0.7821$	0.9485	$y = 0.0226x^2 - 0.3071x + 1.0264$	0.9762
6	Karnali	$y = 0.0267x^2 - 0.3134x + 0.8601$	0.9716	$y = 0.0146x^2 - 0.2527x + 1.062$	0.9716
7	Sudur Paschim	$y = 0.0267x^2 - 0.3083x + 0.8219$	0.9639	$y = 0.0184x^2 - 0.2802x + 1.055$	0.9748
8	Kathmandu Valley	$y = 0.0254x^2 - 0.2731x + 0.6465$	0.8755	$y = 0.0308x^2 - 0.3516x + 0.9202$	0.9407

Mathematical representations specially second-degree quadratic polynomials and R^2 values for PPR among women aged 20-35 and 35-49 across provinces are compiled in Table 6. The fitted quadratic models show a high level of agreement with the observed PPR data in all study regions. For women aged 20–35 years, the R^2 values range from 0.8755 to 0.9826, while for women aged 35–49 years they range from 0.9407 to 0.9762, indicating an excellent model fit for both age groups. Overall, the older cohort exhibits slightly higher and more consistent R^2 values across regions than the younger cohort. The estimated regression coefficients also differ between the two age groups, with the intercept values generally higher among women aged 35–49 years. These results indicate differences in the fitted parity progression patterns between the two cohorts. The validated quadratic equations provide the mathematical basis for estimating the elasticity of the PPR.

Table 7: Elasticity of PPR age 20-35 seven provinces of Nepal and Kathmandu Valley, 2021

i	Koshi	Madhesh	Bagmati	Gandaki	Lumbini	Karnali	Sudur Paschim	Kathmandu Valley
0	0	0	0	0	0	0	0	0
1	-0.53	-0.39	-0.57	-0.54	-0.49	-0.42	-0.45	-0.67
2	-2.95	-1.2	-3.9	-3.87	-2.32	-1.58	-1.84	-7.05
3	-11.98	-3.75	-16.7	-20.73	-8.34	-4.91	-6.06	-43.28
4	-38.2	-11.85	-50	-75.94	-23.66	-13.38	-17.46	-164.98
5	-62.07	-28.18	-70.12	-132.18	-40.04	-24.6	-34.48	-231.82
6	217.34	-8.3	331.05	588.36	99.36	15.24	48.75	1892.96
7	2905.6	632.86	5005.22	8736.77	2203.32	552.43	1150.79	19158.5
8	35187.43	15820.22	81900.99		30676.01	11003.21	22405	

Table 7 tabulates PPR elasticity metric across the seven provinces and capital valley for women aged 20–35. The elasticity values measure the responsiveness of parity progression to increasing birth order. At parity one, elasticity remains below one in all study regions, indicating relatively low responsiveness. The highest values are observed in the Kathmandu Valley (0.67), followed by Bagmati (0.57) and Gandaki (0.54). From parity two onward, elasticity exceeds one in every region, suggesting that parity progression becomes increasingly responsive as birth order increases. The Kathmandu Valley records the highest elasticity at parity two (7.05), followed by Bagmati (3.90), Gandaki (3.87), Koshi (2.95), and Lumbini (2.32). Although Madhesh (1.20), Karnali (1.58), and Sudur Paschim (1.84) exhibit comparatively lower elasticity, their values also exceed unity at parity two, indicating greater responsiveness to higher-order births. Elasticity increases further at parities three and four, with the Kathmandu Valley reaching the highest values (43.28 and 164.98, respectively).

Table 8: Elasticity of PPR aged 35-49 for seven provinces of Nepal & Kathmandu Valley, 2021

i	Koshi	Madhesh	Bagmati	Gandaki	Lumbini	Karnali	Sudur Paschim	Kathmandu Valley
0	0	0	0	0	0	0	0	0
1	-0.34	-0.28	-0.36	-0.34	-0.3	-0.24	-0.27	-0.41
2	-1.06	-0.63	-1.36	-1.13	-0.83	-0.55	-0.65	-2.33
3	-2.79	-1.44	-3.74	-3.4	-1.99	-1.12	-1.4	-10.04
4	-6.14	-3.41	-8.18	-8.46	-4.33	-2.33	-3.03	-30.62
5	-10.44	-7.68	-12.76	-15.69	-8.15	-4.78	-6.28	-50.72
6	-7.57	-15.26	-2.75	-9.32	-10.57	-9.35	-11.45	78.56
7	44.76	-18.36	95.46	100.3	8.04	-16.02	-13.14	980.65
8	391.06	52.16	739.65	910.04	175.19	-20.89	30.18	8038.63

