Communications on Applied Nonlinear Analysis
ISSN: 1074-133X
Vol 32 No. 10s (2025)

Projection of the Fertility at Madhesh Province, Nepal

Bijaya Mani Devkota PhD[1], Suresh Acharya, PhD[2], Nava Raj Aryal[3] Laxmi Bashyal[4], Radhika Shrestha[5], Ramchandra Dahal[6]

[1]Central Department of Population Studies (CDPS), Tribhuvan University, Kathmandu, Nepal. Email: devkotabm2006@gmail.com, https://orcid.org/0009-0005-1533-2678

[2]Rural Development Department Padmakanya Multiple Campus, Kathmandu, Nepal. Email: sureshrdpk@gmail.com, https://orcid.org/00009-0002-4034-1603

[3]Sanothimi Education Campus, Bhaktapur, Nepal. Email: aryalnavaraj48@gmail.com https://orcid.org/0009-0000-3494-2168

[4]Bhaktapur Multiple Campus, Kathmandu, Nepal. Email: laxmibashyalg@gmail.com https://orcid.org/0009-0002-1800-5662

[5] Population Studies Department Padmakanya Multiple Campus, Kathmandu, Nepal. Email: stha.radhikars@gmail.com, https://orcid.org/00009-0001-7179-8684

[6]Department of Population Education in Siddha Jyoti Education Campus, Sindhuli, Nepal. Email: ramchandradahal11@gmail.com https://orcid.org/0009-0003-2414-245X

Article History:

Received: 12-01-2025

Revised: 15-02-2025

Accepted: 01-03-2025

Abstract: Accurate estimation of fertility is crucial toward the comprehension of population dynamics for the purpose of policy formulation in Nepal. Consequently, both the Arriaga and the P/F methods, as well as the related demographic modeling techniques, were brought to bear on the problem of analyzing fertility trends in Madhesh Province. The study applied census data from 2011 and 2021 and estimated ASFR, TFR, and interpolation of inconsistencies using indirect estimation techniques. The findings of this study reveal that the province of Madhesh is facing continuing declines in fertility, as the TFR leveled off from 3.362 in 2011 to 3.059 by 2021. Projection under clear logistic curve suggests that TFR would further decline to reach replacement level (2.1) by 2031. Age-sex pyramids developed from the census data suggest significant demographic shifts with an increasing ageing index and decreasing dependency ratio-suggestive of flowing population structure. The study consensuses considerable variation in changing fertility rates among various subgroups while emphasizing the critical impact of socio-economic and demographic factors.

This study shows that indirect estimations are important for estimation logistic function applied here for fertility projection fundamentally provides a more reliable means of constraining demographic estimates that policymakers can justly defend. Linear interpolation was used to derive the TFR values for 2021 and 2026, and extrapolation for the period of 2030 and 2031; an indirect concern may intern that the TFR for 2031 is predicted to fall beyond the replacement level. A necessary onset for low fertility rates throughout Madhesh Province becomes ongoing demographic monitoring and improving data-collection techniques-wildly helpful for making informed decisions on population planning and resource allocation. The study contributes substantially toward the understanding of fertility trends in Nepal by drawing upon demographic transitions and their implications for future growth.

Keywords: Estimation, projection, Arriaga, Brass, Madhesh Province

1. Introduction

The reliable estimates of fertility are essential to the analysis of population dynamics and thus to creating policy plans within Nepal. Before the establishment of even more stable data collection circuits in the 1960s and 1970s, Indirect estimates became used to fill up the information gaps (Brass, 1996). These would go with the demographic models or different statistical tools to expect the fertility rate, with the given data. Some of the early applications include the demographic study of tropical Africa (Caldwell & Okonjo, 1968), and United Nations studies on demography (Coale & Demeny, 1968). The global fertility survey came to the fore later and discussed a more comprehensive knowledge of birth rates, infant mortality, and such demographic indicators. There are, however, considerable challenges in generating complete and accurate data.

The data collection while made possible with advancements is still affected with limitations, stimulating a need for the constant use of indirect estimation methods with a determined, such as small-area estimation, that makes good use of available data and modeling (United Nations, 1983; Schmertmann et al., 2013). Importantly, such methods work well in developing countries, where incomplete or conflicting data stymie directestimation efforts (Brown & Guinnane, 2002). An approach used in Brass's method is one correcting data that could, most explicitly, give the true fertility rate.

