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Seventy Years of Mortality Transition in India 1950-2021

Aalok Ranjan Chaurasia

Abstract

Mortality in India remains high by international standards. This paper analyses mortality transition in India during the 70 years based on the annual estimates of age-specific probabilities of death prepared by the United Nations Population Division for the period 1950 to 2021. The analysis reveals that characterisation of mortality transition is sensitive to the summary index of mortality used. Mortality transition in India based on the geometric mean of the age-specific probabilities of death is found to be different from that based on the life expectancy at birth. The transition in mortality based on the geometric mean of age-specific probabilities of death accelerated during 2008-2019 but decelerated when based on the life expectancy at birth. The reason is that mortality transition in younger ages has been faster than mortality transition in older ages. The analysis also reveals that there were around 4.3 excess deaths associated with the COVID-19 epidemic in the country leading to a loss of around 3.7 years in the life expectancy at birth between 2019 and 2021.

Introduction

Mortality in India remains high by international standards. Latest estimates prepared by the United Nations Population Division suggest that the life expectancy at birth in India was 67.2 years in 2021 which implies that India ranks 178 among the 236 countries or territories for which estimates have been prepared by the United Nations Population Division (United Nations, 2022). The estimates prepared by the United Nations Population Division also reveal that the rank of India vis-à-vis 236 countries of the world in terms of life expectancy at birth has never been above 160 during the period 1950 through 2021. The rank of India has been the highest (163) across the 236 countries during the period 2015 through 2018 but the lowest (196) in 1966. Between 2018 and 2021, the rank of the country decreased rapidly from 163 in 2018 to 178 in 2021, an indication that mortality transition in India slowed down considerably during the period 2018-2021 compared to mortality transition in other countries of the world. Between 2018 and 2021, the life expectancy at birth in India decreased by almost 3.7 years, from 70.9 years in 2019 to 67.2 years in 2022 (United Nations, 2022). This decrease in the life expectancy at birth in India may be attributed to the increase in mortality due to the COVID19 pandemic. India is one of the only 23 countries of the 236 countries of the world where life expectancy at birth decreased by more than 3 years between 2018 and 2021.

According to the official life tables constructed by the Registrar General and Census Commissioner of India, using the age-specific death rates available from the official sample registration system of the country, the life expectancy at birth in India has been estimated to be 70.0 years during the period 2016-2020 or around the year 2018 (Government of India, 2022). The life expectancy at birth varies widely within the country, across states. Among the 22 states of the country for which life tables are constructed by the Registrar General and Census Commissioner of India, the life expectancy at birth is estimated to be the highest in Delhi (75.8 years) but the lowest (65.1 years) in Chhattisgarh for the period 2016-2020 (Government of India, 2022). Besides Delhi, Kerala is the only other state of the country where the life expectancy at birth is estimated to be at least 75 years. On the other hand, there are 9 states in the country, the life expectancy at birth is estimated to be less than 70 years during the period 2016-2020.

Although, life expectancy at birth is the most commonly used summary measure of mortality universally, yet it has limitations in analysing mortality transition. A recent study has highlighted these limitations (Modig et al, 2020). The relationship between mortality and life expectancy is essentially reciprocal but the exact connection is complicated and becomes important when life expectancy at birth is used for analysing mortality transition (Pollard, 1982). The change in the life expectancy at birth is a weighted function of the changes in mortality at individual ages plus the interaction effects of mortality changes (Pollard, 1982). The difference in life expectancies cannot be directly translated into the difference in the relative risk of mortality because both the level of mortality and the distribution of mortality over age play a role (Keyfitz, 1977; Vaupel, 1986). The implicit age standardisation in the calculation of the life expectancy at birth is construed in such a way that it raises concern about the standardisation of age and, therefore, it is recommended that life expectancy at birth should not be used as the measure of choice to identify risk factors of death. (Modig et al, 2020). Moreover, the life expectancy at birth reflects the mortality experience of a hypothetical population, and not the mortality experience of the actual population.

There are measures other than life expectancy at birth that have been suggested as the summary index of mortality but there is disagreement on the most appropriate index to analyse mortality transition. There are advantages and drawbacks of different summary indexes of mortality (Spiegelman, 1955; Kitagawa, 1964). Age standardised death rate is commonly used but choosing an appropriate standard population is quite difficult. Standardisation does not eliminate the effect of the differences between the age distribution of the two populations but only holds it constant (Schoen, 1970). Standardisation also gives disproportionately higher weights to older ages (Yerushalmy, 1951).

Scheon (1970) has recommended that the geometric mean of the age-specific death rates, termed as ∇, should be used as the summary index of the prevailing mortality. The rationale for opting the geometric mean to construct a summary index of prevailing mortality and important properties of the index ∇ have been discussed by Schoen (1970). However, to the best of our knowledge, geometric mean of either age-specific death rates (∇) or age-specific probabilities of death which we term as index Γ has not been used for analysing mortality transition. Unlike the life expectancy at birth which depicts mortality situation of a hypothetical population, the index ∇ or the index Γ summarises the currently prevailing mortality situation.

In this paper, we analyse the mortality transition in India since independence or, during 1950-2021 in terms of the trend in both life expectancy at birth and geometric mean of the age-specific probabilities of death (Γ). The paper also analyses the impact of COVID-19 pandemic on mortality transition and estimates excess deaths associated with the pandemic. The paper reveals that mortality transition in India since independence has not been consistent, and there has been considerable slowdown in mortality transition because the transition in mortality has been different in different age groups. The analysis is relevant from the health policy perspective as mortality transition reflects improvements in the quality of life of the people through improvements in their health and nutritional status (United Nations, 1973). The analysis of mortality transition also contributes to understanding the evolution of the health policy. Ideally, there should be congruence between mortality transition and evolution of health policy as health policy has a direct reflection on the level and the transition in mortality. At the same time, evolution of the health policy may be viewed as a response to the health status of the population as reflected in through the transition in mortality. It is well known that with the improvement in the health status of the population, the disease profile changes, there is a change in the pattern of causes of death and a shift in the age pattern of mortality. Evolution of the health policy, therefore, is a response to the transition in mortality resulting from the improved health status of the people (Chaurasia, 2009).

The paper is organised as follows. The next section analyses long-term trend in life expectancy at birth and in the geometric mean of age-specific probabilities of death (Γ). The analysis reveals that mortality transition in the country has not been consistent as the trend in the life expectancy at birth and in geometric mean of age-specific probabilities of death (Γ) changed at least five times. Section three analyses transition in the age-specific probabilities of death (Γ) using a polishing approach. The analysis reveals that transition in the probabilities of death in younger ages has been different from the transition in the probabilities of death in the older ages and the slow transition in the probabilities of death at older ages appears to be the reason behind slowing of the improvement in the life expectancy at birth. The fourth section of the paper estimates the number of excess deaths in the country that may be associated with the COVID-19 pandemic while the last section of the paper discusses policy and programme implications of the findings of the analysis in the context of demographic and health transition.

Long-term Trend in Life Expectancy at Birth

The United Nations Population Division has provided, for the first time, annual estimates of annual age-specific probabilities of death for the 70 years period from 1950 through 2021 for 236 countries of the word including India. These estimates permit analysis of mortality transition in each country. Using these estimates, we have analysed the trend in the life expectancy at birth during 1950-2021 to identify periods of acceleration or deceleration or even reversal in mortality transition. We have first examined whether there was a change in the trend in the life expectancy at birth or not. If there is a change in the trend, then we have identified the time point(s) or year(s) when the trend had changed so that the period 1950 to 2021 can be divided into different sub-periods. We have analysed mortality transition in different sub-periods by estimating annual per cent change in both life expectancy at birth and geometric mean of the age-specific probabilities of death in each sub-period assuming that the trend is linear on the log scale in each sub-period. A comparison of annual per cent change in the life expectancy at birth and in the geometric mean of age-specific probabilities of death in different sub-periods helps in identifying periods of acceleration or deceleration or reversal in mortality transition.

The jointpoint regression analysis (Kim et al, 2000) has been used for the analysis of the long-term trend as the long-term trend in mortality may not be assumed to be uniform but varies over time. There are three steps in joinpoint regression analysis. The first is to test whether there is a change in the trend. If there is no change in the trend, then the trend analysis can be carried out by fitting a straight line (on the log scale) and the annual per cent change may be estimated from the slope of the regression line. However, if the trend has changed, then the second step involves identifying time point(s) when the trend has changed or the joinpoint(s). The last step involves fitting straight line (on the log scale) between two identified joinpoint(s). If there are k joinpoints, then the entire reference period is divided into k+1 time-segments and annual per cent change (APC) in the different time-segments is different. The APC in a time-segment characterises mortality transition in that time-segment. The weighted average of APC in different time-segments gives average annual per cent change (AAPC) for the entire trend period with weights proportional to the length of different time-segments. AAPC describes the long-term trend in a better way when compared to the commonly used approach in which a single regression line (on the log scale) is fitted for the entire trend period and the average annual per cent change is calculated from the slope of the regression equation (Clegg et al., 2009). This approach best summarises the trend that varies over time (Marriot, 2010).

The number of times the trend has changed can be determined statistically. There are many methods that have been proposed for the purpose. These include permutation method (Kim et al, 2000); Bayesian Information Criterion (BIC) (Kim et al, 2009); BIC3 method (Kim and Kim, 2016); and modified BIC (Zhang and Siegmund, 2007). Determining the number of times, the trend has changed statistically is driven by the data and not by any a-priori assumption.

Let y_i denotes either the life expectancy at birth or the geometric mean of the age-specific probabilities of death for the year t_i and there are k_j joinpoints or the years when the trend has changed so that the entire trend period is divided into k_j+1 segments and in each segment, the trend is different. Then the long-term trend in y_i can be modelled as

$$\ln(y_i) = \alpha + \beta_1 t_1 + \delta_1 u_1 + \cdots + \delta_j u_j + \epsilon_i$$

where

$$u_j = \begin{cases} (t_j - k_j), if\ t_j > k_j \\ 0 \quad\quad otherwise \end{cases}$$

Actual calculations have been carried out using the Joinpoint Regression Program version 4.8.0.1 developed by the National Cancer Institute of the United States of America (National Institute of Health, 2020). The software requires, in advance, specification of minimum (0) and a maximum number of joinpoints (>0). The Program starts with the minimum number of joinpoints (0, which is a straight line on the Log scale) and tests whether more joinpoints are statistically significant and must be added to the model (up to the pre-specified maximum number of joinpoints). The grid search method has been used to identify joinpoints (Lerman, 1980) which allows a joinpoint to occur exactly at time t. A grid is created for all possible positions of the joinpoint(s) or of the combination of joinpoint(s) and then the model is fitted for each possible position of the joinpoint(s), Finally, that position of joinpoint(s) is selected which minimises the sum of squared errors (SSE) of the model. It may, however, be pointed out that even if the final selected model has k joinpoint(s), the slopes of all of the regression functions of the $k+1$ time segment may not be statistically significant which means that the APC may not be statistically significantly different from zero.

Joinpoint regression analysis has been frequently used in analysing the trend in cause-specific mortality and morbidity (Akinyede and Soyemi, 2016; Chatenoud et al, 2015; Doucet et a., 2016; John and Hanke, 2015; Mogos et al, 2016; Missikpode et al, 2015; Puzo et al, 2016; Qiu et al, 2008; Rea et al, 2017; Tyczynski and Berkel, 2005). It has also been applied for estimating population parameters under changing population structure (Gillis and Edwards, 2019). Chaurasia (2020) has used it for analysing long-term trend in infant mortality rate in India. Jointpoint regression analysis is one of the methods recommended for trend analysis of health-related measures when the trend is not linear (Ingram et al, 2018). The method provides an easily interpretable characterisation of non-linear trend.

The characterisation of mortality transition in India during 1950-2021 in terms of the trend in life expectancy at birth is presented in table 1. The life expectancy at birth in India increased at an average annual per cent change (AAPC) of almost 0.69 per cent per year during 1950-2021, but the trend changed five times so that APC in different time-segments has been different. The life expectancy at birth decreased, instead increased, during 1963-66 and 2019-21, and the decrease was very marked during 2019-2021. The increase in the life expectancy at birth was relatively the most rapid during 1966-1969 but the increase slowed down subsequently and, for more than 30 years (1986-2019), life expectancy at birth in India increased at around 0.68 per cent per year. The increase in the female life expectancy at birth has been more rapid than that in the male life expectancy at birth. Moreover, the trend in male life expectancy at birth changed five times but the trend in female life expectancy at birth changed four times.

Table 1: Long-term trend in life expectancy at birth in India, 1950-2021.

Segment	Endpoint		APC/ AAPC	Confidence interval		't'	P>|t|
	Lower	Upper		Lower	Upper		
			Combined population				
1	1950	1963	0.827	0.791	0.864	45.099	< 0.001
2	1963	1966	-0.787	-1.478	-0.092	-2.267	0.027
3	1966	1969	1.897	1.187	2.611	5.390	< 0.001
4	1969	1986	1.049	1.022	1.076	78.034	< 0.001
5	1986	2019	0.683	0.673	0.692	144.174	< 0.001
6	2019	2021	-2.687	-3.364	-2.005	-7.813	< 0.001
	1950	*2021*	*0.689*	*0.642*	*0.735*	*29.085*	*< 0.001*
			Male population				
1	1950	1963	0.773	0.724	0.822	31.685	< 0.001
2	1963	1966	-0.857	-1.774	0.068	-1.857	0.069
3	1966	1969	2.121	1.177	3.074	4.528	< 0.001
4	1969	1986	0.881	0.845	0.917	49.354	< 0.001
5	1986	2019	0.644	0.631	0.657	102.290	< 0.001
6	2019	2021	-2.612	-3.512	-1.703	-5.709	< 0.001
	1950	*2021*	*0.629*	*0.567*	*0.691*	*19.991*	*< 0.001*
			Female population				
1	1950	1962	0.918	0.841	0.995	24.013	< 0.001
2	1962	1966	-0.151	-0.792	0.494	-0.470	0.640
3	1966	1986	1.255	1.216	1.294	65.424	< 0.001
4	1986	2019	0.717	0.700	0.735	82.034	< 0.001
5	2019	2021	-2.662	-3.908	-1.400	-4.192	< 0.001
	1950	*2021*	*0.756*	*0.702*	*0.81*	*27.623*	*< 0.001*

Source: Author
Remarks: APC – Annual per cent change
AAPC – Average annual per cent change

An assessment of mortality transition in India from the international perspective can be made by comparing the increase in the life expectancy at birth in the country with the model mortality improvement trajectories developed by the United Nations Population Division based on the increase in life expectancy at birth in different countries during 1950-2005, covering life expectancy at birth between 50 and about 85 years (United Nations, 2004). These trajectories are expressed as annual increment in the life expectancy at birth at a given level of life expectancy at birth but are presented as quinquennial increments. This comparison suggests that improvement in the male life expectancy at birth in India has always been somewhere between medium and slow mortality improvement trajectories (Figure 1) whereas improvement in female life expectancy at birth has been close to the medium mortality improvement trajectory (Figure 2). It is clear from figure 2 that mortality transition in India has always been slower than the global average.

The impact of the slowdown in the improvement in the life expectancy at birth in India after 1986 appears to have been quite substantial. If the APC in the life expectancy at birth observed during the period 1969-86 would have been sustained during the period 1986-2019, the life expectancy at birth in India would have increased to more than 80 years by the year in 2019. This means that the slowdown in the improvement in the life expectancy at birth in the country during the period 1986-2019 is estimated to have resulted in a loss of almost 9 years in the life expectancy at birth between 1986 and 2019. The loss in the male life expectancy at birth because of the slowdown in the improvement is estimated to be almost 10 years whereas the loss in the female life expectancy at birth is estimated to have been around 8 years during the post 1986 period.

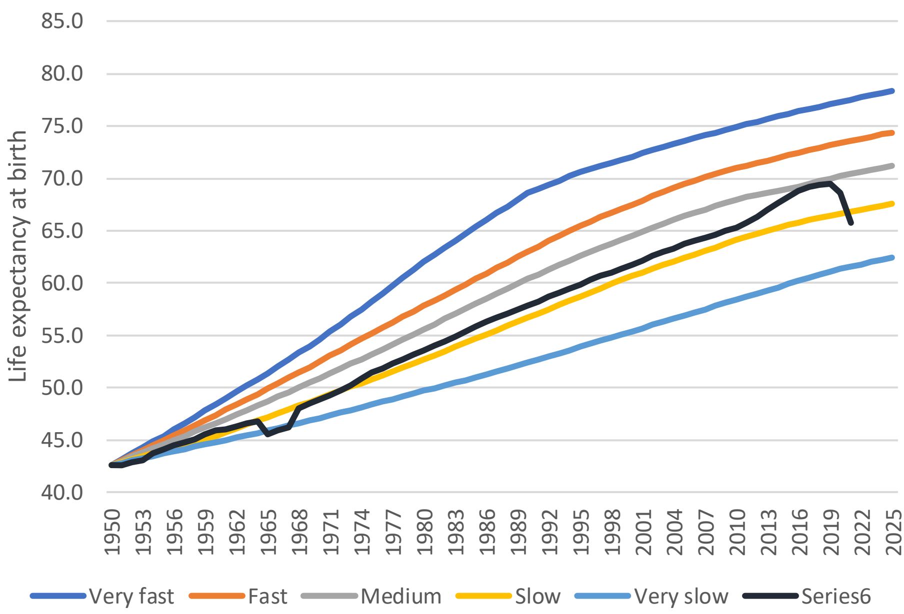

Figure 1: Improvement in male life expectancy at birth in India in relation to model mortality improvement schedules of United Nations.
Source: Author

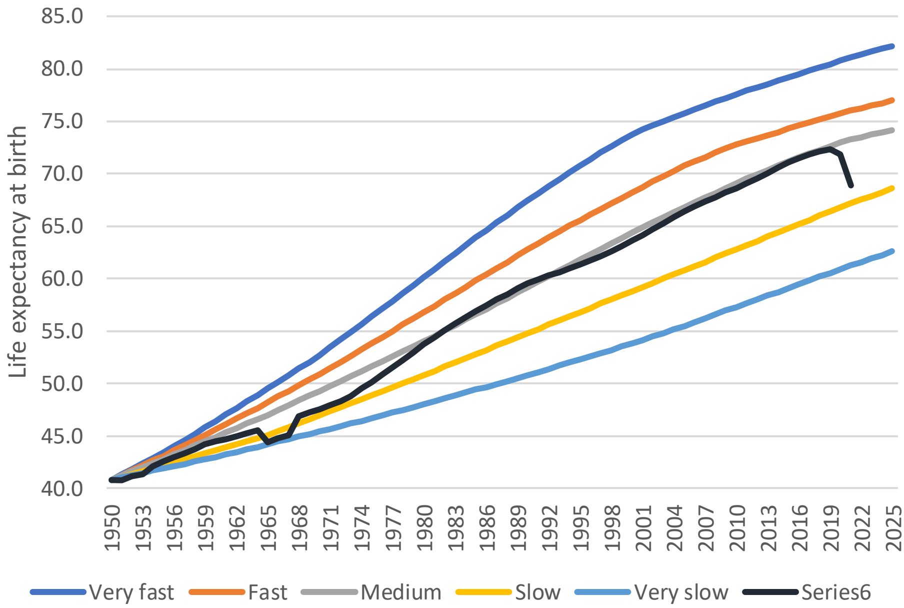

Figure 2: Improvement in female life expectancy at birth in India in relation to model mortality improvement schedules of United Nations.
Source: Author

The analysis of the long-term trend in the geometric mean of the age-specific probabilities of death (Γ), however, depicts a different picture, especially, during the period 2008-2019 (Table 2). The trend in Γ suggests that mortality transition in India accelerated during the period 2008-2019. The trend in the life expectancy at birth suggests that mortality increased more rapidly in females as compared to males during 2019-2021, the period of COVID-19 pandemic but the trend in Γ suggests that mortality increased more rapidly in males as compared to females. Tables 1 and 2 suggest that two different summary measures of mortality depict different perspective of mortality transition. The possible reason is that the life expectancy at birth gives higher weight to the probability of death in older ages whereas Γ or the geometric mean of age-specific probabilities of death gives equal weight to the probability of death in all ages. If transition in the probability of death in older ages is slower than the transition in the probability of death in younger ages, mortality transition depicted by the life expectancy at birth will be slower than the mortality transition depicted by Γ which treats transition in the probability of death in different ages equally. Similarly, if the transition in the probability of death in older ages is faster than the transition in the probability of death in the younger ages, the trend in the life expectancy of birth will depict more rapid transition in mortality compared to the transition in mortality depicted by the index Γ. The mortality transition depicted by the life expectancy at birth will be the same as the mortality transition depicted by Γ only when transition in the probability of death is the same in all ages. The life expectancy at birth depicts the mortality experience of a synthetic or hypothetical population whereas Γ depicts the mortality experience of the real population. Therefore, it is the trend in Γ or the geometric mean of the age-specific probabilities of death that depicts the true transition in mortality. Table 2 suggests that mortality transition in India has actually accelerated, not decelerated, during the period 2008-2019. Similarly, the increase in mortality during the COVID-19 pandemic period, 2019-2021, has been more rapid in males as compared to the increase in mortality in females. Table 2 also indicates that, in the recent past, mortality transition has been faster in males as compared to the mortality transition in females.

Table 2: Long-term trend in the geometric mean of age-specific probabilities of death (Γ) in India, 1950-2021.

Segment	Endpoint		APC/ AAPC	Confidence interval		't'	P>|t|
	Lower	Upper		Lower	Upper		
			Combined population				
1	1950	1962	-0.881	-1.021	-0.740	-12.505	< 0.001
2	1962	1965	0.859	-1.531	3.306	0.715	0.478
3	1965	1984	-1.985	-2.06	-1.909	-52.153	< 0.001
4	1984	2008	-1.528	-1.580	-1.476	-57.898	< 0.001
5	2008	2019	-3.026	-3.207	-2.845	-32.987	< 0.001
6	2019	2021	9.981	7.375	12.65	7.951	< 0.001
	1950	*2021*	*-1.369*	*-1.495*	*-1.243*	*-21.194*	*< 0.001*
			Male population				
1	1950	1963	-0.759	-0.869	-0.648	-13.72	< 0.001
2	1963	1966	0.987	-1.135	3.153	0.927	0.358
3	1966	1972	-2.807	-3.267	-2.345	-12.020	< 0.001
4	1972	2010	-1.365	-1.387	-1.342	-119.134	< 0.001
5	2010	2019	-3.331	-3.555	-3.107	-29.310	< 0.001
6	2019	2021	10.552	8.229	12.924	9.469	< 0.001
	1950	*2021*	*-1.213*	*-1.33*	*-1.096*	*-20.206*	*< 0.001*
			Female population				
1	1950	1963	-0.889	-0.997	-0.782	-16.528	< 0.001
2	1963	1966	1.101	-0.968	3.212	1.061	0.293
3	1966	1988	-2.317	-2.368	-2.266	-89.202	< 0.001
4	1988	2000	-1.405	-1.543	-1.268	-20.353	< 0.001
5	2000	2019	-2.650	-2.714	-2.585	-81.056	< 0.001
6	2019	2021	9.321	7.085	11.604	8.641	< 0.001
	1950	*2021*	*-1.539*	*-1.646*	*-1.431*	*-27.741*	*< 0.001*

Source: Author

Remarks: APC – Annual per cent change

AAPC – Average annual per cent change

The foregoing analysis suggests that the transition in the probability of death in the country has not been the same for all ages and it appears that transition in the probability of death in the younger ages has been faster than the transition in the probability of death in the older ages. In order to examine this hypothesis further, we have analysed the long-term trend in the age-specific probabilities of death during the period 1950-2021 under the assumption that the long-term trend in the age-specific probabilities of death has also not been linear on the Log scale during the period and the trend in the age-specific probabilities of death may have been changed at least once. The joinpoint regression analysis has therefore been carried out to analyse the long-term trend.

Transition in Age-specific Probabilities of Death

Let q_{ij} denotes the probability of death in the year *i* and age *j*, and $q_{..}$ denotes the measure of central tendency of q_{ij} over all *i* and all *j*. Then q_{ij} can be written as

$$q_{ij} = q_{..} \times \frac{q_{ij}}{q_{..}} \tag{1}$$

If $q_{i.}$ denotes the measure of central tendency for each *i* for all *j* and $q_{.j}$ denotes the measure of central tendency for each *j* for all *i*, then equation (1) can be expanded as

$$q_{ij} = q_{..} \times \frac{q_{i.}}{q_{..}} \times \frac{q_{.j}}{q_{..}} \times r_{ij} \tag{2}$$

$$r_{ij} = \frac{q_{ij} \times q_{..}}{q_{i.} \times q_{.j}} \tag{3}$$

Equation (3) suggests that q_{ij} can be decomposed into four components: 1) an overall average ($q_{..}$) across all *i* and all *j*; 2) a row effect ($q_{i.}$) which is common to all *j* of a given *i* and reflects how row average differs from the overall average; 3) a column effect ($q_{.j}$) which is common to all *i* of a given *j* and reflects how column average differs from the overall average; and 4) a residual term (r_{ij}) which is independent of the grand overall average, row effect and column effect.

Equation (2) can be fitted by applying the polishing technique proposed by Tukey (1977) by choosing an appropriate polishing function. The polishing algorithm successively sweeps the polishing function out of rows (divides row values by the polishing function for the row), then sweeps the polishing function out of columns (divides column values by the polishing function for the column), then rows, then columns, and so on and accumulates them in rows, columns, and in 'all' registers to obtain $q_{i.}$, $q_{.j}$ and $q_{..}$ and leaves behind the table of residuals (r_{ij}). When the entire variation in q_{ij} across all *i* and all *j* is explained by overall average $q_{..}$, row average $q_{i.}$ and column average $q_{.j}$, all residuals (r_{ij}) are equal to 1. If this is not the case, then r_{ij} reflects that part of q_{ij} which is not explained by $q_{..}$, $q_{i.}$, and $q_{.j}$. Equation (2) suggests that transition in q_{ij} should be examined after separating the overall average, the row average which is common to all ages of a given row or year in the present case and the column average which is common to all rows of a given column or age, or in terms of residuals r_{ij}.

We have used Γ or the geometric mean of the age-specific probabilities of death as the polishing function because the age distribution of the probability of death is skewed. Results of the polishing exercise for the period 1950-2019 are presented in table 3 for the total population and in tables 4 and 5 for males and females respectively. The period 2020-2021 has not been included in the analysis because mortality levels during this period are biased by the COVID-19 pandemic. The overall average or $q_{..}$ for all i and all j is estimated to be 0.085 for the total population, 0.087 for male population and 0.083 for female population. The polishing exercise also suggests that, in the year 1950, $q_{i.}$ or the geometric mean of the age specific probabilities of death was almost 59 per cent higher than $q_{..}$ but, in the year 2019, $q_{i.}$ was almost 49 per cent lower than $q_{..}$. The age pattern of average mortality across the years or the variation in $q_{.j}$ by age is depicted in the figure 3 which shows that age pattern of average mortality in males is different from that in females.

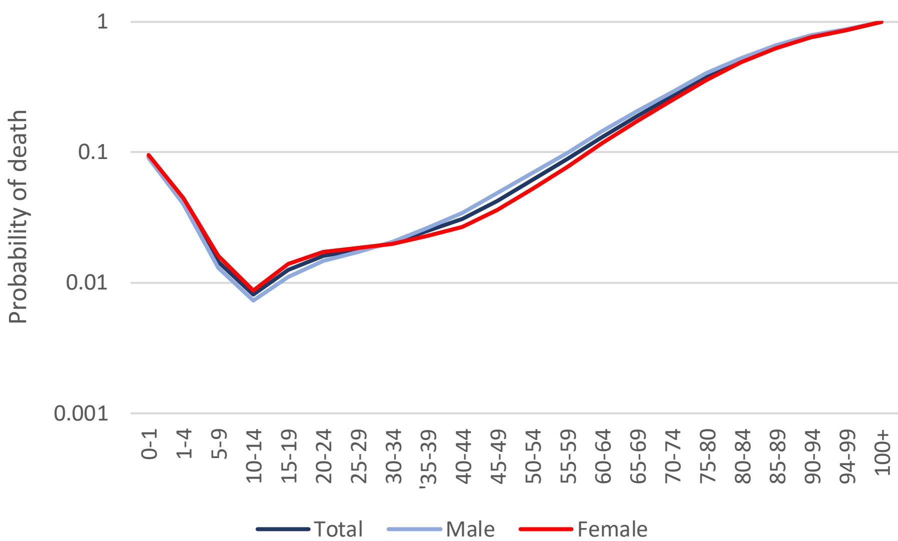

Figure 3: The age-pattern of average mortality during 1950-2019 in India.
Source: Author

The residuals presented in tables 3, 4 and 5 are multipliers and their geometric mean=1. They decide whether probability of death in a particular year and age is higher or lower than the underlying probability of death determined by $q_{..}$, $q_{i.}$, and $q_{.j}$. If $r_{ij}>1$, then the observed q_{ij} is higher than the underlying probability of death. If $r_{ij}<1$, then the observed q_{ij} is lower than the underlying probability of death. Finally, if $r_{ij}=1$, then the observed q_{ij} is the same as the underlying probability of death.

Table 3: Results of the polishing of age-specific probabilities of death (q_{ij}) with geometric mean as the polishing function – total population.

Year	Geometric mean	Age																				
		0-1	1-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	-55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99
	$q_{..}$	$q_{.j}$																				
	0.0854	0.092	0.042	0.014	0.008	0.013	0.016	0.018	0.020	0.025	0.031	0.043	0.061	0.088	0.132	0.189	0.270	0.378	0.505	0.642	0.768	0.862
	$q_{i.}$	r_{ij} (Multipliers)																				
2019	0.0440	0.587	0.305	0.421	0.612	0.653	0.664	0.744	0.844	0.981	1.083	1.097	1.254	1.360	1.273	1.324	1.389	1.422	1.459	1.526	1.616	1.714
2018	0.0444	0.607	0.319	0.432	0.613	0.650	0.658	0.734	0.833	0.966	1.066	1.102	1.266	1.363	1.274	1.312	1.383	1.418	1.448	1.516	1.604	1.702
2017	0.0451	0.632	0.341	0.451	0.618	0.652	0.660	0.730	0.825	0.953	1.048	1.104	1.269	1.352	1.266	1.293	1.368	1.404	1.428	1.495	1.580	1.676
2016	0.0461	0.654	0.361	0.469	0.621	0.661	0.673	0.734	0.821	0.945	1.036	1.097	1.255	1.327	1.251	1.278	1.352	1.388	1.414	1.480	1.561	1.653
2015	0.0476	0.670	0.379	0.489	0.625	0.676	0.697	0.748	0.822	0.943	1.031	1.079	1.222	1.288	1.229	1.270	1.334	1.370	1.405	1.469	1.546	1.629
2014	0.0494	0.682	0.396	0.511	0.631	0.696	0.729	0.767	0.827	0.945	1.029	1.057	1.178	1.240	1.204	1.266	1.316	1.351	1.399	1.462	1.533	1.606
2013	0.0514	0.692	0.415	0.535	0.640	0.720	0.765	0.788	0.835	0.946	1.023	1.035	1.130	1.188	1.178	1.260	1.299	1.330	1.393	1.454	1.518	1.580
2012	0.0533	0.702	0.431	0.560	0.649	0.743	0.799	0.807	0.846	0.946	1.012	1.020	1.086	1.137	1.156	1.253	1.285	1.312	1.388	1.448	1.506	1.556
2011	0.0551	0.716	0.451	0.589	0.664	0.765	0.825	0.820	0.859	0.941	0.988	1.014	1.050	1.090	1.139	1.240	1.273	1.294	1.380	1.439	1.489	1.530
2010	0.0565	0.733	0.474	0.622	0.684	0.783	0.841	0.826	0.874	0.930	0.952	1.019	1.024	1.049	1.128	1.219	1.264	1.278	1.367	1.426	1.471	1.505
2009	0.0578	0.754	0.500	0.658	0.707	0.798	0.850	0.828	0.890	0.917	0.914	1.030	1.006	1.015	1.121	1.196	1.255	1.261	1.351	1.410	1.450	1.481
2008	0.0588	0.775	0.527	0.693	0.731	0.811	0.853	0.827	0.904	0.905	0.878	1.042	0.994	0.991	1.117	1.173	1.246	1.245	1.332	1.390	1.426	1.455
2007	0.0598	0.796	0.555	0.727	0.756	0.823	0.855	0.829	0.916	0.896	0.852	1.048	0.988	0.977	1.113	1.153	1.233	1.227	1.309	1.365	1.398	1.427
2006	0.0609	0.816	0.582	0.757	0.780	0.835	0.859	0.835	0.924	0.892	0.841	1.044	0.986	0.976	1.107	1.139	1.217	1.207	1.282	1.333	1.366	1.395
2005	0.0621	0.833	0.608	0.782	0.801	0.848	0.867	0.849	0.928	0.896	0.847	1.027	0.988	0.987	1.099	1.133	1.195	1.185	1.252	1.295	1.328	1.359
2004	0.0635	0.847	0.634	0.807	0.823	0.863	0.878	0.867	0.929	0.903	0.865	1.002	0.991	1.006	1.087	1.131	1.169	1.160	1.220	1.253	1.287	1.318
2003	0.0646	0.863	0.658	0.821	0.829	0.872	0.888	0.885	0.924	0.911	0.889	0.975	0.998	1.032	1.080	1.136	1.149	1.142	1.193	1.218	1.252	1.284
2002	0.0659	0.878	0.684	0.842	0.837	0.880	0.898	0.902	0.918	0.916	0.913	0.952	1.006	1.056	1.073	1.140	1.129	1.124	1.167	1.183	1.218	1.251
2001	0.0674	0.891	0.710	0.869	0.850	0.887	0.909	0.918	0.912	0.917	0.932	0.936	1.011	1.072	1.069	1.139	1.113	1.109	1.142	1.153	1.186	1.217
2000	0.0684	0.910	0.738	0.895	0.840	0.880	0.909	0.922	0.902	0.908	0.937	0.932	1.018	1.080	1.073	1.141	1.110	1.106	1.130	1.139	1.168	1.198
1999	0.0695	0.927	0.769	0.933	0.843	0.875	0.907	0.922	0.893	0.893	0.932	0.935	1.021	1.076	1.079	1.136	1.109	1.104	1.119	1.128	1.152	1.180
1998	0.0704	0.945	0.798	0.967	0.838	0.867	0.903	0.916	0.883	0.875	0.920	0.943	1.023	1.069	1.089	1.132	1.114	1.107	1.113	1.124	1.142	1.168
1997	0.0713	0.963	0.828	1.001	0.837	0.861	0.896	0.907	0.874	0.857	0.905	0.953	1.023	1.059	1.098	1.127	1.120	1.112	1.111	1.123	1.136	1.158

Year	Geometric mean	Age																				
		0-1	1-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	-55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99
	$q_{..}$	$q_{.j}$																				
	0.0854	0.092	0.042	0.014	0.008	0.013	0.016	0.018	0.020	0.025	0.031	0.043	0.061	0.088	0.132	0.189	0.270	0.378	0.505	0.642	0.768	0.862
	$q_{i.}$	r_{ij} (Multipliers)																				
1996	0.0723	0.980	0.857	1.034	0.844	0.859	0.889	0.895	0.865	0.841	0.891	0.959	1.021	1.051	1.104	1.121	1.124	1.115	1.110	1.122	1.130	1.149
1995	0.0732	0.994	0.884	1.059	0.856	0.864	0.881	0.882	0.856	0.829	0.879	0.960	1.017	1.047	1.107	1.117	1.125	1.118	1.110	1.121	1.126	1.141
1994	0.0742	1.007	0.911	1.080	0.873	0.874	0.874	0.869	0.849	0.822	0.871	0.955	1.011	1.047	1.106	1.113	1.123	1.119	1.111	1.119	1.121	1.133
1993	0.0753	1.018	0.935	1.100	0.897	0.889	0.869	0.858	0.843	0.818	0.867	0.948	1.003	1.048	1.102	1.109	1.118	1.116	1.109	1.114	1.114	1.123
1992	0.0762	1.030	0.959	1.118	0.912	0.902	0.864	0.846	0.837	0.817	0.863	0.940	0.996	1.051	1.098	1.107	1.113	1.114	1.109	1.110	1.108	1.114
1991	0.0773	1.040	0.983	1.145	0.931	0.915	0.862	0.837	0.832	0.817	0.862	0.934	0.990	1.051	1.093	1.104	1.106	1.109	1.105	1.103	1.099	1.103
1990	0.0784	1.052	1.010	1.180	0.944	0.923	0.861	0.830	0.828	0.818	0.863	0.930	0.985	1.048	1.090	1.100	1.100	1.103	1.098	1.094	1.089	1.091
1989	0.0795	1.064	1.037	1.223	0.951	0.927	0.862	0.824	0.825	0.820	0.864	0.930	0.982	1.042	1.089	1.097	1.094	1.095	1.089	1.084	1.076	1.078
1988	0.0807	1.075	1.065	1.270	0.956	0.929	0.867	0.824	0.825	0.824	0.868	0.933	0.981	1.034	1.087	1.091	1.087	1.086	1.076	1.070	1.061	1.061
1987	0.0820	1.086	1.092	1.315	0.960	0.930	0.874	0.827	0.826	0.829	0.874	0.937	0.981	1.027	1.086	1.085	1.079	1.075	1.062	1.055	1.045	1.044
1986	0.0834	1.094	1.117	1.350	0.966	0.933	0.883	0.834	0.830	0.836	0.882	0.943	0.983	1.022	1.085	1.078	1.069	1.063	1.047	1.039	1.027	1.026
1985	0.0850	1.099	1.140	1.371	0.976	0.937	0.895	0.847	0.837	0.845	0.893	0.948	0.987	1.021	1.083	1.069	1.056	1.051	1.031	1.022	1.009	1.007
1984	0.0867	1.103	1.160	1.377	0.991	0.946	0.909	0.864	0.847	0.857	0.907	0.953	0.991	1.023	1.078	1.057	1.040	1.036	1.014	1.003	0.990	0.987
1983	0.0885	1.106	1.181	1.372	1.010	0.958	0.926	0.886	0.860	0.870	0.921	0.957	0.995	1.027	1.072	1.044	1.022	1.020	0.995	0.983	0.970	0.966
1982	0.0904	1.110	1.203	1.363	1.034	0.975	0.947	0.912	0.876	0.886	0.937	0.961	0.998	1.031	1.062	1.028	1.002	1.002	0.975	0.961	0.948	0.945
1981	0.0923	1.116	1.229	1.353	1.060	0.998	0.973	0.942	0.895	0.904	0.953	0.965	0.999	1.031	1.049	1.009	0.979	0.981	0.953	0.937	0.925	0.923
1980	0.0941	1.124	1.260	1.347	1.089	1.028	1.006	0.975	0.919	0.923	0.969	0.970	0.998	1.026	1.032	0.988	0.955	0.956	0.928	0.911	0.900	0.899
1979	0.0958	1.135	1.294	1.346	1.119	1.063	1.045	1.011	0.946	0.945	0.985	0.975	0.995	1.017	1.012	0.964	0.931	0.930	0.902	0.883	0.874	0.876
1978	0.0975	1.146	1.330	1.350	1.149	1.101	1.086	1.046	0.975	0.968	0.999	0.980	0.991	1.004	0.992	0.941	0.908	0.905	0.876	0.857	0.849	0.853
1977	0.0992	1.155	1.364	1.359	1.180	1.135	1.122	1.078	1.004	0.990	1.011	0.986	0.986	0.991	0.972	0.921	0.888	0.882	0.852	0.833	0.826	0.832
1976	0.1008	1.164	1.393	1.354	1.190	1.158	1.149	1.103	1.029	1.009	1.021	0.991	0.984	0.981	0.958	0.908	0.877	0.868	0.837	0.818	0.812	0.818
1975	0.1028	1.168	1.417	1.353	1.198	1.167	1.160	1.116	1.049	1.026	1.027	0.996	0.983	0.974	0.948	0.901	0.872	0.860	0.829	0.810	0.803	0.807
1974	0.1049	1.167	1.434	1.347	1.194	1.157	1.152	1.117	1.062	1.037	1.031	1.000	0.984	0.972	0.946	0.903	0.877	0.862	0.830	0.811	0.802	0.803
1973	0.1077	1.163	1.453	1.345	1.196	1.140	1.135	1.111	1.073	1.047	1.034	1.004	0.987	0.972	0.945	0.908	0.884	0.867	0.833	0.814	0.802	0.798

Year	Geometric mean	Age																				
		0-1	1-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	-55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99
	$q_{..}$	$q_{.j}$																				
	0.0854	0.092	0.042	0.014	0.008	0.013	0.016	0.018	0.020	0.025	0.031	0.043	0.061	0.088	0.132	0.189	0.270	0.378	0.505	0.642	0.768	0.862
	$q_{i.}$	r_{ij} (Multipliers)																				
1972	0.1099	1.157	1.459	1.325	1.185	1.120	1.116	1.105	1.083	1.057	1.037	1.007	0.989	0.972	0.945	0.915	0.894	0.875	0.843	0.824	0.808	0.798
1971	0.1119	1.148	1.456	1.292	1.174	1.109	1.106	1.107	1.098	1.072	1.045	1.010	0.989	0.969	0.942	0.917	0.900	0.882	0.851	0.833	0.815	0.799
1970	0.1138	1.142	1.459	1.248	1.173	1.111	1.109	1.121	1.120	1.093	1.057	1.013	0.986	0.960	0.932	0.912	0.898	0.883	0.856	0.838	0.818	0.798
1969	0.1158	1.136	1.461	1.199	1.193	1.137	1.134	1.153	1.154	1.124	1.077	1.016	0.977	0.943	0.911	0.894	0.884	0.875	0.853	0.836	0.817	0.793
1968	0.1177	1.131	1.465	1.149	1.227	1.180	1.176	1.202	1.196	1.163	1.101	1.020	0.964	0.920	0.884	0.868	0.862	0.859	0.843	0.829	0.811	0.785
1967	0.1246	1.128	1.543	1.214	1.384	1.242	1.224	1.250	1.238	1.202	1.129	1.025	0.951	0.896	0.852	0.833	0.826	0.824	0.807	0.791	0.772	0.745
1966	0.1261	1.126	1.550	1.177	1.419	1.291	1.272	1.299	1.277	1.236	1.151	1.028	0.940	0.876	0.829	0.809	0.804	0.807	0.796	0.781	0.765	0.738
1965	0.1275	1.126	1.561	1.157	1.450	1.330	1.309	1.337	1.306	1.262	1.168	1.030	0.932	0.863	0.813	0.792	0.788	0.794	0.785	0.772	0.757	0.731
1964	0.1230	1.128	1.501	1.034	1.346	1.341	1.331	1.362	1.324	1.277	1.175	1.029	0.928	0.858	0.809	0.790	0.790	0.802	0.803	0.794	0.782	0.756
1963	0.1236	1.134	1.519	1.043	1.345	1.337	1.327	1.358	1.321	1.274	1.173	1.029	0.930	0.862	0.812	0.793	0.791	0.802	0.800	0.791	0.777	0.752
1962	0.1244	1.140	1.540	1.064	1.340	1.323	1.313	1.344	1.311	1.265	1.168	1.030	0.935	0.869	0.820	0.801	0.797	0.804	0.799	0.787	0.772	0.747
1961	0.1250	1.148	1.564	1.085	1.330	1.304	1.295	1.325	1.297	1.253	1.160	1.030	0.941	0.878	0.829	0.810	0.804	0.807	0.799	0.785	0.768	0.743
1960	0.1252	1.160	1.589	1.097	1.314	1.285	1.278	1.307	1.283	1.242	1.152	1.029	0.945	0.885	0.838	0.818	0.811	0.812	0.800	0.785	0.767	0.741
1959	0.1261	1.167	1.612	1.105	1.317	1.285	1.277	1.307	1.284	1.242	1.153	1.030	0.946	0.886	0.838	0.818	0.810	0.810	0.797	0.781	0.762	0.736
1958	0.1278	1.168	1.634	1.110	1.338	1.302	1.294	1.323	1.299	1.255	1.162	1.033	0.945	0.881	0.832	0.810	0.801	0.801	0.788	0.772	0.753	0.726
1957	0.1290	1.174	1.656	1.101	1.353	1.320	1.311	1.340	1.313	1.268	1.170	1.034	0.942	0.875	0.824	0.801	0.793	0.794	0.782	0.766	0.747	0.721
1956	0.1297	1.184	1.682	1.087	1.360	1.334	1.324	1.354	1.324	1.278	1.176	1.034	0.938	0.868	0.817	0.793	0.786	0.789	0.779	0.762	0.744	0.717
1955	0.1308	1.191	1.706	1.083	1.373	1.347	1.336	1.367	1.335	1.288	1.182	1.035	0.936	0.864	0.812	0.787	0.780	0.783	0.773	0.757	0.738	0.712
1954	0.1323	1.195	1.728	1.092	1.386	1.353	1.342	1.373	1.341	1.293	1.186	1.038	0.937	0.864	0.811	0.786	0.777	0.778	0.767	0.750	0.731	0.704
1953	0.1355	1.187	1.749	1.131	1.422	1.364	1.351	1.381	1.352	1.302	1.193	1.045	0.941	0.868	0.812	0.785	0.772	0.769	0.754	0.735	0.714	0.688
1952	0.1354	1.203	1.779	1.132	1.407	1.347	1.335	1.366	1.340	1.292	1.186	1.042	0.943	0.873	0.818	0.791	0.778	0.773	0.757	0.736	0.715	0.688
1951	0.1360	1.216	1.812	1.129	1.407	1.345	1.334	1.365	1.338	1.291	1.185	1.042	0.943	0.873	0.818	0.791	0.777	0.771	0.755	0.734	0.712	0.685
1950	0.1355	1.228	1.834	1.092	1.410	1.355	1.344	1.376	1.346	1.298	1.188	1.040	0.938	0.866	0.810	0.784	0.772	0.769	0.755	0.736	0.715	0.688

Source: Author

Table 4: Results of the polishing of age-specific probabilities of death (q_{ij}) with geometric mean as the polishing function – male population.