Table 8 details how PPR elasticity varies across regions among women aged 35–49 . At parity one, the Kathmandu Valley records the highest elasticity (|E| = 0.41), whereas Karnali Province has the lowest value (|E| = 0.24). At parity two, elasticity exceeds one only in the Kathmandu Valley (2.33), while Karnali (0.55) and Madhesh (0.63) remain below the unity threshold. Elasticity increases further with higher birth orders, reaching 10.04 at parity three and 30.62 at parity four in the Kathmandu Valley, compared with 1.12 and 2.33, respectively, in Karnali Province. These results indicate substantially greater responsiveness of parity progression to increasing birth order in the Kathmandu Valley than in the other regions, whereas Karnali exhibits the lowest responsiveness and continued progression to higher-order births.

A comparison of the two age cohorts further shows that elasticity increases with birth order in both groups. However, women aged 20–35 years consistently exhibit higher elasticity than those aged 35–49 years at comparable birth orders. This pattern suggests greater responsiveness of parity progression among the younger cohort. The regional pattern also remains consistent across both age groups, with the Kathmandu Valley showing the highest elasticity and Karnali Province the lowest.

Table 9: Age specific probability of first marriage of Male and Female, Nepal 2021

Table 9 outlines the age-specific first- marriage probability for females and males across Nepal. The results

Age	Male	Female	$P_f(x)$	Pm(x)
Below 10 years	8575	45773	0.005	0.001204919
10-15	214266	910939	0.102	0.030107667
15-18	872401	2703376	0.303538284	0.122585753
18-21	2318006	3193620	0.358583465	0.32571548
21-25	1908640	1384650	0.155470154	0.268193263
25-30	1322893	522708	0.058690278	0.185886804
30-35	355450	95066	0.010674124	0.04994619
35-40	76590	22477	0.002523744	0.010762072
40-45	20210	6614	0.000742628	0.002839816
45-50	4915	1502	0.000168646	0.000690633
50 and above	2813	833	9.35302E-05	0.00039527
not stated	11900	18653	0.002094381	0.001672133
Total	7116659	8906211		

show clear gender differences in the timing of first marriage. Among females, the highest probability of first marriage is observed in the 18–21-year age group (0.3586), followed by the 15–18-year group (0.3035). Overall, 66.21% of first marriages among females occur between the ages of 15 and 21, while 41.08% take place before the legal minimum age of 18. After age 21, the probability of first marriage declines markedly, with only 22.84% of women entering their first marriage at older ages. In contrast, the age distribution of first marriage is more dispersed among males. Although the highest probability also occurs between ages 18 and 21 (0.3257), substantial proportions of first marriages continue at ages 21–25 (0.2682) and 25–30 (0.1859). Consequently, 51.87% of males enter their first marriage at age 21 or above, whereas only 15.39% marry before age 18. These indicate that females generally enter first marriage at younger ages than males, resulting in a distinct gender gap in the timing of first marriage in Nepal