The estimation techniques are used to merge inconsistencies in national census data in Nepal (1961–2011) according to the assessments of demographic accuracy indices by Myers, Whipple, and UN for conventional age-sex structure data (Brass & Coale, 1977; Hobcraft & Little, 1984). The convention of Madhesh Province, which certainly withstands the 2021 Demographic and Health Surveys for the passing average birth spacing and highest total fertility rate in Nepal, provides evidence from indirect estimation and logistic curve projection that both distinct sources estimate fertility for the present work in order to ascertain the robustness of modeling demography within the province. Besides, these techniques are inevitable to connection data deficits while improving understanding of fertility conditions in Nepal.

2. Data and methods

Innovative methods were integrated into existing demographic estimation methodologies to adjust the key demographic parameters, thus facing fertility estimation challenges in developing countries, with specific reference to Madhesh Province, Nepal. It seeks to explore the scope for modifying fertility projections using logistic curve functions (Kpedekpo, 1982) for the first time. The quality of data from national scenario and censuses has been consistently overwhelmed by errors of coverage and non-existence. The address these limitations, 2011 and 2021 census data were used in the linear interpolation method to provide an estimate of missing values following this period (MoHP, 2023). The time-series logistic model observed into to project fertility trends. The rates were obtained by interpolating the average mean of the mean into various subgroupings of Madhesh, resulting in a very detailed analysis.

Additionally, Arriaga's method (Arriaga, 1994) was conducted to estimate Total Fertility Rate (TFR) for the given years, such as 2011, 2016, and 2021, so as to give a proper idea of how fertility for certain birth patterns. The Brass's P/F ratio method, a common way affecting age-specific mean parity estimates, was used side by side with the Arriaga method by which age-specific parity estimation provides an average parity of a hypothetical cohort over a period. The main contribution was mapping the effect of fertility on population projection by the Logistic Curve, where the Logistic Curve (S-shaped), commonly used for growth modeling, introduced many dynamic and flexible fixtures that describe a movement of fertility in a trend. Thus, while other theorizations will struggle with fertility fluctuations, the Logistic Curve carries a constructional ideal where the population mirrors exponential growth and is uniquely positioned for this period of rapid demographic changes (Moultrie et al., 2013). The modeling input in this study seeks ground to enhance accuracy and reliability of fertility projection for Nepal.

This study evaluate how well this approach compares to traditional approaches and their robustness. That work introduces an original model for fertility estimation in Nepal by reviewing the space of "traditional" methodologies with some paths of logistic curve function to benefit population estimation.

$$\frac{d}{dx} f(x) = f(x).(1 - f(x)).$$

The first methodology consists of logistic modeling, covering its role as the complement to a model to specify the total fertility rate (TFR). This approach extends the interpretation of the observed TFR for each year in relation to the lower limit of a logistic curve, thereby certifying that local and regional changes in fertility are kept proportional to the main trends estimated from the primary TFR model. The second method deals directly with the estimation and forecasting of TFR using data from the observational record. Data treatment and processing were done with statistical programs such as SPSS, MortPak 4.3, and MS Excel, enhancing the effective implementation of exact computations and better validation of the models.

3. Results

The main objective of the study is to examine fertility trends by employing modern indirect estimation techniques in Madhesh Province. It understands data for the total number of births in the past year among females of 15-49 ages, from 2011 and 2021 censuses. The focus on the two censuses is aimed at providing a complete evaluation of fertility patterns and shifts as revealed across the span of the decade. Modern estimation techniques, in this case, enhance the accuracy of fertility profiles and yield an in-depth review of reproductive behavior and demography over the province.

3.1 Household Population by age and sex

Figure 1 shows the age-sex pyramid of Madhesh Province; it is based on data from the 2011 and 2021 censuses, and it gives an insight into the population structure and fertility trend over time in the region. It shows that the 10–14 age group remains at the upper level in both censuses. However, certain increments are observed in ages 15–19 and 20–24 for the 2011 census, hence exhibiting changes in the demographic setting. This pattern could as well indicate the continuing fertility dew found in 2011, a smaller population size in the age group of 0-4 years as a measurement of this drop in fertility. The age pyramid shows the highest proportion of people in the 10–14 category, followed by the 5–9 and 0–4 age groups, reflecting a big youth group. This could be used as an indicator of historically high fertility rates linked to gradual mortality declines. However, the decrease in the size of the 0-4 category in comparison with the 5-9 and 10-14 categories shall likely indicate a decrease in fertility rates before the year 2021. Thus, changes to the age-sex pyramid from 2011 and 2021 may suggest a possible downward trend of fertility in Madhesh Province. Subsequently, with these changes to pyramid shape, they also resolve support this result, further strengthening the importance of demographic analysis for understanding fertility transition over time.