Year	Geometric mean	Age																				
		0-1	1-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	-55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99
	$q_{..}$	$q_{.j}$																				
	0.0871	0.090	0.040	0.013	0.007	0.011	0.015	0.017	0.020	0.026	0.034	0.049	0.069	0.099	0.145	0.206	0.289	0.401	0.527	0.661	0.782	0.871
	$q_{i.}$	r_{ij} (Multipliers)																				
2019	0.0476	0.562	0.296	0.411	0.657	0.712	0.744	0.843	0.965	1.077	1.134	1.104	1.171	1.325	1.245	1.263	1.346	1.354	1.381	1.426	1.502	1.590
2018	0.0480	0.583	0.313	0.427	0.665	0.714	0.742	0.834	0.954	1.056	1.111	1.106	1.171	1.318	1.238	1.243	1.336	1.349	1.370	1.414	1.489	1.576
2017	0.0486	0.607	0.333	0.447	0.672	0.717	0.744	0.826	0.944	1.036	1.089	1.108	1.170	1.305	1.225	1.220	1.322	1.342	1.356	1.401	1.474	1.559
2016	0.0497	0.625	0.350	0.469	0.677	0.722	0.756	0.829	0.939	1.028	1.079	1.105	1.165	1.287	1.208	1.205	1.307	1.330	1.343	1.386	1.456	1.537
2015	0.0514	0.636	0.365	0.493	0.680	0.730	0.778	0.841	0.939	1.032	1.081	1.096	1.153	1.261	1.189	1.200	1.291	1.312	1.328	1.369	1.433	1.506
2014	0.0535	0.643	0.378	0.520	0.682	0.742	0.806	0.861	0.945	1.043	1.090	1.083	1.137	1.230	1.169	1.201	1.275	1.291	1.315	1.352	1.409	1.473
2013	0.0559	0.648	0.392	0.550	0.687	0.756	0.836	0.883	0.954	1.055	1.096	1.071	1.117	1.193	1.150	1.203	1.259	1.269	1.301	1.335	1.384	1.437
2012	0.0582	0.654	0.404	0.580	0.691	0.770	0.863	0.901	0.965	1.063	1.093	1.063	1.098	1.153	1.134	1.206	1.246	1.250	1.291	1.323	1.364	1.408
2011	0.0602	0.664	0.420	0.613	0.700	0.784	0.881	0.913	0.977	1.061	1.073	1.062	1.080	1.109	1.122	1.201	1.234	1.234	1.283	1.314	1.348	1.385
2010	0.0618	0.679	0.440	0.648	0.714	0.799	0.889	0.915	0.990	1.048	1.036	1.069	1.065	1.065	1.113	1.189	1.224	1.222	1.277	1.309	1.338	1.368
2009	0.0630	0.699	0.465	0.686	0.730	0.811	0.889	0.911	1.001	1.029	0.991	1.079	1.052	1.025	1.106	1.173	1.214	1.212	1.271	1.305	1.330	1.355
2008	0.0640	0.720	0.491	0.721	0.750	0.823	0.884	0.905	1.011	1.008	0.948	1.088	1.043	0.993	1.101	1.156	1.203	1.202	1.263	1.299	1.321	1.343
2007	0.0648	0.743	0.518	0.753	0.772	0.834	0.878	0.901	1.018	0.992	0.915	1.091	1.036	0.973	1.097	1.141	1.189	1.191	1.251	1.287	1.307	1.328
2006	0.0657	0.766	0.547	0.781	0.796	0.842	0.873	0.902	1.022	0.982	0.899	1.083	1.032	0.968	1.093	1.132	1.172	1.176	1.233	1.266	1.286	1.307
2005	0.0666	0.784	0.573	0.800	0.823	0.850	0.874	0.912	1.022	0.982	0.902	1.063	1.031	0.980	1.089	1.129	1.151	1.157	1.208	1.234	1.257	1.280
2004	0.0678	0.804	0.602	0.821	0.853	0.858	0.877	0.926	1.017	0.987	0.917	1.034	1.031	1.003	1.084	1.129	1.128	1.135	1.178	1.196	1.220	1.245
2003	0.0686	0.819	0.623	0.825	0.867	0.860	0.880	0.942	1.010	0.994	0.942	1.007	1.036	1.035	1.084	1.136	1.111	1.118	1.153	1.163	1.189	1.215
2002	0.0697	0.838	0.650	0.838	0.882	0.861	0.882	0.955	0.999	0.998	0.967	0.981	1.040	1.065	1.084	1.141	1.096	1.103	1.129	1.131	1.158	1.185
2001	0.0709	0.856	0.681	0.859	0.895	0.864	0.885	0.964	0.986	0.995	0.984	0.963	1.042	1.085	1.084	1.143	1.085	1.091	1.108	1.105	1.130	1.156
2000	0.0716	0.879	0.713	0.877	0.881	0.856	0.876	0.960	0.968	0.979	0.988	0.957	1.045	1.095	1.092	1.146	1.088	1.091	1.101	1.097	1.119	1.144
1999	0.0725	0.901	0.748	0.911	0.874	0.852	0.867	0.948	0.947	0.955	0.980	0.958	1.045	1.092	1.099	1.144	1.095	1.094	1.098	1.095	1.111	1.134
1998	0.0731	0.919	0.776	0.934	0.857	0.847	0.856	0.932	0.928	0.929	0.965	0.966	1.046	1.085	1.110	1.143	1.109	1.105	1.104	1.103	1.113	1.133
1997	0.0739	0.940	0.808	0.963	0.844	0.842	0.845	0.911	0.907	0.900	0.946	0.975	1.044	1.075	1.118	1.140	1.124	1.117	1.112	1.113	1.117	1.133

Year	Geometric mean	0-1	1-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99
	$q_{..}$	$q_{.j}$																				
	0.0871	0.090	0.040	0.013	0.007	0.011	0.015	0.017	0.020	0.026	0.034	0.049	0.069	0.099	0.145	0.206	0.289	0.401	0.527	0.661	0.782	0.871
	$q_{i.}$	r_{ij} (Multipliers)																				
1996	0.0748	0.960	0.841	0.996	0.841	0.841	0.835	0.888	0.887	0.873	0.924	0.981	1.040	1.065	1.123	1.137	1.136	1.128	1.121	1.123	1.122	1.134
1995	0.0757	0.976	0.871	1.023	0.849	0.843	0.826	0.864	0.867	0.851	0.905	0.983	1.035	1.061	1.123	1.135	1.146	1.137	1.131	1.132	1.126	1.133
1994	0.0769	0.991	0.900	1.049	0.866	0.848	0.821	0.842	0.850	0.834	0.889	0.979	1.029	1.061	1.120	1.133	1.151	1.144	1.139	1.138	1.129	1.130
1993	0.0782	1.003	0.927	1.075	0.894	0.857	0.819	0.824	0.835	0.822	0.877	0.972	1.021	1.063	1.113	1.131	1.151	1.146	1.144	1.139	1.126	1.123
1992	0.0793	1.015	0.953	1.098	0.914	0.863	0.820	0.809	0.823	0.815	0.868	0.965	1.015	1.065	1.107	1.130	1.151	1.147	1.147	1.138	1.124	1.116
1991	0.0805	1.027	0.981	1.126	0.937	0.871	0.822	0.798	0.813	0.811	0.863	0.958	1.008	1.064	1.100	1.128	1.147	1.145	1.145	1.133	1.116	1.105
1990	0.0815	1.041	1.009	1.161	0.952	0.875	0.823	0.788	0.805	0.811	0.861	0.954	1.003	1.060	1.095	1.125	1.143	1.140	1.139	1.125	1.106	1.093
1989	0.0824	1.056	1.040	1.200	0.961	0.877	0.824	0.781	0.799	0.813	0.863	0.953	1.000	1.053	1.093	1.122	1.137	1.133	1.129	1.114	1.094	1.081
1988	0.0835	1.070	1.072	1.241	0.966	0.881	0.831	0.783	0.799	0.819	0.869	0.953	0.997	1.043	1.091	1.116	1.128	1.122	1.113	1.099	1.077	1.064
1987	0.0845	1.084	1.102	1.279	0.970	0.884	0.837	0.787	0.800	0.827	0.877	0.956	0.997	1.034	1.090	1.109	1.117	1.109	1.096	1.082	1.059	1.047
1986	0.0857	1.098	1.134	1.315	0.979	0.890	0.843	0.794	0.803	0.836	0.888	0.960	0.998	1.028	1.088	1.099	1.102	1.093	1.076	1.062	1.038	1.029
1985	0.0871	1.108	1.163	1.340	0.996	0.900	0.851	0.804	0.810	0.845	0.899	0.965	1.000	1.027	1.086	1.087	1.083	1.074	1.054	1.040	1.017	1.009
1984	0.0886	1.116	1.188	1.353	1.021	0.915	0.860	0.818	0.820	0.855	0.912	0.970	1.004	1.029	1.083	1.073	1.062	1.054	1.032	1.017	0.996	0.988
1983	0.0901	1.123	1.215	1.360	1.054	0.933	0.870	0.835	0.831	0.865	0.925	0.975	1.009	1.034	1.078	1.056	1.038	1.033	1.010	0.994	0.974	0.967
1982	0.0917	1.131	1.242	1.362	1.090	0.957	0.885	0.855	0.845	0.876	0.937	0.979	1.011	1.038	1.070	1.037	1.012	1.010	0.987	0.969	0.952	0.947
1981	0.0931	1.142	1.274	1.364	1.126	0.985	0.906	0.878	0.861	0.886	0.947	0.981	1.011	1.038	1.059	1.016	0.986	0.986	0.963	0.944	0.930	0.927
1980	0.0944	1.158	1.313	1.368	1.161	1.019	0.934	0.906	0.879	0.898	0.956	0.980	1.006	1.032	1.043	0.993	0.959	0.961	0.937	0.919	0.908	0.907
1979	0.0954	1.178	1.359	1.377	1.189	1.057	0.970	0.937	0.899	0.910	0.961	0.977	0.997	1.020	1.024	0.969	0.934	0.935	0.912	0.894	0.885	0.888
1978	0.0963	1.200	1.410	1.389	1.212	1.096	1.010	0.970	0.920	0.922	0.965	0.972	0.987	1.004	1.004	0.946	0.912	0.912	0.888	0.871	0.864	0.870
1977	0.0973	1.221	1.461	1.407	1.233	1.131	1.048	0.999	0.939	0.933	0.967	0.967	0.976	0.988	0.984	0.926	0.893	0.891	0.867	0.851	0.846	0.854
1976	0.0982	1.238	1.502	1.406	1.230	1.153	1.079	1.023	0.957	0.944	0.971	0.965	0.969	0.975	0.969	0.914	0.882	0.878	0.852	0.838	0.834	0.843
1975	0.0996	1.248	1.535	1.410	1.225	1.162	1.097	1.038	0.969	0.954	0.975	0.965	0.966	0.966	0.959	0.907	0.877	0.870	0.843	0.830	0.826	0.836
1974	0.1013	1.251	1.557	1.409	1.209	1.153	1.098	1.042	0.976	0.962	0.981	0.968	0.969	0.964	0.955	0.909	0.881	0.870	0.842	0.830	0.825	0.832
1973	0.1040	1.246	1.578	1.415	1.205	1.138	1.091	1.041	0.983	0.971	0.989	0.974	0.974	0.964	0.953	0.912	0.886	0.871	0.841	0.830	0.824	0.827

Year	Geometric mean	Age																				
		0-1	1-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99
	$q_{..}$	$q_{.j}$																				
	0.0871	0.090	0.040	0.013	0.007	0.011	0.015	0.017	0.020	0.026	0.034	0.049	0.069	0.099	0.145	0.206	0.289	0.401	0.527	0.661	0.782	0.871
	$q_{i.}$	r_{ij} (Multipliers)																				
1972	0.1062	1.239	1.584	1.398	1.184	1.120	1.082	1.040	0.989	0.981	0.997	0.981	0.980	0.965	0.951	0.918	0.893	0.876	0.847	0.837	0.829	0.826
1971	0.1082	1.229	1.580	1.364	1.162	1.112	1.084	1.048	1.003	0.996	1.008	0.986	0.983	0.962	0.945	0.919	0.897	0.880	0.852	0.844	0.835	0.827
1970	0.1104	1.221	1.581	1.315	1.149	1.118	1.101	1.069	1.026	1.017	1.021	0.990	0.979	0.953	0.933	0.912	0.894	0.879	0.855	0.848	0.838	0.825
1969	0.1125	1.212	1.581	1.258	1.156	1.150	1.143	1.111	1.062	1.046	1.036	0.989	0.967	0.934	0.909	0.893	0.880	0.870	0.853	0.848	0.837	0.820
1968	0.1146	1.204	1.582	1.195	1.175	1.203	1.206	1.171	1.110	1.081	1.052	0.986	0.950	0.910	0.880	0.866	0.858	0.855	0.845	0.843	0.833	0.812
1967	0.1223	1.193	1.655	1.270	1.344	1.280	1.277	1.234	1.164	1.120	1.070	0.984	0.929	0.880	0.842	0.827	0.820	0.819	0.808	0.802	0.791	0.768
1966	0.1239	1.189	1.659	1.222	1.367	1.336	1.342	1.293	1.209	1.151	1.083	0.980	0.913	0.859	0.818	0.803	0.799	0.804	0.800	0.796	0.786	0.761
1965	0.1254	1.188	1.668	1.196	1.390	1.380	1.392	1.338	1.243	1.174	1.093	0.978	0.902	0.845	0.801	0.786	0.784	0.792	0.792	0.788	0.779	0.754
1964	0.1203	1.194	1.610	1.049	1.256	1.387	1.419	1.364	1.259	1.185	1.096	0.975	0.898	0.842	0.800	0.788	0.789	0.804	0.813	0.816	0.809	0.785
1963	0.1210	1.199	1.629	1.060	1.257	1.381	1.412	1.359	1.257	1.184	1.097	0.977	0.901	0.845	0.803	0.790	0.790	0.803	0.810	0.811	0.804	0.780
1962	0.1217	1.206	1.650	1.085	1.256	1.364	1.391	1.342	1.245	1.178	1.097	0.981	0.908	0.853	0.811	0.797	0.794	0.803	0.807	0.806	0.798	0.774
1961	0.1223	1.214	1.674	1.113	1.251	1.341	1.364	1.319	1.230	1.168	1.095	0.985	0.917	0.862	0.821	0.806	0.801	0.805	0.805	0.803	0.793	0.769
1960	0.1224	1.227	1.701	1.129	1.239	1.319	1.340	1.298	1.215	1.159	1.092	0.987	0.923	0.869	0.828	0.813	0.807	0.809	0.805	0.802	0.791	0.768
1959	0.1233	1.234	1.725	1.139	1.243	1.318	1.339	1.298	1.216	1.160	1.094	0.989	0.925	0.870	0.829	0.813	0.805	0.807	0.801	0.797	0.785	0.762
1958	0.1251	1.234	1.746	1.144	1.261	1.337	1.359	1.318	1.233	1.173	1.101	0.991	0.922	0.865	0.823	0.805	0.797	0.797	0.792	0.788	0.775	0.752
1957	0.1262	1.239	1.769	1.132	1.271	1.357	1.382	1.339	1.250	1.186	1.107	0.991	0.917	0.858	0.814	0.796	0.788	0.791	0.787	0.783	0.770	0.746
1956	0.1268	1.251	1.798	1.114	1.272	1.372	1.401	1.356	1.262	1.194	1.110	0.989	0.911	0.850	0.806	0.788	0.782	0.787	0.785	0.781	0.769	0.744
1955	0.1278	1.260	1.826	1.108	1.282	1.385	1.415	1.369	1.272	1.201	1.113	0.988	0.908	0.846	0.800	0.782	0.776	0.781	0.781	0.776	0.764	0.739
1954	0.1290	1.266	1.853	1.116	1.293	1.389	1.419	1.373	1.277	1.206	1.117	0.990	0.909	0.846	0.799	0.780	0.773	0.777	0.775	0.770	0.757	0.732
1953	0.1319	1.261	1.879	1.158	1.330	1.398	1.423	1.380	1.287	1.215	1.126	0.998	0.915	0.849	0.801	0.779	0.766	0.765	0.760	0.753	0.740	0.715
1952	0.1315	1.281	1.916	1.159	1.317	1.375	1.401	1.359	1.269	1.204	1.121	0.997	0.918	0.853	0.806	0.784	0.772	0.770	0.763	0.756	0.742	0.717
1951	0.1319	1.295	1.953	1.156	1.317	1.372	1.399	1.357	1.267	1.202	1.120	0.997	0.918	0.853	0.805	0.784	0.771	0.769	0.761	0.753	0.739	0.715
1950	0.1316	1.306	1.972	1.116	1.315	1.385	1.418	1.372	1.277	1.208	1.120	0.993	0.911	0.846	0.797	0.777	0.767	0.768	0.763	0.756	0.742	0.717

Source: Author

Table 5: Results of the polishing of age-specific probabilities of death (q_{ij}) with geometric mean as the polishing function – female population.

Year	Geometric mean	Age																				
		0-1	1-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	-55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99
	$q_{..}$	$q_{.j}$																				
	0.0829	0.095	0.044	0.016	0.009	0.014	0.017	0.019	0.020	0.023	0.027	0.036	0.052	0.077	0.118	0.173	0.251	0.357	0.486	0.626	0.757	0.857
	$q_{i.}$	r_{ij} (Multipliers)																				
2019	0.0398	0.619	0.318	0.438	0.578	0.609	0.592	0.644	0.705	0.852	1.002	1.076	1.373	1.400	1.303	1.399	1.447	1.514	1.562	1.649	1.749	1.855
2018	0.0404	0.646	0.340	0.455	0.580	0.607	0.588	0.639	0.698	0.846	0.991	1.081	1.391	1.401	1.305	1.386	1.432	1.495	1.533	1.618	1.714	1.819
2017	0.0411	0.673	0.364	0.472	0.581	0.609	0.590	0.639	0.692	0.842	0.979	1.083	1.400	1.391	1.303	1.371	1.415	1.472	1.505	1.589	1.679	1.782
2016	0.0420	0.700	0.388	0.488	0.584	0.621	0.605	0.646	0.689	0.835	0.965	1.069	1.373	1.358	1.290	1.359	1.398	1.452	1.490	1.573	1.659	1.757
2015	0.0432	0.722	0.412	0.506	0.590	0.644	0.634	0.660	0.690	0.826	0.948	1.038	1.307	1.299	1.265	1.350	1.381	1.436	1.488	1.572	1.654	1.743
2014	0.0445	0.742	0.435	0.524	0.600	0.675	0.672	0.680	0.694	0.814	0.928	1.000	1.221	1.228	1.234	1.341	1.365	1.423	1.495	1.579	1.657	1.734
2013	0.0461	0.762	0.461	0.546	0.615	0.711	0.716	0.701	0.702	0.801	0.905	0.963	1.130	1.154	1.200	1.329	1.350	1.409	1.501	1.586	1.658	1.721
2012	0.0475	0.780	0.484	0.567	0.633	0.747	0.761	0.723	0.714	0.790	0.878	0.935	1.048	1.089	1.173	1.314	1.339	1.395	1.506	1.591	1.657	1.706
2011	0.0489	0.799	0.511	0.595	0.656	0.778	0.798	0.740	0.730	0.779	0.848	0.921	0.983	1.036	1.152	1.290	1.329	1.376	1.499	1.584	1.643	1.682
2010	0.0503	0.821	0.540	0.628	0.683	0.801	0.823	0.750	0.748	0.772	0.816	0.922	0.938	0.999	1.139	1.259	1.321	1.353	1.480	1.564	1.617	1.650
2009	0.0515	0.841	0.567	0.662	0.713	0.818	0.840	0.758	0.769	0.768	0.787	0.933	0.910	0.976	1.133	1.225	1.313	1.327	1.451	1.535	1.583	1.613
2008	0.0527	0.861	0.596	0.698	0.742	0.830	0.851	0.763	0.790	0.767	0.764	0.948	0.894	0.964	1.129	1.192	1.302	1.299	1.416	1.498	1.542	1.573
2007	0.0539	0.880	0.624	0.734	0.769	0.842	0.860	0.771	0.809	0.770	0.749	0.960	0.888	0.962	1.125	1.164	1.288	1.269	1.377	1.455	1.497	1.529
2006	0.0552	0.895	0.649	0.765	0.791	0.855	0.871	0.782	0.825	0.777	0.748	0.963	0.890	0.968	1.117	1.145	1.269	1.241	1.339	1.410	1.450	1.483
2005	0.0567	0.909	0.676	0.796	0.806	0.873	0.886	0.800	0.834	0.786	0.760	0.952	0.897	0.980	1.102	1.134	1.244	1.212	1.301	1.362	1.402	1.435
2004	0.0583	0.917	0.698	0.825	0.821	0.894	0.905	0.823	0.841	0.799	0.783	0.935	0.909	0.997	1.084	1.129	1.214	1.184	1.264	1.313	1.352	1.385
2003	0.0598	0.933	0.725	0.850	0.817	0.908	0.921	0.845	0.841	0.808	0.807	0.913	0.923	1.016	1.068	1.132	1.188	1.163	1.235	1.272	1.311	1.343

Year	Geometric mean	Age																				
		0-1	1-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	-55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99
	$q_{..}$	$q_{.j}$																				
	0.0829	0.095	0.044	0.016	0.009	0.014	0.017	0.019	0.020	0.023	0.027	0.036	0.052	0.077	0.118	0.173	0.251	0.357	0.486	0.626	0.757	0.857
	$q_{i.}$	r_{ij} (Multipliers)																				
2002	0.0614	0.942	0.748	0.877	0.819	0.920	0.939	0.868	0.842	0.818	0.833	0.895	0.939	1.033	1.054	1.134	1.163	1.143	1.205	1.233	1.271	1.303
2001	0.0632	0.948	0.770	0.911	0.831	0.930	0.956	0.891	0.846	0.827	0.855	0.885	0.955	1.043	1.044	1.131	1.139	1.124	1.176	1.197	1.232	1.261
2000	0.0644	0.962	0.795	0.942	0.825	0.923	0.962	0.904	0.845	0.826	0.863	0.884	0.969	1.048	1.045	1.129	1.127	1.116	1.157	1.175	1.207	1.235
1999	0.0658	0.971	0.820	0.984	0.835	0.914	0.967	0.915	0.849	0.825	0.864	0.892	0.979	1.045	1.049	1.120	1.116	1.108	1.136	1.154	1.181	1.207
1998	0.0670	0.989	0.852	1.026	0.841	0.902	0.966	0.919	0.851	0.819	0.856	0.903	0.986	1.038	1.057	1.110	1.109	1.103	1.120	1.140	1.161	1.186
1997	0.0681	1.002	0.878	1.063	0.850	0.893	0.962	0.921	0.854	0.813	0.848	0.914	0.990	1.030	1.066	1.100	1.104	1.099	1.107	1.128	1.145	1.169
1996	0.0692	1.014	0.903	1.095	0.865	0.890	0.956	0.920	0.858	0.811	0.842	0.922	0.990	1.023	1.073	1.089	1.097	1.095	1.096	1.118	1.132	1.154
1995	0.0701	1.026	0.928	1.119	0.880	0.897	0.948	0.917	0.861	0.811	0.840	0.923	0.986	1.019	1.077	1.080	1.088	1.090	1.087	1.108	1.121	1.141
1994	0.0710	1.037	0.952	1.136	0.897	0.911	0.939	0.912	0.864	0.815	0.843	0.918	0.979	1.019	1.077	1.072	1.077	1.084	1.080	1.099	1.111	1.130
1993	0.0719	1.046	0.973	1.152	0.919	0.933	0.931	0.908	0.868	0.822	0.850	0.909	0.971	1.019	1.074	1.064	1.064	1.075	1.072	1.087	1.099	1.117
1992	0.0727	1.058	0.996	1.167	0.931	0.951	0.922	0.900	0.869	0.828	0.856	0.901	0.963	1.020	1.071	1.060	1.054	1.069	1.067	1.079	1.091	1.107
1991	0.0736	1.067	1.019	1.192	0.946	0.970	0.916	0.894	0.870	0.834	0.863	0.895	0.957	1.020	1.068	1.055	1.044	1.060	1.059	1.068	1.080	1.094
1990	0.0747	1.077	1.044	1.230	0.956	0.981	0.913	0.888	0.871	0.837	0.867	0.893	0.953	1.017	1.067	1.051	1.036	1.052	1.049	1.056	1.067	1.080
1989	0.0759	1.087	1.070	1.278	0.963	0.987	0.914	0.884	0.871	0.839	0.870	0.897	0.952	1.013	1.066	1.048	1.031	1.043	1.038	1.044	1.052	1.064
1988	0.0773	1.095	1.095	1.331	0.968	0.988	0.918	0.882	0.872	0.842	0.872	0.905	0.954	1.007	1.067	1.044	1.026	1.035	1.026	1.031	1.035	1.046
1987	0.0788	1.102	1.120	1.381	0.971	0.985	0.925	0.885	0.875	0.845	0.876	0.913	0.957	1.002	1.067	1.041	1.022	1.026	1.013	1.017	1.018	1.027
1986	0.0804	1.105	1.138	1.416	0.974	0.983	0.936	0.892	0.879	0.851	0.883	0.923	0.961	1.000	1.066	1.037	1.017	1.018	1.001	1.003	1.001	1.009
1985	0.0822	1.106	1.155	1.433	0.978	0.983	0.951	0.907	0.887	0.861	0.894	0.930	0.965	0.999	1.064	1.032	1.011	1.010	0.989	0.989	0.984	0.989
1984	0.0841	1.105	1.170	1.431	0.983	0.985	0.970	0.928	0.898	0.875	0.909	0.935	0.968	1.002	1.059	1.026	1.003	1.001	0.977	0.973	0.967	0.969
1983	0.0862	1.103	1.186	1.415	0.991	0.991	0.992	0.955	0.912	0.894	0.928	0.939	0.972	1.005	1.052	1.018	0.991	0.990	0.964	0.956	0.948	0.948
1982	0.0884	1.103	1.204	1.394	1.002	1.002	1.018	0.987	0.930	0.916	0.950	0.944	0.975	1.008	1.041	1.006	0.977	0.976	0.947	0.936	0.927	0.925
1981	0.0907	1.103	1.224	1.372	1.019	1.019	1.049	1.022	0.953	0.943	0.975	0.952	0.979	1.010	1.027	0.991	0.959	0.958	0.927	0.912	0.902	0.900
1980	0.0931	1.104	1.246	1.354	1.043	1.044	1.084	1.060	0.981	0.973	1.003	0.965	0.984	1.008	1.010	0.972	0.938	0.935	0.903	0.885	0.875	0.873
1979	0.0955	1.106	1.269	1.343	1.073	1.076	1.124	1.099	1.015	1.007	1.031	0.982	0.990	1.004	0.991	0.950	0.914	0.909	0.875	0.854	0.845	0.845

Year	Geometric	Age																				
	mean	0-1	1-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	-55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99
	$q_{..}$	$q_{.j}$																				
	0.0829	0.095	0.044	0.016	0.009	0.014	0.017	0.019	0.020	0.023	0.027	0.036	0.052	0.077	0.118	0.173	0.251	0.357	0.486	0.626	0.757	0.857
	$q_{i.}$	r_{ij} (Multipliers)																				
1978	0.0980	1.106	1.291	1.337	1.108	1.110	1.162	1.135	1.051	1.042	1.059	1.003	0.996	0.998	0.971	0.928	0.891	0.882	0.847	0.825	0.816	0.817
1977	0.1007	1.104	1.310	1.336	1.146	1.142	1.195	1.167	1.088	1.077	1.085	1.024	1.003	0.992	0.954	0.908	0.871	0.858	0.821	0.799	0.789	0.792
1976	0.1030	1.105	1.329	1.326	1.168	1.163	1.216	1.189	1.121	1.105	1.103	1.042	1.008	0.987	0.941	0.895	0.860	0.843	0.806	0.782	0.772	0.774
1975	0.1056	1.103	1.346	1.320	1.185	1.170	1.220	1.198	1.148	1.128	1.113	1.054	1.011	0.984	0.934	0.889	0.855	0.836	0.798	0.773	0.761	0.761
1974	0.1080	1.099	1.359	1.309	1.189	1.160	1.204	1.194	1.167	1.143	1.115	1.060	1.012	0.983	0.933	0.891	0.861	0.840	0.801	0.775	0.760	0.756
1973	0.1109	1.095	1.377	1.302	1.197	1.141	1.178	1.183	1.181	1.154	1.112	1.060	1.011	0.983	0.935	0.897	0.871	0.848	0.809	0.781	0.762	0.752
1972	0.1132	1.090	1.383	1.279	1.193	1.120	1.149	1.172	1.193	1.165	1.108	1.059	1.009	0.983	0.938	0.905	0.884	0.860	0.822	0.792	0.769	0.753
1971	0.1151	1.082	1.381	1.247	1.191	1.107	1.129	1.169	1.211	1.181	1.112	1.059	1.006	0.979	0.937	0.909	0.891	0.870	0.833	0.803	0.776	0.754
1970	0.1168	1.079	1.385	1.206	1.200	1.106	1.120	1.176	1.232	1.204	1.123	1.060	1.001	0.970	0.929	0.904	0.891	0.873	0.840	0.809	0.780	0.753
1969	0.1186	1.075	1.389	1.165	1.232	1.127	1.130	1.200	1.263	1.238	1.148	1.068	0.994	0.954	0.910	0.887	0.877	0.864	0.836	0.806	0.778	0.749
1968	0.1203	1.071	1.395	1.124	1.278	1.164	1.155	1.238	1.301	1.282	1.183	1.079	0.987	0.933	0.885	0.862	0.854	0.847	0.824	0.797	0.771	0.742
1967	0.1267	1.074	1.478	1.182	1.427	1.213	1.184	1.274	1.332	1.321	1.221	1.093	0.983	0.913	0.857	0.830	0.820	0.813	0.789	0.761	0.736	0.707
1966	0.1280	1.074	1.488	1.153	1.474	1.256	1.216	1.314	1.366	1.360	1.256	1.104	0.977	0.895	0.835	0.807	0.797	0.795	0.774	0.749	0.727	0.700
1965	0.1293	1.075	1.500	1.137	1.512	1.289	1.243	1.345	1.391	1.390	1.281	1.112	0.974	0.883	0.820	0.790	0.780	0.781	0.762	0.738	0.718	0.692
1964	0.1253	1.074	1.438	1.033	1.431	1.302	1.261	1.370	1.413	1.410	1.294	1.114	0.970	0.876	0.813	0.785	0.779	0.786	0.775	0.756	0.738	0.713
1963	0.1260	1.080	1.456	1.040	1.428	1.298	1.259	1.367	1.410	1.406	1.289	1.112	0.971	0.879	0.817	0.789	0.781	0.786	0.773	0.753	0.734	0.709
1962	0.1268	1.086	1.477	1.057	1.416	1.286	1.251	1.355	1.401	1.394	1.277	1.109	0.973	0.886	0.826	0.796	0.788	0.790	0.774	0.751	0.731	0.705
1961	0.1274	1.095	1.501	1.074	1.400	1.270	1.240	1.340	1.389	1.378	1.262	1.104	0.976	0.895	0.836	0.806	0.796	0.795	0.775	0.750	0.728	0.701
1960	0.1276	1.106	1.524	1.082	1.380	1.254	1.228	1.326	1.378	1.364	1.248	1.099	0.977	0.902	0.844	0.815	0.804	0.800	0.778	0.752	0.728	0.700
1959	0.1285	1.113	1.548	1.089	1.381	1.254	1.228	1.326	1.378	1.364	1.247	1.098	0.978	0.903	0.845	0.815	0.803	0.798	0.776	0.748	0.723	0.696
1958	0.1302	1.115	1.570	1.094	1.404	1.269	1.241	1.340	1.391	1.376	1.257	1.103	0.978	0.899	0.839	0.808	0.795	0.790	0.767	0.739	0.715	0.687
1957	0.1314	1.121	1.593	1.087	1.422	1.284	1.253	1.354	1.404	1.390	1.269	1.107	0.976	0.893	0.831	0.799	0.786	0.782	0.761	0.733	0.709	0.681
1956	0.1321	1.130	1.616	1.074	1.433	1.297	1.263	1.367	1.414	1.403	1.280	1.110	0.974	0.888	0.825	0.792	0.779	0.776	0.756	0.729	0.705	0.678
1955	0.1335	1.135	1.637	1.071	1.449	1.309	1.273	1.379	1.425	1.415	1.289	1.113	0.974	0.884	0.820	0.787	0.772	0.770	0.750	0.722	0.699	0.671

Year	Geometric	Age																				
	mean	0-1	1-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	-55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99
	$q_{..}$	$q_{.j}$																				
	0.0829	0.095	0.044	0.016	0.009	0.014	0.017	0.019	0.020	0.023	0.027	0.036	0.052	0.077	0.118	0.173	0.251	0.357	0.486	0.626	0.757	0.857
	$q_{i.}$	r_{ij} (Multipliers)																				
1954	0.1352	1.137	1.655	1.079	1.461	1.316	1.281	1.387	1.432	1.421	1.293	1.116	0.976	0.886	0.821	0.786	0.770	0.765	0.744	0.715	0.691	0.663
1953	0.1387	1.127	1.672	1.116	1.494	1.328	1.294	1.397	1.445	1.429	1.299	1.122	0.980	0.889	0.822	0.785	0.767	0.758	0.733	0.702	0.676	0.647
1952	0.1390	1.140	1.697	1.115	1.476	1.315	1.285	1.387	1.436	1.419	1.289	1.118	0.981	0.895	0.830	0.792	0.773	0.761	0.735	0.702	0.675	0.646
1951	0.1397	1.151	1.727	1.113	1.476	1.314	1.284	1.386	1.436	1.418	1.287	1.117	0.981	0.896	0.831	0.792	0.773	0.760	0.733	0.700	0.672	0.643
1950	0.1390	1.164	1.749	1.078	1.481	1.322	1.288	1.394	1.441	1.427	1.295	1.118	0.978	0.889	0.824	0.785	0.767	0.757	0.732	0.701	0.675	0.646

Source: Author

For example, the underlying probability of death in the age group 0-1 year determined by $q_{..}$, $q_{2019.}$, and $q_{.0\text{-}1}$ was 0.0475 in 2019, but $r_{2019,0\text{-}1}$ was 0.5873 which means that $q_{2019,0\text{-}1}$ was more than 41 per cent lower than the underlying probability of death determined by $q_{..}$, $q_{2019.}$, and $q_{.0\text{-}1}$. Similarly, the underlying probability of death in the age-group 70-74 years determined by $q_{1950.}$, and $q_{.70\text{-}74}$ was 0.4277, but $r_{1950,70\text{-}74}$ was 0.7685 so that $q_{1950,70\text{-}74}$ was about 23 per cent lower than the underlying probability of death determined by $q_{..}$, $q_{1950.}$, and $q_{.70\text{-}74}$. The underlying probability of death in the age group 80-84 years in 2015 determined by $q_{..}$, $q_{2015.}$, and $q_{.80\text{-}84}$ was 0.212, but $r_{2015,80\text{-}84}$ was 1.3969 so that $q_{2015,80\text{-}84}$ was almost 40 per cent higher than the underlying probability of death determined by $q_{..}$, $q_{2015..}$, and $q_{.80\text{-}84}$.

The transition in the age-specific probabilities of death may be analysed in terms of the trend in the age-specific residuals (r_{ij}). An increase in the residuals over time is an indication that there is a deceleration in transition in the probability of death whereas a decrease in the residuals over time is an indication that there is an acceleration in transition in the probability of death. The time trend in the residuals (r_{ij}) in different age groups is depicted in figure 4 for the total population and in figures 5 and 6 for male and female population respectively while average annual per cent change (AAPC) in the residuals for total, male and female populations are presented in table 4 which suggest that the transition in the age-specific probability of death in different age groups has been different in the country.

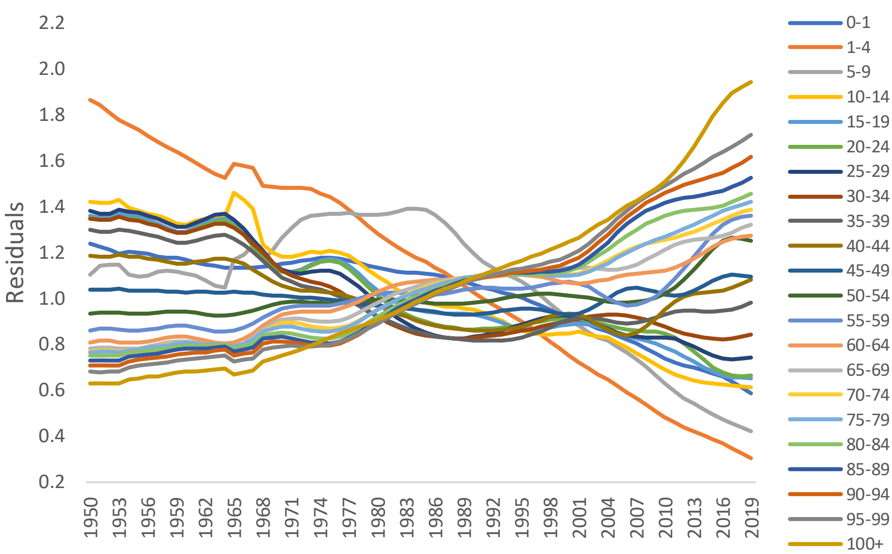

Figure 4: Change in age-specific residuals (r_{ij}) over time – total population.
Source: Author

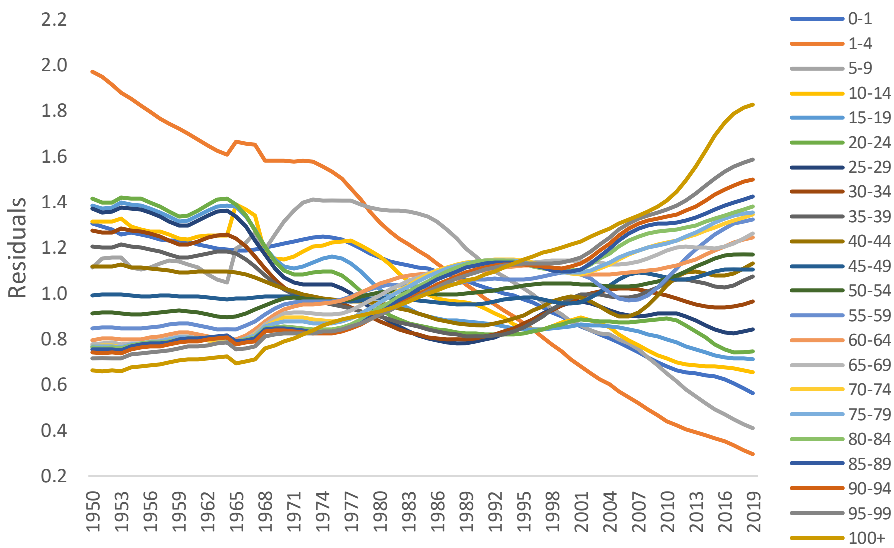

Figure 5: Change in age-specific residuals (r_{ij}) over time - male population.
Source: Author

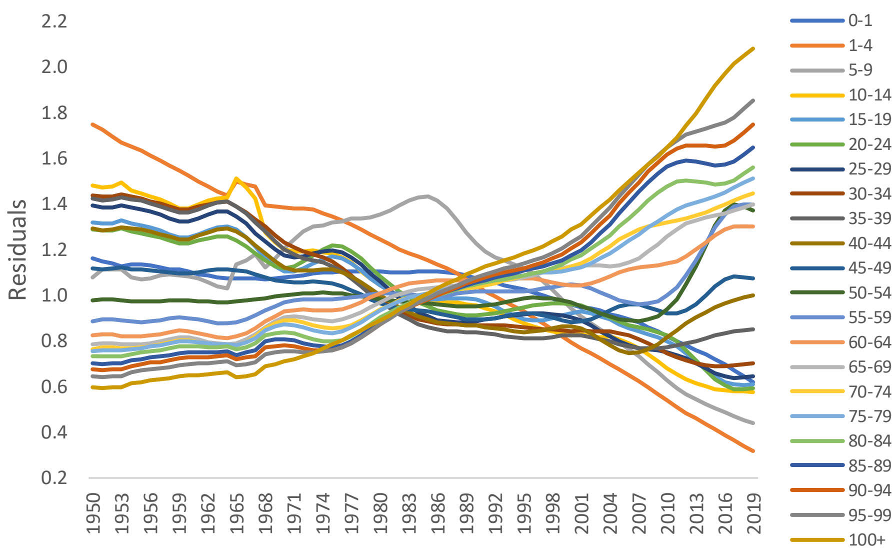

Figure 6: Change in age-specific residuals (r_{ij}) over time - female population.
Source: Author

Table 4: Average annual percent change (AAPC) in r_{ij} during 1950-2019 in India

Age	Person					Male					Female				
	AAPC %	Confidence interval Lower	Confidence interval Upper	't'	P>|t|	AAPC %	Confidence interval Lower	Confidence interval Upper	't'	P>|t|	AAPC %	Confidence interval Lower	Confidence interval Upper	't'	P>|t|
0-1	-1.066	-1.122	-1.010	-37.194	< 0.001	-1.206	-1.270	-1.142	-36.550	< 0.001	-0.901	-0.932	-0.870	-56.215	< 0.001
1-4	-2.559	-2.622	-2.496	-78.212	< 0.001	-2.694	-2.751	-2.637	-90.656	< 0.001	-2.412	-2.492	-2.333	-58.990	< 0.001
5-9	-1.454	-1.564	-1.344	-25.720	< 0.001	-1.511	-1.632	-1.390	-24.285	< 0.001	-1.359	-1.474	-1.243	-22.925	< 0.001
10-14	-1.252	-1.590	-0.913	-7.201	< 0.001	-0.996	-1.243	-0.748	-7.844	< 0.001	-1.378	-1.666	-1.088	-9.278	< 0.001
15-19	-1.098	-1.272	-0.925	-12.355	< 0.001	-0.983	-1.131	-0.834	-12.909	< 0.001	-1.173	-1.391	-0.955	-10.483	< 0.001
20-24	-1.072	-1.260	-0.884	-11.123	< 0.001	-0.961	-1.138	-0.783	-10.571	< 0.001	-1.237	-1.509	-0.965	-8.856	< 0.001
25-29	-0.919	-1.050	-0.788	-13.666	< 0.001	-0.713	-0.877	-0.549	-8.494	< 0.001	-1.151	-1.269	-1.033	-19.019	< 0.001
30-34	-0.681	-0.788	-0.574	-12.430	< 0.001	-0.410	-0.565	0.255	-5.159	< 0.001	-1.038	-1.103	-0.972	-30.738	< 0.001
35-39	-0.412	-0.532	-0.292	-6.725	< 0.001	-0.184	-0.326	-0.041	-2.526	0.012	-0.728	-0.860	-0.596	-10.772	< 0.001
40-44	-0.146	-0.251	-0.042	-2.753	0.006	-0.015	-0.108	0.078	-0.314	0.754	-0.326	-0.479	-0.172	-4.142	< 0.001
45-49	0.104	0.020	0.188	2.431	0.015	0.162	0.076	0.248	3.694	< 0.001	-0.016	-0.171	0.138	-0.207	0.836
50-54	0.426	0.302	0.550	6.736	< 0.001	0.356	0.223	0.488	5.270	< 0.001	0.519	0.436	0.602	12.290	< 0.001
55-59	0.662	0.545	0.779	11.147	< 0.001	0.647	0.519	0.775	9.945	< 0.001	0.662	0.584	0.740	16.663	< 0.001
60-64	0.666	0.546	0.786	10.915	< 0.001	0.638	0.498	0.777	9.005	< 0.001	0.675	0.544	0.806	10.150	< 0.001
65-69	0.764	0.656	0.872	13.904	< 0.001	0.679	0.571	0.787	12.387	< 0.001	0.865	0.729	1.000	12.584	< 0.001
70-74	0.863	0.759	0.967	16.369	< 0.001	0.822	0.714	0.931	14.944	< 0.001	0.935	0.796	1.074	13.252	< 0.001
75-79	0.916	0.816	1.016	18.046	< 0.001	0.841	0.744	0.937	17.110	< 0.001	1.029	0.905	1.154	16.286	< 0.001
80-84	0.967	0.851	1.083	16.435	< 0.001	0.861	0.776	0.947	19.761	< 0.001	1.086	0.966	1.206	17.813	< 0.001
85-89	1.069	0.955	1.182	18.564	< 0.001	0.925	0.821	1.030	17.452	< 0.001	1.231	1.107	1.355	19.536	< 0.001
90-94	1.201	1.094	1.307	22.196	< 0.001	1.036	0.905	1.166	15.630	< 0.001	1.367	1.250	1.484	23.088	< 0.001
95-99	1.354	1.280	1.427	36.236	< 0.001	1.186	1.117	1.254	34.162	< 0.001	1.532	1.457	1.608	40.076	< 0.001
100+	1.701	1.586	1.815	29.328	< 0.001	1.507	1.404	1.610	28.873	< 0.001	1.865	1.792	1.938	50.565	< 0.001

Source: Author

Table 4 reveals that the average annual per cent change (AAPC) in r_{ij} is negative and statistically significant in ages younger than 40 years but positive and statistically significant in ages 50 years and older. This means that transition in the probability of death in ages younger than 40 years accelerated while that in ages 50 years and above decelerated over time. The transition accelerated the most rapidly in the age group 1-4 years where $r_{i,1-4}$ decreased at a rate of more than 2.5 per cent per year during the 70 years period under reference. In 1950, $q_{1950,1-4}$ was almost 87 per cent higher than the underlying probability of death determined by $q_{..}$, $q_{1950,.}$, and $q_{.,1-4}$ but in 2019, $q_{1950,1-4}$ was almost 70 per cent lower than the underlying probability of death determined by $q_{..}$, $q_{1950,.}$, and $q_{.,1-4}$. On the other hand, there has been virtually no acceleration or deceleration in transition in the probability of death in age groups 40-44 and 45-49 years as the AAPC in $r_{i,40-44}$ and $r_{i,45-49}$ has not been found to be statistically significantly different from zero. It is also evident from the table that the pace of deceleration in the transition in the probability of death increased with the advancing age.