Figure 4: Age at First Marriage for Males and Females, Nepal 2021

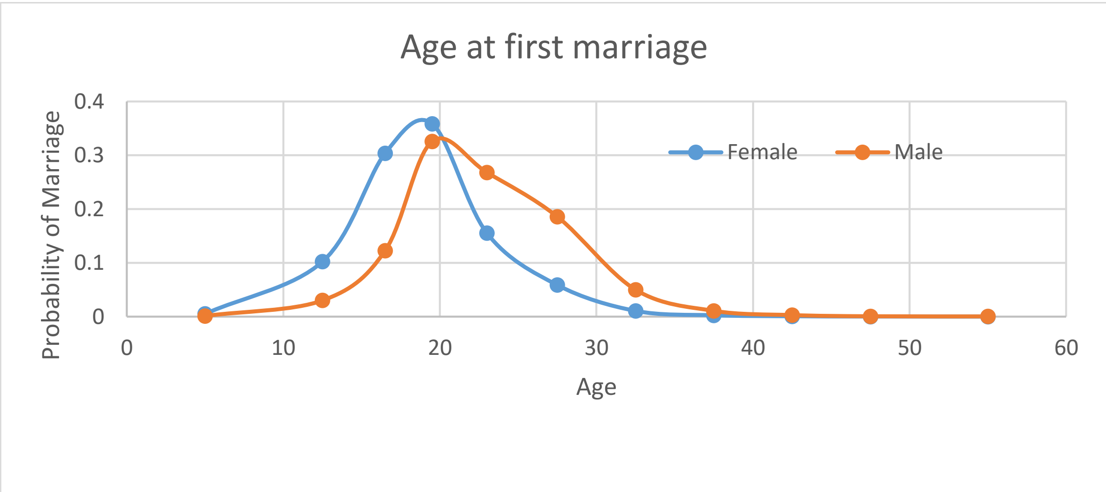
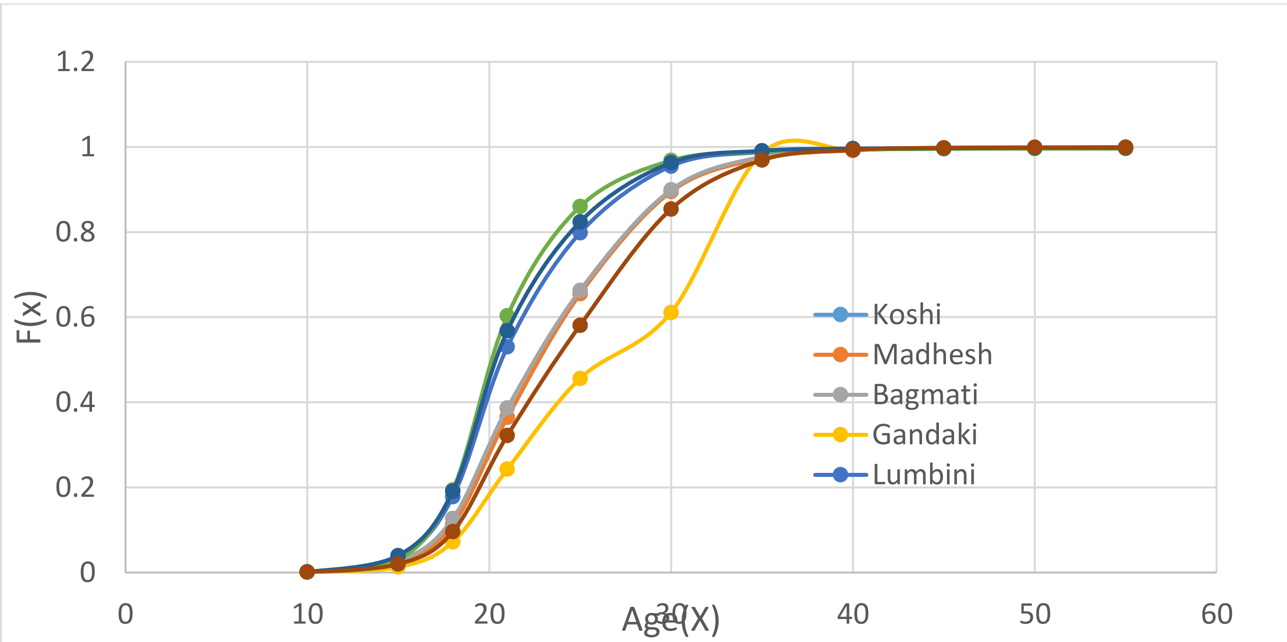


Figure 4 depicts the probability distribution of age at first marriage for both males and females in Nepal. For both sexes, the highest probability of first marriage occurs between ages 18 and 20, accounting for 35.86% of female marriages and 32.57% of male marriages. Female marriage is concentrated at younger ages, with 41.10% of first marriages occurring before age 18, compared with 15.39% among males. After age 20, the probability of first marriage becomes higher among males. Between ages 21 and 29, 45.41% of males and 21.42% of females enter their first marriage. The probability of first marriage declines rapidly after age 30. By this age, the cumulative proportion married reaches 98.37% for females and 93.37% for males, indicating that first marriage is nearly universal by early adulthood.