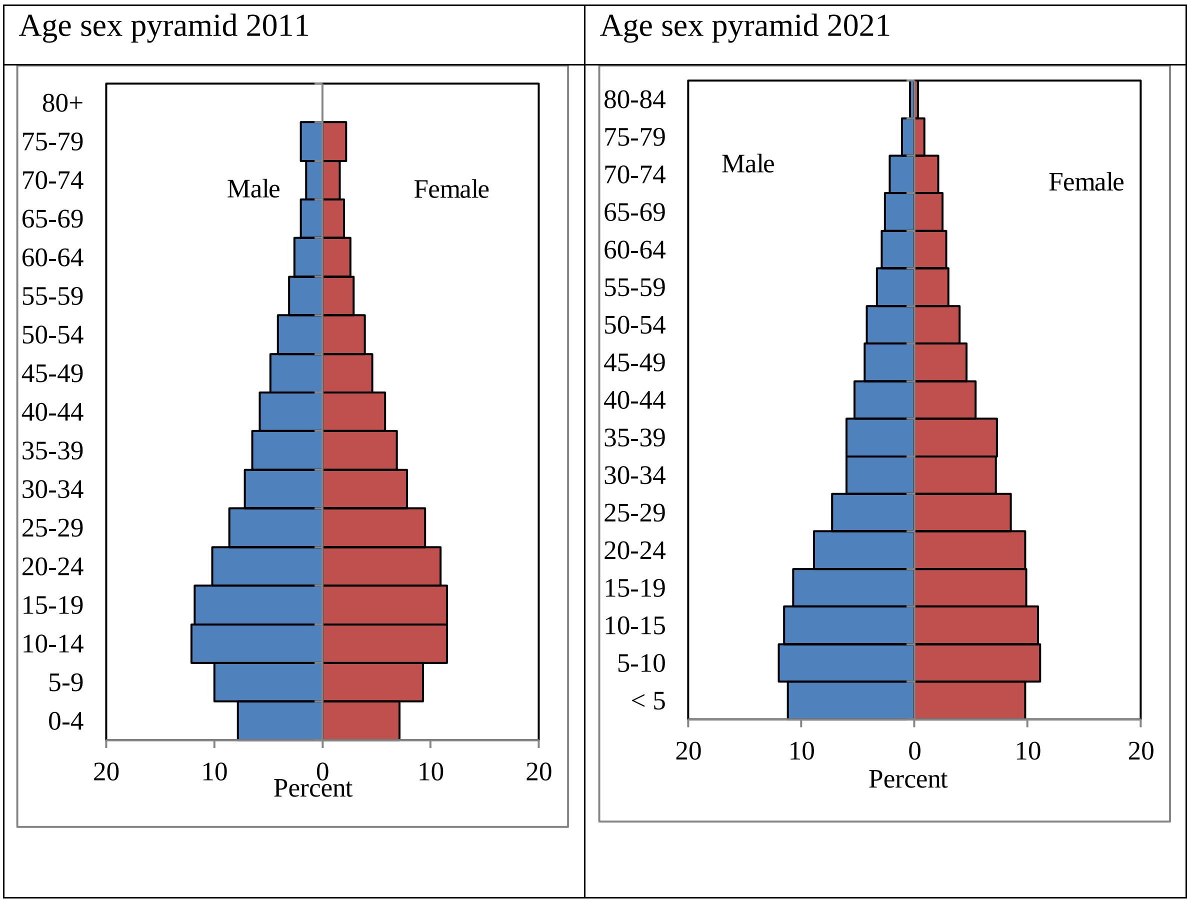

Figure 1: **Age sex pyramid 2011 and 2021 at Madhesh Province**

Source: Census dataset, 2011 and 2021.

In the census during 2011- 2021 gap-filled with a series of really important demographic transitions in the Madhesh Province. Comparing with its structural move of population, workforce participation, and dependency dynamics, the aging index was just important 18.2 to 19.1. This rather would indirectly indicate an increase in life expectancy and perhaps a increasing presence of senior citizens and also in life expectancy-for at least up to 71. Over and beyond, the slight uneasiness could bring about an uncomfortable discussion with the writer, even in respect of the declining sex ratio within the reproductive-age group (15-49 years). Such a situation indicates some demographic shifts awaiting full exploration.