Table 4 also reveals that transition in age-specific probabilities of death in the male population has been different than the transition in the female population. In the age group 0-10 years, transition in male probability of death accelerated more rapidly than the transition in the female probability of death. However, in the age group 10-49 years, transition in the female probability of death accelerated more rapidly than the transition in the male probability of death. In ages 50 years and above, transition in the female probability of death decelerated more rapidly than the transition in the male probability of death. Table 4 and figures 4 to 6 suggest that the transition in the probability of death in ages younger than 50 years in the country accelerated during 1950-2021 whereas the transition in the probability of death in ages 50 years and older decelerated in the country during this period. The deceleration in the transition in the probability of death in ages 50 years and older appears to responsible for the slowing down of the improvement in the life expectancy at birth as the life expectancy at birth gives more weight to the probably of death in older ages than the probability of death in the younger ages. The measure Γ or the geometric mean of the age-specific probabilities of death gives equal weight to age-specific probability of death in all ages and therefore depicts a different picture of mortality transition than that depicted by the life expectancy at birth.

Impact of COVID-19 Pandemic

The estimates prepared by the United Nations suggest that the life expectancy at birth in India decreased from around 70.9 years in 2019 to 67.2 years in 2021 or a decrease of around 3.7 years. Comparable estimates of life expectancy at birth in India from the official sample registration system are not available. The decrease in the life expectancy at birth may be attributed to the excess mortality associated with the COVID-19 pandemic. It is possible to estimate excess deaths associated with COVID-19 pandemic by projecting age-specific probabilities of death that prevailed in the country in 2019 up to 2021 to obtain likely no-COVID-19 scenario and then comparing projected age-specific probabilities of death with the observed age-specific probabilities of death. The WHO defines excess mortality as, "the mortality above what would be expected based on the non-crisis mortality rate in the population of interest." These include both direct effects of COVID-19 (deaths directly attributed to COVID-19) and the indirect knock-on effects on the health system and the society, along with deaths that are averted. (Knutson et al, 2022).

We have projected age-specific probabilities of death up to the year 2021 in the absence of COVID-19 associated mortality by estimating APC in $r_{.j}$ for the most recent period during which the trend has been linear on the log scale for male and female population for different age groups and the results are given in table 5. The Jointpoint regression analysis was carried out to identify the most recent period in which the trend in the probability of death was linear. Based on the values of APC so obtained, we projected r_{ij} for 2020 and 2021 and then the age-specific probabilities of death in the year 2020 and the year 2021 in the absence of the deaths associated with the COVID-19 pandemic. These projected age-specific probabilities of death in the absence of COVID-19 pandemic have then been converted into the likely age-specific death rates in the absence of excess deaths associated with the COVID-19 pandemic. Based on these projected age-specific death rates in the absence of the COVID-19 pandemic, the projected number of deaths in the absence of COVID-19 pandemic have been estimated calculated for the year 2020 and 2021 for male and female population separately. The difference between the actual number of deaths in the year 2020 and 2021 and the projected number of deaths for the year 2020 and 2021 in the no-COVID-19 pandemic scenario provided an estimate of excess deaths associated with the COVID-19 pandemic in the country.

Our estimates suggest that there were around 4.29 million COVID-19 associated excess deaths – 2.44 million male deaths and 1.85 million female deaths - in India during 2020-2021. In 2020, or during the first wave of the pandemic, COVID-19 associated excess deaths are estimated to be around 0.70 million – 0.45 million male and 0.25 million female. COVID-19 associated excess deaths, however, increased to more than 3.59 million – 1.99 million male and 1.60 million female - in 2021 or during the second wave of the pandemic. The estimated number of COVID-19 associated excess deaths are presented in table 6. The number of COVID-19 associated excess death increased rapidly after 45 years of age and peaked in the age group 65-69 years in both 2020 and in 2021. More than 60 per cent of the excess deaths associated with the COVID-19 pandemic were confined to ages above 60 years.

There is reasonable degree of agreement between our estimates of COVID-19 associated excess deaths and estimates prepared by World Health Organization and other researchers. The World Health Organization has estimated around 4.7 million COVID-19 associated deaths in India between January 2020 and December 2021 and around 4.3 million deaths between June 2020 and June 2021 (Knutson et al, 2022). Jha et al (2022), using data collected from a nationally representative telephone survey and official data related to facility-based COVID-19 deaths and the deaths registered under the civil registration system in 10 states, have estimated more than 3.2 million COVID-19 associated excess deaths during June 2020 to June 2021. Anand et al (2021), using different approaches, estimated that COVID-19 associated excess deaths ranged from around 3.4 million to around 4.9 million during April 2021 to June 2021.

Table 5: APC in age-specific probabilities of death in the most recent period.

Age group	Period		APC	Confidence interval		't'	P>|t|
				Lower	Upper		
			Male population				
0-1	2007	2019	-4.854	-4.937	-4.772	-115.453	< 0.001
1-4	2006	2019	-7.042	-7.182	-6.901	-97.013	< 0.001
5-9	2008	2019	-7.987	-8.376	-7.597	-39.396	< 0.001
10-14	2001	2019	-4.100	-4.367	-3.831	-30.025	< 0.001
15-19	2007	2019	-4.279	-4.607	-3.951	-25.607	< 0.001
20-24	2017	2019	-0.376	-6.352	5.981	-0.122	0.903
25-29	2010	2019	-4.174	-4.735	-3.61	-14.567	< 0.001
30-34	2006	2019	-3.522	-3.756	-3.287	-29.597	< 0.001
34-39	2011	2019	-3.145	-3.698	-2.588	-11.192	< 0.001
40-44	2011	2019	-2.787	-3.411	-2.160	-8.815	< 0.001
45-49	2007	2019	-2.723	-2.906	-2.540	-29.473	< 0.001
50-54	2011	2019	-2.047	-2.402	-1.691	-11.425	< 0.001
55-59	2012	2019	-0.980	-1.463	-0.494	-4.038	< 0.001
60-64	1995	2019	-1.538	-1.594	-1.483	-55.164	< 0.001
65-69	2016	2019	0.364	-1.590	2.358	0.371	0.712
70-74	2009	2019	-2.053	-2.323	-1.781	-15.033	< 0.001
75-79	2009	2019	-1.921	-2.118	-1.723	-19.342	< 0.001
80-84	2008	2019	-2.200	-2.370	-2.030	-25.663	< 0.001
85-89	2008	2019	-2.174	-2.336	-2.012	-26.572	< 0.001
90-94	2008	2019	-1.815	-1.947	-1.684	-27.435	< 0.001
95-99	2008	2019	-1.392	-1.490	-1.293	-28.133	< 0.001
			Female population				
0-1	2009	2019	-5.571	-5.683	-5.458	-96.67	< 0.001
1-4	2009	2019	-8.177	-8.394	-7.959	-72.22	< 0.001
5-9	2000	2019	-6.646	-6.805	-6.487	-81.231	< 0.001
10-14	2015	2019	-2.368	-4.449	-0.242	-2.231	0.03
15-19	2005	2019	-5.610	-5.910	-5.309	-36.374	< 0.001
20-24	2016	2019	-2.305	-5.541	1.040	-1.389	0.171
25-29	1999	2019	-4.451	-4.584	-4.318	-65.768	< 0.001
30-34	2015	2019	-1.416	-2.634	-0.184	-2.303	0.025
34-39	2008	2019	-1.593	-1.868	-1.318	-11.512	< 0.001
40-44	2006	2019	-0.104	-0.359	0.151	-0.819	0.416
45-49	2011	2019	-0.352	-0.846	0.144	-1.426	0.16
50-54	2016	2019	-1.822	-3.444	-0.173	-2.214	0.031

Age group	Period		APC	Confidence interval		't'	P>|t|
				Lower	Upper		
55-59	2008	2019	1.366	1.139	1.593	12.152	< 0.001
60-64	2011	2019	-0.949	-1.229	-0.668	-6.749	< 0.001
65-69	1974	2019	-1.205	-1.242	-1.168	-65.226	< 0.001
70-74	2007	2019	-1.717	-1.881	-1.551	-20.695	< 0.001
75-79	2012	2019	-1.376	-1.750	-1.000	-7.310	< 0.001
80-84	2016	2019	-0.053	-1.296	1.206	-0.085	0.933
85-89	2009	2019	-2.240	-2.440	-2.040	-22.202	< 0.001
90-94	2016	2019	-0.167	-1.224	0.902	-0.315	0.754
95-99	2017	2019	0.763	-0.811	2.363	0.969	0.337

Source: Author

Discussion and Conclusions

Mortality transition has not been an area interest in demographic research in India in recent years. There have been studies on mortality transition in India in the past (Bhat, 1987; 1989; Bhat and Navaneetham, 1991; Chaurasia, 2006; 2009; Guha, 1991; Jain et al, 1985; Navaneetham, 1993; Preston and Bhat, 1984; Roy and Lahiri, 1987; Visaria, 2004) but, in recent years, interest in mortality transition in India appears to have waned. This is so when mortality in India remains high by international standards.

A revealing finding of the present analysis is that characterisation of mortality transition is sensitive to the summary index of mortality. Mortality transition based on the geometric mean of the age-specific probabilities of death (Γ) is found to be different from that based on the life expectancy at birth. The geometric mean of age-specific probabilities of death suggests that mortality transition has accelerated in India during 2008-2019 whereas the life expectancy at birth suggests that transition has decelerated. In 2005, India launched the National Rural Health Mission, which was directed towards providing equitable, affordable, and quality health care to the rural population of the country, especially the vulnerable population groups with especial focus on states where mortality transition was slow (Government of India, 2005). The thrust of the Mission was on establishing a fully functional, community-owned, decentralized health delivery system with inter-sectoral convergence at all levels, to ensure simultaneous action on a wide range of determinants of health including water, sanitation, education, nutrition, social and gender equality. In 2013, the National Urban Health Mission (Government of India, 2013a) was launched and the two Missions were merged to constitute the National Health Mission (Government of India, 2013b). The trend in the geometric mean of age-specific probabilities of death suggests that these Missions have contributed towards accelerating mortality transition in the country whereas the trend in the life expectancy at birth indicates that there has been little impact of these Missions on mortality transition.

Table 6: Excess deaths (million) associated with COVID-19 pandemic.

Age	2020			2021			2020-2021		
	Total	Male	Female	Total	Male	Female	Total	Male	Female
0-1	-0.032	-0.016	-0.016	-0.051	-0.026	-0.025	-0.083	-0.042	-0.041
1-4	-0.010	-0.005	-0.005	-0.017	-0.009	-0.008	-0.027	-0.014	-0.014
5-9	-0.003	-0.002	-0.002	-0.006	-0.003	-0.003	-0.009	-0.004	-0.005
10-14	-0.002	-0.001	-0.001	-0.002	-0.001	-0.001	-0.004	-0.002	-0.002
15-19	-0.011	-0.007	-0.004	0.018	0.008	0.010	0.007	0.001	0.006
20-24	-0.017	-0.012	-0.005	0.029	0.013	0.016	0.012	0.001	0.011
25-29	-0.018	-0.013	-0.005	0.035	0.017	0.018	0.018	0.005	0.013
30-34	-0.013	-0.010	-0.003	0.051	0.030	0.021	0.038	0.020	0.018
34-39	-0.004	-0.003	-0.001	0.076	0.047	0.029	0.072	0.044	0.028
40-44	0.009	0.007	0.002	0.101	0.063	0.038	0.110	0.069	0.041
45-49	0.019	0.014	0.005	0.156	0.098	0.057	0.175	0.112	0.063
50-54	0.041	0.027	0.014	0.235	0.136	0.098	0.276	0.164	0.112
55-59	0.071	0.048	0.023	0.312	0.189	0.123	0.383	0.237	0.146
60-64	0.112	0.072	0.040	0.421	0.236	0.184	0.532	0.308	0.224
65-69	0.141	0.087	0.054	0.490	0.274	0.216	0.631	0.361	0.270
70-74	0.126	0.074	0.051	0.479	0.260	0.219	0.604	0.334	0.270
75-79	0.083	0.051	0.032	0.409	0.222	0.187	0.492	0.273	0.219
80-84	0.091	0.060	0.031	0.409	0.212	0.197	0.501	0.272	0.228
85-89	0.084	0.057	0.027	0.316	0.158	0.158	0.400	0.215	0.185
90-94	0.028	0.020	0.008	0.106	0.054	0.052	0.134	0.073	0.061
95-99	0.005	0.004	0.002	0.022	0.011	0.011	0.027	0.015	0.012
100+	0.000	0.000	0.000	0.003	0.001	0.001	0.003	0.002	0.001
Total	0.701	0.454	0.246	3.591	1.991	1.601	4.292	2.445	1.847

Source: Author

The contrasting scenario of mortality transition revealed by the trend in geometric mean of the age-specific probabilities of death and the trend in the life expectancy at birth appears to be due to different weights assigned to age-specific probabilities of death in the calculation of the geometric mean of the age-specific probabilities of death and in the calculation of the life expectancy at birth. In the calculation of the geometric mean, equal weights are assigned to the probability of death in different age groups. In the calculation of the life expectancy at birth, higher weights are assigned to the probability of death in older ages compared to the weights assigned to the probability of death in younger ages. As a result, transition in mortality in older ages has a stronger impact on the improvement in the life expectancy at birth. The deceleration in the life expectancy at birth reflects the deceleration in mortality transition in older ages. The present analysis reveals that mortality transition in older ages has decelerated in India during 1950-2019. From the policy and programme perspective, the present analysis suggests that the geometric mean of the age-specific probabilities of death (index Γ) or the geometric mean of the age-specific death rates (index ∇) should be preferred over the life expectancy at birth as the summary index of mortality to analyse mortality transition as the geometric mean of age-specific probabilities of death or age-specific death rates reflects the mortality experience of the real population.

A comparison of the trend in the geometric mean of the age-specific probabilities of death and the trend in the life expectancy at birth provides valuable insight about mortality transition in different age groups. If the annual per cent change (APC) in the geometric mean of the age-specific probabilities of death and the annual per cent change (APC) in the life expectancy at birth is the same, then it can be interpreted that mortality transition is the same in all age groups. If APC in the geometric mean of the age-specific probabilities of death is higher than APC in the life expectancy at birth, then it can be interpreted that mortality transition is faster in younger ages than in older ages. Finally, if the APC in the geometric mean of age-specific probabilities of death is slower than the APC in the life expectancy at birth, then this means that mortality transition is faster in older ages than in younger ages. In India, mortality transition in younger ages has been faster than that in the older ages since independence. The pace of transition has accelerated the most in the age group 1-4 years. The pace of transition decreases with age and is the slowest in the age group 40-44 years. In ages 45 years and above, the pace of transition has decelerated, and the deceleration increased with age.

The analysis also reveals interesting differences in mortality transition in males as compared to females. In the younger ages (less than 10 years), mortality transition in the country has been faster in males as compared to females. However, in the age group 10-49 years, mortality transition has been faster in females in comparison to males. In the population 50 years and older, on the other hand, mortality transition has again been slower in females than in males as the deceleration in the decrease in the probability of death in the older ages has been more pronounced in females as compared to males.

The present analysis also confirms that the impact of COVID-19 pandemic on mortality in India has been quite substantial as the pandemic appears to have resulted in a loss of almost 3.7 years in the life expectancy at birth and accounted for at least 4 million pandemic associated excess deaths in the country. The loss in the life expectancy at birth in India associated with the pandemic has been amongst the highest across countries for which estimates are prepared by the United Nations Population Division. Moreover, there have been more male excess deaths with the pandemic compared to female deaths.

The analysis suggests that the National Rural Health Mission launched in 2005 and the National Urban Health Mission launched in 2013 have contributed to accelerating mortality transition in the country. This may be viewed as the success of these Missions in meeting the health care needs of the people of the country, although there appears to have been a deceleration in mortality transition in the older ages.

The present analysis calls for promoting health in the substantive and not in the formal context. In the formal context, health of the people is linked to institution-based care whereas, in the substantive context, health is linked to the interaction between the man and the environment. There is a need to strike a balance between the two. Strengthening formal health care is related to creating, strengthening, and expanding the health care delivery system – public or private. In the absence of substantive health care, however, the system may remain unaccepted by the people at large and hence underutilised.

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Population Prospects for Madhya Pradesh in the Twenty-first Century

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Abstract

Madhya Pradesh is passing through the classical demographic transition. Mortality has declined and fertility has also fallen with a lag and is likely to fall below the replacement level. However, population of the state will continue to increase for some time primarily due to momentum and also on account of anticipated fall in mortality. This paper presents population projection of the state up to the end of the twenty-first century The paper suggests that state population is likely to reach a peak of about 113 million around 2070 and will then decline to about 108 million by the end of the century. The age structure of the population will also change. The state is in a position to draw good demographic dividend through the middle of the century. An alternate projection based on the assumption of accelerated and sharper fertility decline suggests that state population will peak around 105 million by 2061. Although, the population of the state will increase in future, yet the rate of growth is not likely to be large. The paper also discusses policy implications of the project population of the state.

Introduction

Madhya Pradesh is one of the large states of India, ranking second in terms of area and fifth in terms of population size at the 2011 population census. State population nearly quintupled during the twentieth century, from 12.7 million in 1910 to 60.3 million in 2001, most of the increase occurred after 1951 (Government of India, 2013). At the 2011 population census state population was enumerated to be 72.6 million. Population growth in the state has been fairly in line with that in India with the annual rate of growth being just under or over two percent since the mid-century but the intercensal decade 2001-2011 did show a notable decline in the rate of growth. Combined with the trend in fertility and mortality, this clearly shows that the state is passing through the classical demographic transition. Recent estimates show that fertility in the state is approaching the replacement level or has perhaps reached it. The fifth round of the National Family Health Survey (NFHS-5) estimated the Total Fertility Rate (TFR) at 1.99 during 2019-21 (Government of India, 2021). The estimate from the

Sample Registration System (SRS) for 2020 (Government of India, 2022) was higher, 2.6, but given the recent trend, fall to and possibly below replacement level is expected. Clearly, we do not expect high population growth in the future and certainly no population explosion as was being talked about in the past. Yet, population will grow for some time due to the momentum of growth. Besides, mortality has been declining in the state and further decline is expected. Population growth in the future will depend on future trend in fertility, mortality, and migration. Besides, changes in demographic parameters will affect the age structure of the population over a long period. As is well recognized, the size of the population, its age structure, and the pace of change have implications for planning and administration. Population projections give an idea of the likely changes in the future and hence provide valuable inputs for policy formulation and planning.

The Technical Group on Population Projections (TGPP) constituted by the Government of India, National Commission on Population has recently prepared population projections for India and states (Government of India, 2020a). These projections go up to 2036 only and hence do not provide the long-term perspective of population growth. The United Nations Population Division also prepares population projections for its member countries but do not give state level projections (United Nations, 2022). Kulkarni (2021a) has projected population of the country and its large states up to the year 2101 based on certain assumptions on future changes in demographic parameters. This paper presents principal results for Madhya Pradesh. It is well-known that even after replacement fertility is achieved, population continues to increase due to the phenomenon of population momentum. Moreover, mortality decline is expected to continue even after attaining replacement level fertility and this would contribute to the increase in population. Further, given the experience of countries which have completed fertility transition, fertility may not remain static after reaching the replacement level but is likely to fall below the replacement level leading to population decline in the long-term. All these factors contribute to future changes in population size. A decomposition of future population changes into contributions of various factors informs policy makers (Andreev et al, 2013). Such a decomposition is presented here for Madhya Pradesh. The paper also discusses implications of future population growth for the development of the state.

Demographic Situation in Madhya Pradesh

The population projection exercise requires information on the present demographic situation - the size and the age and sex structure of the population - as the baseline, and recent trends in the parameters of the components of population change - fertility, mortality, and migration. Data from the decennial population censuses and from the official sample registration system (SRS) give estimates of various demographic parameters. Population growth in Madhya Pradesh was slow in the first half of the twentieth century, but, since 1951, population growth has been rapid, at a pace of over two per cent per annum, until the end of the century. During the intercensal decade 2001-2011, there has been a decline in the population growth rate of the state, with the average annual growth rate falling below two per cent. Population growth in Madhya Pradesh has been slightly more rapid than that in India since 1951, but the population growth trend in India has been similar to that in India.

Table 1: Population Trends in Madhya Pradesh and India, 1901 to 2011

Year	Population (At 2011 population census)		Average annual growth rate (Per cent)	
	Madhya Pradesh	India	Madhya Pradesh	India
1901	12,679,214	238,396,327		
1911	14,249,382	252,093,390	1.17	0.56
1921	13,906,774	251,321,213	-0.24	-0.03
1931	15,326,879	278,977,238	0.97	1.04
1941	17,175,722	318,660,580	1.14	1.33
1951	18,614,931	361,088,090	0.80	1.25
1961	23,217,910	439,234,771	2.21	1.96
1971	30,016,625	548,159,652	2.55	2.20
1981	38,168,507	683,329,097	2.42	2.22
1991	48,566,242	846,421,039	2.41	2.14
2001	60,348,023	1,028,737,436	2.17	1.95
2011	72,626,809	1,210,854,977	1.85	1.63

Source: Government of India (2013).

The indicators of fertility and mortality for the state are available from SRS since 1971. The TFR in the state has declined notably while the life expectancy has increased over time (Table 2). Thus, both fertility and mortality in the state show a clear downward trend. When compared to India, TFR in the state has been higher while life expectancy has been lower than the national average. Although, Madhya Pradesh is passing through demographic transition, yet the pace of transition in the state has been slower than that in several large states of India. The male life expectancy in the state was higher than the female life expectancy during the 1970s and 1980s, but, since mid-1990s, female expectancy has overtaken male expectancy in the state, a pattern which is similar to the national pattern. The gap between the state and national life expectancy at birth was wide in the past but has narrowed recently.

As noted earlier, the SRS estimate of the TFR for the year 2020 is higher than the NFHS-5 estimate of TFR of 1.99 during the period 2019-21. A comparison of the estimates from the earlier rounds of the NFHS with the SRS estimates for the corresponding periods also shows that the NFHS estimates were lower than SRS estimates. Since the SRS estimates are based on continuous registration and half-yearly surveys and verification of events, these are preferred to examine long, or medium-term trend and one can thus infer that fertility in Madhya Pradesh has been declining and is moving towards the replacement level. It can be concluded that Madhya Pradesh is about to complete the fertility transition.

On the other hand, net inter-state migration has been very low in Madhya Pradesh in the recent decades. During 1991-2001, the net inter-state migration rate was -0.01 per 1000 for males and 0.00 for females (Government of India, 2006). During 2001-2011, the net inter-state migration rate was -0.05 per 1000 males and -0.04 per 1000 females (Government of India, 2020a).

Table 2: Indicators of fertility and mortality, Madhya Pradesh and India, 1971-2020

Period	Total fertility rate		Male life expectancy at birth		Female life expectancy at birth	
	Madhya Pradesh	India	Madhya Pradesh	India	Madhya Pradesh	India
1971-75	5.7	5.0	47.6	50.5	46.3	49.0
1976-80	5.4	4.5	49.4	52.5	48.7	52.1
1981-85	5.1	4.5	51.5	55.4	51.9	55.7
1986-90	4.8	4.0	53.7	57.7	53.0	58.1
1991-95	4.3	3.5	54.7	59.7	54.6	60.9
1996-2000	4.0	3.3	56.6	61.2	57.6	62.7
2001-05	3.8	3.0	58.9	63.1	60.5	65.6
2006-10	3.3	2.6	61.1	64.6	63.8	67.7
2011-15	2.9	2.3	63.2	66.9	66.5	70.0
2016-20	2.7	2.2	65.5	68.6	69.5	71.4

Notes: Rates up to 2000 refer to Madhya Pradesh including Chhattisgarh. The life expectancy at birth for 1971-75 refers to the period 1970-75.

Sources: Total fertility rate up to 2013 and life expectancy at birth up to 2010 (Government of India, 2014a). Total fertility rate after 2013 (Government of India, 2016; 2017; 2018; 2019; 2020; 2021; 2022). Life expectancy at birth for (Government of India, 2017a). Life expectancy at birth 2016-20 (Government of India, 2022a).

Data and Methods

The component projection method has been employed for projecting the population. This method requires baseline population size and its age and sex distribution and projected parameters of fertility, mortality, and migration. The 2011 census provides the baseline data. The age distribution has been smoothed in conventional five-year age groups following the method adopted by the Registrar General of India (Government of India, 2020a). The parameters used in the projection exercise are shown in Table 2. Since net inter-state migration for Madhya Pradesh has been found to be quite low during the last two intercensal decades, net migration was deemed negligible and no adjustment was made for it. The projected population for the state is 84.5 million for the year 2021 which is identical to the official population projection for the state (Government of India, 2020).

At the first stage, only one projection, termed as the 'Standard' projection was carried out. The projection of TFR beyond 2021 was carried out by fitting the Gompertz curve. The lower asymptote arrived at is 1.8 by the year 2061. The male and female life expectancies at birth were projected to increase in line with the average gradient seen in different countries at the given level of mortality and are projected to increase to 81.1 years and 83.9 years respectively by the year 2101. The West Model of the Coale-Demeny Regional Model Life Tables has been adopted for projection. Madhya Pradesh has had a slightly higher (more masculine) than natural sex ratio at birth. It is assumed that this will gradually reach 106 male births to 100 female births by the year 2031. The age-pattern of fertility is projected to change to the pattern seen in the 2011-15 SRS estimates of age-specific fertility rates of Tamil Nadu. The change is assumed to be gradual and linear so that by 2031-36 the Tamil Nadu 2011-15 age pattern of fertility is likely to be achieved and the pattern is assumed to remain unchanged thereafter. No adjustment for migration has been made for the reason noted above. The United Nations software package for mortality analysis (MORTPAK) has been used in the projection exercise.

In addition to the standard projection, an alternate projection has also been carried out assuming a sharper fertility decline with the lower asymptote of 1.6 for TFR instead of 1.8 as in the standard projection. The assumption on mortality change remained the same as in the standard projection. Recent data from the SRS show that a few states in India have already achieved TFR lower than 1.6 so that the assumption for the alternate projection is not unrealistic. Moreover, in order to decompose the growth into future contributions of population momentum, mortality decline, and fertility being above or below replacement level, projections under two additional scenarios, 'momentum' and 'mortality decline-replacement level fertility', have also been carried out. In the 'momentum' scenario, TFR in 2021 was brought to a level which resulted in Net Reproduction Rate (NRR) of 1. Given the mortality at the time, the replacement level TFR worked out to 2.21. Fertility and mortality parameters were then held constant after 2021. This is labelled as Projection A and the projected population at time t is denoted by PA(t). Constant mortality, obviously, is not a realistic assumption and one expects mortality to decline with the passage of time though the pace of decline becomes slower as mortality decreases. Therefore, another projection exercise was carried out for the scenario 'mortality decline-replacement level fertility' with the mortality declining as in the standard projection and fertility adjusted accordingly so as to maintain NRR at 1 after 2021. This is labelled as Projection B and the projected population at time t is denoted by PB (t). The Standard projection as described above is labelled as Projection C and the projected population at time t is denoted as PC(t). Growth after the initial time point T_0, 2021 in the standard projection can be decomposed as:

$$PC(t) - P(T_0) = \{PA(t) - P(T_0)\} + \{PB(t) - PA(t)\} + \{PC(t) - PB(t)\} \qquad (1)$$

Here $\{PA(t) - P(T_0)\}$ is the population growth attributed to population momentum, whereas $\{PB(t) - PA(t)\}$ is the population growth attributed to mortality decline; and $\{PC(t) - PB(t)\}$ is the population growth attributed to fertility being above or below replacement. This follows the method of Andreev et al (2013) with the change that, since inter-state migration is assumed to be negligible in Madhya Pradesh, the migration component has been dropped. The decomposition is sequential, momentum, mortality decline, and fertility being above or below replacement, in that order.

Results

The Standard projection shows that population of Madhya Pradesh will increase after 2021 but at a gradually declining pace (Table 3). The state population is projected to cross 100 million before 2041 but after the middle of the present century, population growth will be very slow so that population of the state will peak at 113 million in the early 2070s. The population of the state will then begin to decline slowly and will decrease to just below 110 million at the end of the century.

The crude birth rate (CBR) in the state is projected to decrease throughout the present century reaching just around 10 live births per 1000 population at the end of the century as the result of the projected decline in TFR (Table 3). The crude death rate (CDR) will, however, increase in spite of a fall in mortality because the age distribution of the population will increasingly become older. The crossover is expected in the early 2070s when there will be zero population growth but this will not last long as the CDR will continue to increase so that the growth rate will turn negative.

Table 3: Projected trends in population size and vital Rates, Madhya Pradesh, 2001-2101.

Year	Standard projection				Sharper decline in fertility
	Population (million)	Crude birth rate (Per 1000 population)	Crude death rate (Per 1000 population)	Rate of natural increase (Per cent)	Population (million)
2001	60.3	30.9	10.1	2.09	60.3
2011	72.6	26.9	8.2	1.87	72.6
2021	84.5	21.6	8.0	1.36	84.5
2031	94.6	17.0	7.7	0.94	93.9
2041	102.4	15.0	8.1	0.69	100.4
2051	108.3	13.3	8.9	0.44	104.4
2061	111.7	11.9	9.7	0.21	105.4
2071	113.0	11.2	10.8	0.04	104.2
2081	112.6	10.5	11.6	-0.10	100.8
2091	110.8	10.1	12.0	-0.19	96.0
2101	108.2	9.8	12.6	-0.28	90.2

Sources: For 2001 and 2011: (Government of India, 2014a). For 2021 onwards: projections made by the author.

If it is assumed that the decline in fertility will be sharper with TFR falling to a low value of 1.6, the growth of population will naturally be less than the population growth projected by standard projection (the last column of Table 3 shows the results of this variant). The difference between the standard and the low fertility variant are conspicuous after 2040s. The peak will be lower, at 105 million, and will be achieved earlier, by 2061. At the end of the century, the difference will be nearly twenty million.

Table 4: Projected age distribution, sex ratio, and dependency ratio, Madhya Pradesh, 2001-2101.

Year	Percentage age distribution (Per cent)			Sex Ratio (Females Per 1000 males)	Dependency ratio (Per cent)	
	Below 15 years	15 -64 years	65 years and above		Based on 15-64 years @	Based on 20-64 years $
2001	38.6	56.9	4.5	919	75.8	110.9
2011	33.5	61.6	4.9	931	62.5	95.5
2021	29.6	65.0	5.3	939	53.8	80.2
2031	26.3	67.3	6.4	948	48.7	71.6
2041	22.4	69.2	8.4	960	44.5	63.8
2051	20.3	69.2	10.5	972	44.5	60.6
2061	18.4	68.0	13.6	983	47.0	62.7
2071	17.1	65.9	17.0	995	51.9	67.2
2081	16.4	63.8	19.8	1003	56.8	72.3
2091	15.6	61.3	23.1	1001	63.1	79.3
2101	15.2	59.7	25.1	995	67.4	83.8

Remarks: @ 100* (Population of aged 0-14 and 65 years and above /Population at ages 15-64 years). $: 100* (Population of ages 0-19 years and 65 years and above /Population at ages 20-64 years).
Sources: For 2001: (Government of India, 2006); for 2011: (Government of India, 2020): for 2021-2101: projections by the author.

The age distribution of the population will undergo major changes. The share of the young population (population below 15 years of age) will decline steadily, reaching a low of 15 per cent by the end of the century in contrast to over 38 per cent at the beginning of the century and around 33 per cent in 2011 (Table 4). The share of the old population (population aged 65 years and above) will increase steadily, and, by the end of the century, about one fourth of the population of the state will be at least 65 years old. This will be a major change over the century since this proportion was very low, less than five per cent, until 2011. The share of the working age population (population aged 15-64 years) will rise for some time due to falling share of the young population, reaching a peak of 69 percent in the 2040s, but will decrease gradually after the middle of the century because the increase in the proportion of old population will more than offset the decrease in the proportion of young population.

A direct implication of the change of share of working age population is the change in the dependency ratio which will fall just below 45 per cent in the 2040s. A low dependency ratio yields the well-known demographic dividend or the demographic opportunity conducive to economic growth (Bloom et al, 2003). Madhya Pradesh will be in a favourable situation from 2030s to 2060s with the dependency ratio remaining below 50 per cent. After 2050, the old dependency ratio will rise more rapidly than the decrease in the young dependency ratio, the overall dependency ratio will gradually increase. Conventionally, the age group 15-64 years is treated as working age group and the dependency ratio is computed accordingly. However, as the economy develops, it seems inappropriate to include those below 20 years of age as potential workers. Therefore, the last column of Table 4 also presents an alternative dependency ratio treating 20-64 years as working ages. This is naturally higher than the ratio based on ages 15-64 years, but the pattern is not different. Regardless of the age range chosen for working ages, the state will be in a position to derive demographic dividend through the middle decades of the present century.

Demographic Decomposition of Growth

The results of the decomposition exercise, in conjunction with equation (1) are presented in Table 5. Most of the population growth in the state up to 2071 will be due to population momentum which will add almost 30 million to the population of the state between 2021 and 2071. However, after 2071, population momentum will not make any additional contribution to the state population. Mortality decline will contribute to the growth of the population but the contribution of mortality decline will be low initially but will accumulate over time and will emerge as a major factor of population growth with a contribution of over 17 million. On the other hand, since fertility is projected to fall below the replacement level, some of the effect of mortality decline would be offset by the decline in fertility. This offset effect will be small initially, but after 2071, it will more than make up for the positive contribution of mortality decline to population growth.

Strictly speaking, projections are not 'forecasts' and hence it is customary to provide a set of alternate projections. The United Nations Population Division which publishes population prospects and revises them regularly (the latest revision was in 2022) gives three projections, called high fertility; medium fertility; and low fertility variants usually referred to simply as high, medium, and low variants (United Nations, 2022). In the recent revisions, the United Nations Population Division also gives probabilistic projections. In the projections made in this paper, the 'sharper fertility decline' projection shown in Table 3 may be treated as the 'low' variant, the standard projection shown in Table 3 as the 'medium' variant, and the mortality decline with replacement level fertility projection, shown in Table 5, may be treated as the 'high' variant. In all the three projections, assumptions on mortality are identical and migration has been assumed to be negligible. It is only the projected fertility decline that varies; TFR falling to 1.6 in sharper fertility decline projection, TFR falling to 1.8 in the standard projection, and fertility at replacement level, so that TFR stays just above 2.08 in the mortality decline projection. The population of the state will peak to 105 million in the low variant and 113 million in the standard (or medium) variant. In the high variant the population of the state is projected to 131 million in 2101 will be increasing even beyond 2101 (Figure 1). While no definitive statement can be made on the actual value or the forecast of the state population, the present exercise variants suggest that the population of the state will remain roughly between 90 to 130 million after 2031.

Table 5: Projected population of Madhya Pradesh under different scenarios, 2021-2101.

Year	Population (million)			Decomposition of change since 2021 (million)			
	P(C) Standard projection	P(A) Momentum scenario	P(B) Mortality decline-replacement level fertility scenario	Total change	Due to population momentum	Due to mortality decline	Due to fertility being above/ below replacement
2001	60.3						
2011	72.6						
2021	84.5						
2031	94.6	93.7	93.9	10.1	9.2	0.3	0.7
2041	102.4	101.8	103.0	17.9	17.3	1.2	-0.6
2051	108.3	107.8	110.6	23.8	23.4	2.8	-2.3
2061	111.7	111.5	116.6	27.2	27.0	5.1	-4.9
2071	113.0	113.6	121.6	28.6	29.1	8.0	-8.6
2081	112.6	114.1	125.2	28.1	29.6	11.1	-12.6
2091	110.8	114.1	128.4	26.4	29.6	14.4	-17.6
2101	108.2	114.0	131.3	23.7	29.5	17.4	-23.1

Sources: 2001 and 2011: Table 1. 2021 onwards: projections by the author

Implications for Development and Policy

The population projections clearly show that the growth of population of Madhya Pradesh will not be large in the future. The growth rate has already slowed down and (according to the standard projection), the state is likely to reach zero-growth stage sometimes during 2070s and will subsequently enter a phase of slow population decline. There is, therefore, no longer any fear of population explosion as was the popular belief some time ago. The population of the state will not even double after 2021. The alternate projections of the population of the state will range somewhere between 90-130 by the end of the present century. The standard projection suggests that the state population will peak at around 113 million which amounts to a growth of less than 40 per cent since 2021. This is good news for development planning. Moreover, since fertility has declined and is projected to fall below the replacement level, no specific policy measures are warranted to regulate fertility. According to NFHS-5, during 2019-21, 71.7 per cent of couples of reproductive age (15-49 years) were using some contraceptive method; 65.5 per cent were using a modern method; and 88 per cent couples with two children did not desire to have any more child (Government of India, 2021). This shows that the two-child norm has by and large been widely accepted by the people of the state. This should not be taken to mean that the ongoing programmes on fertility regulation need no longer be pursued. Creating awareness about fertility by choice, contraception, and providing contraceptive services are essential for promoting reproductive health, child health, and aiding couples to meet their reproductive goals. The programme must address the contraceptive needs of couples. So far, Madhya Pradesh has done rather well in this respect. The NFHS-5 has revealed that the unmet need for contraception is only 7.7 per cent in the state (Government of India, 2021).

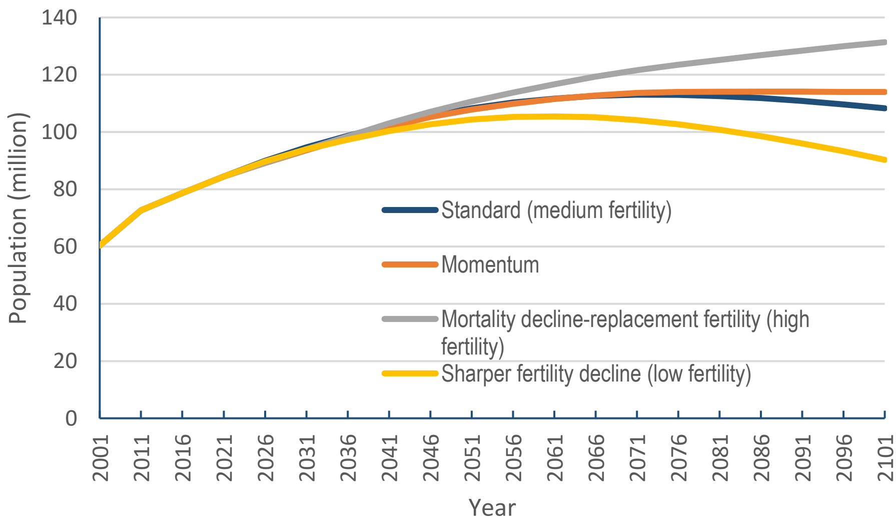

Figure 1: Projected population growth in Madhya Pradesh, 2001-2101.
Source: Author

The finding that the population would grow for some time even after attaining the replacement level fertility may cause some concern. However, achieving zero-growth immediately after reaching the replacement level fertility is not realistic. The growth momentum will make a contribution and as seen above, this factor alone would increase the population of the state by nearly 30 million. This growth cannot be prevented by policy measures unless these are more drastic than the one-child policy introduced by China in 1979 which is abandoned now. When fertility decreases to below replacement level, concerns for low population growth, shortage of working age population, and high old-age dependency become more important as has happened in Japan and in several European countries.

The change in the age structure of the population will bring in the prospects of demographic dividend. The window of demographic opportunity will be quite wide through the 2040s and 2050s but will close after that. The state will have to make efforts to make the best use of the situation in this period. There is a need to generating adequate employment, enhance the quality of the labour force, and raise female participation in the labour force which is presently quite low. Policy measures need to be designed for these purposes.

Ageing of population is a consequence of demographic transition. Care of the old has traditionally been the responsibility of working age adults within the family. With family size shrinking, there is a need to develop some institutional support mechanism to augment the filial support to the old. Government of India has already formulated policies and launched programmes like old age pension scheme, the Maintenance and Welfare of Parents and Senior Citizens Act, health insurance and other health schemes for the old people. Since population ageing is a gradual process, programmes and schemes can be developed progressively so that, by the time the share of the old population reaches a high level, a comprehensive support system is in place.

Madhya Pradesh is lagging behind several large states of India in demographic transition. Although, the state has reached low fertility levels, the momentum of growth will continue for a longer time and will also be relatively larger than many states of the country. The share of the population of the state to the population of the country is, therefore, projected to increase, barring large scale out migration (Kulkarni, 2021a). There has not been large scale migration out of the state in the past but relatively excess growth of population in the state could exert pressure for such out-migration especially of workers. There would also be opportunities to migrate to those states in which population growth has slowed down earlier so that they are likely to face labour shortage. Between 2021 and 2061, working-age population in the state is projected to increase by about 20 million whereas many states may see a decrease working age population during this period (Kulkarni, 2021b). The inter-state migration, however, brings in issues of adjustment to the new place and access to social services including health and education. Large-scale migration also raises the possibility of political resistance to in-migrants at the place of destination.

Concluding Remarks

Madhya Pradesh has passed through decades of high population growth, but it has now entered the phase of low post-transition growth and the projections show that the state is moving towards zero-growth followed by slow decline in population before the end of the present century. The state need not worry about population growth being out of control any longer. Instead, the state can look forward to encashing the opportunity of demographic dividend. The state also needs to take appropriate action to provide institutional support to its ever-increasing old population. Many states of the country are well ahead of Madhya Pradesh in demographic transition and will age much earlier than the state. Madhya Pradesh can learn from the experiences of these states in the introduction and implementation of programmes for the old people. The projected substantial increase in the working age population in Madhya Pradesh in the next few decades and the decrease in the working age population in some other states of the country over the same period provides opportunities for inter-state migration of working age population. However, large-scale inter-state migration is a sensitive issue that needs to be handled with finesse. Overall, the population prospects for Madhya Pradesh during the present century present a positive picture with some challenges to be addressed.

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Morbidity Differentials in India by Gender and Place of Residence: Evidence from National Sample Survey 2004 and 2017-2018

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Abstract

India is experiencing population ageing and a growing burden of non-communicable diseases. This paper analyses age-specific burden of communicable and non-communicable diseases (NCDs) in India by sex and place of residence using the data available from the 60th and the 75th Rounds of National Sample Survey (NSS). We found that, in 2004, prevalence of communicable diseases was higher than that of non-communicable diseases but, in 2017-2018, the prevalence of NCDs became higher than that of communicable diseases. The prevalence of both communicable and non-communicable diseases was higher in females than in males. The prevalence of communicable diseases was higher in the rural areas, but the prevalence of NCDs was higher in the urban areas. Communicable diseases are the primary cause of morbidity in childhood, but NCDs are leading cause of illness among older adults. The paper recommends a comprehensive road map to fight both communicable and non-communicable diseases in the country.