Table 10: Cumulative Distribution Function (CDF) of Male Marriage in the Seven Provinces of Nepal and Kathmandu Valley, 2021

Less than age	Koshi	Madhesh	Bagmati	Gandaki	Lumbini	Karnali	Sudur Paschim	Kathmandu Valley
10	0.0012	0.0012	0.0014	0.001	0.001	0.001	0.001	0.001
15	0.024	0.024	0.0276	0.0201	0.036	0.030	0.040	0.02
18	0.1130	0.113	0.127	0.108	0.178	0.194	0.191	0.096
21	0.365	0.365	0.3865	0.366	0.530	0.603	0.568	0.322
25	0.655	0.655	0.663	0.687	0.798	0.86	0.824	0.581
30	0.895	0.895	0.899	0.921	0.955	0.968	0.963	0.854
35	0.973	0.973	0.977	1.485	0.988	0.989	0.991	0.969
40	0.992	0.992	0.993	1.498	0.994	0.994	0.996	0.993
45	0.997	0.997	0.998	1.501	0.996	0.9956	0.997	0.998
50	0.998	0.998	0.998	1.502	0.997	0.996	0.998	0.999
55	0.9993	0.999	0.9995	1.5034	0.9973	0.996	0.998	0.999

Figure 5: CDF of Male Marriage by Age in seven provinces of Nepal and Kathmandu Valley, Census 2021



The cumulative distribution function (CDF) for male first marriage across Nepal's seven provinces and the Kathmandu Valley is reported in Table 10 and figure 5. The cumulative distributions reveal clear regional differences in the timing of first marriage. Karnali, Sudur Paschim, and Lumbini exhibit the highest cumulative proportions of male first marriage before age 18, at 19.4%, 19.1%, and 17.8%, respectively. These provinces also reach the median cumulative probability of first marriage (F(x) = 0.50) before age 21. Karnali records the earliest pattern, with 60.3% of males entering first marriage before age 21. In contrast, Koshi, Madhesh, Bagmati, and Gandaki show lower cumulative proportions before age 21, with fewer than 39% of males married by this age. The latest pattern is observed in the Kathmandu Valley, where only 9.6% of males marry before age 18 and 32.2% before age 21. By age 30, the cumulative probability of first marriage exceeds 95% in Karnali, Sudur Paschim, and Lumbini, whereas the corresponding value in the Kathmandu Valley is 0.854, indicating that approximately 15% of males remain unmarried at this age. Overall, the cumulative distribution curves demonstrate substantial regional variation in the timing of male first marriage, with earlier marriage observed in western provinces and later marriage in the Kathmandu Valley and other more urbanized regions.

Table 11: **Cumulative Distribution Function (CDF) of Female Marriage in the Seven Provinces of Nepal, 2021**

Less than age	Koshi	Madhesh	Bagmati	Gandaki	Lumbini	Karnali	Sudur Paschim	Kathmandu Valley
10	0.0044	0.0031	0.0056	0.0075	0.0059	0.002	0.0077	0.003
15	0.0833	0.1414	0.0899	0.0929	0.1094	0.0945	0.1391	0.062
18	0.3432	0.5221	0.3355	0.3711	0.4305	0.4454	0.4574	0.264
21	0.6944	0.8919	0.6701	0.7258	0.8006	0.8249	0.8303	0.582
25	0.8935	0.9719	0.8762	0.9134	0.9446	0.9512	0.9551	0.813
30	0.9745	0.9948	0.9743	0.9789	0.9887	0.9881	0.9917	0.96
35	0.9924	0.9977	0.9937	0.9903	0.9948	0.9935	0.9964	0.992
40	0.9972	0.9983	0.9978	0.9935	0.9962	0.9948	0.9974	0.997
45	0.9987	0.9985	0.9989	0.9944	0.9967	0.9952	0.9977	0.998
50	0.9989	0.9986	0.9991	0.9947	0.9968	0.9953	0.9978	0.999
55	0.9991	0.9986	0.9992	0.9948	0.9968	0.9953	0.9978	0.999