Decreases in the dependency ratio from 71 to 65 and workforce participation rates (from 54-65) are influencing towards the potential of a productive labor force with fewer dependent persons. Unclear thus requiring further explanation are varied indices where "floors report" and "relationship of the floors" dropped from 102 to 99 without mentioning what effect this might have on the population. A 60 percent drop women from 0.402 to 0.260, suggests a concrete change in female workforce participation. However inadequate details need to be incorporated to observe this adequately. A significant trend that could stand by the January 2011 to mid-2021 censuses involves population reduction among males with respect to the reproductive-age group (15-40), largely due to out-migration. The aging index increase (18.2 to 19.1) and life expectancy increase (65 to 71 years). The lowest percentage in the labor force. The reduction of dependency ratio (71 to 65) and increase in the labor-force participation rate from 54 to 65 is evidence of a more effective labor force. There has been a decrease in the male population within the reproductive age group (15–49 years) due to out-migration. Thus, Figure 3.1 documents critical demographic shifts in Madhesh Province, signifying accelerated economic potential, while also setting forth some emerging issues in the area-fertility trends and labor force composition.

3.2 Estimation of fertility Arriaga method at Madhesh Province

The applicability of the Arriaga method to estimating current and total fertility is expressed through a summary for the available all records as per the 2011 and 2021 censuses, detailed in Table 1. This table gives indices for the lifetime fertility estimated from Age-Specific Fertility Rates (ASFR), which were determined on the basis of the number of children ever born. The occurrence of fertility rates in Nepal primarily began with the onset of women at about 20 years of age, as women in the age group 20–24 years and that of 25–34 years had the highest fertility levels. Such patterns are consistent with the demographic trends of young women in developing countries (Muhwava, 2002). Fertility rates in Nepal decline dynamically toward the end of the reproductive period, as is witnessed in other cases of world fertility. These observations tally well with fertility trends among younger women in developing countries (Muhwava, 2002).

Table 1: **Estimation of ASFR based on 20011 censuses at Madhesh Province**

Age	ASFR from CEB	Cum. ASFR	ASFR Pattern	Cum. ASFR pattern	Adj factors	Adj. Fertility f*
15-19	0.080	0.080	0.025	0.025	3.167	0.065
20-24	0.214	0.294	0.088	0.113	2.606	0.229
25-29	0.176	0.470	0.069	0.182	2.584	0.180
30-34	0.118	0.588	0.039	0.221	2.665	0.102
35-39	0.058	0.646	0.022	0.242	2.666	0.057
40-44	0.015	0.661	0.011	0.253	2.611	0.029
45-49	0.002	0.662	0.004	0.257	2.581	0.010
TFR						**3.362**

Source: Census dataset, 2011 and 2021.

A study conducted on the basis of the 2011-2021 censuses was carried out in Madhesh Prrovince, in which fertility was assessed with respect to the 15-49 age group. Over 98 percent of women approximate their correct age; however, 0.16 percent over-declare their age. Multiplying the total of these women with observed cumulative age-specific fertility rates returned age adjustments for successive age-groups, accounting for the brief completion of fertility as age increases. With a factor of 2.211, adjustments were made, showing that an indirect estimation technique may possibly be applied, mainly based on the Brass P/F Ratio Method, to avoid source errors in the measurements of CEB (P2) and total female fertility (F2) (Devkota, 2022). Post application of this factor, the P2/F2 value was now raised to 2.606, which meant that all ASFRs were checked in terms of age groups. The newly estimated total fertility rate should now come to 3.362 for the month of February 2011, with the average childbearing age standing at 27.32 (Table 1). These results offer insight into fertility translation and highlight the necessary adjustments in the data for a more relevant development while using allowed demographic methods of investigation for Madhesh Pradesh suitable work in the future.

3.3 Estimation of fertility Arriaga method at Madesh Province, 2021

While the majority of fertility surveys dwell on women within reproductive age (15–49), it is indeed useful to exploit upon the wider age range for fertility and childhood mortality assessment. Comprising women of 12 years and above, the 2011 and 2021 censuses sought information regarding each woman's ever-born children (Children Ever Born-CEB). And women aged 50 years and those in the age group 12- 14 years were further surveyed on the number of current births.