Introduction

India is experiencing population ageing as the result of declining fertility and increase in life expectancy. The share of the elderly population was only 5.6 per cent in 1961, which is projected to increase to more than double by 2026 (Government of India, 2020). Therefore, it is anticipated that the prevalence of chronic diseases like diabetes, hypertension etc., will also increase. The available evidence shows that the burden of non-communicable diseases (NCDs) is higher than the burden of communicable diseases (India State-level Disease Burden Initiative Collaborators, 2017). In 1990, the proportion of cardiovascular disease (CVD) burden to total disability-adjusted life years (DALYs) was 6.9 per cent, which soared to 14.1 per cent in 2016 (India State-level Disease Burden Initiative CVD Collaborators, 2018). The latest research on NCDs finds that the increase in the prevalence of diabetes and hypertension is alarming among the middle-aged and the old population in the country (Geldsetzer et al, 2018). On the other hand, the prevalence of communicable diseases in the country has decreased marginally between 2004 and 2014 (Banerjee and Dwivedi, 2016). In 2017-18, one-third of those who received in-patient care reported communicable diseases (Ram and Thakur, 2022). Moreover, in the last three decades, India has seen several significant outbreaks of infections (Nipah, Chikungunya, HINI influenza, and most importantly, Corona), some of which were of zoonotic origin (Dikid et al, 2013). Against this backdrop, this paper analyses the age-specific burden of communicable and non-communicable diseases (NCDs) in India by sex and place of residence. This type of analysis is vital because appropriate policy measures depend on the information about the share of communicable and non-communicable diseases in a particular age group.

Theoretical Background

The changes in the disease pattern in any part of the world result from various factors. The epidemiological transition theory (Omran, 1971) throws light on the complex interrelationship between the socioeconomic transformation of the society and the changes in health and disease patterns. Omran recognised three different models for epidemiological transition: (a) the classical or western model, (b) the accelerated transition model, and (c) the contemporary or delayed model. The first model is applied to the western European countries where the agricultural and industrial revolutions and modernisation led to the slow progressive transition from high fertility and mortality to low fertility and mortality. The second model exemplified by Japan was associated with a very short period for fertility and mortality transition owing to national and individual aspirations. The third model is applied to most of the developing countries. In these countries, public health intervention and improvement in medical sciences helped in the rapid decline in mortality, but fertility remained high.

Based on historical evidence of changing mortality, Omran identified three successive phases of epidemiological transition: (i) the age of pestilence and famine characterised by high and erratic mortality and slow population growth; (ii) the age of receding pandemics associated with mortality decline and exponential population growth; and (iii) the age of delayed degenerative diseases characterised by stability in mortality at a relatively low level and fertility dependent population growth. In its journey from the first to the third stage, any society experiences specific changes in the patterns of diseases. In the age of pestilence and famine, communicable diseases dominate, the infant mortality and the prevalence of undernutrition remain high, and the proportion of cardiovascular diseases (CVDs) to all diseases ranges between 5-10 per cent. The life expectancy at birth during this period remains 20-40 years. India was in the first stage of epidemiological transition before independence.

In the age of receding pandemics, improved sanitation and a better diet led to the decrease in the prevalence of communicable diseases and a slow increase in the prevalence of degenerative diseases. The life expectancy in this period remains between 30-50 years. After independence, India's health conditions improved, and life expectancy increased due to the expansion of public health facilities and the control of epidemics and famines. The declining mortality and high fertility led to a population explosion in India. This situation existed till the 1980s.

According to Omran, increased ageing and the rise of lifestyle-related (diet, physical inactivity, etc.) non-communicable diseases are the features of the age of degenerative diseases. India is in this stage at present. Life expectancy at birth in India was estimated at 70 years in the period 2016-20 (Government of India, 2022). In 2016 India reported 63 per cent of deaths due to NCDs, of which 27 per cent were attributed to CVDs (World Health Organization, 2023). Globalisation and increased urbanisation have led to the change in the lifestyle and food habits of the Indians, which are associated with the growing burden of diabetes, hypertension, obesity, and mental stress in the country (Pingali and Khwaja, 2004; Nethan, et al, 2017; Fricchine, 2018).

Data and Method

Our analysis is based on the data from 60th and 75th rounds of the National Sample Survey (NSS). The 60th round was conducted from January to June 2004 whereas the 75th round was conducted from July to June 2018. During these rounds of NSS, data about the 'spells of ailment' of household members during 15 days before the survey were collected. In the 60th round, 36510 persons reported at least one spell of illness. This number was 39902 in the 75th round carried out during 2017-2018. In both rounds, information about the 'nature of the ailment' and the 'status of the ailment' was also collected. The status of ailment was grouped into the following four categories:

Status 1: Started more than 15 days ago and was continuing on the date of the survey.
Status 2: Started more than 15 days ago but ended before the survey.
Status 3: Started within 15 days and was continuing on the date of the survey.
Status 4: Started within 15 days but ended before the survey.

Status 1 and 3 have been used to estimate the reported prevalence of the ailment, while status 3 and 4 have been used to estimate the incidence of the ailment. Since there were no recall laps, the point prevalence rate is used in the analysis.

The analysis of disease-specific morbidity by age is not possible from the data available from NSSO because of the sample size limitations. Besides, the nature of the ailment reported during the 60th round of the survey was not the same as that during the 75th round of the survey. We have, therefore, grouped ailments reported at the 60th round of the survey into the following four categories: I) communicable diseases; II) non-communicable diseases (NCDs); III) accidents/injuries; and IV) all other diagnosed and undiagnosed ailments. Communicable diseases include tuberculosis, hepatitis/jaundice, diarrhoea/dysentery, amoebiosis, worm infestation, mumps, conjunctivitis, diseases of skin, diseases of mouth/teeth/gum, respiratory disease, diphtheria, sexually transmitted diseases (STDs), filariasis/elephantiasis, malaria, fever of unknown origin, eruptive and whooping cough. Non-communicable diseases include diabetes mellitus, gastritis/gastric/peptic ulcer, goitre, anaemia, cataract, heart disease, diseases of kidney/urinary system, asthma, psychiatric disorders, neurological disorders, hypertension, under-nutrition, joint and bone disorders, gynaecological disorders, prostatic disorders, glaucoma, tetanus, visual disability (excluding cataract), hearing disability, speech disability, locomotor disability, and cancers and other tumours. Accidents/injuries/burns/fractures/poisoning are put under the broad heading of 'accidents/injuries. Other undiagnosed and diagnosed diseases are considered as a separate category for the analysis.

The nature of ailments in the 75th round of the survey is more complex and detailed. We have, therefore, grouped reported ailments into five categories: I) communicable diseases; II) non-communicable diseases; III) accidents/injuries; IV) childbirth; and V) all other diagnosed and undiagnosed ailments. Communicable diseases include fever with loss of consciousness or altered consciousness, malaria, fever due to diphtheria and whooping cough, all other fevers (including typhoid, fever with rash/ eruptive lesions and fevers of unknown origin), tuberculosis, filariasis, HIV/AIDS, other sexually transmitted diseases, jaundice, diarrhoea/dysentery/increased frequency of stools with or without blood and mucus in stools, worms infestation, discomfort/pain in the eye with redness or swelling/boils, earache with discharge/ bleeding from ear/infections, acute upper respiratory infections, cough with sputum with or without fever and not diagnosed as TB, skin infection (boil, abscess, itching) and other skin diseases, pain in pelvic region/ reproductive tract infections/pain in male genital area and diseases of mouth/teeth/gum. Non-communicable diseases included tetanus, cancers and occurrence of any growing painless lump in the body, anaemia, bleeding disorders, diabetes, under-nutrition, goitre and other diseases of thyroid, except the previous two other nutritional/metabolic/endocrine disorders (including obesity), mental retardation, mental disorders, headache, seizures or unknown epilepsy, weakness in limb muscles and difficulty in movements, stroke/hemiplegia/sudden loss of speech, other psychiatric and neurological disorders including memory loss and confusion, cataract, glaucoma, decreased vision (chronic), other eye problems including disorders of eye movements (strabismus, nystagmus, ptosis and adnexa), decreased hearing or loss of hearing, hypertension, heart disease including chest pain and breathlessness, bronchial asthma, gastric and peptic ulcer/acid reflux/acute pain in abdomen, lump or fluid in abdomen or scrotum, gastrointestinal bleeding, joint or bone disease/pain or swelling in any of the joints, back or body ache, any difficulty or abnormality in urination, and change/irregularity in menstrual cycle or excessive bleeding/pain during menstruation and any other gynaecological and andrological disorders including male/female infertility. The category 'accidents/ injuries' includes accidental injury, road traffic accidents and falls, accidental drowning and submersion, burns and corrosions, poisoning, intentional self-harm, assault and contact with venomous/harm-causing animals and plants. childbirth is not considered as disease but a physiological process. It is kept as a separate category.

The appendix tables 1 and 2 give details of the reported prevalence of the four categories of ailments at the 60th round of NSS whereas appendix tables 3 and 4 gives the reported prevalence of the five categories of ailments at the 75th round of NSS. It may be emphasised here that data on morbidity available through the NSS are based on the ailments reported by the respondents and, therefore, may be associated with respondent bias which may under-estimate or over-estimate the reported prevalence of different categories of ailments.

Results and Discussion

Table 1 presents reported prevalence of different categories of ailments by age in 2004 as revealed through the 60th round of NSS. The all-cause morbidity prevalence rate in India was 5.7 per cent in the year 2004. The prevalence was the lowest in the age group 5-14 years and very high in population aged 60 years and above. In the population aged 60 years and above, the prevalence of non-communicable diseases was substantially higher than the prevalence of communicable diseases. Table 1 also shows that the prevalence of other diagnosed and undiagnosed ailments was 1.0 per cent which is considerably high. Proper identification of these ailments into communicable and non-communicable diseases can alter the prevalence rates of both communicable and non-communicable diseases.

Table 1: Age-specific reported prevalence rate by broad ailment types, India, 2004.

Age	Prevalence rate (Per cent)	Ailment type			
		Communicable diseases (Per cent)	Non-communicable diseases (Per cent)	Accidents/ injuries (Per cent)	Others (Per cent)
0-4	4.9	3.85	0.18	0.07	0.80
5-14	2.0	1.39	0.19	0.07	0.35
15-29	2.6	1.32	0.60	0.10	0.58
30-44	5.0	1.98	1.77	0.18	1.07
45-59	9.4	2.86	4.66	0.26	1.62
60-74	24.9	4.51	16.75	0.44	3.20
75 +	35.6	4.27	26.12	0.65	4.56
All ages	5.7	2.51	2.03	0.16	1.00

Source: Computed from unit-level data of 60th round of NSS.

Table 2 shows the age-specific morbidity prevalence of different ailment categories in 2017-2018. The prevalence of all-cause morbidity in the country decreased to 4.6 per cent in 2017-2018. During the 75th round of NSS, the surveyors were provided with the working definitions of different ailments/main symptoms. The response on questions related to morbidity, therefore, seems more accurate compared to the 60th round of NSS. In the 60th round and in earlier round surveys on health, persons with disabilities were regarded as ailing persons. In the 75th round of NSS, however, pre-existing disabilities were classified as chronic ailments if the duration of the treatment of the ailment was at least one month long. Otherwise, these disabilities were not considered as ailments (Government of India, 2019). These changes in the classification of ailments between 60th and 75th rounds of NSS appears to be a factor in the lower prevalence of all cause morbidity in 2017-2018 compared to 2004.

Table 2: Age-specific morbidity prevalence rate by broad ailment types, India, 2017-2018.

Age	Prevalence rate (Per cent)	Ailment type				
		Communicable diseases (Per cent)	NCDs (Per cent)	Accidents/ Injuries (Per cent)	Others (Per cent)	Childbirth (Per cent)
0-4	2.4	2.27	0.11	0.01	0.01	0.00
5-14	1.2	1.07	0.10	0.02	0.01	0.00
15-29	1.1	0.81	0.24	0.02	0.03	0.01
30-44	3.4	1.53	1.76	0.06	0.04	0.00
45-59	8.8	2.16	6.49	0.10	0.06	0.00
60-74	22.7	3.52	18.70	0.14	0.34	0.00
75+	31.5	4.31	26.59	0.30	0.30	0.00
All ages	4.6	2.08	2.41	0.06	0.05	0.00

Source: Computed from unit-level data from the 75th round of NSS.

*Non-communicable Diseases

The data available from the 75th round of NSS suggest that the prevalence of non-communicable diseases in India is now higher than the prevalence of communicable diseases. An earlier study has also concluded that between 1990 and 2016, the proportion of DALYs attributed to non-communicable diseases and accidents/injuries increased in India while DALYs attributed to communicable diseases decreased significantly (India State-level Disease Burden Initiative Collaborators, 2017). Another important observation of tables 1 and 2 is that the prevalence of ailments categorised as 'others' decreased considerably between 2004 and 2017-2018. The reason for this decrease may be attributed to the fact that the 75th round of NSS used a more comprehensive framework than the 60th round to identify reported ailment/main symptom.

Figure 1 compares the prevalence of communicable diseases and non-communicable diseases by age in 2004 and 2017-2018. In both 2004 and 2017-2018, females had higher prevalence of communicable and non-communicable diseases compared to males. However, the prevalence of communicable diseases was higher in males compared to females in population less than 15 years of age. This observation is not unexpected as it is well-known that females have immunological advantages compared to males during infancy and childhood so that the prevalence of communicable diseases is lower in females below 15 years of age as compared to males below 15 years of age (WHO, 2007). On the other hand, the prevalence of non-communicable diseases is found to be higher in females compared to males in the age group 15 to 74 years but, in the age group 75 years and above, the prevalence of non-communicable diseases was higher in males compared to females in 2004. In 2017-2018, the prevalence of non-communicable diseases was higher in females compared to males, although the sex-difference in the prevalence of non-communicable disease in 2017-2018 was at best, marginal. The prevalence of communicable diseases was, however, higher in females aged 75 years and above compared to males aged 75 years and above in both 2004 and 2017-2018.

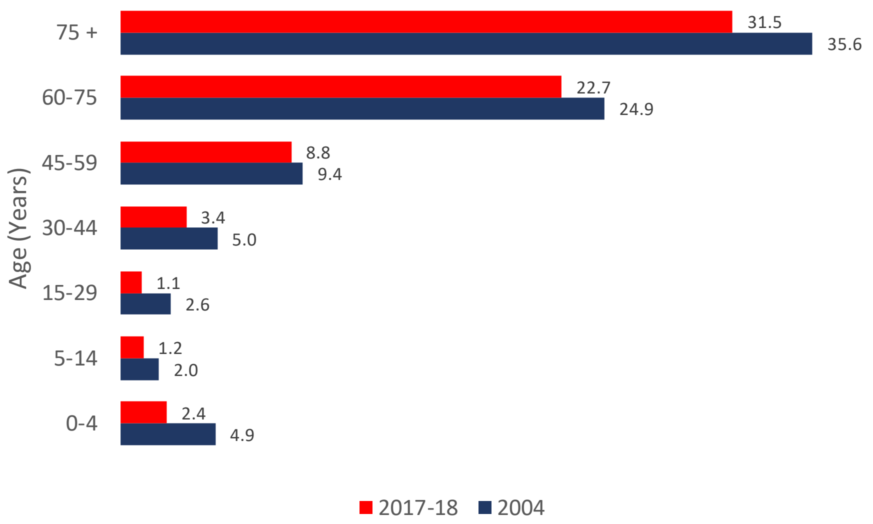

Figure 1: Reported prevalence of ailments (per cent) in India, 2004 and 2017-2018.
Source: Author

A better idea about the change in the reported prevalence of ailments or morbidity by age can be made in terms of odds ratios. Figure 2 shows that for all ages combined, the odds of reporting an ailment at the 75th round of NSS was 20 per cent lower than the odds of reporting an ailment at the 60th round of NSS. In different age groups, the odds of reporting an ailment at the 75th round compared to the 60th round varies widely. In the age group 0-4 years, the odds of reporting an ailment at the 75th round was 52 per cent lower than that at the 60th round of NSS. On the other hand, in the age group 45-59 years, the odds of reporting an ailment at the 75th round of NSS was only 7 per cent lower than that at the 60th round which suggests that there has been only a marginal decrease in the reported prevalence of ailments in population of this age group between the 60th and the 75th round of NSS. It may also be seen from the figure that in population aged at 45 years and above, the odds of reporting an ailment at the 75th round of NSS was only marginally lower than that at the 60th round whereas in population aged younger than 45 years, the odds of reporting an ailment at the 75th round was substantially lower than that at the 60th round. This suggests that the reported prevalence of ailments had decreased more rapidly in the population younger than 45 years of age as compared to the reported prevalence of ailments in the population aged at least 45 years.

It may also be seen from the figure 2 that the odds of reporting a communicable disease at the 75th round was lower than that in the 60th round of NSS in all age groups. This is, however, not the case in the reporting of non-communicable diseases. In population aged 45 years and above, the odds of reporting a non-communicable disease at the 75th round was higher than that in the 60th round of NSS.

More specifically, in the age group 45-59 years, the odds of reporting a non-communicable disease at the 75th round of NSS was more than 40 per cent higher than that at the 60th round. However, in population aged less than 45 years, the odds of reporting a non-communicable disease at the 75th round of NSS was lower than that at the 60th round. For example, in the age group 15-29 years, the odds of reporting a non-communicable disease at the 75th round was 60 per cent lower than the odds of reporting a non-communicable disease at the 60th round of NSS. Figure 2 suggests that the increase in the reported prevalence of non-communicable diseases in the country between the 60th round and the 75th round of NSS has been the result of the increase in the reported prevalence of these diseases in the population aged 45 years and older.

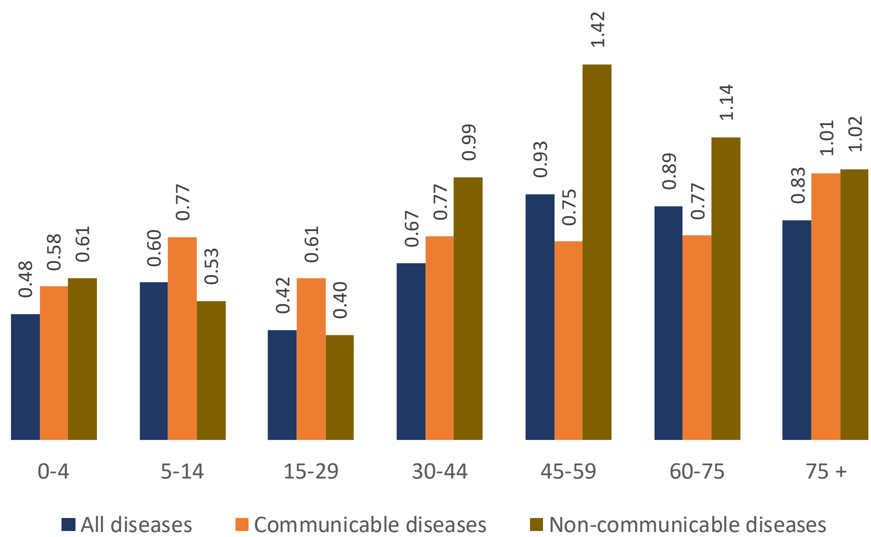

Figure 2: Odds of reporting an ailment at the 75th round of NSS relative to the 60th round of NSS.
Source: Author

In both rounds of the National Sample Survey, the odds of reporting an ailment were higher in females relative to males and the odds ratio has increased over time (Figure 3). At the 60th round, females were 16 per cent more likely to report an ailment compared to males. This proportion increased to 28 per cent at the 75th round. This increase in the odds ratio has largely been due to the increase in the odds ratio of reporting a non-communicable disease. At the 60th round of NSS, females were 28 per cent more likely to report a non-communicable disease compared to males but, at the 75th round of NSS, female were 46 per cent more likely to report a non-communicable disease compared to males. By contrast, the likelihood of a female reporting a communicable disease relative to a male increased only marginally between the 60th and the 75th rounds of NSS.

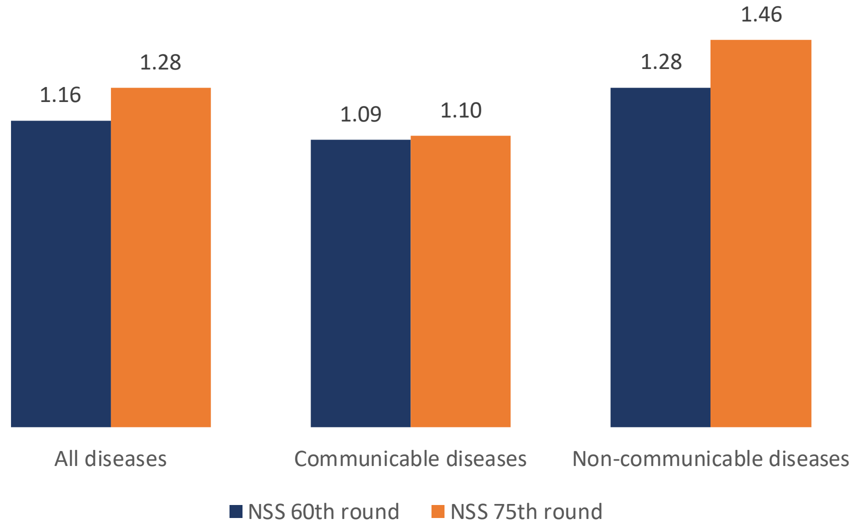

Figure 3: The odds ratio of the gender difference in the reporting of ailments at the 60th round and the 75th round of NSS.
Source: Authors

The likelihood of reporting an ailment has, however, decreased in both males and female at the 75th round of NSS compared to the 60th round of NSS. The odds of a male reporting an ailment at the 75th round of NSS were around 24 per cent lower compared to the odds of a male reporting an ailment at the 60th round of NSS. Similarly, the odds of a female reporting an ailment at the 75th round of NSS were around 15 per cent lower than the odds of female reporting an ailment at the 60th round of NSS. Similarly, a male was 17 per cent less likely to report a communicable disease at the 75th round compared to the 60th round whereas a female was 16 per cent less likely to report a communicable disease at the 75th round relative to the 60th round of NSS. However, the likelihood of reporting non-communicable diseases by both males and females increased at the 75th round of NSS relative to the 60th round of NSS. At the 75th round, males were 11 per cent more likely while females were almost 27 per cent more likely to report a non-communicable disease compared to the 60th round of NSS. In the age group 45-59 years, males were at least 33 per cent more likely to report a non-communicable disease at the 75th round of NSS compared to the 60th round whereas females were 50 per cent more likely to report a non-communicable disease at the 75th round of NSS compared to the 60th round. By contrast, in the age group 5-29 years, both males and females were less likely to report a non-communicable disease at the 75th round of NSS compared to the 60th round of the survey. In case of communicable diseases, however, the likelihood of reporting a communicable disease by both males and female has been lower at the 75th round of NSS compared to the 60th round in all age groups with the only exception of males aged 75 years and above. Table 3 suggests that there has been an increase in the self-reported prevalence of non-communicable diseases in population aged 45 years and above in the 75th round of NSS when compared to the 60th round of NSS. This has, however, not been the case with communicable diseases. There has been a decrease in the self-reported prevalence of communicable diseases by both males and females at the 75th round of NSS compared to the 60th round of NSS.

Table 3: Odds ratios of reporting an ailment at the 75th round of NSS relative to the 60th round of NSS by males and females.

Age	All diseases		Communicable diseases		Non-communicable diseases	
	Male	Female	Male	Female	Male	Female
0-4	0.467	0.477	0.565	0.558	0.499	1.000
5-14	0.559	0.607	0.747	0.767	0.499	0.499
15-29	0.449	0.426	0.664	0.596	0.399	0.570
30-44	0.632	0.663	0.702	0.823	1.000	0.915
45-59	0.860	1.011	0.687	0.801	1.335	1.500
60-74	0.900	0.873	0.730	0.793	1.173	1.107
75 +	0.815	0.857	1.072	0.949	0.995	1.059
All ages	0.764	0.844	0.830	0.843	1.113	1.269

Source: Authors

A similar situation appears to have prevailed in the reporting of ailments in rural areas of the country as compared to the urban areas. At the 60th round of NSS, the odds of reporting an ailment in the urban areas of the country were 24 per cent higher than the odds of reporting an ailment in the rural areas of the country. This proportion increased to 56 per cent at the 75th round of NSS primarily because the odds of reporting a non-communicable disease in the urban areas relative to the rural areas increased from 57 per cent at the 60th round of NSS to 98 per cent at the 75th round of NSS. According to the 75th round of NSS, the odds of reporting a non-communicable disease in the urban areas of the country is now almost two times the odds of reporting a non-communicable disease in the rural areas of the country. The odds of reporting a communicable disease in the urban areas of the country relative to the odds of reporting a communicable disease in the rural areas has also increased between the two rounds of NSS but the increase was not as marked as in case of non-communicable diseases. At the 60th round, the odds of reporting a communicable disease in the rural areas was marginally higher than the odds of reporting a communicable disease in the urban areas. However, at the 75th round of NSS, the odds of reporting a communicable disease in the urban areas was higher than the odds of reporting a communicable disease in the rural areas, although the difference has been marginal.

The odds of reporting an ailment have decreased in both rural and urban areas in all age groups at the 75th round of NSS compared to the 60th round of NSS (Table 4). This has also been the case in the odds of reporting a communicable disease with the only exception of population aged 75 years and above in the rural areas. However, the odds of reporting a non-communicable disease in the rural areas was just around 5 per cent higher at the 75th round than at the 60th round of NSS whereas the odds of reporting a non-communicable disease at the 75th round was more than 37 per cent higher than that in at the 60th round in the urban areas. In the age group 45-59 years, the odds of reporting a non-communicable disease at the 75th round was almost 43 per cent higher than that in the 60th round in the rural areas. In the urban areas, the odds of reporting a non-communicable disease at the 75th round of NSS was more than 37 per cent higher than that at the 60th round of NSS. Table 4 suggests that the reported prevalence of non-communicable diseases has increased between 2004 and 2017-2018 in both rural and urban areas.

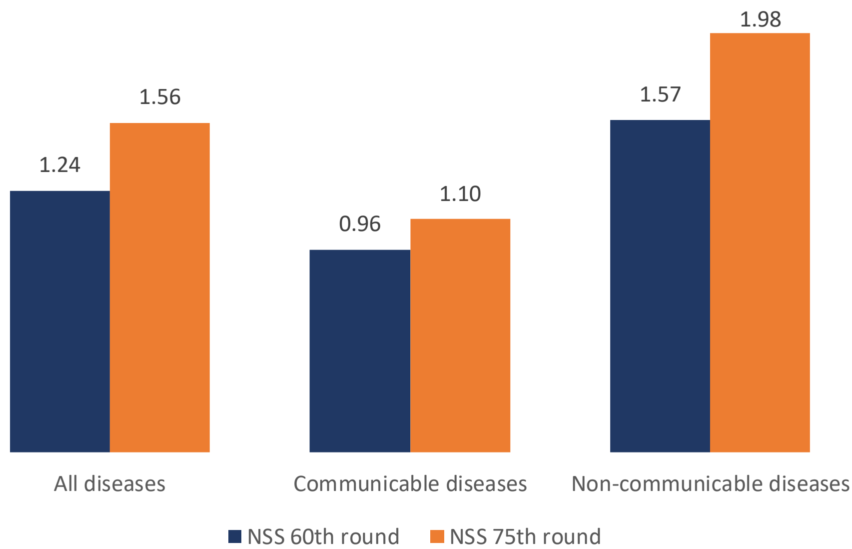

Figure 4: Odds ratio of the urban-rural difference in the reporting of ailments at the 60th round and the 75th round of NSS.
Source: Authors

Table 4: Odds ratios of reporting an ailment in rural and urban areas at the 75th round of NSS relative to the 60th round of NSS.

Age	All diseases		Communicable diseases		Non-communicable diseases	
	Rural	Urban	Rural	Urban	Rural	Urban
0-4	0.446	0.553	0.543	0.710	0.499	1.000
5-14	0.545	0.540	0.711	0.783	0.499	0.499
15-29	0.417	0.493	0.612	0.690	0.332	0.599
30-44	0.588	0.779	0.746	0.840	0.881	1.146
45-59	0.897	0.981	0.781	0.672	1.428	1.374
60-74	0.835	0.860	0.741	0.970	1.108	1.005
75 +	0.737	0.929	1.140	0.707	0.899	1.132
All ages	0.730	0.919	0.796	0.915	1.057	1.334

Source: Authors

Discussion and Conclusions

This paper has analysed morbidity transition in India between 2004 and 2017-2018 based on the data available from the 60th and the 75th round of the National Sample Survey (NSS). The analysis suggests that the reported prevalence of the communicable diseases has decreased in the country but that of non-communicable diseases has increased, especially in the urban areas of the country so that the burden of non-communicable diseases in the country is now more than the burden of the communicable diseases. There are many studies that have observed that the prevalence of non-communicable diseases such as diabetes, hypertension, and obesity are much higher in the urban areas as compared to that in the rural areas (Aroor et al, 2013; Anjana et al, 2014; Oommen et al, 2016). The increase has particularly been marked in population aged 45 years and above. On the other hand, the reported prevalence of communicable diseases has decreased in the country with the remarkable reduction in children below five years of age. The analysis also indicates that the reported burden of diseases on the females has always been higher than that on the males of the country and the difference between reported female and male burden of diseases has increased over time. Similarly, the reported burden of diseases has always been higher in the urban areas as compared to that in the rural areas. More specifically, between 2004 and 2017-18, the decrease in the reported prevalence of communicable diseases has been much higher in the rural areas than in the urban areas in the population below 45 years of age. On the other hand, in population aged 75 years and above, the reported prevalence of communicable diseases has increased in the rural areas but decreased in the urban areas leading to the widening of the rural-urban gap in the reported prevalence of communicable diseases.

The analysis suggests that the burden of non-communicable diseases has increased in the country, especially in population aged 45 years and above. This observation has implications for the health policy and suggests that the health care services delivery system in the country should be oriented towards dealing with the non-communicable diseases. On the other hand, the burden of communicable diseases appears to be on the decline in the country, but the prevalence of these diseases appears to have increased in population aged 75 years and above probably because of antibiotic resistance and lower immunity power (Bijkerk et al, 2010). There is, therefore, a need of formulating a comprehensive road map to address the burden of both communicable and non-communicable diseases in the country. It is important that only balanced policies and resource allocations can contribute towards reducing the burden of communicable and degenerative diseases in the country simultaneously.

An important limitation of the present analysis is that it is based on reported ailments both communicable and non-communicable and, therefore, are subject to reporting bias. There are many factors that influence reporting of ailments. It is also well-known that reporting of non-communicable diseases is more difficult than that of communicable diseases, especially, in the absence of diagnostic facilities. For example, diagnosis of diabetes is not possible in the absence of testing of blood glucose levels. The same is the case with hypertension and other similar diseases. If the necessary diagnostic facilities are not available, there may be possibility of low reporting of non-communicable diseases. This may be one reason why the reported prevalence of non-communicable diseases is found to be lower in the rural population as compared to that in the urban population and the increasing urban-rural gap in the reported prevalence of these diseases.

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Appendix Table 1: Prevalence of four categories of ailments by sex in India, 2004.

Age group	Prevalence rate (Per cent)		Ailment type: Communicable diseases (Per cent)		Non-communicable diseases (Per cent)		Accidents/ Injuries (Per cent)		Others (Per cent)	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
0-4	5.2	4.5	4.0	3.7	0.2	0.1	0.1	0.0	0.9	0.7
5-14	2.3	1.8	1.6	1.3	0.2	0.2	0.1	0.0	0.4	0.3
15-29	2.2	3.0	1.2	1.5	0.5	0.7	0.2	0.0	0.4	0.8
30-44	3.9	6.2	1.7	2.3	1.2	2.4	0.2	0.1	0.8	1.4
45-59	8.5	10.2	2.6	3.1	4.1	5.2	0.3	0.2	1.5	1.8
60-75	24.4	25.5	4.6	4.5	16.3	17.3	0.5	0.4	3.0	3.4
75 +	36.7	34.4	4.4	4.1	26.6	25.6	0.6	0.7	5.2	3.9
All ages	5.3	6.1	2.4	2.6	1.8	2.3	0.2	0.1	0.9	1.1

Source: Computed from unit-level data from 60th round of NSS.

Appendix Table 2: Prevalence of four categories of ailments by sex in India, 2017-2018.

Age group	Prevalence rate (Per cent)		Ailment type: Communicable diseases (Per cent)		Non-communicable diseases (Per cent)		Accidents/ Injuries (Per cent)		Others (Per cent)	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
0-4	2.5	2.2	2.3	2.1	0.1	0.1	0.0	0.0	0.0	0.0
5-14	1.3	1.1	1.2	1.0	0.1	0.1	0.0	0.0	0.0	0.0
15-29	1.0	1.3	0.8	0.9	0.2	0.4	0.0	0.0	0.0	0.0
30-44	2.5	4.2	1.2	1.9	1.2	2.2	0.1	0.0	0.0	0.1
45-59	7.4	10.3	1.8	2.5	5.4	7.6	0.1	0.1	0.0	0.1
60-75	22.5	23.0	3.4	3.6	18.6	18.8	0.2	0.1	0.3	0.4
75 +	32.1	31.0	4.7	3.9	26.5	26.7	0.4	0.2	0.4	0.2
All ages	4.1	5.2	2.0	2.2	2.0	2.9	0.1	0.0	0.0	0.1

Source: Computed from unit-level data from 75th round of NSS.

Appendix Table 3: Prevalence of four categories of ailments by residence in India, 2004.

Age group	Prevalence rate (Per cent)		Ailment type							
			Communicable diseases (Per cent)		Non-communicable diseases (Per cent)		Accidents/ Injuries (Per cent)		Others (Per cent)	
	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban
0-4	4.8	5.3	3.8	3.9	0.2	0.2	0.1	0.1	0.7	1.1
5-14	2.0	2.2	1.4	1.4	0.2	0.2	0.1	0.1	0.3	0.5
15-29	2.6	2.6	1.3	1.3	0.6	0.5	0.1	0.1	0.5	0.7
30-44	5.0	5.2	2.0	1.9	1.7	2.1	0.2	0.2	1.1	1.0
45-59	8.4	11.8	2.8	2.8	3.7	7.1	0.2	0.3	1.6	1.6
60-75	22.7	32.2	4.8	3.4	14.3	25.1	0.4	0.5	3.2	3.2
75 +	32.5	43.5	4.5	3.5	22.4	35.7	0.7	0.7	4.9	3.6
All ages	5.4	6.6	2.5	2.4	1.8	2.8	0.1	0.2	1.0	1.1

Source: Computed from unit-level data from 60^{th} round of NSS.

Appendix Table 4: Prevalence of four categories of ailments by residence in India, 2017-2018.

Age group	Prevalence rate (Per cent)		Ailment type							
			Communicable diseases (Per cent)		Non-communicable diseases (Per cent)		Accidents/ Injuries (Per cent)		Others (Per cent)	
	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban
0-4	2.2	3.0	2.1	2.8	0.1	0.2	0.0	0.0	0.0	0.0
5-14	1.1	1.2	1.0	1.1	0.1	0.1	0.0	0.0	0.0	0.0
15-29	1.1	1.3	0.8	0.9	0.2	0.3	0.0	0.0	0.0	0.0
30-44	3.0	4.1	1.5	1.6	1.5	2.4	0.1	0.1	0.0	0.1
45-59	7.6	11.6	2.2	1.9	5.2	9.5	0.1	0.1	0.0	0.1
60-75	19.7	29.0	3.6	3.3	15.6	25.2	0.2	0.1	0.3	0.4
75 +	26.2	41.7	5.1	2.5	20.6	38.6	0.3	0.3	0.3	0.3
All ages	4.0	6.1	2.0	2.2	1.9	3.7	0.1	0.1	0.0	0.1

Source: Computed from unit-level data from 75th round of NSS

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Dimensions of Child Deprivation in Madhya Pradesh, India

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Abstract

This paper constructs a multi-dimensional composite index to measure the deprivation faced by children in the context of their well-being in terms of survival. Physical growth, cognitive development, and protection from social, cultural, and economic hazards. Application of the index to Madhya Pradesh, using the data available from the National Family Health Survey 2015-2016 and 2019-2021, reveals that the deprivation faced by the children is quite pervasive in Madhya Pradesh, although there is improvement in the situation over time. The paper also reveals that there is marked variation in the deprivation faced by children of different population sub-groups with the situation alarming in Scheduled Tribes children. The paper calls for a social protection approach to mitigate child deprivation and promote child well-being.

Introduction

Madhya Pradesh is one of the poorly developed states of India. Among the 36 states and Union Territories of the country, Madhya Pradesh ranks a poor 28 in terms of the per capita income. Poor social and economic development of the state is also reflected in the well-being of the children. The infant mortality rate in the state was 43 infant deaths per 1000 live births in the year 2020 while the under-5 mortality rate was 51 under-five deaths for every 1000 live births (Government of India, 2022a). Madhya Pradesh is the only state/Union Territory in the country where the infant mortality rate is more than 40 infant deaths per 1000 live births while the under-five mortality rate is more than 50 under-five deaths for every 1000 live births as late as in 2020. On the other hand, the life tables based on the sample registration system suggests that out of every 1000 new-born in the state, around 75 fail to survive to their 20th birthday (Government of India, 2022b). The persistence of exceptionally high risk of death during childhood suggests that the children of the state face extreme forms of deprivation that has implications for their well-being.

Children are not full economic and social agents. They cannot secure resources necessary for their well-being (Chaurasia, 2016). They have no or very limited freedom in making decisions related to their own welfare (White et al 2002). They depend upon family elders including parents in meeting the basic needs necessary for their well-being. Their well-being is also contingent upon the production of public goods and services, especially, in education and health (Gordon et al 2003a, 2003b; Minujin et al 2005; Notten and de Neubourg 2011; Waddington 2004; White et al 2002). These and many other dependencies of children get manifested in poor social and economic settings. Poverty, at the early stages of life, has enduring consequences on those children who survive into the adulthood. It condemns them to recurrent poverty spells and a life full of hardship (Grinspun 2004).

The United Nations Convention on the Rights of the Child has laid down principles of non-discrimination in the best interest of the child along with common standards for various rights of children. The Convention considers different cultural, social, economic, and political realities in which children live (United Nations 1989). By ratifying the Convention in 1992, India has committed herself to protecting and advancing the rights of the child; to develop and undertake all actions and policies in the best interests of children; and to hold herself accountable before the international community. The rights of the child in India are enshrined in the fundamental rights and the directive principles of state policy as inscribed in the Constitution of India. Rights of children have also been reaffirmed through the National Policy on Children first announced in 1974 and later revised in 2013 (Government of India 1974; 2013). The mainstreaming of child rights issues in the development discourse of the country is reflected in the Integrated Child Protection Scheme (Government of India 2007). However, protecting rights of the child in India remains a major development challenge. Traditional structures of patriarchy and other social groupings continue to justify extreme forms of chastisement of children including adolescents (Kushwah and Prasad 2009).

Mitigating child deprivation requires an understanding of the child well-being context which varies by social, cultural, economic, and environmental considerations. Child well-being is a multi-dimensional construct and different domains of child well-being have been identified under different perspectives (Brown 1997; Hauser et al 1997; Land et al 2001; Pollard et al 2002; Raidy and Winjie 2002; Child Trend 2003). These include, among others, child rights perspective (Ben-Arieh 2001); child needs perspective (Ryan and Deci 2001); child development perspective (Mickelwright and Stewart 1999); and child outcomes perspective (Maryland Partnership for Children, Youth and Families 2002). Different domains of child well-being can also be identified following the capabilities approach first propounded by Sen (1985) and later discussed in Nussbaum and Sen (1993) and Nussbaum (2000). In terms of Sen's capability approach, domains of child well-being can be defined in terms of child endowments, child capacities and child opportunities (Chaurasia 2010).

This paper analyses the deprivation faced by children of Madhya Pradesh in the context of their well-being. Deprivation may be defined as circumstances or situations that are highly likely to have adverse implications to the well-being of an individual. People are deprived if they lack access to facilities and services necessary for their well-being. People are poor if they lack resources to escape deprivation (Townsend, 1987). Child deprivation, then, means circumstances or situations or both that are highly likely to have adverse implications to child well-being. Children are deprived if they lack access to services and facilities necessary for their well-being. Children are poor if they lack resources to escape deprivation. Mitigating the deprivation is critical to child well-being and to realise their full potential (Minujin et al 2006). Deprivation measures reflect the degree to which well-being needs of children are actually met (de Neubourg 2012). Mitigating child deprivation is necessary to address child poverty.

The measurement and analysis of the deprivation faced by the children of the state is based on a composite child deprivation index that has been developed for the purpose. The index captures the multi-dimensional perspective of child deprivation and explores how child deprivation varies across different population sub-groups and across districts of the state. The paper presents a comprehensive, multidimensional picture of child deprivation in the state and provides the empirical evidence that is may be required for increased investment in children.

The paper is divided into six sections in addition to this introduction. The next section describes the composite child deprivation index used in the analysis. The third section describes the data used for measuring child deprivation. The fourth section presents findings of the analysis. The last section summarises the findings of the analysis and discusses their implications in the context of increased investment in children of the state.

Measuring Child Deprivation

The United Nations Convention on the Rights of the Child (United Nations, 1989) provides a framework to measure and monitor child deprivation. It identifies four rights: 1) right to survival and health; 2) right to physical growth and development; 3) right to cognitive development; and 4) right to protection from a range of social, economic, cultural, and environmental hazards as critical to child well-being. This means that child deprivation should be measured and monitored in terms of services and facilities that address the survival, growth; development; and protection needs of children. Moreover, household standard of living has a strong impact on all the four rights of children.

The United Nations Convention on the Rights of the Child defines a child as a person who has not yet reached her or his 18th birthday. The National Policy on Children in India (Government of India, 2013) also defines a person as child if she or he has not reached 18 years of age. The relative importance of different domains of child well-being, however, is different for children of different ages. The survival context of child well-being is the most critical to children below one year of age whereas the protection context may be the most important for children aged at least 15 years. Therefore, an age-specific approach needs to be adopted to measure child deprivation. Children may be grouped into the following six age categories as well-being needs of children of different age groups are different:

1. Less than one year (0 years)
2. 1 year and older but less than 3 years (1-2 years)
3. 3 years and older but less than 6 years (3-5 years)
4. 6 years and older but less than 11 years (6-10 years)
5. 11 years and older but less than 15 years (11-14 years)
6. 15 years and older but less than 20 years (15-19 years)

The foregoing considerations call for a two-dimensional framework for measuring child deprivation as shown in table 1. This framework identifies that child well-being context that is the most relevant for children of different age groups – the darker the colour of the cell the more important the domain of child well-being. Using this framework, a domain- and age-specific objective criteria for measuring child deprivation is presented in table 2 which recognises that relevance of different domains of well-being is different for children of different age groups.

The application of the deprivation criteria outlined in table 2 requires identification of objectively measurable indicators for each component of the framework. An indicator is a measure of a condition or status or behaviour that can be tracked over time, across individuals or across geographical or administrative units (Child Trends 1997). Friedman (1997) has suggested a three-point simple criterion for identifying an indicator. Ben-Arieh et al (2001) have advocated a two-dimensional approach, the first of which is related to the validity and the relevance while the second is related to the policy and the programme. Moore (1995; 1997; 1999) has suggested a thirteen-point criterion, many of which are like those suggested by Ben-Arieh et al (2001). An important consideration in the selection of indicators is the availability of data, although indicators may also be selected through the policy perspective or based on some underlying theory (Hanafin and Brooks 2005). It is recommended that all the three approaches should be considered while selecting indicators of child well-being (Bauer et al 2003). Other considerations for selecting indicators include comparability (consistency over time, nationally and internationally), ease of understanding, strength of data source, significance, accessibility, validity, and coverage (Jennifer, 2009). In practice, however, selection of indicators is essentially a prerogative of the researcher, although, this prerogative is influenced, to a significant extent, by data considerations.

Table 1: The theoretical construct of child well-being.

Age	Domains of child well-being				
	Survival	Physical growth	Cognitive development	Protection	Household living standard
< 1					
1-2					
3-5					
6-10					
11-14					
15-19					

Source: Author

Based on the above considerations, a set of 24 indicators have been identified, four in each of the six age groups, that correspond to the objective criteria of measuring child deprivation. These indicators are given in table 3 along with the threshold level of each indicator to classify a child as deprived or not deprived.

The most common approach to measure child deprivation is the 'counting' approach (Atkinson 2003). This approach involves classifying a child into two categories – deprived and not deprived - based on a pre-decided threshold. One extreme of this approach is that a child may be classified as deprived in all indicators of well-being while the other extreme is that the child is not classified as deprived in any indicator. Since deprivation is indicator specific, deprivation with respect to different indicators needs to be combined into a single composite index of child deprivation. The construction of such a composite index is, however, not straightforward and efforts in this direction have often been found to be controversial (Ravallian 2010a, 2010b) or challenging (Atkinson 2003). A composite index of child deprivation is unavoidable when one investigates the breadth, or the complexity of child deprivation (Apablaza and Yalonetzky 2011). A composite index of child deprivation is a good way of enforcing the uniqueness of the multiple domains of child deprivation as it presents multidimensional perspective of deprivation in one aggregate that can be used for planning and programming to mitigate child deprivation.

Table 2: Objective criteria for analysing child deprivation.

Age group	Domain of child well-being				
	Survival	Physical growth	Cognitive development	Protection	Living standard
<1 year	Birth weight Breastfeeding Care after birth				Living status
1-2 years	Basic vaccination	Linear growth			Living status
3-5 years		Parenteral growth	Early childhood education	Civil registration	Living status
6-10 years			Schooling	Social security	Living status
11-14 years			Schooling	Social security	Living status
15-19 years		Nutrition	Schooling	Social security	Living status

Source: Author

There are two approaches of aggregating children who are classified as deprived with respect to selected well-being indicators (Mickelwright 2001). The first is to count the number of indicators in which a child is classified as deprived and then count the number of children who are deprived in one, more than, all, and in no indicator. The second approach sums across children to estimate the prevalence of deprivation with respect to each indicator and then combines indicator-specific prevalence deprivation into a composite index of child deprivation. The second approach is similar to the human poverty index proposed by Anand and Sen (1997).