Figure 6: CDF of Female Marriage by Age in seven provinces of Nepal, Census 2021

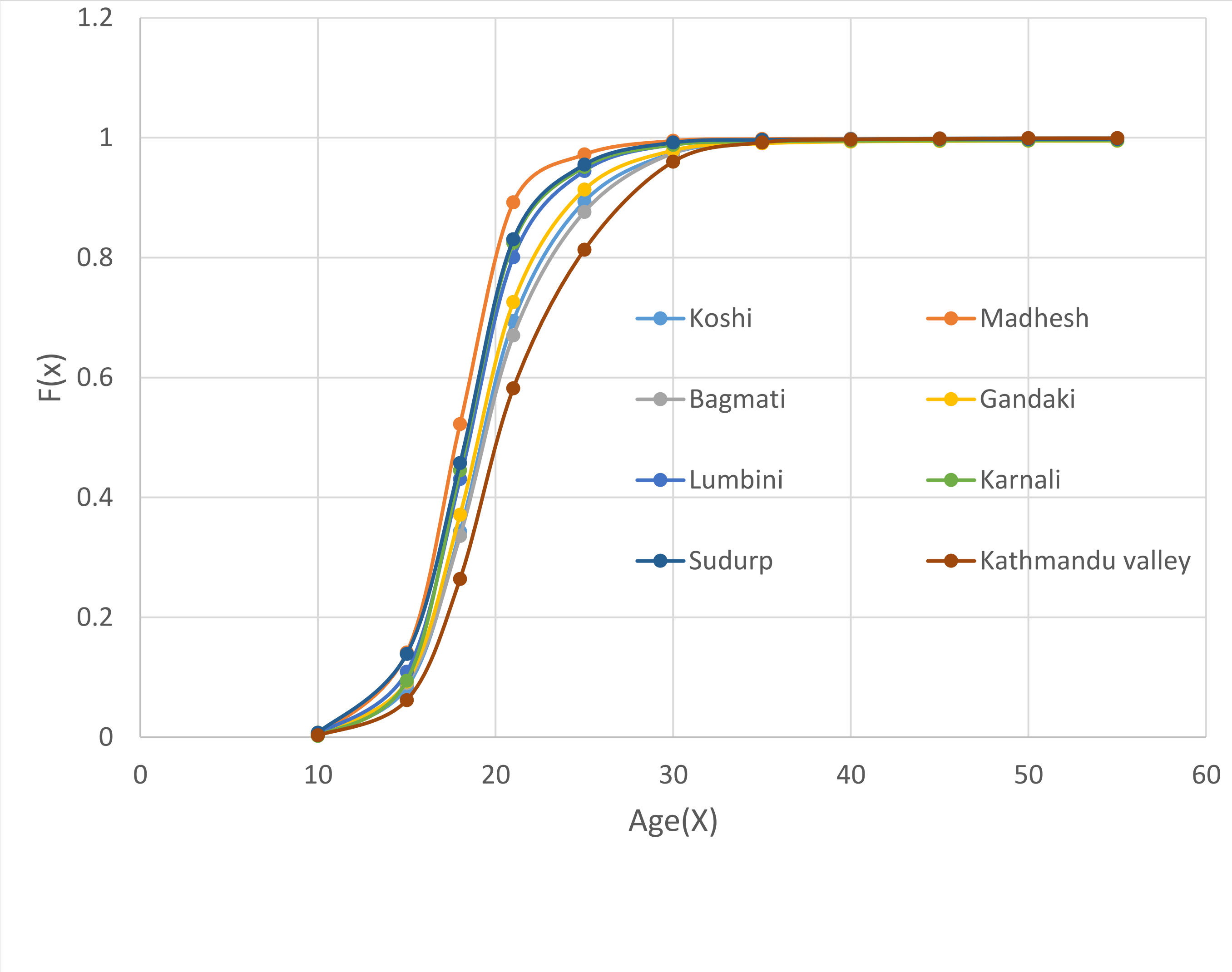


Table 11 and Figure 6 delineate the cumulative distribution function (CDF) of first marriage among females across regions. The cumulative distributions reveal substantial regional differences in the timing of first marriage. Madhesh Province records the earliest pattern, with 14.14% of females marrying before age 15 and 52.21% before age 18. It is also the only region where the median age at first marriage occurs before 18 years. High levels of early marriage are also observed in Sudur Paschim (45.74%), Karnali (44.54%), and Lumbini (43.05%), where more than 80% of females are married by age 21. In contrast, Koshi, Bagmati, and Gandaki exhibit lower proportions of marriage before age 18, ranging from 33.55% to 37.11%, with the median age at first marriage occurring around 20 years. The latest pattern is observed in the Kathmandu Valley, where 26.40% of females marry before age 18 and 58.20% before age 21, resulting in the highest median age at first marriage. Compared with the male cumulative distributions, females consistently enter first marriage at younger ages across all regions, indicating a persistent gender difference in the timing of first marriage in Nepal.