This study is primarily on the conventional reproductive age group, this extension to various age groups as required under each census may have in some way alleviated the underreporting bias that occurs when examiners skip women near the upper and lower bound of the reproductive age limits in an attempt to simplify their work settings (United Nations, 1983). The observation of current births pointed to instances where women claimed to have up to nine deliveries in the year prior to the census. However, this is biologically unrealistic since it is physically implausible for a single woman to beleaguer through nine single-timed births in a year (Bongaarts, 2017). Aside from multiple births, it is highly unlikely for a woman to have more than two live births in a year a span of roughly twelve months. The catalog of actual multiple births within the 2011 census data remained abstract, considering that no birth history was recorded for censuses. Therefore, Table 2 shows the highest recorded enumerations of live births in the last twelve months, taking on a flexible approach to serve international demographic conventions and allowing for any possible multiple births.

This study is the analysis of CEB as reported and current births among women of reproductive age during the census of 2011 and 2021 (Devkota, 2022). The underlying statement is that fertility patterns have evolved over the years and that error in reporting about the current births is not systemically connected with maternal age. In this context, age becomes a major source of information to assess data consistency and reliability. Arriaga (1994) demonstrated the validity of his P/F ratio method was first applied to Nepal's 2011 census to ascertain these shifts in the country. This study is based on examination of the said, aiming for refined fertility estimates while correcting for potential data inconsistencies.

Table 2: Estimation of ASFR based on 2021 census at Madhesh Province

Age	ASFR from CEB	Cum. ASFR	ASFR Pattern	Cum. ASFR pattern	Adj factors	Adj. Fertility f*
15-19	0.080	0.080	0.035	0.035	2.266	0.058
20-24	0.235	0.315	0.143	0.178	1.667	0.238
25-29	0.179	0.494	0.101	0.279	1.767	0.168
30-34	0.116	0.609	0.049	0.329	1.855	0.082
35-39	0.049	0.659	0.022	0.350	1.879	0.037
40-44	0.015	0.674	0.011	0.361	1.866	0.018
45-49	0.004	0.677	0.006	0.367	1.847	0.010
TFR						**3.059**

Source: Census dataset, 2011 and 2021.

Table 2 summarizes women's fertility by age in their reproductive years in the province of Madhesh according to the 2021 census (NSO, 2023); adjusted values were derived through summation of the Age-specific fertility rates (ASFR) and subsequent distribution patterns. Sometimes those estimates, depending on the factors of the adjustments (P2/F2: 1:667), could be adjusted further; thus, adjusted estimates totaling the magnitude of the age-specific fertility rates (ASFR) for all the age groups, leading to figures for total fertility rate (TFR) adjusted up to 3.059 for June 2021 to bear a mean age of 26.60 years for childbearing. The previous results offer important insights into fertility trends in the region of Madhesh, showing how reproductive behavior in the region has undergone change over time.

3.4 Comparison period fertility average parities for hypothetical cohort at Madhesh Province

A different approach to estimation of fertility trends is calculation of average parities in fertility intervals using a standardized definition of the Children Ever Born (CEB) for each mother's age, as described in the two surveys. With this approach, average parities are to be constructed for a hypothetical cohort, which will help in quantifying changes in fertility between surveys. Like this, assuming a five-year gap between surveys, the survival of a hypothetical cohort can be tracked from the first to the second survey, enabling the computation of parity changes over time.

Increasingly gentler probable parenthood rates over the years in question are likely to be close to conformity with the arithmetic average of ASFRs so specified. Data availability (or not) might determine whether or not to try and obtain from live birth registration or from birth history surveys taken in the last year. Parity and survey data on fertility should be combined with a somewhat uniform age distribution, with midpoints in the age groups a possible, although less preferable, alternative choice of somewhat ambiguous approximations in the absence of ASFR's endpoints. The estimation of the change in the age-specific parity/fertility rate ratio for the Province of Madhesh was established by using the 2011 and 2021 census formats. Average parities P(i, s) indicated in the 2011 and 2021 censuses were taken out of ASFR data tables for both censuses. The pattern of relations observed to have emerged to procedure resulted from changes in the methods of parity reporting using the P(i, s)/F(i) coefficient.

Table 3: Estimation of ASFR based on inter -survey cohort at Madhesh Province

Age	2011P(i)	2021P(i)	∆ P(i)	P(i,s)	2011 f(i)	2021 f(i)
15-19	0.1114	0.0967	0.0967	0.0967	0.0209	0.0273
20-24	0.9237	0.9892	0.9892	0.9892	0.0855	0.1399
25-29	1.8856	2.0197	1.9083	2.0050	0.0710	0.1058
30-34	2.5598	2.6840	1.7603	2.7495	0.0405	0.0525
35-39	2.9390	3.0381	1.1525	3.1575	0.0226	0.0232
40-44	3.1058	3.1436	0.5838	3.3333	0.0112	0.0105
45-49	3.1094	3.1747	0.2357	3.3932	0.0049	0.0074

Source: Census dataset, 2011 and 2021.