There are many studies that have measured and analysed child deprivation following the first approach (Nyangara et al 2008; Bradshaw 2009; de Neubourg et al 2012; Alkire and Roche 2012; Foundation for Child Development 2013; Roche 2013; UNICEF 2014;). There are also many studies that have followed the second approach (Kanamori and Pullum 2013, Dreze and Khera 2012, Chaurasia 2010). The present paper uses the second approach.

Following Anand and Sen (1997), the deprivation index for children of age i, D_i, is defined as

$$D_i = \left(\frac{\sum_{j=1}^{n} D_{ij}^{\alpha}}{n}\right)^{1/\alpha}$$

where n is the number of indicators, and α is the power of the mean and is greater than 1. When $\alpha=1$, D_i is equal to the simple arithmetic mean which implies that the impact of a unit increase (or decrease) in all indicators of well-being is the same irrespective of the progress in terms of different indicators. This contradicts the logical assumption that as deprivation with respect to a well-being indicator increases, the weight of that indicator in deciding the deprivation index should also increase. To ensure that this assumption holds, α must be greater than 1. The use of power mean also addresses the problem of additive compensability associated with arithmetic mean. There is, however, an escapable arbitrariness in selecting α. When $\alpha = 3$, the impact of the indicator in which the deprivation is the highest on the index D_i is four times the impact of the indicator in which the deprivation is the lowest.

Table 3: Threshold level used for classifying children as deprived.

Indicator		Child is classified as deprived if
1	The weight of the child at birth	Less than 2.5 Kg
2	Child check-up within two days of birth by a trained health personnel	No check-up
3	Initiation of breastfeeding within one hour of birth	No breastfeeding within 1 hour
4	Standard of living index of the household	Less than first quintile
5	Vaccination status of the child	Not received all basic vaccinations
6	Height-for-age of the child	Low height-for-age
7	Child received Vitamin A in the last six months	Not received
8	Standard of living index of the household	Less than first quintile
9	Weight-for-height of the child	Low weight-for-height
10	Availability of the birth certificate	Not available
11	Schooling status of the child	Not attending school regularly
12	Standard of living index of the household	Less than first quintile
13	Schooling status of the child	Not attending school regularly
14	Orphan status of the child	Child is orphan
15	Child is having a bank account	Not having a bank account
16	Standard of living index of the household	Less than first quintile
17	Schooling status of the child	Not attending school
18	Orphan status of the child	Child is orphan
19	Marital status of the child	Ever married
20	Standard of living index of the household	Less than first quintile
21	Schooling status of the child	Not attending school regularly
22	Body mass index (BMI) of the child	Less than 18.5
23	Marital status of the child	Ever married
24	Standard of living index of the household	Less than first quintile

Source: Author

It may be noticed that D_{ij} for each i and j are headcounts of children classified as deprived with respect to a specific well-being indicator. However, the index D_i cannot be thought of the proportion of children deprived in the well-being space. If the proportion of children who are deprived happens to be the same with respect to all indicators of well-being, then D_i will be equal to this common proportion. D_i may be interpreted as the degree of overall deprivation faced by children of a particular age group that is equivalent to having D_{ij} proportion of children classified as deprived with respect to different well-being indicators relevant to the age group (Anand and Sen, 1997).

Table 4: Goal posts used for normalising indicators of well-being.

Indicator		Minimum	Maximum
1	Proportion of children with low weight at birth	0.0	62.6
2	Proportion of children not checked-up within two days of birth by a trained health personnel	27.5	100.0
3	Proportion of children not initiation breastfeeding within one hour of birth	5.3	100.0
4	Proportion of children living in households with the poorest standard of living index	0.0	100.0
5	Proportion of children who did not receive all basic vaccinations	0.0	100.0
6	Proportion of children low height-for-age	0.0	83.3
7	Proportion of children not received Vitamin A in the last six months	0.0	72.2
8	Proportion of children living in households with the poorest standard of living index	0.0	100.0
9	Proportion of children low weight-for-height	0.0	55.5
10	Proportion of children not having birth certificate	7.1	96.9
11	Proportion of children 3-5 years not attending school regularly	63.2	100.0
12	Proportion of children living in households with the poorest standard of living index	0.0	100.0
13	Proportion of children 6-10 years not attending school regularly	0.0	43.7
14	Proportion of children orphan	0.0	12.0
15	Proportion of children not having bank account	0.0	63.5
16	Proportion of children living in households with the poorest standard of living index	0.0	100.0
17	Proportion of children 11-14 years not attending school regularly	0.0	51.8
18	Proportion of children orphan	0.0	16.9
19	Proportion of children ever married	0.0	4.1
20	Proportion of children living in households with the poorest standard of living index	0.0	100.0
21	Proportion of children 15-19 years not attending school regularly	8.9	80.6
22	Children with body mass index (BMI) less than 18.5	9.1	84.0
23	Proportion of children ever married	0.0	28.4
24	Proportion of children living in households with the poorest standard of living index	0.0	100.0

Source: Author

The composite child deprivation index D for all children aged 0-19 years may now be defined as weighted average of D_i with weights equal to the proportionate share of children of age i to children of all ages (0-19 years). If p_i is the proportion of children in age group i, then,

$$D = \sum_{i=1}^{k} p_i * D_i$$

$$\sum_{i=1}^{k} p_i = 1$$

The index *D* depicts the 'big picture' of the deprivation faced by children that considers all age groups and different domains of child well-being. Although, the index *D* masks the spatiotemporal variation in individual indicators of well-being, yet it leads to a simple and straightforward comparison across space and over time which may be the starting point for deeper analysis.

The construction of the index *D* requires normalisation of the indicators used in its construction by setting the goal posts. These goal posts are given in table 4. They have been arrived at by analysing the variation in indicators across districts of the state using the exploratory data analysis methods.

Data Source

The present analysis is based on the data available through the fourth (2015-2016) and the fifth round (2019-2021) of the National Family Health Survey (NFHS). The NFHS programme has been instituted by the Government of India, Ministry of Health and Family Welfare and is implemented by the International Institute for Population Sciences, Mumbai. The objective of NFHS is to provide data related to fertility, mortality including infant and child mortality, nutrition, and use of reproductive and child health services in addition to household level characteristics. The survey also provides data pertaining to the key population characteristics including education, marital status, and work status of the population. Details regarding the NFHS including the method of selection of the households for the survey are discussed elsewhere and are not repeated here (Government of India, 2022c). Since its inception in 1992, the NFHS has become the primary source of data related to health and family welfare situation in the country, especially its maternal and child health component. Women and children are regarded as the most vulnerable groups of the population as regards survival and health.

The NFHS covered all districts of Madhya Pradesh, as they existed at the time of the fourth round and the fifth round of the survey. There were 50 districts in the state at the time of the fourth round of the survey whereas the number of districts increased to 51 in the fifth round of the survey. The fourth round of NFHS covered 52,042 households in the state while the fifth round covered 43,552 households. All children identified in the selected households were covered during the two rounds of the survey.

State level estimates of the 24 indicators of child deprivation used in the present study to construct a composite child deprivation index are presented in table 5. Different indicators of child deprivation or, equivalently, child well-being depict different perspectives of child deprivation that prevails in the state. At the same time, the deprivation faced by children of different age-groups is also different. This means that simple averaging of child deprivation as reflected by different indicators or in different domains of child well-being is not possible and a composite index based on the simple averaging of the deprivation reflected through different indicators of child well-being may lead to erroneous conclusions. Because of this very reason, we have used the weighted or power mean to combine the deprivation faced by children as reflected through different indicators of child well-being into a composite index of child deprivation.

Table 5: Indicators of child deprivation in Madhya Pradesh. Evidence from National Family Health Survey 2015-2016 and 2019-2021

Indicator	2015-2016	2019-2021
Children below 1 years of age		
Proportion of children having birth weight less than 2.5 Kg	22.2	21.7
Proportion of children who were not checked-up by a trained health personnel within 2 days of birth	80.5	80.2
Proportion of children not initiated breastfeeding within 1 hour of birth	65.2	59.7
Proportion of children with the poorest standard of living index	32.8	35.6
Children aged 1-2 years		
Proportion of children who have not received all basic vaccinations	47.1	31.8
Proportion of children low height-for-age	46.6	40.2
Proportion of children who did not receive Vitamin A in the last six months	25.0	10.6
Proportion of children with the poorest standard of living index	33.7	34.4
Children aged 3-5 years		
Proportion of children low weight-for-height	20.8	19.2
Proportion of children who do not have birth certificate	51.9	41.9
Proportion of children not going to school regularly	88.1	84.9
Proportion of children with the poorest standard of living index	36.6	35.0
Children aged 6-10 years		
Proportion of children not attending school regularly	11.9	10.4
Proportion children who are orphan	4.1	3.8
Proportion of children not having bank account	13.9	4.4
Proportion of children with the poorest standard of living index	38.3	38.0
Children aged 11-14 years		
Proportion of children not attending school regularly	9.9	8.9
Proportion children who are orphan	6.3	6.2
Proportion of children who are ever married	0.9	0.8
Proportion of children with the poorest standard of living index	36.2	36.7
Children aged 15-19 years		
Proportion of children not attending school regularly	48.8	40.9
Proportion children having body mass index (BMI) less than 18.5	46.1	43.4
Proportion of children ever married	9.4	6.6
Proportion of children with the poorest standard of living index	29.8	32.5

Source: Author

Child Deprivation in Madhya Pradesh

The composite child deprivation index, *D*, for all children (0-19 years) in Madhya Pradesh is estimated to be 0.360 in 2019-21 and 0.399 in 2015-16 which suggests that, although there has been some improvement in the child well-being scenario in the state over time. The analysis also suggests that the decrease in the composite child deprivation index *D* in the state has not been large enough to reflect a marked improvement in the well-being of state children in the recent past and the deprivation faced by the children of the state remains quite pervasive.

Across different population sub-groups, the index *D* varies widely. It has been found to be higher in female compared to male children, in rural compared to urban children and in Scheduled Tribes children compared to children of other social classes. On the other hand, there is only a marginal difference between the deprivation faced by Hindu children and the deprivation faced by Muslim children. The good sign, however, is that deprivation faced by children of all population sub-groups has decreased over time, although, the decrease has been different in different population sub-groups - most rapid in Scheduled Tribes children, but the least rapid in children of other social classes.

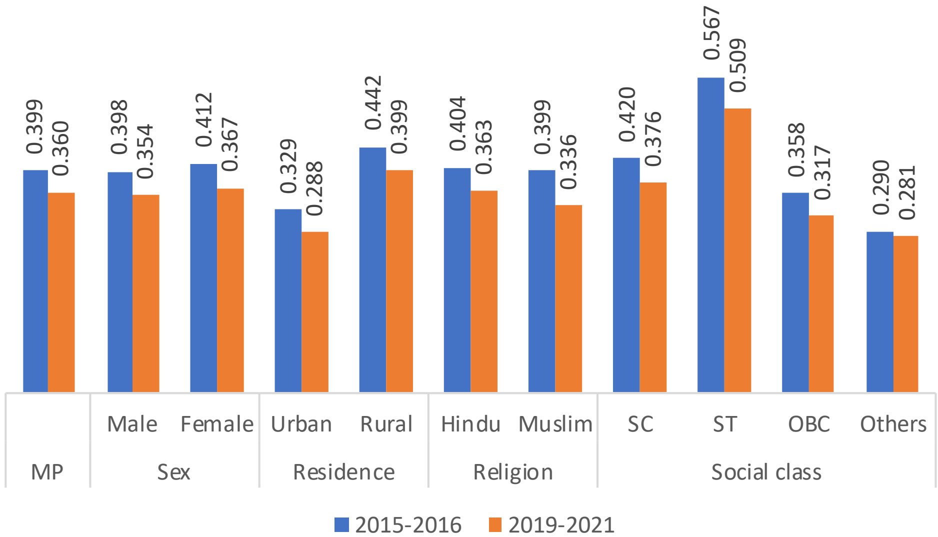

Figure 1: The composite child deprivation index, D, in Madhya Pradesh.
Source: Author

The deprivation faced by children is also different in different domains of child well-being - relatively the highest in the survival domain but the lowest in the protection domain (Figure 2). The decrease in the index *DJ* has been the most rapid in the protection domain whereas the deprivation in the living standards domain has increased, instead decreased, between 2015-16 and 2019-21. The decrease in the index *DJ* has also been marginal in the survival domain. It is also clear from the figure that the deprivation faced by children of the state is not confined to any one domain of child well-being. There is substantial gap in meeting the basic needs of children in all domains of child well-being.

The deprivation also varies the age of the child (Figure 3) - highest in children below 1 year of age but the lowest in children aged 6-10 years. Moreover, the index *DJ* increased in the age group 15-19 years compared to the age group 11-14 years. On the other hand, there has been virtually little change in the index *DJ* in the age group 11-14 years between 2015-2016 and 2019-2021. The decrease in the index *DJ* has comparatively been the most rapid in children aged 1-2 years between 2015-2016 and 2019-2021.

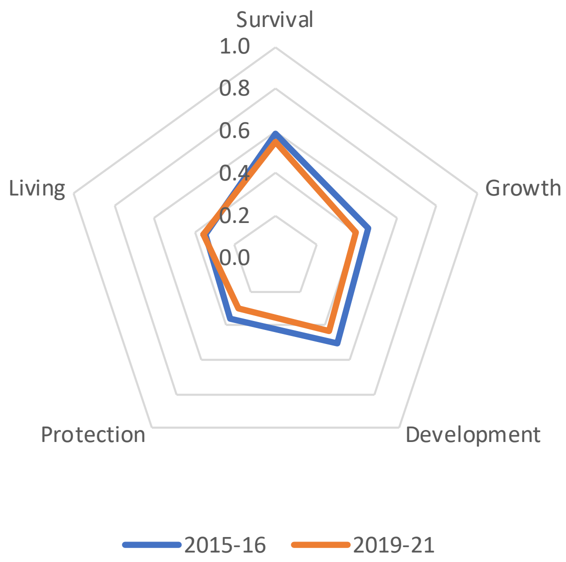

Figure 2: Deprivation in different domains of child well-being in Madhya Pradesh.
Source: Author

Across districts of the state, the deprivation faced by children varies widely (Figures 4 and 5). The composite child deprivation index *D* was the highest in district Jhabua in both 2015-2016 and 2019-2021. On the other hand, the composite child deprivation index *D* was the lowest in district Hoshangabad in 2015-2016 but in district Indore in 2019-2021. In 6 districts – Satna, Rewa, Dewas, Hoshangabad, Jabalpur and Narsimhapur – child deprivation increased as the index *D* increased between 2015-2016 and 2019-2021. There are 8 districts – Sheopur, Panna, Sidhi, Singrauli, Jhabua, Dindori, Alirajpur, and Barwani – where child deprivation remains very high, albeit decreasing. On the other hand, there are 6 districts – Gwalior, Neemuch, Bhopal, Raisen, Sehore and Indore – where child deprivation remains very low.

The deprivation faced by children of different age-groups varies widely across districts. The deprivation in children below 1 year of age was relatively the highest in district Sidhi in 2015-2016 but in district Indore in 2019-2021 (Table 7). By comparison, deprivation in children below 1 year of age was the lowest in district Jabalpur in 2015-2016 but in district Agar Malwa in 2019-2021. Ten districts where deprivation in children below 1 year of age was very high in 2015-2016 are Datia, Rewa, Sidhi, Shahdol, Vidisha, Bhopal, Shajapur, Ratlam, Jhabua, and Alirajpur. In 2019-2021, ten districts where deprivation in children below 1 year of age was high are Bhind, Chhatarpur, Satna, Shahdol, Anuppur, Rajgarh, Shajapur, Indore, Dhar, and Balaghat. Districts Shajapur and Shahdol are the only two districts where deprivation in children below 1 year of age has remained very high. In district Satna, deprivation in children below 1 year of age was very low in 2015-16 but very high in 2019-2021 as reflected through the increase in the index *DI*.

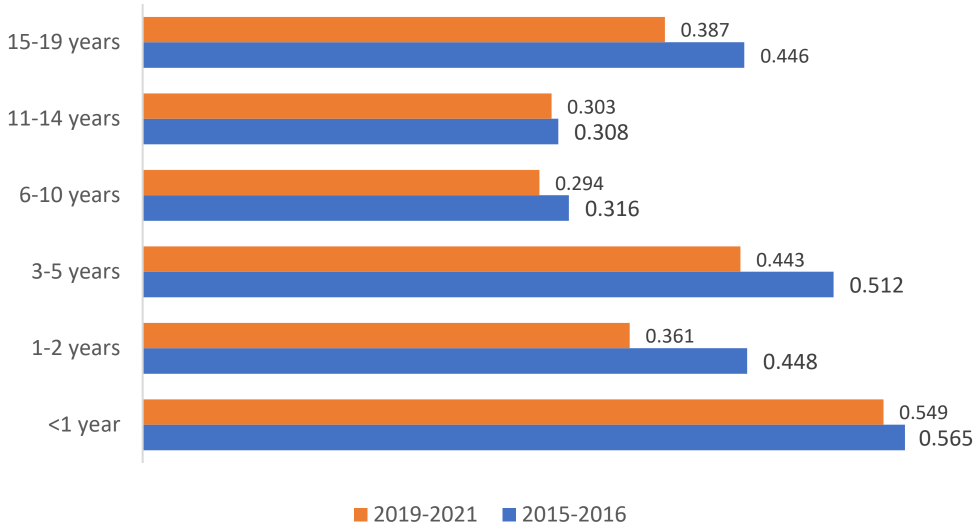

Figure 3: Deprivation in children of different age groups (Index D_i).
Source: Author

The deprivation index D_i, in children aged 1-2 years, ranged between 0.349 in district Sehore to 0.662 in district Jhabua in 2015-2016, and from 0.255 in district Jabalpur to 0.523 in district Dindori in 2019-2021 (Table 8). Deprivation in children 1-2 years of age was very high in Datia, Tikamgarh, Panna, Sidhi, Shahdol, Dindori, Vidisha, Jhabua, Alirajpur and Barwani districts in 2015-2016, but in Sheopur, Panna, Satna, Rewa, Sidhi, Singrauli, Katni, Umaria, Dindori, and Jhabua districts in 2019-2021. In Panna, Sidhi, Jhabua, and Dindori districts, very high level of deprivation faced by children 1-2 years of age appears to have persisted during the period 2015-2016 through 2019-2021. By contrast, deprivation faced by children 1-2 years of age was very low in Ujjain, Indore, Dewas, Sehore, Khandwa, Betul, Chhindwara, Seoni, Balaghat, and Jabalpur districts in 2015-2016, but in Ujjain, Indore, Bhind, Tikamgarh, Neemuch, Ratlam, Shajapur, Khargone, Burhanpur and Jabalpur districts in 2019-2021. There are only two districts – Ujjain and Indore – where the deprivation faced by children of 1-2 years of age was relatively very low in 2015-2016 and in 2019-2021. The index D_i decreased very rapidly in district Burhanpur.

The index D_i, in children aged 3-5 years varied from 0.311 in district Mandsaur to 0.599 in district Alirajpur in 2019-2021 but from 0.374 in district Indore to 0.700 in district Jhabua in 2015-2016 (Table 9). In Rajgarh, Sidhi, Singrauli, Umaria, Shahdol, Dindori, Mandla, Jhabua, Alirajpur, and Barwani districts deprivation faced by children aged 3-5 was very high in 2015-2016 but in Sheopur, Panna, Rewa, Sidhi, Singrauli, Jabalpur, Dindori, Jhabua, Alirajpur, and Ashoknagar districts in 2019-2021. In Sidhi, Singrauli, Dindori, Jhabua and Alirajpur districts, deprivation faced by children aged 3-5 years remained very high in both 2015-16, and 2019-21. On the other hand, deprivation faced by children aged 3-5 years was very low in Gwalior, Datia, Shivpuri, Neemuch, Bhopal, Ujjain, Indore, Hoshangabad, Narsimhapur, and Khargone districts in 2015-2016, but in Neemuch, Mandsaur, Agar Malwa, Ratlam, Ujjain, Indore, Dewas, Sehore, Narsimhapur and Chindwara districts in 2019-2021. In Neemuch, Ujjain, Indore, and Narsimhapur districts, deprivation faced by children aged 3-5 years remained very low in 2015-2016 and in 2019-2021. There has been a rapid increase in the deprivation faced by children aged 3-5 years in district Shivpuri between 2015-16 and 2019-21. In Datia, Sagar, Satna, Hoshangabad, and Jabalpur districts also, deprivation faced by children aged 3-5 years increased between 2015-2016 and 2019-2021.

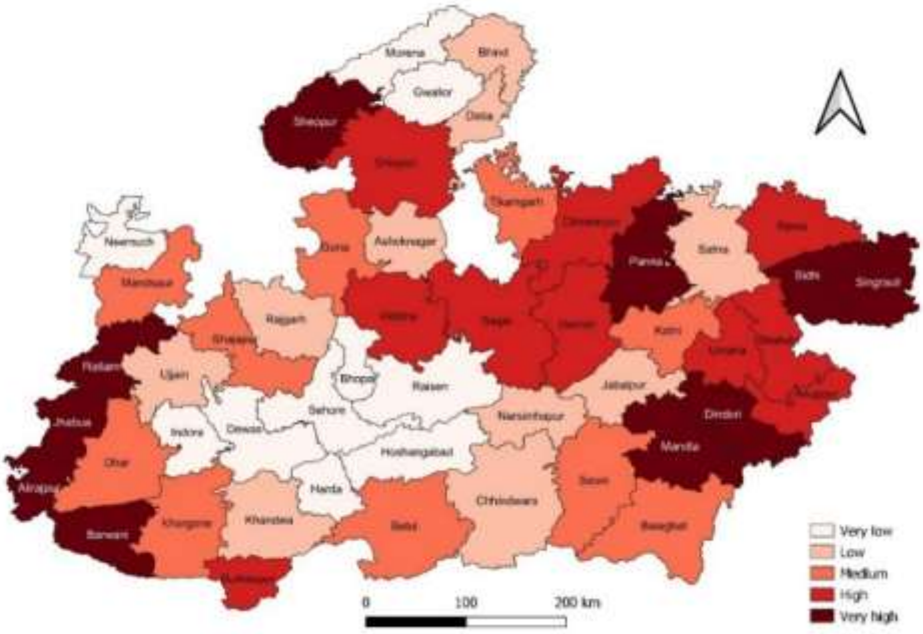

Figure 4: Child deprivation in districts of Madhya Pradesh, 2015-2016.
Source: Author

The index D_i, in children aged 6-10 years, was the highest in district Jhabua and the lowest in district Indore in both 2015-2016 and in 2019-2021 (Table 10). In Sagar, Panna, Sidhi, Singrauli, Dindori, Mandla, Ratlam, Jhabua, Alirajpur and Barwani districts deprivation in children aged 6-10 years was very high in 2015-2016 whereas in Morena, Panna, Rewa, Singrauli, Dindori, Katni, Shahdol, Jhabua, Alirajpur, and Barwani districts, child deprivation was very high in 2019-2021. In six districts – Panna, Singrauli, Dindori, Jhabua, Alirajpur, and Barwani – deprivation in children aged 6-10 years remained very high in both 2015-2016 and 2019-2021. By contrast, in Bhind, Gwalior, Bhopal, Raisen, Sehore, Indore, Dewas, Hoshangabad, Harda, and Khandwa districts, deprivation in children aged 6-10 years was very low in 2015-2016 whereas in Datia, Tikamgarh, Bhopal, Neemuch, Sehore, Agar Malwa, Shajapur, Ratlam, Harda, and Khandwa districts, it was very low in 2019-2021. In Bhopal, Sehore, Indore, Harda, and Khandwa districts, deprivation in children aged 6-10 years has been very low in both 2015-2016 and 2019-2021. In district Hoshangabad, deprivation in children aged 6-10 years increased very rapidly between 2015-2016 and 2019-2021.

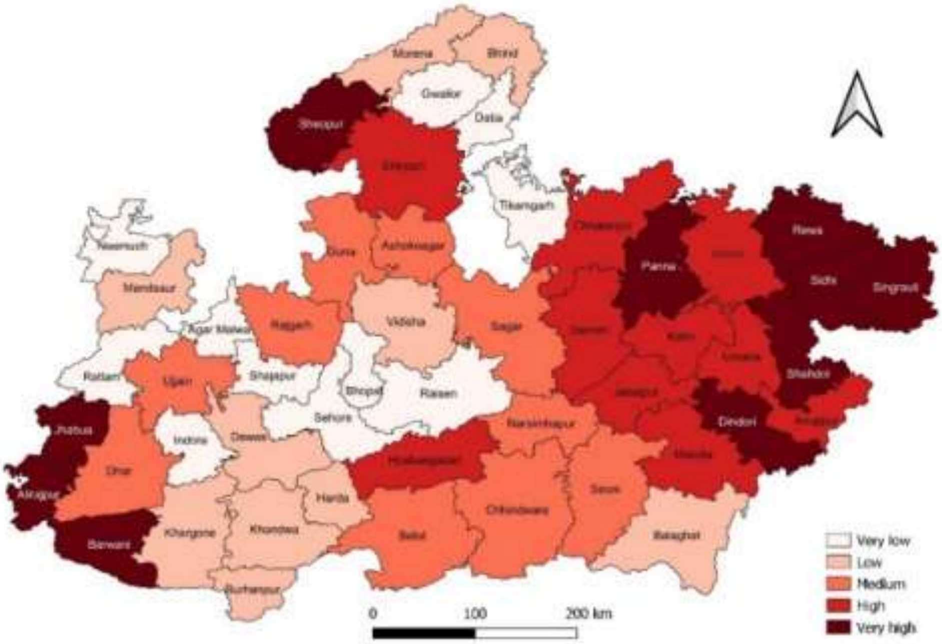

Figure 5: Child deprivation in districts of Madhya Pradesh, 2019-2021.
Source: Author

In children aged 11-14 years, the index D_i ranged from 0.169 in district Neemuch to 0,616 in district Alirajpur in 2015-2016 and from 0.165 in district Shajapur to district Alirajpur in 2019-2021 (Table 11). In Sidhi, Singrauli, Umaria, Shahdol, Dindori, Mandla, Ratlam, Jhabua, Alirajpur, and Barwani districts, deprivation in children aged 11-14 years was very high in 2015-2016 whereas child deprivation was very high in Panna, Satna, Rewa, Jabalpur, Dindori, Hoshangabad, Ujjain, Jhabua, Alirajpur and Barwani districts in 2019-2021 according to NFHS. In Dindori, Jhabua, Alirajpur and Barwani districts of the state, deprivation faced by children aged 11-14 years has remained very high in both 2015-2016 and in 2019-2021.

In children aged 15-19 years, the deprivation index D_i ranged from 0.334 in district Gwalior to 0.666 in district Jhabua in 2015-2016 but from 0.254 in district Raisen to 0.503 in district Dindori in 2019-2021 (Table 12). In Sheopur, Shivpuri, Tikamgarh, Shajapur, Dindori, Mandla, Jhabua, Alirajpur, Barwani and Khargone, deprivation was very high in 2015-2016 whereas, in 2019-21, deprivation was very high in Sheopur, Agar Malwa, Rewa, Sidhi, Dindori, Panna, Jhabua, Alirajpur, Barwani, and Damoh districts. In Sheopur, Dindori, Jhabua, Alirajpur and Barwani districts, the deprivation faced by children aged 15-19 years have remained very high. In district Rewa, deprivation faced by children aged 15-19 years was very low in 2015-2016 but very high in 2019-2021. On the other hand, the deprivation faced by children aged 15-19 years decreased markedly in district Tikamgarh where the index *DI* decreased from 0.532 in 2015-2016 to 0.352 in 2019-2021.

Summary and Conclusions

The evidence available from the fourth round and the fifth round of NFHS reveals that the deprivation faced by children of the state is quite pervasive and there has been only a marginal improvement in the situation if data from the National Family Health Survey is any indication. There is also marked variation in the deprivation faced by children across different population sub-groups and across districts which indicates that population-specific and district level factors contribute substantially to the deprivation faced by children of the state. Very little is currently known about these factors. The analysis also reveals that the deprivation faced by children with respect to the standard of living domain appears to have increased over the years. This essentially implies that the resources necessary for children to escape the deprivation are getting limited over time. This trend has implications for mitigating deprivation faced by state children. The situation appears to be alarming in Scheduled Tribes children of the state. More than half of the Scheduled Tribes children of the state appears to be deprived in at least one of the 24 indicators of child well-being.

The present analysis calls for concerted efforts to mitigate the deprivation faced by children in the context of their well-being which appears to be quite pervasive in Madhya Pradesh. One approach that may contribute to mitigating the deprivation faced by the children of the state is the social protection approach. There is now an increased recognition that social protection policies and programmes can play an important role in promoting and securing child well-being, particularly when considered in concert with the broader development framework. The first requirement to this direction is a strong policy response. Madhya Pradesh does not have an explicit policy directed towards well-being of children. A child-sensitive social protection policy is the need of the time for Madhya Pradesh to reflect the resolve and the commitment of Madhya Pradesh towards the well-being of its children.

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Table 6: Child deprivation index (*D*) in districts of Madhya Pradesh, 2015-2021.

District	2015-2016		2019-2021	
	D	Rank	*D*	Rank
Sheopur	0.491	42	0.439	42
Morena	0.372	10	0.367	20
Bhind	0.381	13	0.366	19
Gwalior	0.328	3	0.323	10
Datia	0.388	17	0.315	8
Shivpuri	0.447	31	0.416	39
Tikamgarh	0.443	28	0.317	9
Chhatarpur	0.468	38	0.407	34
Panna	0.491	41	0.486	47
Sagar	0.450	33	0.389	27
Damoh	0.461	36	0.410	35
Satna	0.387	15	0.439	41
Rewa	0.452	34	0.505	48
Umaria	0.465	37	0.415	37
Neemuch	0.367	9	0.272	2
Mandsaur	0.409	21	0.351	16
Ratlam	0.540	46	0.327	11
Ujjain	0.393	18	0.378	24
Shajapur (Undivided)	0.430	25	0.292	na
Dewas	0.335	5	0.340	13
Dhar	0.411	22	0.395	30
Indore	0.324	2	0.254	1
Khargone (West Nimar)	0.413	23	0.365	18
Barwani	0.594	48	0.465	46
Rajgarh	0.397	20	0.382	25
Vidisha	0.471	39	0.357	17
Bhopal	0.361	8	0.307	5
Sehore	0.330	4	0.315	7
Raisen	0.355	7	0.287	3
Betul	0.446	30	0.399	31
Harda	0.353	6	0.344	15
Hoshangabad	0.312	1	0.404	33
Katni	0.439	26	0.415	38
Jabalpur	0.379	12	0.427	40
Narsimhapur	0.375	11	0.376	22
Dindori	0.552	47	0.523	50
Mandla	0.500	43	0.403	32
Chhindwara	0.388	16	0.378	23
Seoni	0.445	29	0.389	29
Balaghat	0.440	27	0.342	14
Guna	0.418	24	0.387	26
Ashoknagar	0.393	19	0.389	28

District	2015-2016		2019-2021	
	D	Rank	*D*	Rank
Shahdol	0.488	40	0.442	43
Anuppur	0.449	32	0.412	36
Sidhi	0.509	44	0.451	45
Singrauli	0.513	45	0.445	44
Jhabua	0.667	50	0.543	51
Alirajpur	0.634	49	0.515	49
Khandwa (East Nimar)	0.386	14	0.339	12
Burhanpur	0.457	35	0.373	21
Agar Malwa	na	na	0.310	6
Shajapur	na	na	0.291	4

Remarks: District Shajapur (undivided) in 2015-2016 was divided into Agar Malwa and Shajapur districts in 2019-2021.
Source: Author

Table 7: Deprivation index (*DI*) in children below 1 year of age in districts of Madhya Pradesh, 2015-2021

District	2015-2016		2019-2021	
	D_i	Rank	D_i	Rank
Sheopur	0.615	35	0.482	5
Morena	0.546	16	0.591	35
Bhind	0.589	25	0.628	43
Gwalior	0.594	26	0.571	28
Datia	0.651	44	0.561	25
Shivpuri	0.529	11	0.572	31
Tikamgarh	0.612	32	0.470	3
Chhatarpur	0.613	33	0.654	48
Panna	0.532	12	0.585	34
Sagar	0.555	19	0.617	39
Damoh	0.629	39	0.539	15
Satna	0.517	9	0.683	50
Rewa	0.642	43	0.550	18
Umaria	0.503	5	0.560	24
Neemuch	0.598	28	0.549	17
Mandsaur	0.601	30	0.513	9
Ratlam	0.658	46	0.521	11
Ujjain	0.619	36	0.574	32
Shajapur (Undivided)	0.701	49	0.575	na
Dewas	0.516	8	0.568	27
Dhar	0.597	27	0.637	46
Indore	0.622	38	0.687	51
Khargone (West Nimar)	0.630	40	0.502	7
Barwani	0.581	24	0.531	13
Rajgarh	0.600	29	0.631	44
Vidisha	0.652	45	0.516	10
Bhopal	0.640	42	0.572	30
Sehore	0.543	14	0.602	37
Raisen	0.487	3	0.620	40
Betul	0.489	4	0.480	4
Harda	0.509	7	0.563	26
Hoshangabad	0.521	10	0.602	36
Katni	0.607	31	0.542	16
Jabalpur	0.458	1	0.555	21
Narsimhapur	0.577	23	0.556	22
Dindori	0.614	34	0.571	29
Mandla	0.577	22	0.458	2
Chhindwara	0.485	2	0.553	19
Seoni	0.504	6	0.484	6
Balaghat	0.554	17	0.626	42
Guna	0.541	13	0.555	20

District	2015-2016		2019-2021	
	D_i	Rank	D_i	Rank
Ashoknagar	0.567	20	0.610	38
Shahdol	0.672	47	0.656	49
Anuppur	0.554	18	0.636	45
Sidhi	0.711	50	0.532	14
Singrauli	0.622	37	0.524	12
Jhabua	0.639	41	0.620	41
Alirajpur	0.681	48	0.574	33
Khandwa (East Nimar)	0.545	15	0.506	8
Burhanpur	0.569	21	0.557	23
Agar Malwa	na	na	0.370	1
Shajapur	na	na	0.644	47

Remarks: District Shajapur (undivided) in 2015-2016 was divided into Agar Malwa and Shajapur districts in 2019-2021.
Source: Author

Table 8: Deprivation index (*DI*) in children 1-2 years of age in districts of Madhya Pradesh, 2015-2021

District	2015-2016		2019-2021	
	D_i	Rank	D_i	Rank
Sheopur	0.527	37	0.478	44
Morena	0.495	32	0.379	30
Bhind	0.462	25	0.318	11
Gwalior	0.419	14	0.343	21
Datia	0.541	41	0.376	27
Shivpuri	0.487	29	0.418	35
Tikamgarh	0.600	45	0.317	10
Chhatarpur	0.523	36	0.438	39
Panna	0.630	48	0.478	45
Sagar	0.494	31	0.431	38
Damoh	0.507	35	0.441	40
Satna	0.429	17	0.496	48
Rewa	0.443	23	0.471	43
Umaria	0.480	28	0.491	47
Neemuch	0.458	24	0.291	6
Mandsaur	0.431	20	0.326	14
Ratlam	0.532	38	0.289	5
Ujjain	0.394	8	0.302	9
Shajapur (Undivided)	0.495	33	0.287	na
Dewas	0.359	2	0.326	15
Dhar	0.408	11	0.332	17
Indore	0.389	7	0.294	7
Khargone (West Nimar)	0.430	18	0.297	8
Barwani	0.589	44	0.428	37
Rajgarh	0.497	34	0.377	28
Vidisha	0.578	43	0.398	32
Bhopal	0.420	15	0.342	20
Sehore	0.349	1	0.331	16
Raisen	0.442	22	0.335	19
Betul	0.361	3	0.409	33
Harda	0.431	19	0.281	4
Hoshangabad	0.411	12	0.344	22
Katni	0.493	30	0.480	46
Jabalpur	0.373	5	0.255	1
Narsimhapur	0.464	26	0.347	24
Dindori	0.623	47	0.523	51
Mandla	0.441	21	0.417	34
Chhindwara	0.368	4	0.346	23
Seoni	0.400	10	0.320	12
Balaghat	0.377	6	0.381	31
Guna	0.416	13	0.324	13

District	2015-2016		2019-2021	
	D_i	Rank	D_i	Rank
Ashoknagar	0.469	27	0.360	25
Shahdol	0.550	42	0.454	41
Anuppur	0.426	16	0.378	29
Sidhi	0.605	46	0.461	42
Singrauli	0.536	40	0.501	49
Jhabua	0.662	50	0.522	50
Alirajpur	0.650	49	0.421	36
Khandwa (East Nimar)	0.397	9	0.332	18
Burhanpur	0.534	39	0.277	3
Agar Malwa	na	na	0.370	26
Shajapur	na	na	0.274	2

Remarks: District Shajapur (undivided) in 2015-2016 was divided into Agar Malwa and Shajapur districts in 2019-2021.
Source: Author

Table 9: Deprivation index (*DI*) in children 3-5 years of age in districts of Madhya Pradesh, 2015-2021

District	2015-2016		2019-2021	
	D_i	Rank	D_i	Rank
Sheopur	0.572	37	0.542	44
Morena	0.495	14	0.434	16
Bhind	0.536	26	0.453	20
Gwalior	0.466	7	0.427	12
Datia	0.465	6	0.469	24
Shivpuri	0.476	8	0.530	40
Tikamgarh	0.542	29	0.496	33
Chhatarpur	0.591	40	0.480	30
Panna	0.555	34	0.550	46
Sagar	0.495	15	0.528	39
Damoh	0.534	25	0.488	31
Satna	0.510	20	0.531	41
Rewa	0.560	35	0.533	42
Umaria	0.598	43	0.513	37
Neemuch	0.448	3	0.349	2
Mandsaur	0.491	12	0.311	1
Ratlam	0.548	32	0.427	11
Ujjain	0.478	9	0.395	7
Shajapur (Undivided)	0.511	21	0.411	na
Dewas	0.488	11	0.361	3
Dhar	0.542	28	0.432	15
Indore	0.374	1	0.375	6
Khargone (West Nimar)	0.459	5	0.432	14
Barwani	0.648	46	0.504	36
Rajgarh	0.595	41	0.478	29
Vidisha	0.543	30	0.412	9
Bhopal	0.479	10	0.464	23
Sehore	0.501	16	0.426	10
Raisen	0.508	19	0.497	34
Betul	0.521	24	0.435	17
Harda	0.520	23	0.457	22
Hoshangabad	0.427	2	0.475	27
Katni	0.494	13	0.456	21
Jabalpur	0.503	17	0.561	47
Narsimhapur	0.451	4	0.411	8
Dindori	0.658	47	0.589	49
Mandla	0.601	44	0.514	38
Chhindwara	0.515	22	0.374	5
Seoni	0.561	36	0.471	25
Balaghat	0.545	31	0.440	18
Guna	0.538	27	0.473	26

District	2015-2016		2019-2021	
	D_i	Rank	D_i	Rank
Ashoknagar	0.586	39	0.544	45
Shahdol	0.597	42	0.492	32
Anuppur	0.550	33	0.501	35
Sidhi	0.615	45	0.541	43
Singrauli	0.659	48	0.595	50
Jhabua	0.700	50	0.579	48
Alirajpur	0.695	49	0.599	51
Khandwa (East Nimar)	0.506	18	0.441	19
Burhanpur	0.577	38	0.476	28
Agar Malwa	na	na	0.370	4
Shajapur	na	na	0.429	13

Remarks: District Shajapur (undivided) in 2015-2016 was divided into Agar Malwa and Shajapur districts in 2019-2021.
Source: Author

Table 10: Deprivation index (*DI*) in children 6-10 years of age in districts of Madhya Pradesh, 2015-2021

District	2015-2016		2019-2021	
	D_i	Rank	D_i	Rank
Sheopur	0.433	37	0.358	37
Morena	0.287	17	0.388	42
Bhind	0.223	4	0.347	33
Gwalior	0.233	6	0.243	12
Datia	0.254	14	0.194	5
Shivpuri	0.326	25	0.387	41
Tikamgarh	0.377	27	0.235	11
Chhatarpur	0.422	33	0.331	29
Panna	0.511	47	0.474	47
Sagar	0.496	45	0.293	23
Damoh	0.424	34	0.325	27
Satna	0.308	22	0.359	39
Rewa	0.426	35	0.522	50
Umaria	0.411	32	0.332	30
Neemuch	0.302	21	0.163	3
Mandsaur	0.326	24	0.271	15
Ratlam	0.490	44	0.229	10
Ujjain	0.256	15	0.312	24
Shajapur (Undivided)	0.247	11	0.172	na
Dewas	0.241	9	0.268	14
Dhar	0.317	23	0.290	19
Indore	0.162	1	0.100	1
Khargone (West Nimar)	0.331	26	0.359	38
Barwani	0.553	48	0.436	46
Rajgarh	0.250	13	0.290	21
Vidisha	0.427	36	0.283	17
Bhopal	0.234	7	0.190	4
Sehore	0.222	3	0.223	9
Raisen	0.230	5	0.290	20
Betul	0.457	40	0.321	26
Harda	0.236	8	0.217	7
Hoshangabad	0.211	2	0.356	36
Katni	0.393	29	0.394	44
Jabalpur	0.265	16	0.292	22
Narsimhapur	0.298	20	0.288	18
Dindori	0.509	46	0.519	49
Mandla	0.466	41	0.353	34
Chhindwara	0.293	19	0.315	25
Seoni	0.401	30	0.344	31
Balaghat	0.404	31	0.265	13
Guna	0.288	18	0.345	32

District	2015-2016		2019-2021	
	D_i	Rank	D_i	Rank
Ashoknagar	0.249	12	0.331	28
Shahdol	0.436	38	0.398	45
Anuppur	0.444	39	0.356	35
Sidhi	0.482	43	0.384	40
Singrauli	0.469	42	0.394	43
Jhabua	0.704	50	0.574	51
Alirajpur	0.608	49	0.508	48
Khandwa (East Nimar)	0.244	10	0.219	8
Burhanpur	0.382	28	0.277	16
Agar Malwa	na	na	0.196	6
Shajapur	na	na	0.160	2

Remarks: District Shajapur (undivided) in 2015-2016 was divided into Agar Malwa and Shajapur districts in 2019-2021.
Source: Author

Table 11: Deprivation index (*DI*) in children 11-14 years of age in districts of Madhya Pradesh, 2015-2021

District	2015-2016		2019-2021	
	D_i	Rank	D_i	Rank
Sheopur	0.389	31	0.385	35
Morena	0.264	12	0.235	10
Bhind	0.321	20	0.323	20
Gwalior	0.254	10	0.224	8
Datia	0.238	6	0.229	9
Shivpuri	0.418	40	0.338	23
Tikamgarh	0.254	11	0.220	6
Chhatarpur	0.349	26	0.335	22
Panna	0.399	34	0.444	46
Sagar	0.332	23	0.298	17
Damoh	0.390	32	0.358	29
Satna	0.366	27	0.442	44
Rewa	0.409	38	0.495	48
Umaria	0.421	41	0.349	25
Neemuch	0.169	1	0.185	4
Mandsaur	0.267	13	0.320	19
Ratlam	0.601	49	0.250	11
Ujjain	0.312	19	0.442	45
Shajapur (Undivided)	0.395	33	0.178	na
Dewas	0.201	2	0.332	21
Dhar	0.300	18	0.419	40
Indore	0.328	22	0.167	3
Khargone (West Nimar)	0.250	8	0.315	18
Barwani	0.541	47	0.434	42
Rajgarh	0.251	9	0.284	16
Vidisha	0.372	29	0.256	12
Bhopal	0.321	21	0.263	13
Sehore	0.237	5	0.165	2
Raisen	0.222	3	0.194	5
Betul	0.406	36	0.434	41
Harda	0.241	7	0.403	37
Hoshangabad	0.222	4	0.441	43
Katni	0.378	30	0.384	34
Jabalpur	0.334	25	0.541	51
Narsimhapur	0.285	16	0.356	28
Dindori	0.488	46	0.497	49
Mandla	0.452	45	0.366	30
Chhindwara	0.285	15	0.375	31
Seoni	0.411	39	0.376	32
Balaghat	0.400	35	0.282	15
Guna	0.372	28	0.350	26

District	2015-2016		2019-2021	
	D_i	Rank	D_i	Rank
Ashoknagar	0.282	14	0.274	14
Shahdol	0.431	43	0.404	38
Anuppur	0.406	37	0.397	36
Sidhi	0.428	42	0.409	39
Singrauli	0.433	44	0.378	33
Jhabua	0.579	48	0.485	47
Alirajpur	0.616	50	0.523	50
Khandwa (East Nimar)	0.300	17	0.344	24
Burhanpur	0.333	24	0.356	27
Agar Malwa	na	na	0.222	7
Shajapur	na	na	0.165	1

Remarks: District Shajapur (undivided) in 2015-2016 was divided into Agar Malwa and Shajapur districts in 2019-2021.
Source: Author

Table 12: Deprivation index (*DI*) in children 15-19 years of age in districts of Madhya Pradesh, 2015-2021

District	2015-2016		2019-2021	
	D_i	Rank	D_i	Rank
Sheopur	0.560	47	0.469	44
Morena	0.414	7	0.356	9
Bhind	0.428	12	0.333	4
Gwalior	0.334	1	0.354	8
Datia	0.511	38	0.358	10
Shivpuri	0.544	44	0.414	27
Tikamgarh	0.523	41	0.352	7
Chhatarpur	0.501	34	0.440	35
Panna	0.465	21	0.484	47
Sagar	0.443	15	0.399	20
Damoh	0.468	26	0.454	42
Satna	0.389	5	0.416	28
Rewa	0.418	10	0.485	48
Umaria	0.480	27	0.449	38
Neemuch	0.481	28	0.350	6
Mandsaur	0.516	40	0.445	36
Ratlam	0.515	39	0.431	31
Ujjain	0.492	31	0.377	16
Shajapur (Undivided)	0.546	45	0.393	na
Dewas	0.434	13	0.367	13
Dhar	0.466	23	0.435	33
Indore	0.377	3	0.322	3
Khargone (West Nimar)	0.525	42	0.367	12
Barwani	0.656	49	0.507	51
Rajgarh	0.467	25	0.450	40
Vidisha	0.506	37	0.438	34
Bhopal	0.396	6	0.309	2
Sehore	0.379	4	0.395	18
Raisen	0.447	18	0.254	1
Betul	0.445	16	0.399	19
Harda	0.417	9	0.346	5
Hoshangabad	0.335	2	0.370	14
Katni	0.463	20	0.401	22
Jabalpur	0.441	14	0.446	37
Narsimhapur	0.415	8	0.435	32
Dindori	0.557	46	0.503	50
Mandla	0.527	43	0.405	24
Chhindwara	0.467	24	0.407	25
Seoni	0.456	19	0.408	26
Balaghat	0.445	17	0.364	11
Guna	0.499	33	0.401	21

District	2015-2016		2019-2021	
	D_i	Rank	D_i	Rank
Ashoknagar	0.485	30	0.430	30
Shahdol	0.483	29	0.449	39
Anuppur	0.424	11	0.402	23
Sidhi	0.465	22	0.483	46
Singrauli	0.502	35	0.451	41
Jhabua	0.666	50	0.502	49
Alirajpur	0.612	48	0.480	45
Khandwa (East Nimar)	0.497	32	0.381	16
Burhanpur	0.504	36	0.419	29
Agar Malwa	na	na	0.459	43
Shajapur	na	na	0.377	15

Remarks: District Shajapur (undivided) in 2015-2016 was divided into Agar Malwa and Shajapur districts in 2019-2021.
Source: Author

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Family Planning Performance in India, 1992-2021

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Abstract

This paper measures family planning performance in India using a composite family planning performance index. Using the data available from different rounds of the National Family Health Survey, the paper concludes that although family planning performance in India has improved during since 1992-93, it remains poor and there is significant inter-state/Union Territory and inter-district variation in the performance. The paper also analyses the inequality in the performance of three dimensions of family planning performance – met demand for permanent methods, met demand for spacing methods and family planning methods mix.