Figure 7: Gender differential of CDF for age at first marriage, Nepal 2021

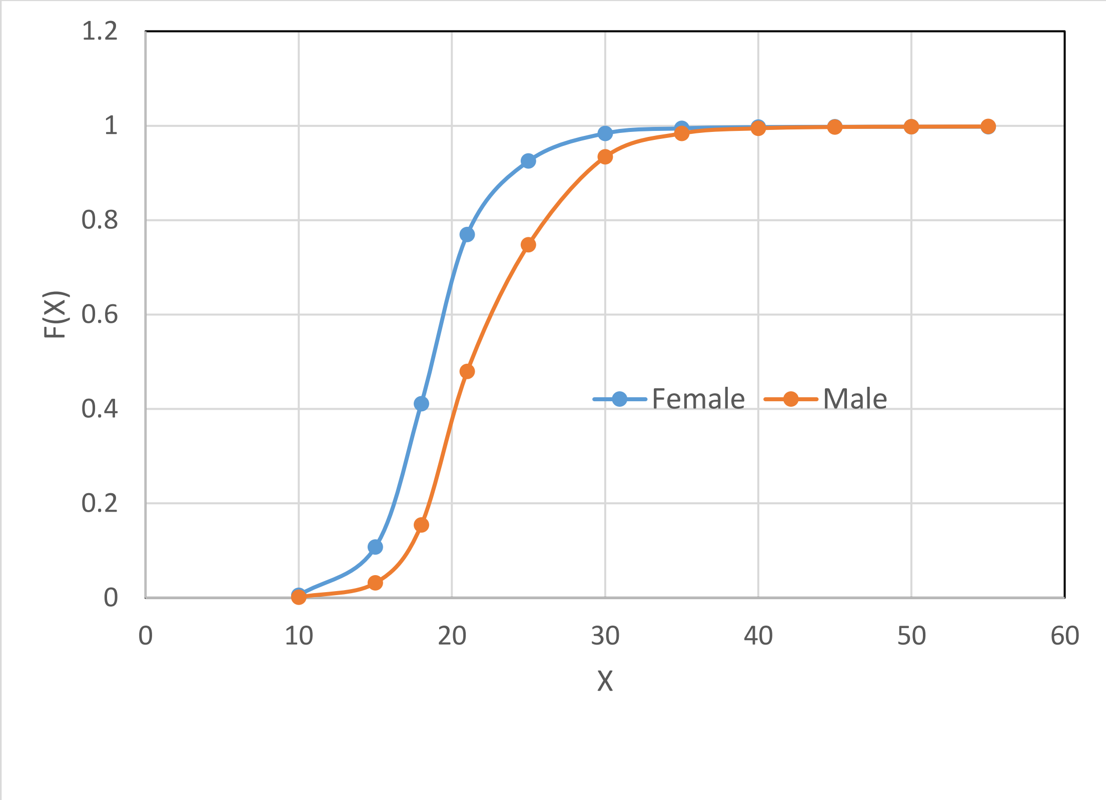


Figure 7 illustrates the cumulative distribution functions (CDFs) of age at first marriage for males and females in Nepal. The CDF curves show clear gender differences in the timing of first marriage. By age 18, 41.10% of females have entered their first marriage, compared with 15.39% of males. The gender difference is greatest by age 21, when the cumulative proportion married reaches 76.95% for females and 47.96% for males. After age 30, the two curves gradually converge, with cumulative marriage proportions of 98.37% for females and 93.37% for males. Beyond age 35, both distributions approach complete marriage, reaching 99.44% among females and 98.36% among males. These results indicate that first marriage occurs earlier among females than males, while the gender difference narrows substantially at older ages.

Table 12: Probability that Age at first marriage is at most X, Census 2021

Sr. No.	Region	Male	R^2	Female	R^2
1	Koshi	$y = 3E\text{-}06x^4 - 0.0004x^3 + 0.0187x^2 - 0.2833x + 1.3357$	0.991	$y = 2E\text{-}06x^4 - 0.0003x^3 + 0.0098x^2 - 0.0843x + 0.053$	0.963
2	Madhesh	$y = 3E\text{-}06x^4 - 0.0004x^3 + 0.0155x^2 - 0.1963x + 0.7125$	0.9626	$y = 1E\text{-}06x^4 - 0.0001x^3 + 0.0018x^2 + 0.0784x - 0.9375$	0.9371
3	Bagmati	$y = 3E\text{-}06x^4 - 0.0004x^3 + 0.0181x^2 - 0.2711x + 1.2594$	0.9912	$y = 2E\text{-}06x^4 - 0.0003x^3 + 0.0102x^2 - 0.0945x + 0.1253$	0.9687