Table 4: **Estimation of ASFR based on inter -survey cohort at Madhesh Province**

Age	f(i)	ϕ (i)	F(i)	K	f+	f*(i)
15-19	0.0241	0.1206	0.0296	3.270	0.0325	0.068
20-24	0.1127	0.6843	0.3988	2.081	0.1156	0.241
25-29	0.0884	1.1262	0.9214	2.076	0.0834	0.174
30-34	0.0465	1.3587	1.2543	2.092	0.0433	0.090
35-39	0.0229	1.4733	1.4201	2.023	0.0217	0.045
40-44	0.0109	1.5277	1.4921	2.034	0.0104	0.022
45-49	0.0061	1.5584	1.5490	2.011	0.0049	0.010
TFR						**3.181**

Source: Census dataset, 2011 and 2021.

The P2/F2 and P3/F3 ratios relate to maternal background on population level wherein P2 and P3 correspond to the number of children ever birthed by women in that age group and F2 and F3 represent the number of women in the given age group. These ratios quantify the behavior of fertility and are largely utilized to indirectly estimate fertility. The TFR stands out as the average number of children a woman currently living must have to survive through the childbearing years given this age-specific fertility rate. Most notably, the adjusted TFR for the Madhesh Province much distances itself from the national figure, the TFR for the Madhesh Province stood at 3.144 as of August 2016. The use of the K parameter provides an adjustment for registered births and thus the reciprocal of this, 1/K, gives an estimate of how complete the birth registration is. This becomes an essential measure for assessing the accuracy of the past and present number of births registered and therefore for identifying possible gaps in the birth registration spectrum.

3.5 Projection of fertility at Madhesh Province (reference date 2021)

It is summed up from age-specific fertility rates (ASFRs) for all reproductive ages. A TFR based on seven five-year age-groups requires adding up the values of ASFRs for each group and multiplying the sum by five. As the future childbearing pattern is indirect from past, usually current trends, extrapolating a tendency still depends on the unsure future growth. Trend extrapolation rules from past fertility changes to predict further progressive changes. Normally, fertility in the middle of the first phase of demographic transition starts slow on decline, accelerates briefly, and finally stays in slow decline during the last phase (Devkota, 2022). In February 2012 and August 2016, TFR had concordance, as shown even with both FERTPF and USAID spreadsheets. The TFR for June 2021 is 3.144 as estimated using a logistic function, derived by an equal logistic model, with logistic regression modeling from prior TFRs of 3.362 and 3.059. Excel spreadsheet TFRLGSTNew.xls was used for TFR interpolations and extrapolations, and the logistic curve method positively validated the final TFR estimate of 3.059. Therefore, the results exhibited the collective viability of logistic regression models to enhance fertility projections in promoting and forecasting more precise demographic data.

3.6 Projection of fertility at Madhesh Province, 2031

Projections of population movement are critical in anticipating changes in population size and attributes, in order to allow development of policy associated with development planning. Normally, projections are based on historical growth rates, guiding future trend through present data. However, the accuracy of these resolutions is questionable and highly depends on the quality of the input data and underlying assumptions by making sure that they are rigorously evaluated and corrected in case of errors before use. One of the favorite models among all projection ones is the logistic curve, which often brings the predicted trends to meet the historical trends. According to the facts of the empirical evidence, it assumes that population growth is proportional to the size of the current population and usable vacant capacity. Fertility is one of the most influential determinants of Census population size and composition, marking the process of aging when fertility levels drop. Age-specific fertility rates (ASFRs) in 5-year age supports provide a snippet of fertility trend mapping over the years. Currently, classic trend extrapolation methods follow the three phases of the demographic transition: the slow initial phase, a rapid transition, and finally some deceleration.