Introduction

Planned family planning efforts in India are now 70 years old. They were conceived and implemented in the context of controlling population growth by reducing birth rate. Family planning, however, is only one of the many proximate determinants of fertility (Davis and Blake, 1956; Bongaarts, 1972). A decrease in fertility, therefore, is attributed to the combined effect of the change in its different proximate determinants. Family planning is now increasingly being recognised as a development strategy and not just an intervention to reduce fertility. There is evidence to suggest that family planning improves health, reduces poverty, and empower women (Bongaarts et al, 2012). It is one of the most cost-effective instruments of health and development (Bongaarts et al, 2012; Cleland et al, 2006). The United Nation 2030 Agenda for Sustainable Development (United Nations, 2015) recognises family planning as a cross-sectoral intervention that can hasten progress across the five themes of the agenda - People, Planet, Prosperity, Peace, and Partnership – in terms of its implications to human rights, gender equality, and empowerment, its impact on maternal, new born, child, and adolescent health, and its role in shaping economic development and environmental and political futures (Starbird et al, 2016). The progress in family planning is critical to achieving sustainable development goals. However, family planning needs of the people are very diverse and dynamic. This means that family planning performance should be analysed not in terms of fertility reduction but in terms of meeting the diverse and changing family planning needs of the people.

Family planning performance has traditionally been measured in terms of contraceptive prevalence rate (CPR) which is a crude measure similar to birth rate. The popularity of CPR as a measure of family planning performance is based on its strong inverse relationship with total fertility rate (TFR) (Bongaarts, 1978; Bongaarts and Potter, 1983; Ross and Mauldin, 1996; Jain, 1997; Tsui, 2001; Stover, 1998; United Nations, 2020). There are, however, studies that show inconsistency between CPR and TFR (United Nations, 2020). Srinivasan (1988) has observed that, as one goes down the level of aggregation, variation in CPR explains less and less of the variation in TFR. Srinivasan (1993) has also shown how TFR can be zero even if CPR is only 25 per cent or CPR may not affect TFR at all even if CPR is as high as 75 per cent. Using the below district-level data from Madhya Pradesh, India, Chaurasia (2004) has observed that variation in CPR explained only around 20 per cent of the variation in total marital fertility rate (TMFR).

CPR has many limitations a measure of family planning performance. It is a ratio, not rate or incidence of family planning practice. It does not consider variation in the use of different family planning methods by age. A scale to measure family planning performance based on CPR is difficult to establish as a substantial proportion of women may not be using any family planning method because they are either wanting a child, or pregnant, or they or their partner sterile. It has therefore been suggested that family planning performance should be measured in terms of the demand for family planning satisfied (Population Reference Bureau, 2016). The proportion of women aged 15-49 years who have their family planning needs satisfied by modern methods is also identified by United Nations as one of the indicators (indicator 3.7.1) to monitor the progress towards sustainable development goals.

The demand for family planning satisfied or the met demand of family planning can be divided further into the met demand of family planning for spacing births and met demand of family planning for limiting or stopping births. This distinction is important as the context of family planning for limiting births is different from the context of family planning for spacing births. Couples stop or limit births only when they have achieved the desired family size whereas couples space births to plan their family. It is therefore important that met demand for limiting births is treated separately from met demand for spacing births in analysing family planning performance.

It is also well-known that family planning needs are different in different phases of the family building process and are conditioned by such factors as personal circumstances, individual knowledge and changing childbearing preferences. Family planning needs are also influenced by the availability and accessibility of different family planning methods and their effectiveness. It has, therefore, important that family planning performance takes into consideration the range and types of family planning methods being used or the method-mix (United Nations, 2019). The method mix is also one of the elements of quality of family planning services (Bruce, 1990). It reflects both availability of different family planning methods and user preferences (Bertrand et al, 2020). Choice of family planning method is a key principle in both quality of care and rights-based approach to family planning. Method- mix has also been identified as one of the core set of indicators to monitor family planning progress (FP2020, nd).

Recently, Chaurasia () has developed a composite index to measure family planning performance which considers met demand of limiting, met demand of spacing, and method-mix as the three dimensions of family planning efforts. The index provides more rounded assessment of the performance of family planning efforts than CPR or met demand of family planning. The objective of the present paper is to analyse the performance of family planning efforts in India during 1992-2021 using the composite family planning performance index developed by Chaurasia (2023). In an earlier paper, Chaurasia (2021) has analysed the performance of family planning efforts during 1992-2016. This paper extends the analysis to the period 1992-2021 to include the most recent data on family planning use available through the National Family Health Survey.

The paper is organised as follows. The next section of the paper describes the composite family planning performance index. Section three describes the data source. Section four analyses family planning performance in India and in its constituent states/Union Territories and districts. Section five classifies districts in terms of the met need of permanent methods, met need of spacing methods and method mix. The last section of the paper summarises the findings of the analysis and their policy and programme relevance in the context of meeting the family planning needs of the people.

Composite Family Planning Performance Index

The rationale and the details of the construction of the composite family planning performance index used in this paper are discussed elsewhere (Chaurasia, 2023). If p denotes the composite family planning performance index, p_s denotes the performance index that reflects the met demand of modern spacing methods; p_p denotes the performance index that reflects the met demand of permanent methods; and p_q denotes the performance index that reflects the method-mix, then the index p is defined as

$$p = \frac{(\sqrt{p_s}*\sqrt{p_p})+(\sqrt{p_p}*\sqrt{p_q})+(\sqrt{p_q}*\sqrt{p_s})}{3} = \frac{p_{sp}+p_{pq}+p_{qs}}{3} \quad (1)$$

$$p_{sp} = \sqrt{p_s} * \sqrt{p_p} \quad (2)$$

$$p_{pq} = \sqrt{p_p} * \sqrt{p_q} \quad (3)$$

$$p_{qs} = \sqrt{p_q} * \sqrt{p_s} \quad (4)$$

The indexes p_s, p_p and p_q are defined as

$$p_s = \frac{c_s}{c_s+c_t+u_s} \quad (5)$$

$$p_p = \frac{c_p}{c_p + u_p} \tag{6}$$

$$p_q = 1 - \sqrt{\frac{\sum x_j^2 - \left(\frac{1}{n}\right)}{1 - \left(\frac{1}{n}\right)}} \; when\ n > 1\ and\ s = 1\ when\ n = 1;\ \sum_{j=1}^{n} x_j = 1 \tag{7}$$

Here c_s is the prevalence of modern spacing methods, c_p is the prevalence of permanent methods, c_t is the prevalence of traditional methods, u_s is the unmet need for spacing, u_p is the unmet need for limiting and x_j is the proportionate prevalence of family planning method j among n family planning methods. It may be noticed that the indexes p_s, p_p and p_q range between 0 and 1 and the higher the index the higher the performance. When $p_s=p_p=p_q=0$, $p=0$. Similarly, when $p_s=p_p=p_q=1$, $p=1$. When $p_s=p_p=p_q=v$ for any v, $p=v/3$. When $p_s \neq p_p \neq p_q$, $p<p_a$ so that the difference $p_i=(p_a-p)$ reflects performance inequality in three dimensions of family planning efforts, the larger the difference the larger the performance inequality.

Chaurasia (2023) has also shown that the change in the index p can be decomposed into the change in indexes p_s, p_p and p_q. If p^2 is the composite performance index at time t^2 and p^1 is the composite performance index at time t^1 then the difference p^2 - p^2 can be decomposed as

$$p^2 - p^1 = \nabla p = \partial p_s + \partial p_p + \partial p_q \tag{8}$$

where

$$\nabla p_s = \frac{1}{3}\left[\ln\left(\frac{\sqrt{p_s^2}}{\sqrt{p_s^1}}\right) * \frac{\left(LM_{sp} + LM_{qs}\right)}{3}\right] \tag{9}$$

$$\nabla p_p = \frac{1}{3}\left[\ln\left(\frac{\sqrt{p_p^2}}{\sqrt{p_p^1}}\right) * \frac{\left(LM_{sp} + LM_{pq}\right)}{3}\right] \tag{9}$$

$$\nabla p_q = \frac{1}{3}\left[\ln\left(\frac{\sqrt{p_q^2}}{\sqrt{p_q^1}}\right) * \frac{\left(LM_{pq} + LM_{qs}\right)}{3}\right] \tag{10}$$

where LM_{sp} is the logarithmic mean (Carlson, 1972) and is defined as

$$LM_{sp} = \frac{(p_{sp}^2 - p_{sp}^1)}{ln\left(\frac{p_{sp}^2}{p_{sp}^1}\right)} \tag{11}$$

Data Source

The analysis is based on the estimates of the prevalence of different family planning methods and the unmet need of spacing and unmet need of limiting available from District Level Household Survey (DLHS) and National Family Health Survey (NFHS).

NFHS was carried out in 1992-1993, 1998-1999, 2005-2006, 2015-2016 and 2019-2021. DLHS was carried out in 1998-1999, 2002-2004, 2007-2008 and is now discontinued. The first round (1992-1993) of NFHS provided estimates of the prevalence of different family planning methods and unmet need of spacing and limiting for the states only and not for the Union Territories and districts of the country. The second and third rounds provided estimates of prevalence rates and unmet needs of spacing and limiting for states and Union Territories but not for districts. The fourth and the fifth rounds, on the other hand, provided estimates of method-specific prevalence and unmet need of spacing and limiting for all states/Union Territories and districts of the country which permit family planning performance assessment up to the district level. Details of the NFHS and DLHS are given elsewhere and are not repeated here (Government of India, 2010; 2022).

Family Planning Performance in India

Organised family planning efforts in India date back to 1952 when the country launched the first official family planning programme of the world. Although, controlling population growth through reducing birth rate has always been the underlying rationale of the programme, yet, in its initial phase, the programme focussed on improving health and welfare of the family, especially children and women (Chaurasia and Singh, 2014). The programme adopted a target-based approach for its implementation. Programme performance, in this approach, was measured in terms of equivalent sterilisations and couples effectively protected (Chaurasia, 1985; Government of India, 1990). In 1969, the first nationally representative family planning survey was conducted which revealed that only 14 per cent of the currently married women aged 15-44 years in the country were using a family planning method while less than 10 per cent were using a modern family planning method (Operations Research Group, 1970). The second all India survey, conducted in 1980, revealed that family planning use among the currently married women aged 15-44 years was around 35 per cent while about 28 per cent women were using a modern family planning method (Khan and Prasad, 1980). The first round of the National Family Health Survey (NFHS) 1992-93 revealed that the proportion of currently married women aged 15-49 (MWRA) using a family planning method (CPR) was 40 per cent while the prevalence of modern family planning methods (mCPR) was 36 per cent (Government of India, 1995). In 1996, Government of India abolished the target-based approach of programme implementation and CPR and mCPR became the basis for measuring programme performance. The second round of NFHS (1998-1999) revealed that CPR had increased to 45 per cent (Government of India, 2000) while the third round (2005-2006) estimated a CPR of 55 per cent (Government of India, 2007). The fourth round (2015-2016), however, reported a decrease in CPR to 53 per cent while mCPR stagnated at around 48 per cent (Government of India, 2017). The fifth and the latest round of NFHS (2019-2201) suggests that CPR in the country has increased to 66.7 per cent while mCPR has increased to 56.5 per cent (Government of India, 2021).

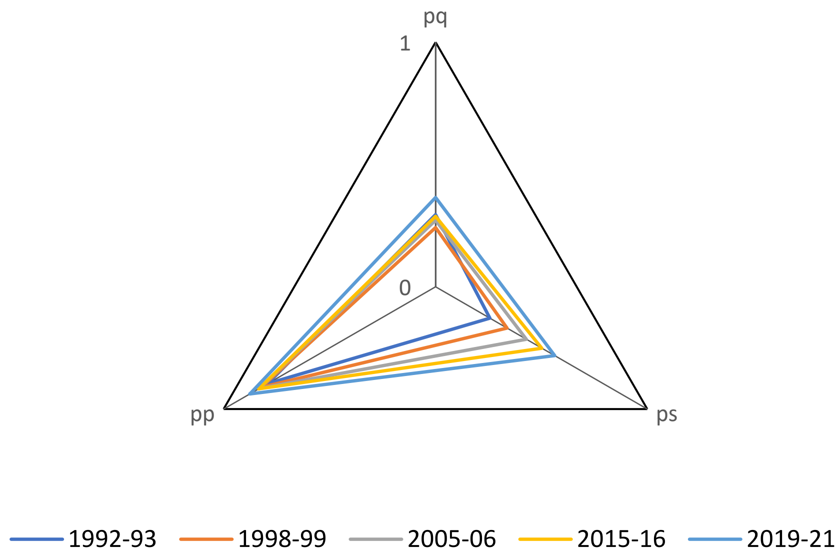


Figure 1: Family planning performance in India, 1992-2021
Source: Author

Estimates of method-specific prevalence of different family planning methods and unmet need for spacing and limiting available from different rounds of NFHS suggest that the composite performance index, *p*, increased from 0.403 in 1992-1993 to 0.574 in 2019-2201 in the country. The met demand of modern spacing methods increased from 25.7 per cent to 56.3 per cent while the met demand of permanent methods increased from 79.2 per cent to 87.6 per cent. At the same time, the index of method-mix increased from 0.295 to 0.365 (Table 1). Figure 1 depicts the family planning performance triangle in 1992-1993, 1998-1999, 2005-2006, 2015-2016 and 2019-2021. The trend in different indicators of family planning performance is depicted in figure 2.

Family planning performance has been different in the rural areas of the country as compared to its urban areas as defined at the 2011 population census. In the rural areas of the country, the composite family planning performance index *p* increased from 0.335 in 1992-1993 to 0.552 in 2019-2201. In the urban areas, on the other hand, the index *p* increased from 0.522 in 1992-1993 to 0.576 in 2005-2006 but then decreased to 0.560 in 2015-2016 and further to 0.559 in 2019-2201. If the trend in the index *p* is any indication, then family planning performance in the urban areas of the country appears to have deteriorated after 2005-2006 whereas it has improved in the rural areas.

The difference between the simple average of indexes p_s, p_p and $p_{q \text{ and}}$ the index *p* reflects the performance inequality in the three dimensions of family planning efforts. The average of the indexes p_s, p_p and p_q has always been higher than the index *p* which implies that performance in the three dimensions of family planning efforts has not been the same. This difference has, however, decreased from 0.045 in 1992-1993 to 0.028 in 2019-2201, although it increased between 1992-1993 and 1998-1999. The decrease in the performance inequality has been particularly sharp during 2015-2021. This decrease is one of the welcome features of family planning performance in the country. Although, the performance inequality has always been higher in the rural areas as compared to that in the urban areas of the country, yet the decrease in the performance inequality across different dimensions of family planning has been consistent and sharp in the rural areas but inconsistent and marginal in the urban areas. Performance inequality in the urban areas increased between 1992-1993 and 1998-1999 and again between 2005-2006 and 2015-2016.

Table 2 decomposes the improvement in family planning performance measured in terms of the index p into the improvement attributed to the increase in the met demand of modern spacing methods (index p_s), increase in the met demand of permanent methods (p_p) and improvement in the method-mix (index p_q) in conjunction with equation (8). More than 70 per cent of the increase in the index p during 1992-1993 through 2019-2201 may be attributed to the increase in the met demand of modern spacing methods whereas the increase in the met demand of permanent methods accounted for an increase of only around 10 per cent. The improvement in the method-mix, on the other hand, accounted for an increase of around 18 per cent. In the urban areas of the country, the increase in the met demand of modern spacing methods accounted for more than 87 per cent of the increase in the index p whereas the met demand of permanent methods decreased, instead increased, during this period. On the other hand, improvement in the method-mix has very nearly been the same in both rural and urban areas of the country. It may also be seen from the table that the deterioration in family planning performance in the urban areas during 2005-2006 through 2015-2016 has been the result of the decrease in the met demand of permanent methods, a substantial increase in the skewness in the method-mix (decrease in the index p_q); and virtually little increase in the met demand of modern spacing methods. By comparison, the deterioration in family planning performance in the urban areas during 2015-2016 through 2019-2201 has been due to the decrease in the met demand of both modern spacing methods and permanent methods, although, there has been a decrease in the skewness in the method-mix.

Among constituent states and Union Territories of the country, family planning performance has varied widely currently and in the past. In 2019-2021, performance was relatively the best in Union Territory of Ladakh which is the only state/Union Territory where family planning performance can be rated as good as the index p is more than 0.700 (Table 3). On the other hand, there are 20 states/Union Territories where the index p ranges between 0.550 to 0.750 which implies that family planning performance, in these states/Union Territories, can be rated as average. By contrast, in 14 states/Union Territories, family planning performance may be rated as poor as the index p ranges between 0.300 and 0.550. This leaves only one state, Andhra Pradesh, where family planning performance may be rated as very poor as the index p is estimated to be less than 0.300. Family planning use in Andhra Pradesh is characterised by very low met demand of modern spacing methods and very high met demand of permanent methods leading to very high degree of skewness in the method-mix.

The inequality in performance in the three dimensions of family planning also varies widely across states/Union Territories. Sikkim is the only state in the country where the performance in the three dimensions of family planning is nearly the same. The met demand of modern spacing methods in Sikkim is around 67 per cent while the met demand of permanent methods is almost 70 per cent. On the other hand, the index of method-mix is almost 0.687 so that the difference between the average of p_s, p_p, and p_q and p is negligible. In addition to Sikkim, there are 8 states/Union Territories where performance inequality across the three dimensions of family planning is low whereas, in six states/Union Territories where, performance inequality is high with the highest performance inequality in Andhra Pradesh followed by Telangana.

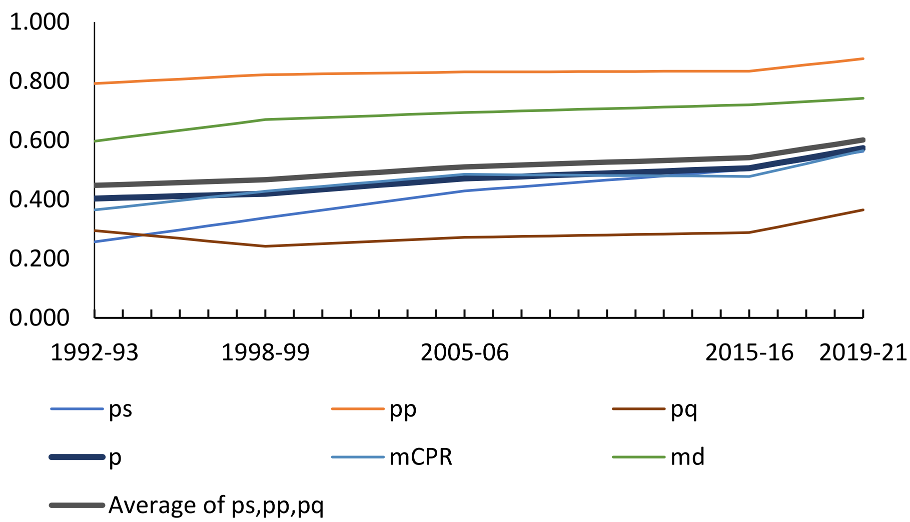


Figure 2: Trend in different indicators of family planning performance in India, 1992-2021
Source: Author

The performance in terms of the met demand of modern spacing methods and met demand of permanent methods has been contrastingly different in states and Union Territories (Figure 4). There is only one state/Union Territory where performance in terms of the met demand of modern spacing methods can be rated as good. There is no state/Union Territory where performance in meeting the demand of modern spacing methods can be rated as very good. By contrast, performance in meeting the demand of permanent methods is rated as very good in 7 states/Union Territories and good in 22 states/Union Territories. There is no state/Union Territory where performance in terms of the met demand of permanent methods is very poor but there are 4 states/Union Territories where the met demand of modern spacing methods is very poor. Similarly, the method mix is either very highly or highly skewed in 30 states/Union Territories of the country.

Improvement in family planning performance has also been different in different states/Union Territories (Table 4). There are 20 states for which data are available for 1992-1993 and 2019-2021. Among these 20 states, performance of family planning efforts appears to have deteriorated in Delhi, Kerala, Manipur, and Punjab. On the other hand, improvement in the performance has been the most rapid in West Bengal. In Goa, Nagaland, Odisha, and Rajasthan also, improvement in the performance has also been remarkable. In Himachal Pradesh, Maharashtra, Meghalaya, Tamil Nadu, and Tripura, improvement in performance has been marginal. In Delhi and Manipur, performance in the met demand of modern spacing methods decreased whereas in 9 states, performance in the met demand of permanent methods decreased in 2019-2021 compared to that in 1992-1993. The skewness in method-mix increased in Assam, Delhi, Himachal Pradesh, Perala, Maharashtra, Nagaland, Tamil Nadu, and Tripura. Between 2015-2016 and 2019-2021, family planning performance deteriorated in four states. Performance in met demand of modern spacing methods deteriorated in 11 states whereas performance in met demand of permanent methods deteriorated in 8 states while skewness in method-mix increased in 6 states/Union Territories.

District-level estimates of prevalence of different family planning methods and unmet need for spacing and limiting are available from District Level Household Survey (DLHS) 2002-04 (Government of India, 2006) and 2007-08 (Government of India, 2010) and from NFHS for 2015-16 and 2019-21. District level analysis of family planning performance is important as family planning efforts are conceptualised the national level, customized at state/Union Territory level and implemented at district level. Table 5 presents distribution of districts in the index p. During 2002-04, performance was very poor ($p<0.300$) in more than 25 per cent of 593 districts; poor ($0.300\leq p<0.550$) in more than 60 per cent districts. There was only one district in which the performance was good ($p\geq 0.750$). In 2007-08, performance was very poor ($p<0.300$) in 19 per cent of 600 districts, poor ($0.300\leq p<0.550$) in 57 per cent districts and good ($0.750\leq p<0.900$) in only one district. In 2015-16, performance was very poor ($p<0.300$) in around 18 per cent of 640 districts, and poor ($0.300\leq p<0.550$) in more than 57 per cent districts. There was no district in which performance was either good or very good. Finally, in 2019-21, performance was very poor in only about 4 per cent of 707 districts but was poor in around 51 per cent districts, average in around 44 per cent districts and good in only 9 districts. In Prakasam district of Andhra Pradesh, performance was the poorest among all districts in 2019-21 while performance was the best in district Badgam in Jammu and Kashmir. Table 5 suggests that, although, there is improvement in family planning performance at the district level, yet there are only a few districts where performance may be termed as good even in 2019-21. There is still no district where performance is very good. The good sign, however, is that there are now only a few districts where the performance is very poor.

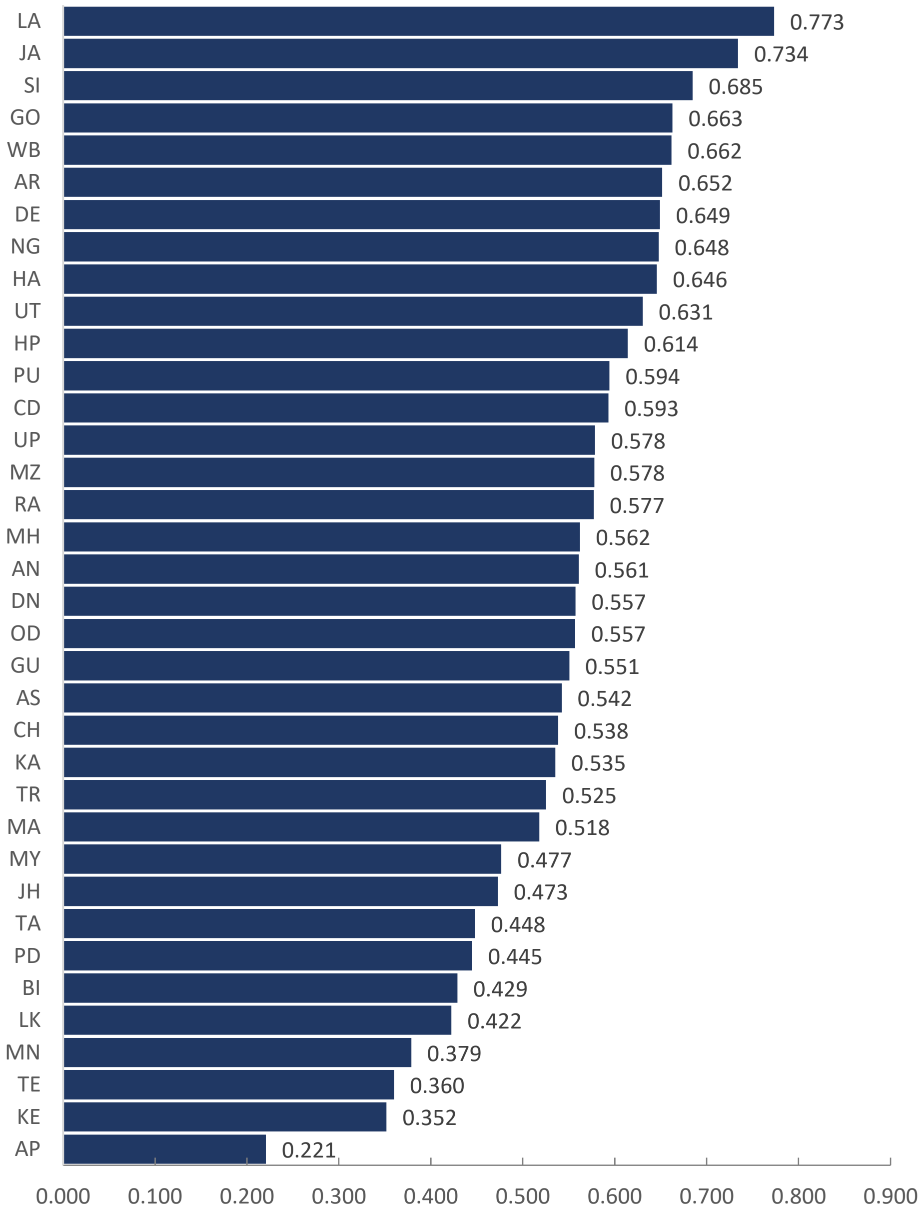
Table 1: Family planning performance indexes in India, 1992-2021

Performance indexes	Period				
	1992-93	1998-99	2005-06	2015-16	2019-21
Combined population					
Composite index of family planning performance (p)	0.403	0.420	0.471	0.506	0.574
Met demand of modern spacing methods (p_s)	0.257	0.338	0.429	0.502	0.563
Met demand of permanent methods (p_p)	0.792	0.822	0.831	0.834	0.876
Contraceptive method-mix index (p_q)	0.259	0.242	0.272	0.288	0.365
Simple arithmetic mean of p_s, p_p and p_q (p_a)	0.448	0.467	0.511	0.541	0.601
Performance inequality (PI)	0.045	0.048	0.039	0.036	0.028
Met demand of modern family planning methods (p_m)	0.600	0.670	0.694	0.720	0.742
Modern contraceptive methods prevalence	0.365	0.428	0.485	0.478	0.565
Rural population					
Composite index of family planning performance (p)	0.335	0.356	0.406	0.470	0.552
Met demand of modern spacing methods (p_s)	0.169	0.253	0.340	0.453	0.534
Met demand of permanent methods (p_p)	0.787	0.814	0.819	0.833	0.874
Contraceptive method-mix index (p_q)	0.244	0.191	0.215	0.252	0.340
Simple arithmetic mean of p_s, p_p and p_q (p_a)	0.400	0.419	0.458	0.513	0.583
Performance inequality (PI)	0.065	0.063	0.052	0.042	0.031
Met demand of modern family planning methods (p_m)	0.573	0.651	0.669	0.709	0.755
Modern contraceptive methods prevalence	0.333	0.399	0.453	0.460	0.555
Urban population					
Composite index of family planning performance (p)	0.522	0.536	0.576	0.560	0.559
Met demand of modern spacing methods (p_s)	0.440	0.502	0.579	0.580	0.529
Met demand of permanent methods (p_p)	0.806	0.846	0.855	0.837	0.793
Contraceptive method-mix index (p_q)	0.386	0.346	0.369	0.345	0.404

Performance indexes	Period				
	1992-93	1998-99	2005-06	2015-16	2019-21
Simple arithmetic mean of p_s, p_p and p_q (p_a)	0.544	0.565	0.601	0.587	0.575
Performance inequality (*PI*)	0.022	0.028	0.025	0.027	0.017
Met demand of modern family planning methods (p_m)	0.663	0.717	0.747	0.740	0.668
Modern contraceptive methods prevalence	0.453	0.512	0.558	0.512	0.585

Source: Author

Figure 4: Family planning performance in states and Union Territories



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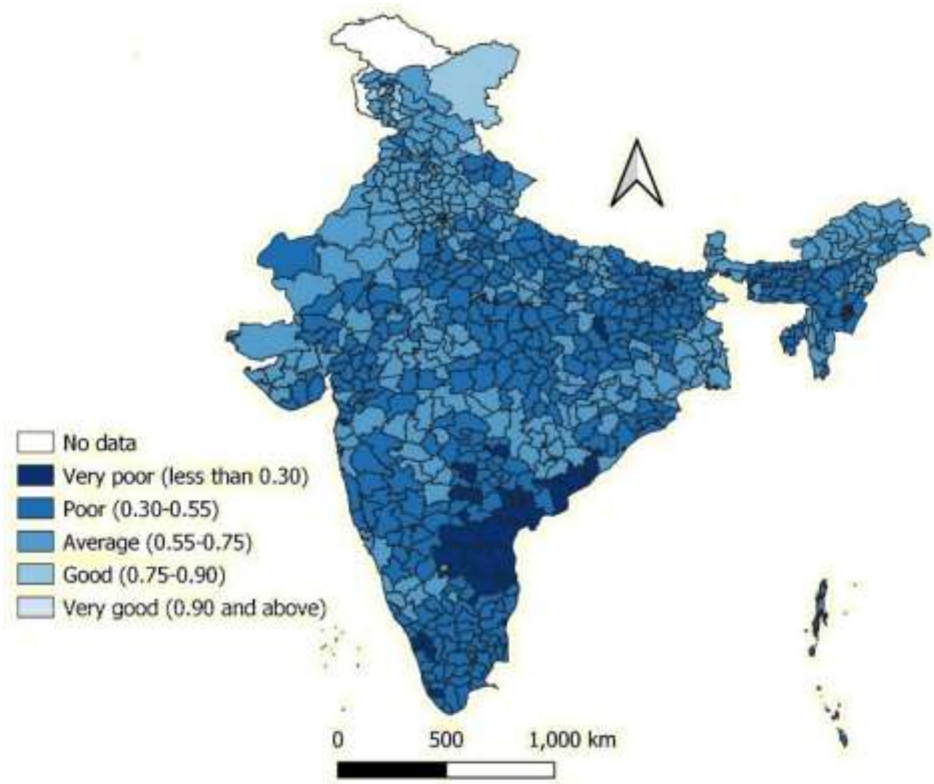

Figure 5: Family planning performance in districts of India, 2019-21.
Source: Author

The inequality in the performance in the three dimensions of family planning has also varied widely across the districts as reflected through the inter-district coefficient of variation in the difference between the average of the indexes p_s, p_p and p_q and the index p (Table 6). In 2019-2021, there were almost 17 per cent districts in the country where the inequality in performance the three dimensions of family planning is very low whereas this inequality is high or very high in almost 11 per cent districts as they existed at the time of the survey. In more than two-third districts of the country, however, the inequality in the performance in the three dimensions of family planning remains either low or very low. There has been very rapid increase in the proportion of districts in which the inequality in performance in the three dimensions of family planning is either high or very high between 2002-2004 and 2007-2008. However, after 2007-2008, this proportion appears to have decreased. At the same time, the proportion of districts where inequality in performance in the three dimensions of family planning has been either low or very low has also increased after 2007-2008. Reducing the inequality in performance in different dimensions of family planning contributes to improving family planning performance.

Table 2: Decomposition of the change in the index p in India during 1992-21

Index	Period				
	1992-93 to 1998-99	1998-99 to 2005-06	2005-06 to 2015-16	2015-16 to 2019-21	1992-93 to 2019-21
			Combined population		
∇p	0.016	0.051	0.035	0.068	0.171
∂p_s	0.035	0.034	0.026	0.021	0.121
∂p_p	0.006	0.002	0.001	0.010	0.018
∂p_q	-0.025	0.015	0.008	0.037	0.031
			Rural population		
∇p	0.021	0.050	0.065	0.081	0.216
∂p_s	0.041	0.036	0.042	0.028	0.155
∂p_p	0.005	0.001	0.003	0.009	0.018
∂p_q	-0.025	0.013	0.020	0.044	0.044
			Urban population		
∇p	0.015	0.039	-0.016	-0.002	0.037
∂p_s	0.023	0.027	0.000	-0.017	0.032
∂p_p	0.009	0.002	-0.004	-0.011	-0.003
∂p_q	-0.017	0.011	-0.012	0.027	0.008

Source: Author

Classification of Districts

Family planning performance, as measured by the index p, is contingent upon the met demand of modern spacing methods, the met demand of permanent methods and the skewness in the method-mix. We have used the classification modelling approach to classify districts in terms of family planning performance with respect to indexes p_s, p_p, and p_q. The classification and regression tree (CRT) methodology was used for the purpose. CRT classifies districts into mutually exclusive groups in such a manner that variation in performance in districts of the same group is the minimum. The exercise suggests 707 districts of the country, as they existed in 2019-2021 can be grouped into 14 mutually exclusive clusters and performance of family planning efforts in different clusters is different (Table 6, Figure 7). Performance is the poorest in cluster 7 comprising of 15 districts. The average index p in this cluster is 0.189 ± 0.071. This cluster is characterised by very poor performance in meeting the demand of modern spacing methods and very high degree of skewness in method-mix. The performance is the best in cluster 26 comprising of 26 districts. The average index p in this cluster is 0.748 ± 0.032. The met demand of modern spacing methods is the highest in this cluster while the method-mix is the most balanced. In 7 of the 14 clusters, comprising of 326, performance is poor while in 6 clusters, comprising of 366 districts, performance is average. This leaves only one cluster, comprising of 15 districts, in which performance is good. Most of the districts in this cluster are geographically contiguous.

Table 3: Family planning performance indexes in states/Union Territories, 2019-21

State/Union Territory	p	p_s	p_p	p_q	p_a	PI	p_m	$mCPR$
Andaman and Nicobar Islands	0.561	0.563	0.842	0.355	0.587	0.026	0.728	0.577
Andhra Pradesh	0.221	0.216	0.971	0.020	0.402	0.182	0.934	0.708
Arunachal Pradesh	0.652	0.605	0.768	0.592	0.655	0.004	0.659	0.472
Assam	0.542	0.649	0.569	0.427	0.548	0.006	0.631	0.453
Bihar	0.429	0.352	0.823	0.249	0.475	0.046	0.640	0.444
Chandigarh	0.593	0.599	0.814	0.416	0.610	0.017	0.660	0.556
Chhattisgarh	0.538	0.585	0.908	0.266	0.586	0.048	0.811	0.617
Dadra & Nagar Haveli and Daman & Diu	0.649	0.656	0.816	0.503	0.589	0.031	0.699	0.577
Delhi	0.557	0.571	0.864	0.331	0.659	0.009	0.748	0.598
Goa	0.663	0.719	0.872	0.451	0.681	0.018	0.788	0.601
Gujarat	0.551	0.519	0.862	0.355	0.579	0.028	0.709	0.536
Haryana	0.646	0.632	0.885	0.470	0.662	0.016	0.750	0.605
Himachal Pradesh	0.614	0.622	0.889	0.402	0.638	0.024	0.772	0.634
Jammu and Kashmir	0.734	0.735	0.846	0.633	0.738	0.004	0.777	0.525
Jharkhand	0.473	0.410	0.849	0.282	0.513	0.041	0.676	0.495
Karnataka	0.535	0.715	0.955	0.183	0.618	0.082	0.907	0.682
Kerala	0.352	0.290	0.895	0.135	0.440	0.088	0.721	0.528
Ladakh	0.773	0.809	0.814	0.701	0.775	0.001	0.811	0.480
Lakshadweep	0.422	0.236	0.828	0.350	0.471	0.049	0.464	0.301
Madhya Pradesh	0.518	0.561	0.933	0.235	0.576	0.058	0.825	0.655
Maharashtra	0.562	0.694	0.897	0.254	0.615	0.053	0.842	0.638
Manipur	0.379	0.233	0.330	0.660	0408	0.029	0.248	0.182
Meghalaya	0.477	0.421	0.394	0.641	0.486	0.009	0.414	0.225
Mizoram	0.578	0.574	0.681	0.490	0.582	0.004	0.615	0.308

State/Union Territory	p	p_s	p_p	p_q	p_a	PI	p_m	$mCPR$
Nagaland	0.648	0.651	0.758	0.548	0.652	0.004	0.681	0.453
Odisha	0.557	0.424	0.858	0.458	0.580	0.023	0.600	0.488
Puducherry	0.445	0.530	0.881	0.153	0.521	0.076	0.812	0.621
Punjab	0.594	0.579	0.790	0.450	0.606	0.012	0.660	0.505
Rajasthan	0.577	0.583	0.916	0.338	0.612	0.035	0.777	0.621
Sikkim	0.685	0.670	0.698	0.687	0.685	0.000	0.678	0.549
Tamil Nadu	0.448	0.555	0.928	0.135	0.539	0.091	0.861	0.655
Telangana	0.360	0.400	0.947	0.084	0.477	0.117	0.895	0.667
Tripura	0.525	0.611	0.648	0.356	0.538	0.013	0.618	0.491
Uttar Pradesh	0.578	0.548	0.677	0.519	0.581	0.003	0.591	0.445
Uttarakhand	0.631	0.658	0.827	0.450	0.645	0.014	0.726	0.578
West Bengal	0.662	0.651	0.881	0.495	0.676	0.014	0.746	0.607

Source: Author

Table 4: Decomposition of the improvement in family planning performance in states/Union Territories, 1992-2021.