4	Gandaki	y =3E-06x^4 - 0.0005x^3 + 0.0225x^2 - 0.3736x + 1.9279	0.9905	y =2E-06x^4 - 0.0002x^3 + 0.0087x^2 - 0.0613x - 0.0873	0.9582
5	Lumbini	y =3E-06x^4 - 0.0004x^3 + 0.0165x^2 - 0.2234x + 0.9025	0.9754	y =2E-06x^4 - 0.0002x^3 + 0.006x^2 - 0.0063x - 0.4277	0.9485
6	Karnali	y =3E-06x^4 - 0.0004x^3 + 0.0157x^2 - 0.2001x + 0.7286	0.9613	y =0.0246i^2 − 0.2997i + 0.8734	0.992
7	Sudurpashc	y =3E-06x^4 - 0.0004x^3 + 0.0158x^2 - 0.2067x + 0.7904	0.9707	y =1E-06x^4 - 0.0002x^3 + 0.0044x^2 + 0.0252x - 0.607	0.9483
8	Kathmandu Valley Combine	y =3E-06x^4 - 0.0004x^3 + 0.0194x^2 - 0.3067x + 1.5188	0.9953	y = 3E-06x^4 - 0.0003x^3 + 0.0137x^2 - 0.1669x + 0.569	0.9761

Goodness of fit estimates (R^2) and polynomial models for male and female cumulative first marriage probabilities across Nepal regions are compiled in Table 12. The fitted polynomial models provide an excellent representation of the cumulative age-at-first-marriage distributions across all study regions. For males, the R^2 values range from 0.9613 to 0.9953, while for females they range from 0.9371 to 0.9920. Overall, the models show slightly higher goodness-of-fit for males than for females. The highest R^2 values are observed in the Kathmandu Valley, Bagmati, and Koshi, whereas comparatively lower values occur in some provinces, particularly Madhesh for females. Unlike the other regions, the cumulative distribution for females in Karnali is best represented by a second-degree quadratic model ($R^2 = 0.9920$), while fourth-degree polynomial models provide the best fit for all remaining regions. These fitted equations provide the mathematical basis for estimating the elasticity of the cumulative probability of first marriage in the subsequent analysis.

3.4 Elasticity for Cumulative distribution of Age at first marriage

Elasticity of Age at first marriage measures the responsiveness of age at first marriage to changes in age. In this study, elasticity is calculated by the formula:

$$E = \frac{\frac{dy}{y}}{\frac{dx}{x}} = \frac{dy}{dx} \cdot \frac{x}{y}$$

where y is the quartic equation explaining CDF given in Table 12 and x represents age. The term $\frac{dy}{dx}$ indicates the change in y with respect to a unit change in age. In other words, it measures the sensitivity in CDF with respect to parity change. The elasticity formula expresses the relative change in CDF with respect to relative change in age x.

Table13: Elasticity of the Cumulative Distribution of Age at First Marriage-Male, 2021

Less than Age	Koshi	Madhesh	Bagmati	Gandaki	Lumbini	Karnali	Sudur Paschim	Kathmandu Valley
10	-134.46	61.44	-119.88	-380.28	-10.26	106.89	11.25	-208.83

15	30.08	15.14	22.99	26.82	17.52	20.69	13.86	40.38
18	11.32	4.06	8.69	10.97	5.21	4.29	4.06	15.78
21	4.83	1.25	3.86	4.77	2.04	1.43	1.44	6.39
25	3.4	0.48	2.69	3.28	1.22	0.65	0.63	4.46
30	2.77	-0.69	1.97	2.57	0.33	-0.44	-0.46	3.55
35	2.52	-2.35	1.45	1.27	-0.85	-2	-1.98	3.46
40	2.45	-4.34	1	0.66	-2.23	-3.87	-3.8	3.76
45	2.85	-6.21	0.96	-0.01	-3.38	-5.59	-5.47	4.64
50	4.34	-7.32	1.95	-0.39	-3.68	-6.53	-6.35	6.67
55	7.72	-6.87	4.75	-0.01	-2.31	-5.88	-5.63	10.66

Regional responsiveness in male marriage timing is summarized in Table 13 through cumulative distribution function (CDF) elasticity estimates. The elasticity values indicate that responsiveness is highest during ages 15–18 in all study regions, with the maximum value occurring at age 15. The Kathmandu Valley records the highest elasticity (40.38), whereas Sudur Paschim shows the lowest (13.86). After age 21, regional differences become more pronounced. The Kathmandu Valley, Koshi, Gandaki, and Bagmati maintain elasticity values greater than one up to ages 25 and 30, indicating continued responsiveness of the cumulative probability of first marriage to increasing age. In contrast, Madhesh, Lumbini, Karnali, and Sudur Paschim exhibit a rapid decline in elasticity, with values falling below one by around age 25 and becoming negative by age 30. These results suggest that the cumulative probability of first marriage approaches its upper limit at earlier ages in these provinces.