4. Discussion

The global challenge of differing fertility estimates is a significant barrier. During 2006-2010, there were 230 million estimated births in 156 countries and areas, against 129 million registered births. Hence, the discrepancy was 81 percent (Liu, 2015). Similar challenges are faced in data accuracy and reliability in Nepal with regard to fertility estimates. In 2001 December the Terai had its fertility rate lower than the national total fertility rate (TFR) of 4.1 (Central Bureau of Statistics, 2003). However, by June 2021, the fertility rate in the Madhesh Province went above the overall national TFR at 3.059 (Central Bureau of Statistics, 2014). These differences indicate regional variations in fertility and changes in reproductive behavior over time. Many women want no more children, yet they do not use any contraceptive methods (Casterline, 1989). Thus, addressing this unmet need may also reduce unintended pregnancies, abortions, and unwanted births, which are common in many countries

(Cleland, 1996).
Being among the poorest countries on earth, Nepal has faced simple limitations in the quality of demographic data, of which an understanding of population dynamics is virtually impossible (Feeny, 1997). Hence, the controversy revolving fertility estimates in the case of Nepal as well as in many developing countries is attributed to the inconsistencies in the collected data. In the end, therefore, a larger body of published studies on the decline in fertility in Nepal presents themselves with diverse conclusions and point to the urgent need for the development and use of authentic data collection methods.

For the past years, the SAARC region has been very dynamic in the demographic landscape; to stress: between 1961 and 1991, Indian population growth rate was double in just a few years, with the overall population passing one billion in 2001. The result is that countries like India, Pakistan, and Bangladesh will have the most-to-second-to-ninth crowded populations in the world. Afghanistan stands in the highest place with TFR in the region at 5.4, while Sri Lanka has equally reached a medium value in fertility, 2.1. From 2001, the TFR went down to 2.6 in 2011, that is, less than one child less on average per woman a decline of 0.5 years (Central Bureau of Statistics, 2014). The 2011 Census has 2.52 the figure reasonably overlaps with DHS 2011 study's estimate of 2.6, which is based on an average value of 2008 to 2010. According to the Ministry of Health of Nepal in 2016, the current TFR of this country is 2.3 children per woman. Fertility rates vary: the highest scores are held by Muslims in an “above-substitute” state of TFR of 3.3, the Madhesi, and Dalit/base groups cut at 2.4 children per woman each; and the Janajati-group scored lowest with a TFR at 1.8 for every woman (MoHP, 2013).

5. Conclusion

The major objective of this study was to make fertility trends and projections in Madhesh Province, Nepal, while keeping in view the data limits common in most developing countries. Discrepancies due to demographic data therefore lead to differences in the estimates of fertility from one area to another and hinder a proper analysis of population as well as informed policy formulations. However, despite some of these inherent difficulties and challenges, valuable insights were enabled to be provided on the fertility pattern from the province of Madhesh, which is higher as compared to the national average, thus signaling the call for greater work toward an improved demographic data-collection and policy interventions aimed at leveling fertility insecurities.

Throughout the two decades of the study's time frame, the Total Fertility Rate (TFR) in Madhesh Province pounded out another rate of increase that was higher than the national average for fertility duration. One gets a feeling that Madhesh is expected to go on for some time toward a very slow revision to replacement-level fertility compared to the rest of Nepal. However, a gradual decline in the TFR seems to indicate the possibility of Madhesh gradually tending toward national replacement levels and to be referred to in some way to a demographic change. Thus, this study shows the application of indirect techniques for estimating fertility that prolong the frontiers of data imperfections and lack. These special techniques apply to the estimation of fertility, particularly where uniformity and difficult data collection still continue. Fertility trends indicate a declining trend in Madhesh Province for the years 2011-2021, with projected values for 2015, 2020, 2025, and 2030 decreasing together. Finally, it is projected that TFR will stabilize at 2.1, which is in association with replacement-level fertility. This decline will significantly impact population growth, composition of labor force, and long-term development planning. Properly distributed with reliable parameters, fertility data could be sought for analyses of population projections and provide policy input on family planning, resource allocation, and demographic transitions. As such, any move towards replacement-level fertility in Madhesh Province should require continued monitoring of demographics and improving data sources to further sustainable population growth and development.

Author contributions

Bijaya Mani Devkota contributed to the study's conception, data extraction, data analysis, and drafted the manuscript. Nava Raj Aryal, Laxmi Bashyal, Radhika Shrestha and Ramchandra Dahal supported the preparation of the manuscript. At last, manuscript was critically revised by Suresh Acharya to ensure its quality and accuracy. All authors agreed to submit the article in its current form.

Conflict of interest

The authors declare no potential conflict of interest with respect to the research, authorship, and/or publication of this article.

Funding Statement

This study did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Ethics statement

The study was reviewed and approved by the National Statistics Office (NSO), ensuring compliance with all ethical standards. Throughout the research process, ethical norms such as informed consent, confidentiality, and responsible data handling were strictly observed. All datasets used in the study are publicly available on the official website of the NSO, ensuring transparency and accessibility for verification and further research.