States/Union Territories	1992-2021				2015-2021			
	∇p	∂p_s	∂p_p	∂p_q	∇p	∂p_s	∂p_p	∂p_q
Andaman and Nicobar Islands					0.118	0.040	0.000	0.078
Andhra Pradesh					0.037	0.037	-0.001	0.001
Arunachal Pradesh	0.196	0.117	0.049	0.029	0.132	0.051	0.063	0.018
Assam	0.198	0.207	-0.001	-0.007	0.032	0.025	0.011	-0.005
Bihar					0.157	0.061	0.034	0.061
Chandigarh					-0.072	-0.025	-0.004	-0.044
Chhattisgarh					0.091	0.037	0.004	0.051
Dadra & Nagar Haveli and Daman & Diu					0.182	0.088	0.028	0.066
Delhi	-0.031	-0.015	0.020	-0.036	0.016	-0.022	0.048	-0.010
Goa	0.264	0.162	0.016	0.086	0.189	0.084	0.062	0.042
Gujarat	0.112	0.059	-0.006	0.058	0.085	0.015	0.022	0.048
Haryana	0.137	0.087	0.014	0.036	0.004	-0.028	0.003	0.030
Himachal Pradesh	0.069	0.085	-0.001	-0.015	0.050	0.004	0.030	0.016
Jammu & Kashmir					0.082	0.024	0.010	0.048
Jharkhand					0.082	0.025	0.016	0.041
Karnataka	0.186	0.156	0.015	0.015	0.240	0.136	0.007	0.098
Kerala	-0.068	0.012	-0.005	-0.075	0.023	0.003	0.000	0.021
Ladakh					0.060	-0.012	0.008	0.063
Lakshadweep					0.071	0.043	0.022	0.006
Madhya Pradesh					0.077	0.026	0.013	0.037
Maharashtra	0.089	0.101	0.002	-0.014	0.035	0.017	-0.002	0.020
Manipur	-0.103	-0.035	-0.086	0.018	0.057	-0.023	0.079	0.001
Meghalaya	0.088	0.116	-0.088	0.060	-0.016	-0.017	-0.040	0.041

States/Union Territories	1992-2021				2015-2021			
	∇p	∂p_s	∂p_p	∂p_q	∇p	∂p_s	∂p_p	∂p_q
Mizoram	0.128	0.047	-0.063	0.144	-0.004	-0.005	-0.005	0.005
Nagaland	0.264	0.131	0.144	-0.011	0.170	0.080	0.096	-0.006
Odisha	0.243	0.125	0.017	0.100	0.014	-0.031	0.024	0.021
Puducherry					0.092	0.038	-0.011	0.065
Punjab	0.000	0.010	-0.014	0.004	-0.076	-0.042	-0.031	-0.002
Rajasthan	0.247	0.157	0.030	0.060	0.069	0.023	0.013	0.034
Sikkim					0.010	-0.016	0.026	0.000
Tamil Nadu	0.055	0.085	0.012	-0.042	0.115	0.057	0.004	0.053
Telangana					0.090	0.065	0.001	0.024
Tripura	0.097	0.150	-0.014	-0.040	0.005	0.025	-0.008	-0.011
Uttar Pradesh					0.095	0.050	0.020	0.025
Uttarakhand					0.016	-0.012	0.027	0.001
West Bengal	0.272	0.194	0.019	0.058	0.023	0.011	0.003	0.009

Source: Author

Table 5: Inter-district variation in family planning performance

Performance	2002-04		2007-08		2015-16		2019-21	
	Number	%	Number	%	Number	%	Number	%
	Frequency distribution							
Very poor ($p<0.300$)	149	25.1	115	19.2	116	18.1	26	3.7
Poor ($0.300 \leq p<0.550$)	361	60.9	342	57.0	368	57.5	364	51.5
Average ($0.550 \leq p<0.750$)	82	13.8	142	23.7	156	24.4	308	43.6
Good ($0.750 \leq p<0.900$)	1	0.2	1	0.2	0	0	9	1.3
Very good (≥ 0.900)	0		0	0	0	0	0	0
N	593		600		640		707	
	Summary statistics of inter-district distribution							
Minimum	0.080		0.059		0.000		0.000	
Q1	0.299		0.325		0.344		0.452	
Median	0.396		0.440		0.447		0.523	
Q3	0.479		0.540		0.548		0.601	
Maximum	0.786		0.763		0.760		0.829	
IQR	0.180		0.215		0.203		0.149	
Coefficient of variation	0.320		0.326		0.320		0.221	
Skewness	0.228		0.012		-0.153		-0.542	
Excess kurtosis	-0.425		-0.660		-0.483		0.777	

Source: Author

Table 6: Performance inequality across three dimensions of family planning

Performance	2002-04		2007-08		2015-16		2019-21	
	Number	%	Number	%	Number	%	Number	%
				Frequency distribution				
Very low ($p<0.010$)	173	29.2	40	6.7	119	19.0	118	16.7
Low ($0.010\leq p<0.050$)	294	49.6	264	44.0	247	39.4	350	49.5
Medium ($0.050\leq p<0.100$)	89	15.0	189	31.5	172	27.4	161	22.8
Good ($0.100\leq p<0.200$)	37	6.2	103	17.2	89	14.2	72	10.2
Very good (≥ 0.200)	0	0.0	4	0.67	0	0.0	6	0.8
N	593		600		640		707	
				Summary statistics of inter-district distribution				
Minimum	0.000		0.002		0.000		0.000	
Q1	0.008		0.023		0.014		0.015	
Median	0.020		0.050		0.037		0.030	
Q3	0.045		0.086		0.077		0.065	
Maximum	0.180		0.271		0.330		0.318	
IQR	0.036		0.062		0.064		0.051	
Coefficient of variation	1.053		0.748		0.963		0.942	
Skewness	1.732		1.056		1.596		1.741	
Excess kurtosis	-3.064		1.001		3.197		4.277	

Source: Author

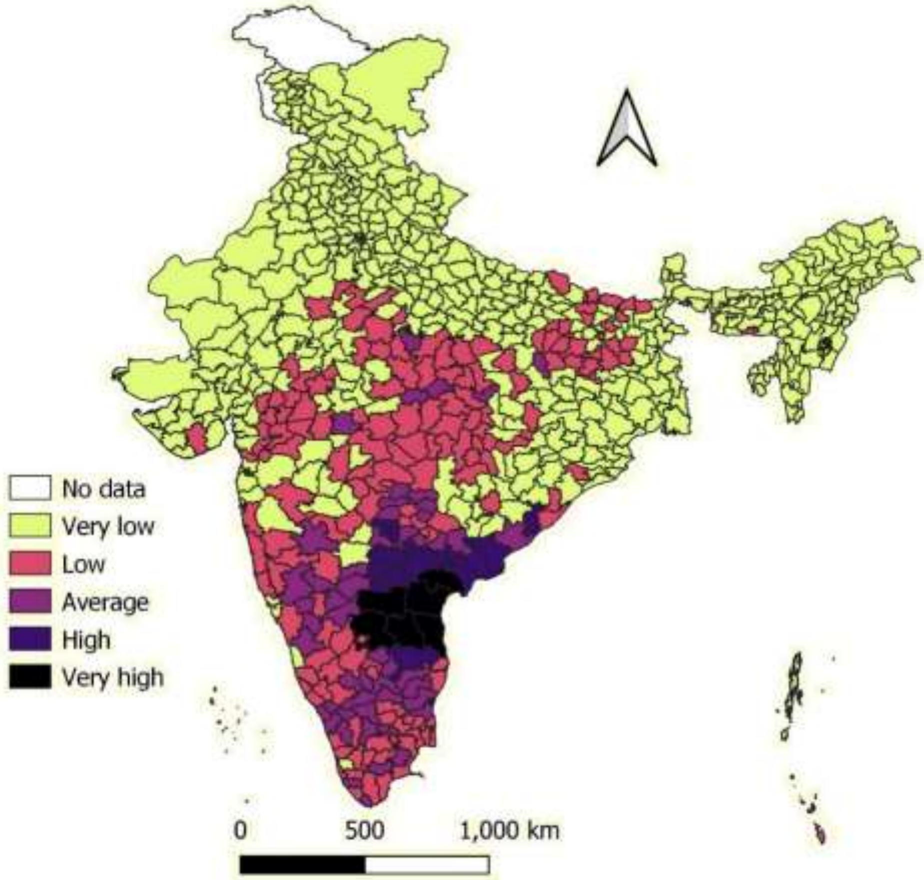

Figure 6: Inequality in family planning performance in districts of India, 2019-20
Source: Author

Discussions and Conclusions

The present analysis reveals that family planning performance in India remains far from satisfactory in terms of meeting the diverse and dynamic family planning needs of the people, although the performance has improved over time. Family planning efforts in India continue be primarily limited to meeting the demand of permanent methods of family planning or towards birth limitation. There is substantive scope of improving the performance in terms of meeting the demand of modern spacing methods. Another concern is that the method-mix continues to be heavily skewed towards permanent methods, particularly, female sterilisation despite improvement in the met demand of modern spacing methods. The analysis also suggests that the scope of further improving the met demand of permanent methods in the country is limited so that further improvement in family planning performance is contingent upon improvement in meeting the demand of modern spacing methods and reducing the skewness in method-mix. The vision 2020 of the Government of India anoints family planning as a critical intervention to reduce maternal and child mortality and morbidity beyond the simple strategy for achieving population stabilisation (Government of India, 2014). In this context, the present analysis suggests that there is a need to substantially reinvigorate official family planning efforts towards improving the performance in meeting the needs of modern spacing methods as the official family planning efforts continue to be the mainstay of the family planning movement in India. However, the latest available evidence available from the latest round of NFHS suggests that progress in this direction remains lethargic. The inability of the organised family planning efforts in effectively meeting the demand of modern spacing methods is also reflected in the increase in the prevalence of traditional methods from around 5 per cent in 2015-2016 to more than 10 per cent in 2019-2021.

Table 7: Results of the classification modelling exercise.

SN	Cluster number	p_s	p_p	p_q	p Mean	p SD	Number of districts
1	7	≤0.456		≤0.031	0.189	0.071	15
2	8	≤0.456		>0.031, ≤0.132	0.324	0.039	38
3	9	≤0.331		>0.132	0.394	0.042	48
4	15	>0.331, ≤0.456		>0.132, ≤0.280	0.439	0.026	48
5	11	>0.456		≤0.165	0.442	0.041	60
6	17	>0.456	≤0.908	>0.165, ≤0.327	0.449	0.044	51
7	19	>0.456	≤0.504	>0.327	0.492	0.048	25
8	16	>0.331, ≤0.456		>0.280	0.502	0.044	56
9	18	>0.456	>0.908	>0.165, ≤0.327	0.552	0.042	78
10	20	>0.456	>0.504, ≤0.733	>0.327	0.576	0.041	65
11	23	>0.456, ≤0.683	>0.733	>0.327, ≤0.459	0.589	0.029	102
12	24	>0.456, ≤0.683	>0.733	>0.459	0.644	0.031	61
13	25	>0.683	>0.733	>0.328, ≤0.542	0.669	0.027	36
14	26	>0.683	>0.733	>0.542	0.748	0.032	24

Source: Author

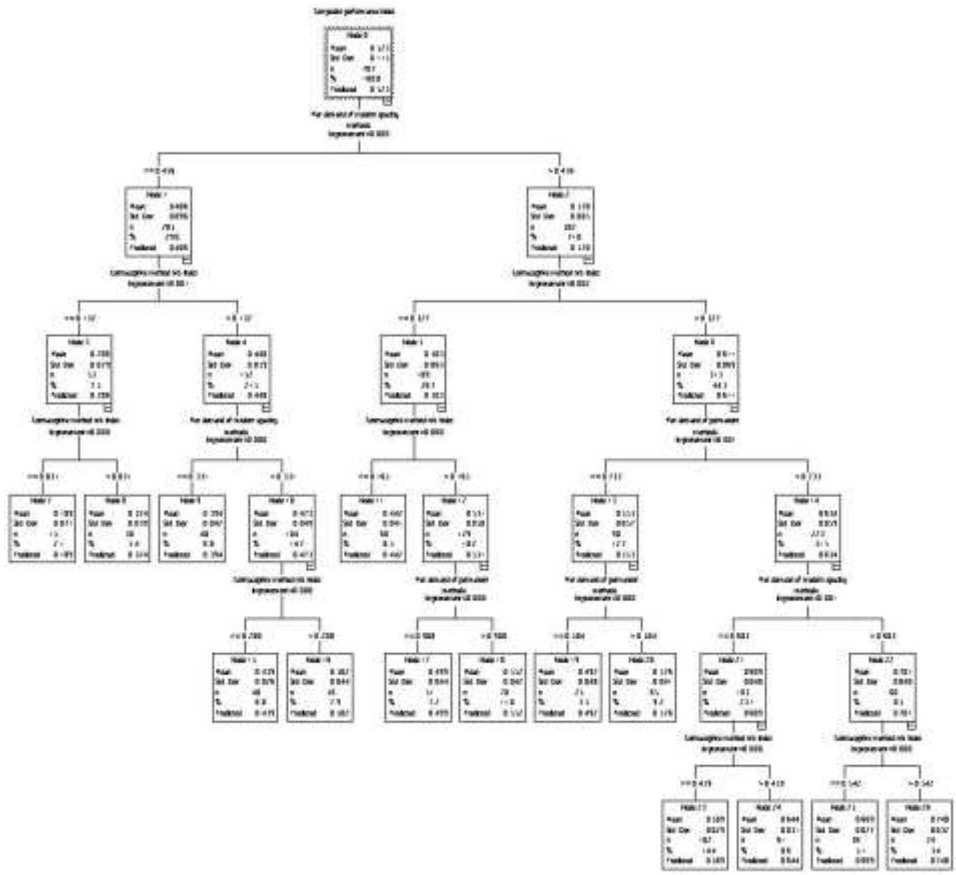

Figure 7: The classification tree
Source: Author

The latest NFHS 2019-2021 suggests that fertility in India has now decreased to below the replacement level so that fertility reduction imperative of family planning is now largely irrelevant. It is now the opportune time that family planning in India is pursued as a development strategy rather than just an intervention to limit births and reduce fertility. Potential benefits of family planning as the development strategy include economic development, improvement in maternal and child health, educational advancement, empowerment of women, and protection of the environment (Bongaarts et al, 2012; Cleland et al, 2006). Family planning has also been found to be a proven, cost-effective intervention for preventing mother-to-child transmission of HIV (Reynolds et al, 2005; Reynolds et al, 2006; Reynolds et al, 2008) and can protect against both unintended pregnancy and sexual transmission of HIV (Wilcher et al, 2009).

Benefits of family planning impact all the 17 Sustainable Development Goals (Starbird et al, 2016). It is estimated that 'every dollar invested in family planning saves four dollars in other health and development areas" (Toure et al, 2012; Frost et al, 2008). Reinvigorating family planning, especially, official family planning efforts, therefore, is the need of the time for India in its quest towards rapid social and economic development.

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Inter-District Variation in the Prevalence of Girl Child Marriage in Madhya Pradesh, India

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Abstract

This paper analyses the inter-district variation in the prevalence of girl child marriage in Madhya Pradesh, which is one of those states of India where the prevalence of girl child marriage remains high. The paper reveals that the prevalence of girl child marriages varies widely across the districts and there are districts where the prevalence has increased, instead decreased, over time. The districts of the state can be classified into seven groups having different prevalence of girl child marriage and the distinguishing characteristics of the different groups are different in terms of education of women, fertility, and social class composition of the population. The paper recommends that a decentralised district-based approach should be adopted for ending girl child marriages in Madhya Pradesh.

Introduction

Marriage is an important pillar of the family institution in the Indian society, although it is not a new thing that the patriarchy system is the soul of this pillar, which resides in its centre. In simple words, all decisions in the family are taken from the perspective of masculine mentality, irrespective of whether the decision is taken either by men or women. An implication of this masculine mentality is the practice of marriage, especially of girls, at a young age or girl child marriage. Girl child marriage is an age-old practice in India that has both social and religious sanction and that cuts across all sections of the Indian society. Although, efforts to prevent child marriage in general and girl child marriage in particular, in India date back to 1929 when the Child Marriage Restraint Act, popularly known as the Sharda Act was enacted in the country (Government of India, 1929). The 1929 Child Marriage Restraint Act which prohibited marriage of girls younger than 15 years of age and marriage of boys younger than 18 years of age was reformulated and enacted in 2006 as Prohibition of Child Marriages Act 2006 which prohibits marriage of girls younger than 18 years of age and marriage of boys younger than 21 years of age (Government of India, 2006). However, despite these legal provisions, all evidence suggests that girl child marriage remains a major social evil in India.

There are many reasons behind the persistence of marriage of children, especially girls, in India. It is well-known that girls, in the traditional Indian social system is generally considered as a burden on her parents and the family, and, therefore, the commonly prevailing attitude is to get the girl married as early as possible. An important consideration in this attitude is the dowry compulsion associated with the marriage of girls in India. The demand for a younger bride by the in-laws also creates an incentive for the parents and the families to marry the girl as earliest as possible. Child marriage is also an easy way out for parents who want their children to accept their choice of the partner (Government of India, 2008). Another compulsive factor in favour of marriage of girls during childhood is the protection of the girl from a range of hazards including sexual exploitation, especially when the parents, the family of the girl, the society, even the state, is unable to guarantee such protection. It has also been argued that marrying girls during their childhood protect them from unwanted male attention and promiscuity. Marriage of the girl before she attains puberty is also seen as the way to ensure the chastity and the virginity of the bride. Young brides are also get easily adjusted in the new family environment after marriage.

The United Nations defines a marriage before 18 years of age as a child marriage (Koski et al, 2017). This definition, however, is ambiguous, especially when marriage is a process comprising of different steps, in which situation it is difficult to decide which point in the process corresponds to the age at marriage. In the Indian social tradition, for example, the ritual of marriage is usually different from the ritual of the consummation of marriage and, before the ritual of the consummation of marriage, there is no cohabitation as the married girl goes to her in-laws only after the consummation of marriage. There is a generally a time gap between the ritual of marriage and the ritual of the consummation of marriage and the younger the age of the girl at the ritual of marriage the longer the period between the ritual of marriage and the ritual of the consummation of marriage. Factors that influence the time of the ritual of marriage are primarily economic, social, and cultural but not biological whereas factors that influence the time of the ritual of the consummation of marriage are primarily biological; the rural of the consummation of marriage takes place only when the girl has achieved a certain age. Since cohabitation does not start before the consummation of marriage, the age of the girl or the boy is hardly a consideration in the organizing the ritual of marriage whereas it is a primary consideration in the organisation of the ritual of the consummation of marriage. Deciding the age at marriage, therefore, is a complex issue.

During the fifth (2019-2021) round of the National Family Health Survey in India, all women aged 15-49 years were asked about their age at the first cohabitation. Cohabitation included living together after marriage and living with partner without marriage. Based on the response to this question, the proportion of women aged 20-24 years who reported that they first cohabited before reaching 18 years of age is calculated. This proportion has been taken as the prevalence of girl child marriage in the present analysis. The National Policy on Children also defines a person as child who has not yet completed 18 years of age (Government of India,) while the Prohibition of Child Marriage Act 2006 legally prohibits marriage of any female below 18 years of age and marriage of any male before 21 years of age. The Act, however, does not distinguish between the age of the girl or the boy at the time of the ritual of marriage and the time of the ritual of the consummation of marriage that is so common in the Indian social tradition and culture.

This paper has two objectives. The first objective is to analyse the variation and trend in the prevalence of girl child marriage in India across states and Union Territories of India and across districts of Madhya Pradesh, one of the states of India on the basis of the data available through the fourth (2015-2016) and fifth (2019-2021) rounds of the National Family Health Survey. The second objective of the paper, on the other hand, is to analyse the inter-district variation in the prevalence of child marriage and to identify district-specific factors that are responsible for inter-district variation in the prevalence of girl child marriage in Madhya Pradesh. The analysis is expected to help in formulating a district-based approach of ending the social evil of girl child marriage in the state. The available evidence suggests that the prevalence of the girl child marriage is quite pervasive in the state, although the prevalence has decreased over time.

Source of Data

The paper is based on the information about the age at first cohabitation collected from all women aged 15-49 years during the fourth (2015-2016) and the fifth (2019-2021) round of the National Family Health Survey. This information is available for all states and Union Territories of the country and for all districts of Madhya Pradesh as they existed at the time of the respective surveys. At the time of the fourth (2015-2016) round of the survey, there were 50 districts in the state but the number of districts in the state increased to 51 at the time of the fifth (2019-2021) round of the survey as the erstwhile district of Shajapur at the time of the fourth round of the Survey was divided into Agar Malwa and Shajapur districts at the time of the fifth round of the Survey. The National Family Health Survey Programme has been instituted by the Government of India, Ministry of Health, and Family Welfare in 1992 and is executed by the International Institute for Population Sciences, Mumbai to provide estimates of a range of population and health related indicators. The information available from the survey is based on the interaction with a statistically representative sample of households in each district covering both rural and urban areas. Technical details about the National Family Health Survey including the methodology adopted for the selection of the sample of the households for the survey are given elsewhere and not repeated here (Government of India, 2022). In each district, around 900-1100 households were selected in a statistically representative manner. The National Family Health Survey is currently the only source in India that provides the information related to the practice of child marriage at the district level.

Methods

The prevalence of girl child marriage is calculated as the proportion of women aged 20-24 years who were got married before reaching 18 years of age, the legal minimum age at marriage for females in the country. Estimates of the prevalence of the girl child marriage are available for all states and Union Territories of the country and for all districts based on the information collected at the fourth and the fifth round of the National Family Health Survey. We have used district level estimates of the prevalence of girl child marriage in Madhya Pradesh in the present analysis. The classification modelling approach (Han, Kamber, Pei, 2012; Tan, Steinbach, Kumar, 2006) has been used to group the districts by the prevalence of girl child marriage taking into consideration inter-district variation in factors that influence the prevalence of girl child marriage. Classification modelling involves classifying districts on the basis of a set of factors influencing the marriage of girls and then analysing the distribution of the prevalence of girl child marriage in different groups of districts so identified. The classification and regression tree (CRT) technique (Brieman, et al, 1984) has been applied for the purpose. The CRT is a nonparametric method that divides districts into mutually exclusive yet exhaustive groups in such a manner that group homogeneity with respect to the dependent variable is the maximum. The technique sorts districts into mutually exclusive yet exhaustive groups based on the independent variable that causes the most effective split. The process is repeated till either the perfect similarity is achieved or the stopping criterion is met (Ambalavanan et al, 2006; Lemon et al, 2003). A group in which all districts have the same value of the of the classification or dependent variable is termed as "pure." If a group is not "pure," then the impurity within the group can be measured. We have used the Gini coefficient of impurity in the present analysis. If the dependent variable is a categorical one, then the method provides the distribution of the dependent variable across districts in each group. If the dependent variable is continuous, then the method gives estimates of the arithmetic mean and standard deviation of the dependent variable in each group of districts.

We have taken into consideration seven factors that inter-district variation in which may have bearings on inter-district variation in the prevalence of girl child marriage. The first factor that we have considered is the degree of urbanisation or the proportion of the urban population to the population of the district following the definition of the urban area adopted at the 2011 population census. It is well-known that the practice of girl child marriage is different in the rural areas as compared to the urban areas because of a number of reasons so that the rural-urban composition of the population of the district is argued to have a strong bearing on the prevalence of girl child marriage in the district. At the nation al level, the prevalence of the prevalence of girl child marriage is found to be higher in the rural areas as compared to that in the urban areas because of many social, economic and cultural factors which suggests that the prevalence of girl child marriage should be lower in those districts of the state where the proportion of the urban population is high as compared to districts where the proportion of the urban population is low.

The second factor that we have considered in the present analysis is the income per capita of the district measured in terms of the gross domestic output per capita. Income per capita is an indicator of the standard of living of the people, the higher the income per capita the higher the standard of living. It has been found that the income per capita varies widely across the districts of the state. It is argued that the prevalence of child marriage is high in the poor population as compared to the prevalence in the rich or the affluent population. This means that the prevalence of the girl child marriage should be high in districts where the income per capita is low as compared to districts where the income per capita is high.

The third factor that has been assumed to have an impact on the prevalence of girl child marriage is the male-female balance in the population or the sex ratio of the population measured in terms of the number of females for every 1000 males. The male-female balance in the population has implications for the marriage market for girls which has an impact on the age at marriage, especially of females. In India, the marriage market is narrow because of many considerations so that, it is conjectured that the inter-district variation in the male-female balance in the population, measured in terms of the number of females for every 1000 males has an impact on the inter-district variation in the prevalence of girl child marriage.

The next two factors that we have considered in the present analysis are related to the social class composition of the population measured in terms of the proportion of Scheduled Castes and the proportion of Scheduled Tribes in the district. It is well-known that the cultural and social norms, traditions, and practices related to marriage are different in different social classes and these differences have persisted over time. As such, it is conjectured that inter-district variation in the proportion of the Scheduled Castes population and inter-district variation in the proportion of the Scheduled Castes population has implications for the inter-district variation in the prevalence of girl child marriage.

The last two factors that we have considered in the present analysis are related to the characteristics of the women – the highest level of education attained by the women and her fertility. The relationship of education and age at marriage is well-known. The higher the level of education of females the higher the female age at marriage. As such, we argue that the higher the proportion of women aged 20-24 years with at least 10 years of schooling in the district the lower the prevalence of girl child marriage in the district.

Finally, the level of fertility in the district has been measured in terms of the proportion of third and higher order births in the district during the five years preceding the survey, the higher this proportion the higher the fertility in the district. It is well-known that the level of fertility and the female age at marriage are closely related so that inter-district variation in the proportion of third and higher order births are assumed to be related with the inter-district variation in the prevalence of the girl child marriage.

Girl Child Marriage in India

The evidence available from the National Family Health Survey suggests that the prevalence of girl child marriage in India remains quite pervasive and is a cause of concern from both population and development perspectives. According to the latest (2019-2021) round of the National Family Health Survey, more than 23 per cent of women aged 20-24 years reported that they were got married before reaching 18 years of age, the legal minimum age of marriage for females in India. This proportion has, however, decreased from almost 27 per cent in 2015-2016 (Government of India, 2022). Among different states and Union Territories of the country, the prevalence of girl child marriage varies from more than 41 per cent in West Bengal to just around 1 per cent in Lakshadweep. In addition to West Bengal, there are two states/Union Territories – Bihar and Tripura – where the prevalence of girl child marriage is at least 40 per cent. On the other hand, the prevalence of girl child marriage is found to be less than 10 per cent in 12 states and Union Territories of the country (Figure 1).

The evidence available from the National Family Health Survey also suggest that the prevalence of girl child marriage has not decreased in all states and Union Territories of the country during 2015-2021. There are five states and Union Territories - Goa, Punjab, Chandigarh, National Capital Territory of Delhi, and Manipur – where the prevalence of girl child marriage has increased during 2015-2021 as revealed through the fourth and the fifth round of the National Family Health Survey. If the evidence available from the National Family Health Survey is any indication, then ending child marriage, especially, girl child marriage, remains an elusive dream in India. At the age when a child should hold a pen or a pencil or should go to school for its cognitive development, a substantial proportion of children, especially girls, in India, are engrossed in the worries of fulfilling the responsibilities of the family and face the brunt of becoming pregnant and mother at a tender age.

Madhya Pradesh ranks 8 amongst the 36 states and Union Territories of the country in terms of the prevalence of girl child marriage. The good sign, however, is that the prevalence of girl child marriage has decreased quite rapidly in the state during the period 2015-2021. During 2015-2016, more than 35 per cent of women aged 20-24 years in the state reported that they were married before reaching 18 years of age. This proportion has decreased to 23 per cent during 2019-2021. Within Madhya Pradesh, this proportion varies widely across its constituent districts. The National Family Health Survey 2019-2021 indicates that, within Madhya Pradesh, the proportion of women aged 20-24 years who were married before reaching 18 years of age varies from 46 per cent in district Rajgarh to less than 5 per cent in district Balaghat. District Rajgarh is the only district where the proportion of women aged 20-24 years who were married before reaching 18 years of age is more than 40 per cent whereas there are only two districts – Balaghat and Jabalpur – where this proportion is less than 10 per cent. In 10 districts of the state, the prevalence of girl child marriage appears to be very high as 30-40 per cent women aged 20-24 years in these districts reported that they were married before reaching 18 years of age (Figure 2).

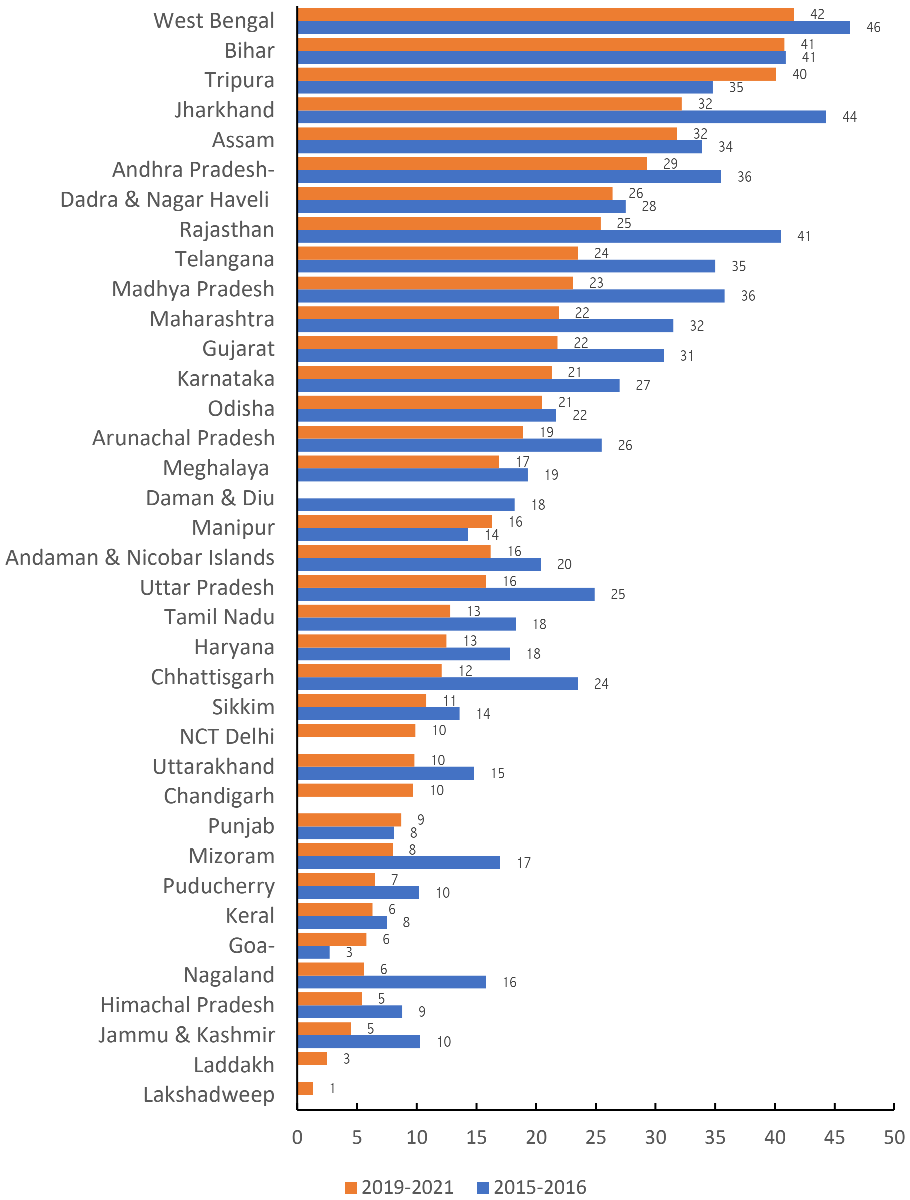

Figure 1: Prevalence of child marriage in states and Union Territories of India.
Source: Author

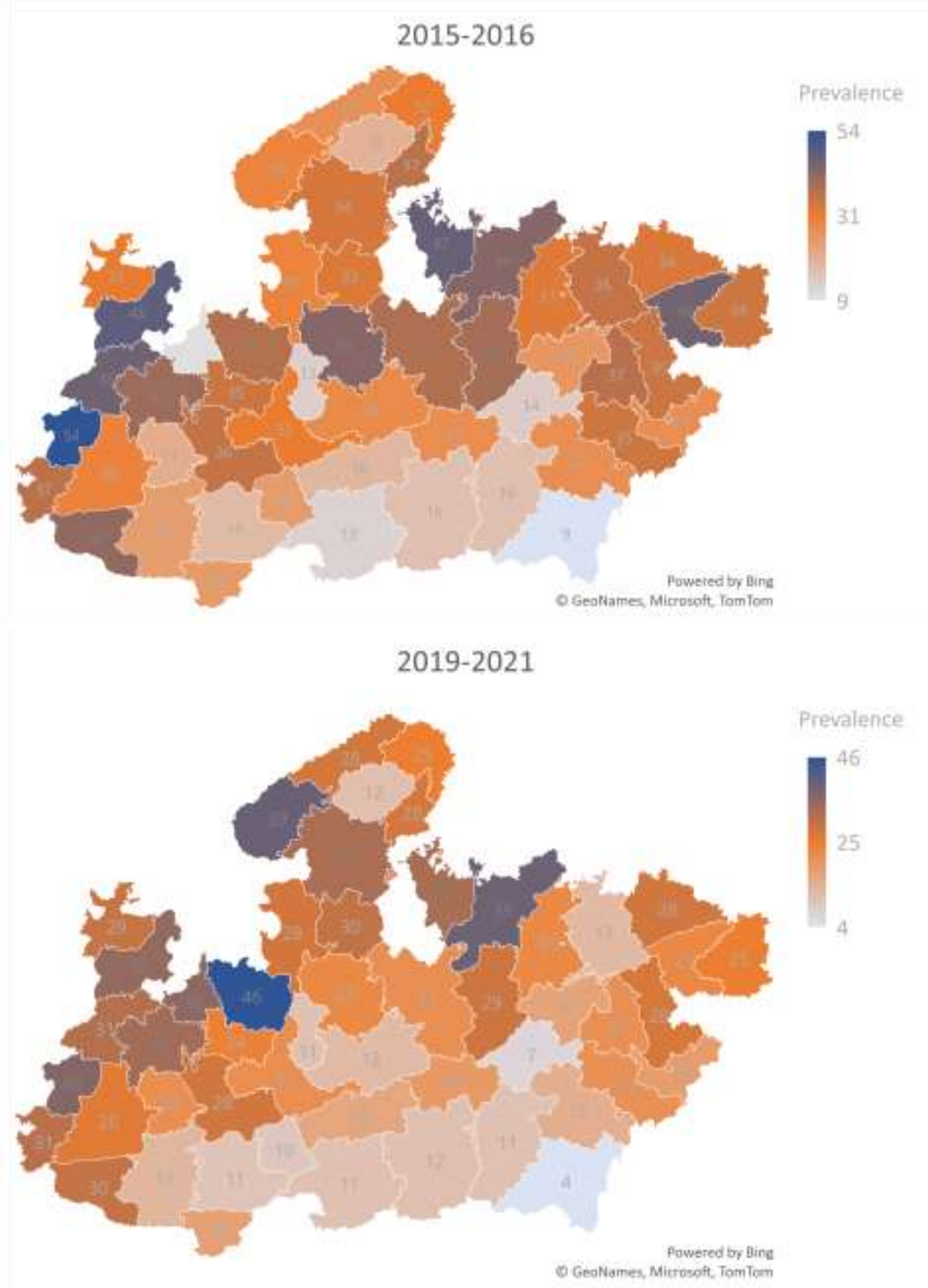

Figure 2: Inter-district variation in the prevalence of child marriage in Madhya Pradesh.
Source: Author

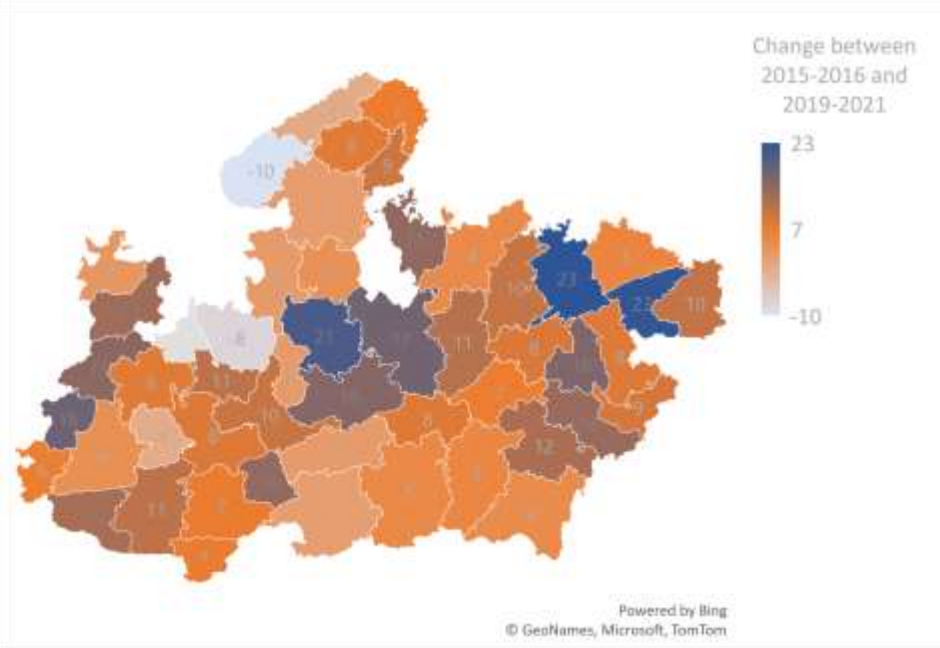

Figure 3: Change in the prevalence of girl child marriage in districts of Madhya Pradesh between 2015-2016 and 2019-2021.
Source: Author

The trend in the prevalence of girl child marriage also varies across the districts of Madhya Pradesh. The decrease in the prevalence of girl child marriage has been the most marked in district Satna where the prevalence of girl child marriage decreased from 36 per cent to 13 per cent between 2015-2016 and 2019-2021 according to the National Family Health Survey. In Sidhi and Vidisha districts also, the prevalence of girl child marriage decreased by more than 20 per cent between 2015-2016 and 2019-2021. On the other hand, there are four districts – Indore, Morena, Rajgarh, and Sheopur – where the prevalence of girl child marriage appears to have increased between 2015-2016 and 2019-2021 and the increase in the prevalence has been quite sharp in Rajgarh and Sheopur districts (Figure 3). At the same time, there has been virtually no change in the prevalence of girl child marriage in Betul, Bhopal, Guna, Hoshangabad, Neemuch and Shivpuri districts. The inter-district variation in both the level and the trend in the girl child marriage suggests that the change in the prevalence of girl child marriage is influenced by district-specific factors but very little is currently known about these factors. It is obvious from the information available through the National Family Health Survey that there is no common prescription for ending girl child marriage in the state. Rather, a decentralised district-based approach must be institutionalised as the first step towards ending the practice of girl child marriage in the state. This approach must give due consideration to district-specific factors that influence the prevalence of girl child marriage in the district.

The relationship between the inter-district variation in the prevalence of girl child marriage and inter-district variation in the seven factors or variables that have an influence on the prevalence of the girl child marriage is depicted in figures 4 through 10. These figures reveal how inter-district variation in different independent variables is related to the inter-district variation in the prevalence of child marriage. It is evident from these figures that the higher the degree of urbanisation in the district the lower the prevalence of girl child marriage. On the other hand, inter-district variation in the proportion of Scheduled Tribes population does not appear to have any impact on the inter-district variation in the prevalence of girl child marriage. However, inter-district variation in the proportion of Scheduled Castes population has an impact on the prevalence of girl child marriage and the higher the proportion of the Scheduled Castes population the higher the prevalence of girl child marriage. Similarly, the higher the per capita income and the higher the population sex ratio measured in terms of females per 1000 males the lower the prevalence of girl child marriage in the district. It is also clear from these figures that inter-district variation in the proportion of females having at least 10 years of schooling is strongly related to the inter-district variation in the prevalence of girl child marriage and the higher the proportion of women with at least 10 years of schooling the lower the prevalence of the girl child marriage. Similarly, the inter-district variation in the proportion of third and higher order births is also related to the inter-district variation in the prevalence of girl child marriage and the higher the level of fertility the higher prevalence of the girl child marriage.

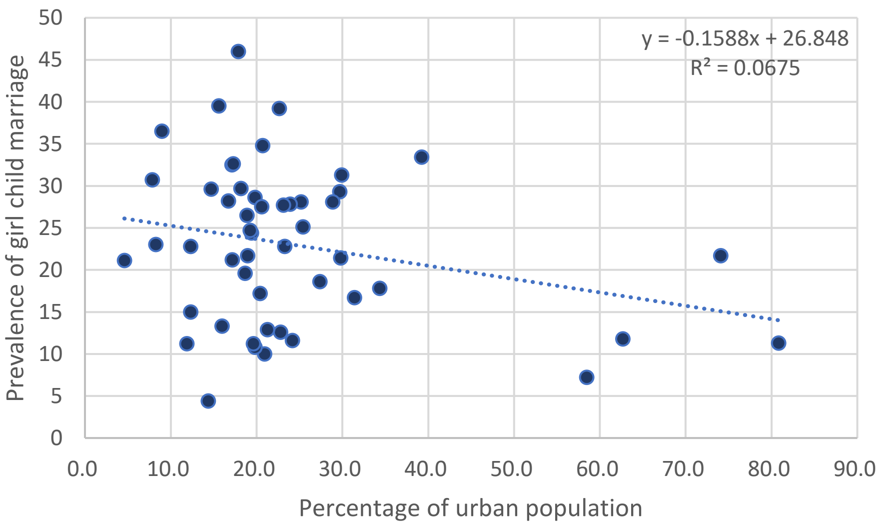

Figure 4: Prevalence of girl child marriage and degree of urbanisation in the district.
Source: Author

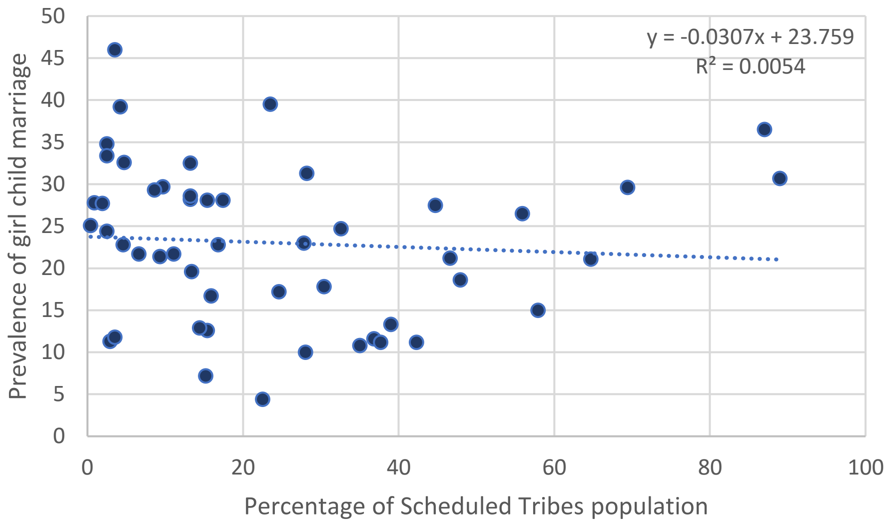

Figure 5: Prevalence of girl child marriage and Scheduled Tribes population.
Source: Author

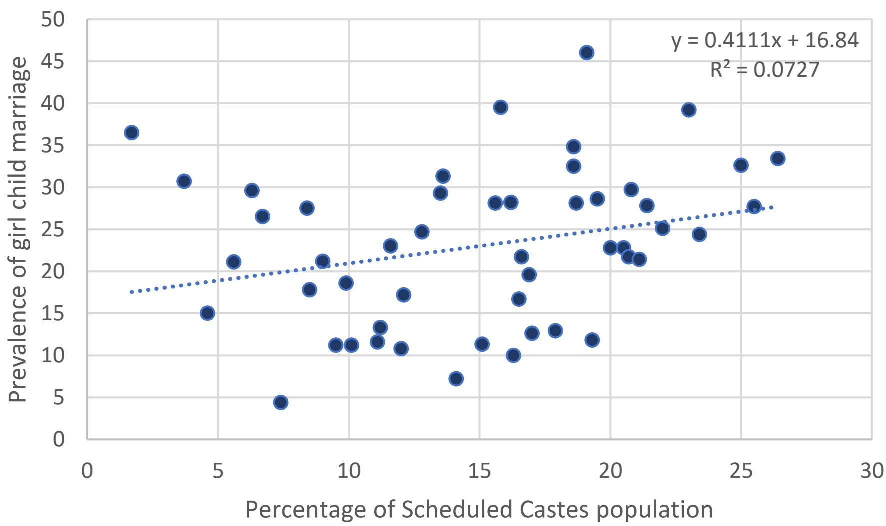

Figure 6: Prevalence of girl child marriage and Scheduled Castes population.
Source: Author

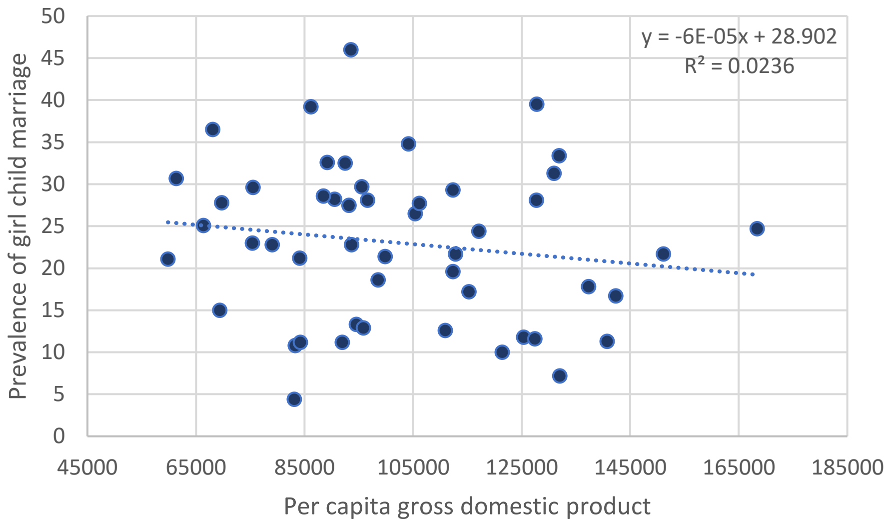

Figure 7: Prevalence of girl child marriage and per capita income.
Source: Author

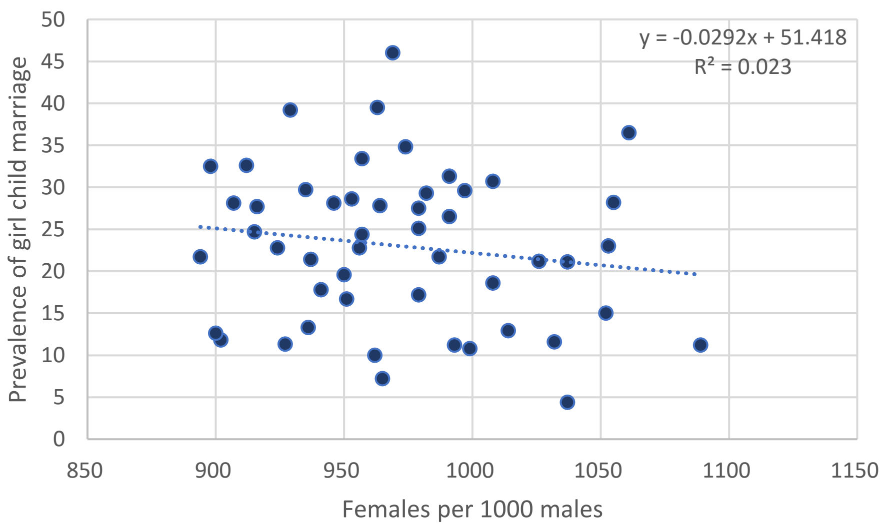

Figure 8: Prevalence of girl child marriage and population sex ratio.
Source: Author

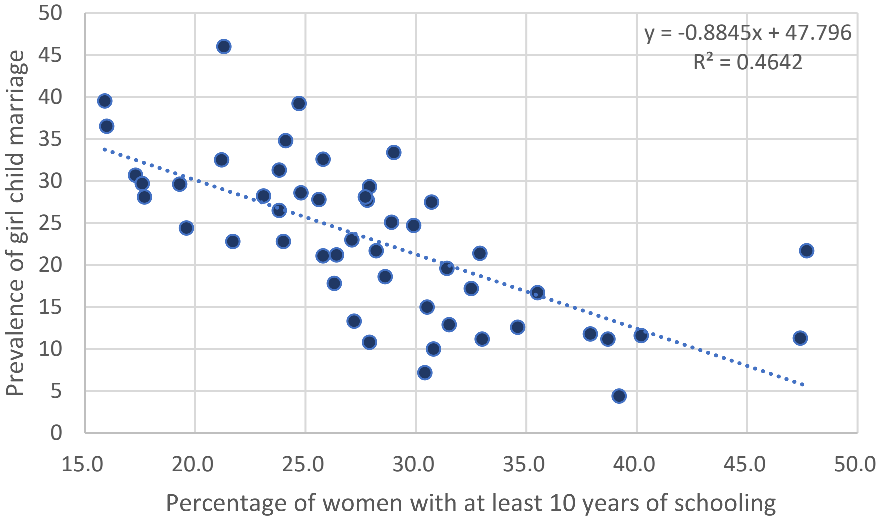

Figure 9: Prevalence of girl child marriage and education of women.
Source: Author

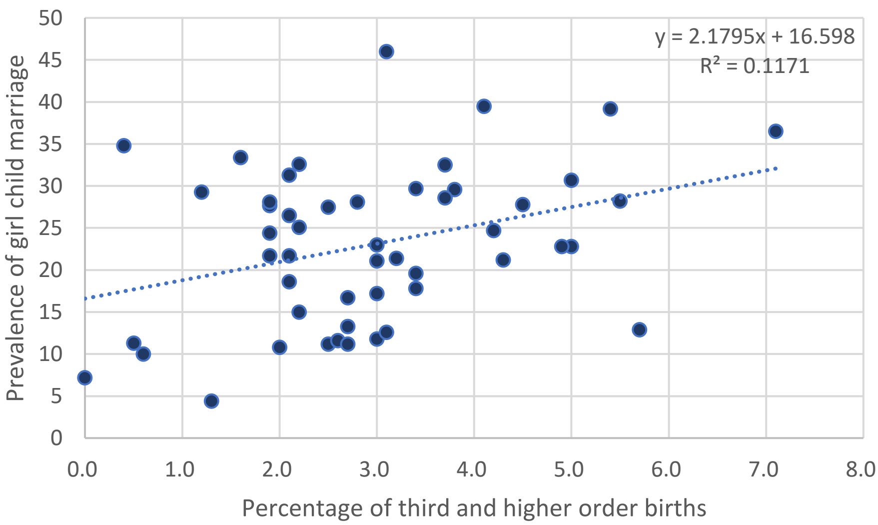

Figure 10: Prevalence of girl child marriage and fertility.
Source: Author

Classification of Districts

Results of the classification modelling exercise are presented in table 1. The exercise suggests that the districts of the state can be classified into seven groups and the average prevalence of girl child marriage in the seven groups is different. The largest group comprises of 11 districts. The unweighted average prevalence of girl child marriage in this group of districts is estimated to be 33.06±5.80 which is the highest amongst the seven groups identified in the present analysis. This group of districts is characterised by very low level of education of women and very low proportion of the Scheduled Tribes population in the district. On the other hand, smallest group comprises of 4 districts and the unweighted average prevalence of girl child marriage in this group is estimated to be 8.23±3.07 which is the lowest amongst the seven groups of districts. This group of districts is characterised by high level of education of women and low level of fertility as is reflected through the proportion of third and higher order births.