Table 14: Elasticity of the Cumulative Distribution of Age at First Marriage-Female, 2021

Less than Age	Koshi	Madhesh	Bagmati	Gandaki	Lumbini	Karnali	Sudur Pascim	Kathmandu valley
10	67.59	-452.43	48.84	81.02	-2.36	324.69	369.76	62.04
15	6.16	-19.77	6.01	14.8	5.77	9.99	28.3	19.87
18	1.24	-7.48	1.49	5.05	2.17	2.27	9.42	7.36
21	0.14	-5.87	0.35	3.29	1.35	1.18	5.29	4.43
25	-0.89	-7.55	-0.63	3.39	1.03	0.81	4.18	4.34
30	-2.78	-10.51	-2.36	4.19	0.32	0.36	2.54	5.26
35	-5.57	-14.05	-4.93	5.5	-0.84	-0.04	-0.12	7.2
40	-9.16	-17.89	-8.28	7.52	-2.22	-0.08	-4.01	10.31
45	-13.33	-21.79	-12.16	10.67	-3.38	0.67	-9.13	15.18
50	-17.74	-25.46	-16.24	15.52	-3.68	2.81	-15.43	22.67

55	-21.9	-28.55	-20.04	22.76	-2.31	7.01	-22.79	33.79

Table 14 details the cumulative distributive function elasticity for female age at first marriage across Nepal's provinces and the Kathmandu valley. The Kathmandu Valley records the highest elasticity from the below-15 to below-25 age groups, with values increasing from 19.87 to 4.34. Beyond age 30, regional differences become more evident. Elasticity rises substantially in the Kathmandu Valley and Gandaki, reaching 33.79 and 22.76, respectively, by the below-55 age group, indicating greater responsiveness of the cumulative distribution at older ages. In contrast, Madhesh, Koshi, Bagmati, and Sudur Paschim exhibit negative elasticity after approximately age 30, with the largest negative values observed in Madhesh and Sudur Paschim, suggesting that most first marriages occur at younger ages in these provinces. Based on the absolute elasticity values, Madhesh shows the highest sensitivity at the youngest age group (below 10 years), followed by Sudur Paschim and Karnali. Sudur Paschim records the highest elasticity for the below-15, below-18, and below-21 age groups, whereas Madhesh becomes the most responsive region from age 25 onwards, with absolute elasticity increasing steadily to 28.55 by the below-55 age group.

4. Conclusion

Fertility is important to demographers sometimes more interesting than mortality because mortality happens only once in a lifetime, while fertility happens more often. Especially in developing countries including Nepal there is a stigma around having children outside marriage. As a result, accurate fertility data is often missing and reliable information about illegitimate children can be hard to obtain. Further, people forget details about deseeded children, especially girls. In addition to this due to remote geographical location many births occur at home and these births and deaths often go unrecorded. Hence analysis and prediction of fertility patterns is of utmost important.

This study modeled parity progression and marriage timing across Nepal using 2021 Census data. Quadratic models ($R^2 > 0.93$) accurately captured birth progression. PPR-based fertility estimates generally exceeded census figures, though Madhesh Province showed an inverse pattern due to reporting and migration disparities. Overall, birth progression drops sharply after the second child, especially in the Kathmandu Valley. A clear generational shift also emerged: younger women (aged 20–35) show a lower completed fertility of 1.65 children compared to 2.72 among older cohorts. Marriage timing reveals a distinct gender gap, with women marrying significantly earlier (expected age 18.98) than men (22.24). Early female marriage remains high in Madhesh, Karnali, and Sudur Paschim, whereas urban women delay marriage. Mathematically, PPR elasticity turns elastic ($|E| > 1$) at parity two in urban areas, confirming a strict two-child stopping norm. Meanwhile, marriage CDF elasticity peaks between ages 15 and 18. Ultimately, Nepal's fertility decline is driven by urban family limitation, contrasting with lingering early marriage in rural provinces.

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