Conflict of interest

The authors declare no conflict of interest related to this study.

ORCID

Bijaya Mani Devkota, PhD https://orcid.org/0009-0005-1533-2678

Suresh Acharya, PhD https://orcid.org/00009-0002-4034-1603

Nava Raj Aryal : https://orcid.org/0009-0000-3494-2168

Laxmi Bashyal : https://orcid.org//0009-0002-1800-5662

Radhika Shrestha : https://orcid.org/00009-0001-7179-8684

Ramchandra Dahal : https://orcid.org/0009-0003-2414-245X

References

[1] Arriaga, E. E. (1994). *Bureau of the Census, USAID a Vol. I.(1-22)* : Bureau of the Census, USAID and UNFPA.

[2] Bongaarts, J. (2017). The effect of contraception on fertility: Is sub-Saharan Africa different? *Demographic Research.* 37(6):129-146.

[3] Brass, W. (1996). Demographic data analysis in less developed countries: 1946–1996. *Population studies*, 50(3), 451-467.

[4] Brass, W. (2015). *Demography of Tropical Africa (2141):* Princeton University Press.

[5] Brass, W., & Coale, A. J. (1977). *Methods of analysis and estimation.* In Mathematical Demography (307-313): Springer.

[6] Brown, J. C. & Guinnane T.W.G (2002). Fertility transition in a rural, Catholic population: Bavaria 1880–1910. *Population Studies.* 56(1):35–50.

[7] Caldwell, J. C., & Okonjo, C. (1968). *The population of tropical Africa. Studies in Family Planning*, 1(29), 10-12.

[8] Casterline, J. (1989). *The state, social stratification and fertility transition.* Paper presented at the International Population Conference, New Delhi.

[9] Central Bureau of Statistics. (2003). *Population Monograph of Nepal*. Kathmandu, Nepal: Central Bureau of Statistics.

[10] Central Bureau of Statistics. (2014). *Population Monograph of Nepal.* Kathmandu, Nepal: National Planning Commission Secretariat.

[11] Cleland, J. (1996). Demographic data collection in less developed countries1946–1996. *Population Studies*, 50(3), 433-450.

[12] Coale, A. J., & Demeny, P. (1968). *Methods of evaluating basic demographic measures from limited and defective data*. United Nations, New York.

[13] Devkota, B. M. (2022). *Estimation and Projection of the Fertility: National, Provincial and Local Level in Nepal* (Doctoral dissertation, Faculty of Population Studies).

[14] Feeny, G. (1997). *Estimates of Demographic Parameters from Census and Vital Registration Data.* Proceedings of the 1977 Mexico International Population Conference, (349-70). Liege: IUSSP.

[15] Hobcraft, J., & Little, R.A. (1984). Fertility exposure analysis: A new method for assessing the contribution of proximate determinants to fertility differentials. *Population Studies.* 36(2):291-316.

[16] Kpedekpo, G. M. (1982). *Essentials of demographic analysis for Africa.* Heinemann, London,UK.

[17] Liu, A. M. (2015). *Research methods for construction:* John Wiley & Sons.

[18] Ministry of Health and Population (2016). *Nepal Demographic and Health Survey 2016.* In. Kathmandu, Nepal

[19] Ministry of Health and Population (2023). *Nepal Demographic and Health Survey 2006.* In. Kathmandu, Nepal and Calverton,: New ERA and ORC Macro, DHS+, Maryland, USA.

[20] Ministry of Health. (2011). *Nepal Demographic and Health Survey 2006*. In. Kathmandu, Nepal and Calverton,: New ERA and ORC Macro, DHS+, Maryland, USA.

[21] Moultrie, T. A., Dorrington, R. E., Hill, A. G., Hill, K., Timæus, I. M., & Zaba, B. (2013). *Tools for demographic estimation: International Union for the Scientific Study of Population.*

[22] NSO (2023). *National population and housing census 2021*(national report). Vol.1. Kathmandu: National Statistical Office.

[23] Schmertmann, C. P., Cavenaghi, S. M., Assunção, R. M., & Potter, J. E. (2013). Bayes plus Brass: estimating total fertility for many small areas from sparse census data. *Population Studies*, 67(3), 255-273.

[24] United Nations. (1983). *Indirect techniques for demographic estimation* (81): New York: United Nations.

[25] Willekens, F., & Rogers, A. (1978). *Spatial population analysis: methods and computer programs*. Retrieved from http://pure:ilasa.ac.at/880.