Table 1 shows how inter-district variation in for variables – level of education of women, proportion of Scheduled Tribes population, level of fertility and sex ratio of the population – influences inter-district variation in the prevalence of girl child marriage. For example, there are 13 districts where both level of education of women and proportion of third and higher order births is high. In 8 of these 13 districts, there are less than or equal to 990 females for every 1000 males whereas in 5 districts, there are more than 990 females for every 1000 males. This difference in the sex ratio has a telling impact on the prevalence of girl child marriage in the two groups of districts as may be seen from the table. Similarly, in districts where around 26 per cent of women have at least 10 years of schooling, there is marked difference in the prevalence of girl child marriage in those districts where the proportion of Scheduled Tribes population is less than or equal to around 12 per cent as compared to those districts where the proportion of the Scheduled Tribes population is more than 12 per cent. The same is true for those districts where less than 25 per cent of women have at least 10 years of schooling.

The classification modelling exercise also suggests that the inter-district variation in the proportion of women having at least 10 years of schooling is the most important in deciding the inter-district variation in the prevalence of girl child marriage followed by the inter-district variation in the proportion of the Scheduled Tribes population, the inter-district variation in the proportion of third and higher order births. On the other hand, inter-district variation in the population sex ratio is important in characterising the inter-district variation in the prevalence of girl child marriage in only those districts where the level of fertility is high. By contrast, inter-district variation in per capita income, inter-district variation in the proportion of the urban population, and inter-district variation in the proportion of the Scheduled Castes population has not been found to have a substantial influence on the inter-district variation in the prevalence of girl child marriage.

Table 1: Results of the modelling exercise.

Node	Education	Fertility	Scheduled Tribes	Sex ratio	Prevalence of girl child marriage (Per cent)		N	
	Women aged 20-24 years having at least 10 years of schooling (Per cent)	Proportion of 3^{rd} and higher order births (Per cent)	Proportion of Scheduled Tribes population (Per cent)	Females per 1000 males	Mean	SD		
0	All	All	All	All	23.0140	9.28681	50	
1	<= 30.15	All	All	All	27.4970	7.37337	33	
2	> 30.15	All	All	All	14.3118	5.78618	17	
3	<= 25.70	All	All	All	31.0556	6.16319	18	
4	> 25.70 <= 30.15	All	All	All	23.2267	6.50554	15	
5	> 30.15	<= 1.60	All	All	8.2250	3.07069	4	Terminal node
6	> 30.15	> 1.60	All	All	16.1846	5.11205	13	
7	<= 25.70	All	<=19.30	All	33.0636	5.79643	11	Terminal node
8	<= 25.70	All	> 19.30	All	27.9000	5.71110	7	Terminal node
9	> 25.70	All	<= 12.40	All	17.9714	4.45672	7	Terminal node
10	➢ 25.70	All	> 12.40	All	27.8250	3.97950	8	Terminal node
11	> 30.15	> 1.60	All	<= 990	18.5625	5.14724	8	Terminal node
12	> 30.15	> 1.60	All	> 990	12.3800	1.62234	5	Terminal node

Source: Author

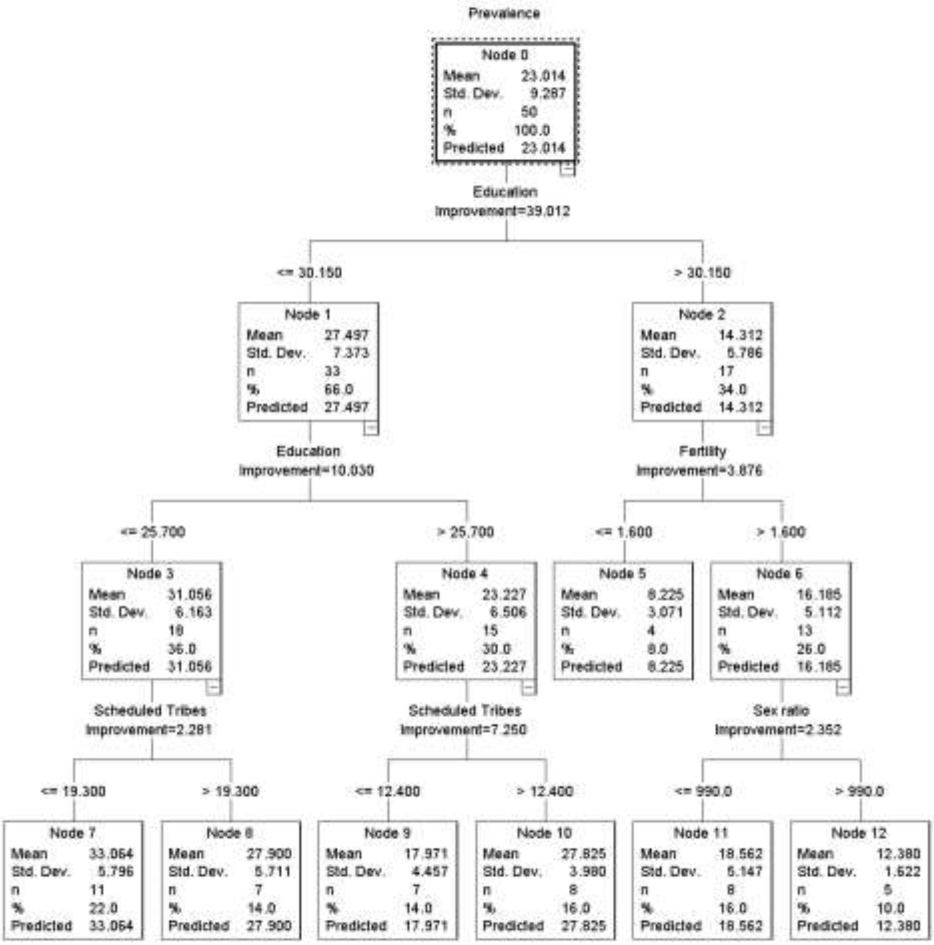

Figure 11: The classification of districts by the prevalence of girl child marriage.
Source: Author

Figure 11 shows the classification tree that depicts how districts of the state are grouped in terms of the prevailing level of the education of women, fertility, share of the Scheduled Tribes population and the population sex ratio in the context of the prevalence of girl child marriage. The distribution of the 7 groups of districts or Terminal Nodes identified through the classification modelling exercise is shown in figure 12. It is clear from the figure that, except for the districts included in Node 5, majority of the districts of other Nodes or groups are geographically clustered with only a few exceptions.

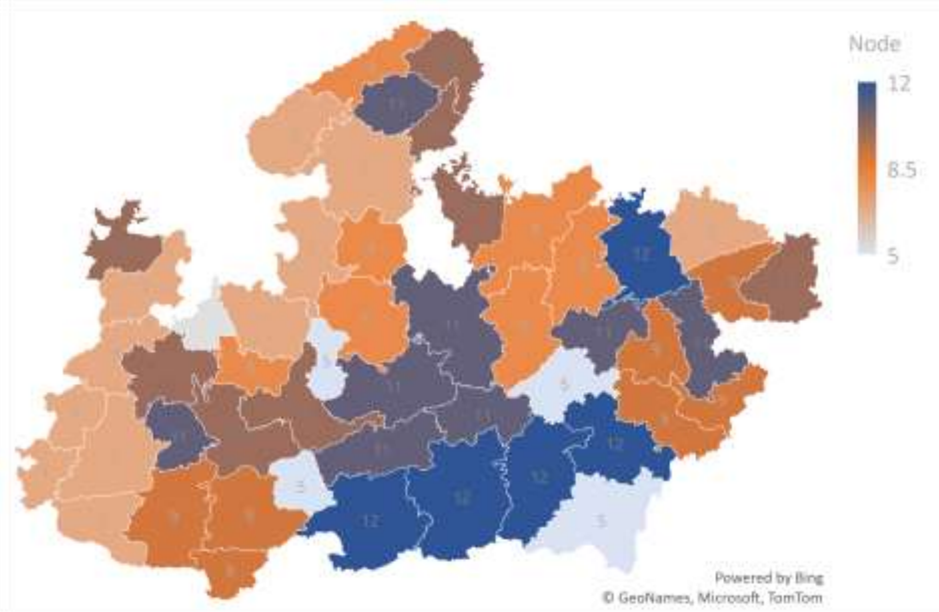

Figure 12: Groups of districts identified through the classification modelling exercise.
Source: Author

Discussion and Conclusions

Madhya Pradesh is one of those states of India where the prevalence of girl child marriage remains unacceptably high, and this prevalence varies widely across the districts of the state. In district Rajgarh of the state, the prevalence of girl child marriage is exceptionally high whereas in district Balaghat, it is exceptionally low. The paper reveals that the most important factor in explaining the inter-district variation in the prevalence of girl child marriage is the inter-district variation in the education of women as measured in terms of women aged 20-24 years having at least 10 years of schooling followed by inter-district variation in the level of fertility as measured in terms of the proportion of third and higher order births during five years prior to the survey. On the other hand, inter-district variation in the degree of urbanisation in the measured in terms of the proportion of urban population to the total population and inter-district variation in the income per capita measured in terms of the gross domestic product per capita have not been found to be very relevant as far as the inter-district variation in the prevalence of girl child marriage in the state is concerned.

The analysis presented here suggests that legal provisions to end child marriage, especially of girls may not be effective in the absence of other development efforts in ending the social evil of child marriage. Any strategy towards ending child marriage, especially girl child marriage must focus on universalising women education and in regulating fertility. All the four districts where the prevalence of girl child marriage is found to be less than 10 per cent are those districts where the proportion of women having at least 10 years of schooling is high and the proportion of third and higher order births low. The analysis also reveals that inter-district variation in the prevalence of girl child marriage is also influenced by the inter-district variation in the social class composition of the population measured in terms of the proportion of the Scheduled Tribes population. The analysis suggests that a decentralised district-based approach should be adopted for ending girl child marriages in Madhya Pradesh. There is a need of identifying district-specific factors that have strong bearings on the prevalence of girl child marriage. Identifying and addressing these factors is important in preventing child marriages.

Ending child marriages, especially of girls, is a priority from both demographic and development perspectives. Girls married during their childhood face many social, health and economic disadvantages. Although, the available data do not conclude that marriage during childhood causes these adverse outcomes, yet the association between marriage during childhood, poverty and low educational attainment is well established (Miller and Lester, 2003). Girls married during childhood have been found to show symptoms of sexual abuse and post-traumatic stress such as hopelessness, helplessness, and severe depression (Lal, 2015). Marriage during childhood reduces the likelihood of girls completing secondary school by 4 to 6 per cent and, associated with school dropout, it reduces the lifetime earning potential of a girl by 9 per cent. Marriage during childhood reduces the ability of girls to access economic resources and perpetuates their oppression. They have less decision-making and bargaining power in the family and face a higher risk of domestic and intimate partner violence. Marriage during childhood is commonly associated with child birth at an early age, which leads to high maternal mortality (Das, 2018).

Given the implications of child marriage to both demography and development, ending child marriage, especially of girls, must be a priority development agenda and a development-based strategy should be adopted to end child marriage rather than forced implementation of legal provisions. Given the very strong inter-district variation in the prevalence of girl child marriage, this strategy must follow a decentralised district-based approach that considers the local level factors of girl child marriage.

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Table 2: Inter-district variation in the proportion (per cent) of women aged 20-24 years who reported that they were married before reaching 18 years of age.

District	Women aged 20-24 years who were married before reaching 18 years of age (Per cent)		Change
	2015-2016	2019-2021	
Agar Malwa	na	35.6	na
Alirajpur	37.1	30.7	-6.4
Anuppur	27.3	18.6	-8.7
Ashoknagar	33.2	29.7	-3.5
Balaghat	8.6	4.4	-4.2
Barwani	42.2	29.6	-12.6
Betul	12.5	11.2	-1.3
Bhind	31.7	25.1	-6.6
Bhopal	13.1	11.3	-1.8
Burhanpur	24.7	17.8	-6.9
Chhatarpur	43.5	39.2	-4.4
Chhindwara	16.3	11.6	-4.7
Damoh	39.9	28.6	-11.3
Datia	37.1	27.7	-9.4
Dewas	36.1	28.1	-8.0
Dhar	30.1	26.5	-3.6
Dindori	34.9	21.1	-13.8
Guna	29.8	28.1	-1.7
Gwalior	19.4	11.8	-7.6
Harda	24.3	10.0	-14.3
Hoshangabad	18.4	16.7	-1.7
Indore	20.7	21.7	1.0
Jabalpur	13.9	7.2	-6.7
Jhabua	54.0	36.5	-17.5
Katni	25.5	17.2	-8.3
Khandwa (East Nimar)	17.6	10.8	-6.8
Khargone (West Nimar)	24.0	13.3	-10.7
Mandla	27.3	15.0	-12.3
Mandsaur	48.2	34.8	-13.4
Morena	27.0	27.8	0.8
Narsimhapur	27.4	19.6	-7.8
Neemuch	31.8	29.3	-2.5
Panna	32.9	22.8	-10.1
Raisen	28.1	12.6	-15.5
Rajgarh	38.2	46.0	7.8
Ratlam	46.2	31.3	-14.9
Rewa	33.6	28.2	-5.4

District	Women aged 20-24 years who were married before reaching 18 years of age (Per cent)		Change
	2015-2016	2019-2021	
Sagar	38.6	21.4	-17.2
Satna	36.1	12.9	-23.2
Sehore	31.5	21.7	-9.8
Seoni	16.3	11.2	-5.1
Shahdol	35.4	27.5	-7.9
Shajapur	35.2	24.4	-10.8
Sheopur	29.6	39.5	9.9
Shivpuri	34.0	32.5	-1.5
Sidhi	45.7	23.0	-22.7
Singrauli	34.9	24.7	-10.2
Tikamgarh	47.2	32.6	-14.6
Ujjain	41.0	33.4	-7.7
Umaria	37.3	21.2	-16.1
Vidisha	43.5	22.8	-20.7

Source: Government of India (2022)

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Population Effects on Biodiversity and Climate Change: Evidence from Recent Scientific Literature, 2010-2022

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Abstract

A search of the recent scientific literature on the impact of human population growth and population density on biodiversity resulted in 131 substantial papers and books published during 2010-2022. A review of this literature found that, in general, population growth and high population density are important drivers of deforestation, defaunation, and biodiversity loss. Increasing human numbers undermine the creation and effectiveness of protected areas and lead to conversion of essential wildlife habitat for agricultural production and other human uses that displace other species. Conversely, local human population decline sometimes provides opportunities for ecological restoration and improves chances of successfully restoring extirpated species. These findings appear to hold at most scales, from local to global, and for most taxa studied. Since large human populations cause biodiversity loss while small populations foster biodiversity protection, future human numbers will play an important role in enabling or preventing a sixth mass extinction of species on the planet Earth.

Introduction

There is a consensus among scientists that biodiversity is rapidly declining. In the last 50 years, wild vertebrate populations decreased by 69 per cent globally (World Wildlife Fund, 2022). Anthropogenic extinction levels are an estimated 1,000 times higher than the historical background rate and predicted to continue climbing (Pimm et al, 2014). The Secretariat of the United Nations Convention on Biological Diversity (2010) has estimated that humanity could extinguish one out of every three species on Earth within the next one to two hundred years. Even using conservative estimates for current extinction rates, and holding these rates steady, projecting them forward a few hundred years predicts immense losses (Ceballos et al, 2015).

The cause of global biodiversity loss is clear. Other species are being displaced by a rapidly growing human economy, driven, in part, by growing human numbers (Diaz et al, 2019). The Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES) has observed in its first global assessment: "today, humans extract more from the Earth and produce more waste than ever before" (IPBES, 2019). During 1970-2020, when wild vertebrate populations declined by 69 per cent, human numbers doubled, the size of the global economy quadrupled, and international trade increased tenfold. The wildlife decline has been caused by human expansion. People took habitat and resources away from other species, displacing them, because there were a lot more of us and because our economy became more successful at transforming the wild world into resources for human profit and use.

It is standard in the conservation biology literature to explain causes of biodiversity loss in terms of five main direct drivers, the most important of which are habitat loss and overexploitation of wildlife, followed by pollution, invasive species, and climate change. All these direct drivers do enormous harm to other species on the land and in the oceans. These direct drivers are "underpinned by a set of demographic and economic indirect drivers that have increased, and that furthermore interact in complex ways" (IPBES, 2019). The term "indirect driver" is misleading - fundamental causes would be more accurate - yet the message is clear enough: "anthropogenic drivers of biodiversity loss, including habitat loss as a result of land-use and sea-use change, unsustainable agriculture, aquaculture and forestry, unsustainable fishing, pollution, and invasive alien species are [all] increasing globally" (IPBES, 2019). They are increasing due to escalating human numbers, wealth, and overall economic activity.

The IPBES has called for more research into the fundamental drivers of biodiversity loss (and, more tentatively, for public policies that directly address them). In response, the authors have recently published a paper exploring the roles that population growth and high population density play in biodiversity loss (Cafaro et al, 2022). In researching that paper, we became aware of many good recently published scientific studies. In this paper, we review this material, and present main findings in an effort to spur more work and debate on these essential topics.

The paper is organised as follows. The next section describes the methods that we adopted to search the published literature on aspects of population effects on biodiversity and climate change. This search resulted in 154 research papers and books. The third section of the paper presents main findings of this literature that highlight population effects on biodiversity. These population effects on biodiversity have been further classified in terms of ecological restoration, deforestation, protected areas, agriculture and defaunation. We also present main findings of selected literature on population impacts on climate change and biodiversity ethics. The last section of the paper puts forward a set of recommendations for securing and sustaining biodiversity on the planet. The regional perspective of the population effects on biodiversity, as revealed through the published literature reviewed by us, is presented in the table appended to the paper.

Methods

We searched the published titles and abstracts in the Web of Science that included the words 'biodiversity' and 'population' during the thirteen years between 2010 and 2022 inclusive. We then read this literature and listed those studies that have dealt in a substantive way with the connections between human numbers and biodiversity loss or protection. To be included in the review, papers needed to go beyond just reporting human population trends or mentioning them as impacting biodiversity. All papers included in the review grapple with population impacts quantitatively or report them as an important part of their results. Our aim was comprehensive coverage of peer-reviewed scientific papers that deal substantively with the connection between human numbers and biodiversity. In addition, we have also included 21 select publications from the previous decade (2000-2009) which seemed particularly relevant or influential. Finally, we queried first authors of these studies regarding any papers that we might have missed and took the opportunity afforded by the revision to add several more studies published since our initial review.

We have also searched and reviewed selected published literature on the connection between human population and climate change and on the ethics of biodiversity. We found that the recent literature on both topics is large and the selected published studies reviewed in the paper only provide an introduction. Nevertheless, we have included them in this paper as they deal with important adjacent and relevant topics of interest.

Results

Population Effects on Biodiversity

We have identified 154 studies providing significant analyses of the impact of human numbers on biodiversity (Table 1). We have grouped them into eight thematic areas. We list each study only once, despite some overlap in topics they cover. These studies have also been classified by geographical areas in an appendix to the paper.

The six key findings that we have been able to make in our review of 154 studies are as follows:

1. Much recent work has been done on population and biodiversity, spanning all parts of the globe, and examining the impact of population from many perspectives. While a few conservation biologists have called for such efforts in the past (Noss et al, 2012; Rust and Kehoe, 2017), it appears that their colleagues are finally taking up this suggestion. Although there remains ideological resistance to writing about population matters (see for example Hughes et al, 2023), the obvious, ongoing failure of conservation efforts that ignore the fundamental drivers of biodiversity loss seems to have tipped the scales. Just as biologists are coming to recognise continued economic growth

is incompatible with biodiversity conservation (Pacheco et al, 2016; Dasgupta, 2021), they now are documenting the ways through which excessively large populations harm biodiversity (Kraussman et al, 2013; Rees, 2023).

2. Population growth and high population densities are important drivers of deforestation, defaunation, and general biodiversity loss. It is striking that studies exploring the importance of population growth as a driver of biodiversity loss, and the importance of high population density as an impediment to conservation success, nearly always find their effects compelling. Many studies find population impacts as dominant in determining conservation success (McKee et al, 2013; Whitmee et al, 2015), particularly when paired with per capita resource consumption (Driscoll et al, 2018; Marques et al, 2019) or the proportion of the landscape in protected areas (Brashares et al, 2002; Krishnadas et al, 2018). The rest reliably find an important effect of human population, whether focused on preserving birds (Deinet et al, 2013; Gagné et al, 2016), mammals (Ripple et al, 2015; Berger et al, 2020), fish (Vincent, 2008; Lavides et al, 2020), insects (Sánchez-Bayoa and Wyckhuysb, 2019; Raven and Wagner, 2021), or plants (Thompson and Jones, 1999).

3. Smaller human numbers and lower human population densities increase chances to establish protected areas (PAs) and increase the effectiveness of PAs in preserving biodiversity. There are many reasons for this. More people make it harder to establish protected areas (Corlett, 2016; Crist et al, 2021). They also increase poaching in and near PAs (Qiu et al, 2018); decrease support for existing PAs (Guerbois et al, 2013; Symes et al, 2016); undermine connectivity between PAs (Wade and Theobald, 2010; Radeloff et al, 2015); and increase harvesting of essential resources in PAs (Shahabuddin and Rao, 2010; Figueroa, 2015). Increasing the size, number and effectiveness of PAs is necessary for preserving the remaining biodiversity on the planet. The biodiversity benefits of smaller human populations are, therefore, clear.

4. Decreasing human populations foster success in ecological restoration as they open up new areas as candidates for restoration (Dinerstein et al, 2017; Cafaro and Götmark, 2019) and make such efforts more likely to succeed (Navarro and Pereira, 2015; Pereira and Navarro, 2015). The decreasing extractive economic opportunities associated with depopulation may increase willingness among local residents to try new approaches to living with wildlife (Schnitzler, 2014; Rewilding Europe, 2021).

5. Larger populations increase agriculture demand and hence lead to the conversion of forests, wetlands, and other biodiverse ecosystems for agricultural use. In this way, population growth fuels a leading cause of biodiversity loss through agricultural (and aquacultural) conversion (Laurance

et al, 2014; Crist et al, 2017; D'Odorico et al, 2018). Similarly, population growth increases urban development, which is another important cause of habitat loss and habitat degradation leading to significant biodiversity loss (Hughes, 2017; Kolankiewicz et al, 2022).

6. Since large human populations cause biodiversity loss while small populations foster biodiversity protection, future human numbers will play an important role in building our capacity to preserve biodiversity going forward (Wilson, 2016; Crist et al, 2022). This is true at all scales, from the local (Parks and Harcourt, 2002; Robson and Rakotozafy, 2015) to the global (Molotoks et al, 2018; Pyšek et al, 2020). Studies from many parts of the world suggest this for particular taxa and for preserving biodiversity in general (Appendix Table). The present review suggests that growing numbers of conservation biologists are making this connection explicit (Chapron et al, 2019; Albert et al, 2021) and are willing to advocate policies to curb or reduce human numbers (Lopez-Carr and Ervin, 2017; Yi and Borzée, 2021).

To summarise, the published literature on population effects on biodiversity and climate change, reviewed in this paper, suggests that continued human population growth and high population densities are major causes of biodiversity loss, and, therefore, smaller human populations are necessary to preserve the biodiversity that is left on the planet.

Table 1 presents detailed results of the published literature on population effects on biodiversity that we have reviewed. The 154 studies identified in our literature search and reviewed here are grouped into eight categories of population effects on biodiversity: 1) human population and ecological restoration; 2) human population and deforestation; 3) human population and protected areas; 4) warnings and policy recommendations regarding population effects on biodiversity; 5) human population, agriculture, and biodiversity; 6) human population and biodiversity in large, multi-author syntheses; 7) human population and defaunation; and 8) human population and general biodiversity loss. This classification has been done to make the literature review thematic and, therefore, more appealing, and useful to the reader. It may, however, be noted that many studies included in this review cover more than one of the eight thematic areas described above. To avoid repetition, we have classified each study in only one of the eight categories based on the substantive findings of the study. The table presents name of author(s), year of publication and the title of the study. The key population-relevant findings of each study are summarised in one sentence that describes the main thematic area and the context in which the study has been carried out. This one sentence approach of literature review has been purposely adopted to keep the review findings short and simple. The studies reviewed here have also been presented in the Appendix Table by geographical areas, once again listing each study only once, so as to provide the regional context of population effects on biodiversity.

Table 1: Population effects on biodiversity. Review of published literature.

	Author(s) and title	Main findings
		Human population and ecological restoration
1.	Cafaro and Götmark, 2019. The potential environmental impacts of EU immigration policy: future population numbers, greenhouse gas emissions and biodiversity preservation.	Population reductions have facilitated major ecological restoration projects in Europe and could help European nations meet their targets for increasing protected area acreage in the future.
2.	Dinerstein et al, 2017. An ecoregion-based approach to protecting half the terrestrial realm.	Current trends in rural population decrease facilitate the increased protected area acreages necessary to preserve global biodiversity.
3.	Navarro, 2014. *Rewilding Abandoned Landscapes in Europe: Biodiversity Impact and Contribution to Human Well-being.*	Nations with decreasing populations have opportunities to expand rewilding efforts and transform marginal agricultural lands into more valuable national parks and other protected areas.
4.	Navarro and Pereira, 2015. Rewilding abandoned landscapes in Europe.	Decreasing human populations reduce hunting pressures on European natural areas.
5.	Pereira and Navarro, 2015. *Rewilding European landscapes*.	Biodiversity restoration projects in Europe often depend on population decrease and land abandonment to succeed.
6.	Rewilding Europe, 2021. Our rewilding areas.	Major ecological restoration sites in Europe correspond closely to areas experiencing declining populations and reduced agricultural activity.
7.	Schnitzler, 2014. Towards a new European wilderness: embracing unmanaged forest growth and the decolonisation of nature.	Accepting depopulation and the spontaneous rewilding of former agricultural lands can help preserve Europe's biodiversity.
8.	Weisman, 2007. *The World Without Us*.	Areas depopulated by war, nuclear meltdown, and other anthropogenic debacles show how quickly wild nature returns when human beings leave.
9.	Wilson, 2016. *Half Earth: Our Planet's Fight for Life*.	Population growth has driven biodiversity loss in the Anthropocene epoch and ending population growth will be necessary to share Earth generously with other species.
10.	World Wildlife Fund, 2020. Bringing life to the lower Danube – a real success story for WWF in Ukraine.	Dike removal, species reintroductions, and other ecological restoration activities have been facilitated by population decline and agricultural abandonment.

	Author(s) and title	Main findings
		Human population and deforestation
1.	Brink and Eva, 2009. Monitoring 25 years of land cover change dynamics in Africa: a sample based remote sensing approach.	A high rate of population increase contributes to deforestation and loss of other natural areas in Africa.
2.	Defries et al, 2010. Deforestation driven by urban population growth and agricultural trade in the twenty-first century.	Urban population growth is a significant driver of tropical forest loss in Africa, Asia, and Latin America.
3.	Fentahun and Gashaw, 2014. Population growth and land resources degradation in Bantneka watershed, southern Ethiopia.	There is a strong correlation between human population growth and deforestation and reductions in wildlife populations.
4.	Gorenflo et al, 2011. Exploring the association between people and deforestation in Madagascar.	Human population size is positively correlated with deforestation and species extirpation in Madagascar, although certain activities greatly increase human impacts.
5.	Jha and Bawa, 2006. Population growth, human development, and deforestation in biodiversity hotspots.	Correlation between population growth and deforestation was positive in global biodiversity hotspots, although human development may ameliorate its effects.
6.	Laurance et al, 2002. Predictors of deforestation in the Brazilian Amazon.	Highways and population growth played a critical role in Amazonian Forest destruction in the last four decades of the twentieth century.
7.	López-Carr and Burgdorfer, 2013. Deforestation drivers: population, migration, and tropical land use.	Frontier colonization by small holder farmer migrants may be the main proximate cause of deforestation in Latin America, exceeding forest conversion caused by commercial logging and industrial agriculture.
8.	Lu and Bilsborrow, 2011. A Cross-cultural analysis of human impacts on the rainforest environment in Ecuador.	In all cases and for all ethnicities, rapidly growing populations and sedentarization ensure that biodiversity loss and other environmental impacts continue to grow.
9.	Morales-Hidalgo et al, 2015. Status and trends in global primary forest, protected areas, and areas designated for conservation of biodiversity from the Global Forest Resources Assessment.	A global assessment found a 1% increase in national population density and per capita GDP were associated with a 0.2% decrease in forest area.

	Author(s) and title	Main findings
10.	Potapov et al, 2012. Quantifying forest cover loss in Democratic Republic of the Congo, 2000–2010, with Landsat ETM+ data.	Within Congo, forest loss is higher in areas with growing human populations, higher human population densities, and greater mining activity.
11.	Sisay and Gitima, 2020. Forest cover change in Ethiopia: extent, driving factors, environmental implication and management strategies, systematic review.	Forest loss in Ethiopia is closely linked to ongoing population growth.
12.	Whitmee et al, 2015. Safeguarding human health in the Anthropocene epoch: report of the Rockefeller Foundation–Lancet Commission on Planetary Health.	Population growth is an important driver of deforestation and biodiversity loss, particularly in tropical hotspots.
13.	Wright and Muller-Landau, 2006. The future of tropical forest species.	Remaining forest cover is closely correlated with human population density among countries in both the tropics and the temperate zone.
	Human population and protected areas	
1.	Brashares et al, 2002. Human demography and reserve size predict wildlife extinction in West Africa.	Human population and reserve size accounted for 98% of the observed variation in extinction rates between wildlife reserves in West Africa.
2.	Corlett, 2016. The role of rewilding in landscape design for conservation.	Rural population decreases have facilitated the creation of new protected areas.
3.	Crist et al, 2021. Protecting half the planet and transforming human systems are complementary goals.	To limit biodiversity losses, humanity must greatly expand protected areas, which will require much smaller human populations.
4.	DeSilvey and Bartolini, 2018. Where horses run free? Autonomy, temporality and rewilding in the Côa Valley, Portugal.	Creation of new protected areas has been facilitated by rural population decreases.
5.	Figueroa, 2015. Socioeconomic context of land use and land cover change in Mexican biosphere reserves.	Higher human and cattle populations increased habitat loss in Mexican biosphere reserves.
6.	Guan et al, 2021. Global patterns and potential drivers of human settlements within protected areas	Human access to protected areas is a better predictor of biodiversity loss than formal level of protection.

Author(s) and title	Main findings
7. Guerbois et al, 2013. Insights for integrated conservation from attitudes of people toward protected areas near Hwange National Park, Zimbabwe.	Migration and rapid population growth into adjacent areas decreased local support for protecting biodiversity in an African national park.
8. Krishnadas et al, 2018. Parks protect forest cover in a tropical biodiversity hotspot, but high human population densities can limit success.	In India's Western Ghats, the habitat value of protected areas declined precipitously as local human population densities increased.
9. Leverington et al, 2010. Management effectiveness evaluation in protected areas –a global study.	Increased human population density reduces the effectiveness of protected areas in sustaining native biodiversity.
10. Parks and Harcourt, 2002. Reserve size, local human density, and mammalian extinctions in US protected areas.	In the western United States, extirpation rates of large mammals within national parks increased with human population density outside park boundaries.
11. Perino et al, 2019. Rewilding complex systems.	Evacuation of the entire local population from the Chernobyl Radiation and Ecological Biosphere Reserve has led to one of the most successful rewilding experiments in recent history.
12. Qiu et al, 2018. Human pressures on natural reserves in Yunnan Province and management implications.	Reducing human population density and encouraging residents' outmigration can help preserve biodiversity in Yunnan, China.
13. Radeloff et al, 2015. Housing growth in and near United States protected areas limits their conservation value.	Housing growth poses the main threat to protected areas in the United States, directly linking population growth to biodiversity loss.
14. Robson and Rakotozafy, 2015. The freedom to choose: integrating community-based reproductive health services with locally led marine conservation initiatives in southwest Madagascar.	Through integrating community-based reproductive health services and marine conservation initiatives, more than 800 unintended pregnancies were averted, and a community-managed marine protected area was created.
15. Shahabuddin and Rao, 2010. Do community-conserved areas effectively conserve biological diversity? Global insights and the Indian context.	Population growth may undermine biodiversity protection under customary management institutions, while declining populations help preserve stable forest cover.

	Author(s) and title	Main findings
16.	Spear et al, 2013. Human population density explains alien species richness in protected areas.	Human population density surrounding parks was a significant and strong predictor of numbers of alien and invasive species across plants and animals.
17.	Symes et al, 2016. Why do we lose protected areas? Factors influencing protected area downgrading, downsizing and degazettement in the tropics and subtropics.	Increased human population densities within or near protected areas is an important cause of their being downgraded or downsized, leading to habitat loss and degradation.
18.	Veldhuis et al, 2019. Cross-boundary human impacts compromise the Serengeti-Mara ecosystem.	Regional population growth increases human impacts on biodiversity both within and outside important protected areas.
19.	Wade and Theobald, 2010. Residential development encroachment on U.S. protected areas.	Population growth-driven housing development is reducing biological connectivity around protected areas in the United States.
20.	Wittemyer et al, 2008. Accelerated human population growth at protected area edges.	Rates of deforestation are highest around protected areas where human population growth is greatest, linking population growth to habitat loss and fragmentation.
	Warnings and policy recommendations on population and biodiversity	
1.	Attenborough, 2011. Impact of population growth on the planet	More people lead to less wildlife.
2.	Albert et al, 2021. Scientists' warning to humanity on the freshwater biodiversity crisis.	The rapid rise of human populations and associated food production is increasing pressures on freshwater resources in many regions of the world, driving a rapid loss of freshwater biodiversity.
3.	Cafaro and Crist, 2012. *Life on the Brink: Environmentalists Confront Overpopulation*.	Population policies involve a choice about whether to share the Earth with other species or whether to continue to crowd them off the landscape.
4.	Cafaro et al, 2022. Overpopulation is a major cause of biodiversity loss and smaller human populations are necessary to preserve what is left.	Population growth is a fundamental driver of biodiversity loss, and population decrease facilitates ecological restoration efforts.
5.	Ceballos et al, 2015. Accelerated modern human-induced species losses: Entering the sixth mass extinction.	Avoiding a sixth mass extinction will require rapid, greatly intensified efforts to reduce habitat loss, overexploitation, and climate change—all of which are related to human population size and growth.

Author(s) and title		Main findings
6.	Crist, 2019. *Abundant Earth: Toward an Ecological Civilization*.	Justice and prudence both counsel reducing human numbers to 1 or 2 billion and sharing Earth generously with other species.
7.	Crist et al, 2022. Scientists' warning on population.	Reducing the human population is necessary to address the collapse of global biodiversity and ensure long-term human wellbeing.
8.	Engelman and Johnson, 2019. Removing barriers to family planning, empowering sustainable environmental conservation: a background paper and call for action.	Conservation organizations can and should build family planning into their efforts to preserve biodiversity.
9.	Engelman et al, 2016. *Family Planning and Environmental Sustainability: Assessing the Science*.	Contraceptive availability benefits environmental sustainability, including biodiversity and forest protection.
10.	Foreman and Carroll, 2014. *Man Swarm: How Overpopulation is Killing the Wild World*.	Human overpopulation is the main driver of biodiversity loss and species extinction in the United States and globally.
11.	Ganivet, 2020. Growth in human population and consumption both need to be addressed to reach an ecologically sustainable future.	Limiting population growth and decreasing per capita consumption are both necessary to preserve global biodiversity.
12.	Hughes et al, 2023. Smaller human populations are neither a necessary nor sufficient condition for biodiversity conservation.	Human numbers have little impact on biodiversity losses and population control has no positive role to play in conservation.
13.	International Union for the Conservation of Nature (IUCN), 2020. Importance for the conservation of nature of removing barriers to rights-based voluntary family planning.	Nations should include rights-based voluntary family planning in their national biological strategic action plans to limit the negative impacts of human population growth on biodiversity.
14.	Kolankiewicz, 2012. Overpopulation versus biodiversity: how a plethora of people produces a paucity of wildlife.	In both tropical and temperate regions, human population increase leads to decreases in native biodiversity.
15.	Lidicker, 2020. A scientist's warning to humanity on human population growth.	Human-caused extinctions have reached an unprecedented rate, thanks in part to unprecedented human population growth.
16.	Lopez-Carr and Ervin, 2017. Population-health-environment (PHE) synergies? Evidence from USAID-sponsored programs in African and Asian core conservation areas.	Review of population-health-environment programs in eight developing countries found they achieved substantial improvements in maternal and child health and biodiversity conservation.

	Author(s) and title	Main findings
17.	Mora, 2014. Revisiting the environmental and socioeconomic effects of population growth: a fundamental but fading issue in modern scientific, public, and political circles.	Although tackling overpopulation will be difficult, continued neglect of this issue will decrease chances for humanity to reverse rapid biodiversity loss.
18.	Mora and Sale, 2011. Ongoing global biodiversity loss and the need to move beyond protected areas: a review of the technical and practical shortcomings of protected areas on land and sea.	The only scenarios that end ongoing biodiversity loss require concerted efforts to reduce human population growth and consumption.
19	Noss et al, 2012. Bolder thinking for conservation.	Accepting continued population growth and economic growth ensures conservationists will make limited headway in stemming extinction.
20.	Pacheco et al, 2016. Conservation as the new paradigm for development.	Development planning should include judgements on how many people ecosystems can sustain without degrading ecosystem services and losing species.
21.	Pyšek et al, 2020. Scientists' warning on invasive alien species.	Rising human population size is driving biological invasions around the world, reducing overall global biodiversity.
22.	Rewilding Charter Working Group, 2020. *Global Charter for Rewilding the Earth*.	Nations should enact laws and policies to lower human numbers in order to stem plummeting wildlife populations.
23.	Ripple et al, 2017. World scientists' warning to humanity: A second notice.	Rapid population growth is a primary driver of biodiversity loss and other ecological threats.
24.	Rust and Kehoe, 2017. A call for conservation scientists to empirically study the effects of human population policies on biodiversity loss.	High human population density and large size are linked with biodiversity loss, so conservation biologists should study the connections between them.
25.	Shi et al, 2005. Integrating habitat status, human population pressure, and protection status into biodiversity conservation priority setting.	Areas with growing human populations should be prioritized for protection efforts since more people increase demand for land and resources and threaten natural habitats.
26.	Shragg, 2022. On the wrong track: why the Endangered Species Act isn't enough.	Population growth undermines legal efforts to protect endangered species.

	Author(s) and title	Main findings
27.	Yi and Borzée, 2021. Human population and efficient conservation: are humans playing ostriches and rabbits?	Current societies need to reject outmoded taboos against discussing overpopulation, which is the main cause of biodiversity loss and other global environmental problems.
	Human population, agriculture, and biodiversity	
1.	Crist et al, 2017. The interaction of human population, food production, and biodiversity protection.	Research suggests that the scale of human population and the current pace of its growth contribute substantially to the loss of biological diversity.
2.	Dinerstein et al, 2019. A global deal for nature: guiding principles, milestones, and targets.	The success of plans to boost food production while protecting biodiversity will depend on limiting human population growth.
3.	D'Odorico et al, 2018. The global food-energy-water nexus.	Human pressure on global water resources is increasing at alarming rates in response to population growth and changes in diet, leading to biodiversity losses in many parts of the world.
4.	Estes et al, 2012. Land-cover change and human population trends in the greater Serengeti ecosystem from 1984-2003.	Agricultural conversion of natural habitats to agriculture was greatest in areas with the highest rates of human population growth.
5.	Keenleyside and Tucker, 2010. Farmland abandonment in the EU: an assessment of trends and prospects.	Europe's rural population decline, and its extensive abandonment of less productive farmland have helped restore many formerly rare biological species.
6.	Kehoe et al, 2017. Biodiversity at risk under future cropland expansion and intensification.	Both agricultural expansion and agricultural intensification, driven by human population growth, are set to decrease biodiversity.
7.	Laurance et al, 2014. Agricultural expansion and its impacts on tropical nature.	Population growth in the tropics threatens to detonate an "agricultural bomb" that extinguishes numerous species.
8.	Maja and Ayano, 2021. The impact of population growth on natural resources and farmers' capacity to adapt to climate change in low-income countries.	Addressing rapid population growth is a crucial step in curbing biodiversity loss, particularly in Sub-Saharan Africa.
9.	Matanle, 2017. Towards an Asia-Pacific depopulation dividend in the 21st century: regional growth and shrinkage in Japan and New Zealand.	Rural population decrease in the Asia-Pacific region is creating opportunities to preserve biodiversity and revive traditional cultural activities.

	Author(s) and title	Main findings
10.	McKee and Chambers, 2011. Behavioral mediators of the human population effect on global biodiversity losses.	Human population density, agricultural land use, and species richness are the best combined predictors of threats to mammal and bird species.
11.	Molotoks et al, 2018. Global projections of future cropland expansion to 2050 and direct impacts on biodiversity and carbon storage.	Global population increase threatens biodiversity, by driving habitat loss as a result of increasing cropland.
12.	Ngwira and Watanabe, 2019. An analysis of the causes of deforestation in Malawi: a case of mwazisi.	The expansion of subsistence agriculture to meet the food needs of a burgeoning population has been one of the main causes of deforestation in Malawi.
13.	Raven and Wagner, 2021. Agricultural intensification and climate change are rapidly decreasing insect biodiversity.	To limit the mass extinction of invertebrates, a lower human population and sustainable consumption levels will be necessary.
14.	Scharlemann, 2005. The level of threat to restricted-range bird species can be predicted from mapped data on land use and human population.	Increasing rural populations lead to agricultural habitat conversion and loss of biodiversity.
	Human population and biodiversity in large multi-author syntheses	
1.	Barnosky et al, 2013. Scientific consensus on maintaining humanity's life support systems in the 21st century: information for policy makers.	Global population growth is driving species extinctions and human over-appropriation of the biosphere; limiting future population growth is key to reversing these trends.
2.	Duraiappah and Naeem 2005. *Millennium Ecosystem Assessment: Ecosystems and Human Well-Being: Biodiversity Synthesis*.	The growth of agriculture is the primary driver of habitat loss in all human-dominated landscapes, and the primary threat to biodiversity worldwide.
3.	Diaz et al, 2019. Pervasive human-driven decline of life on Earth points to the need for transformative change.	The human impact on life on Earth has increased sharply since the 1970s, driven by the demands of a growing population with rising average per capita incomes.
4.	Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES), 2019. *Summary for Policymakers. Global Assessment Report on Biodiversity and Ecosystem Services*.	Biodiversity loss is underpinned by demographic and economic growth, which have increased in recent decades.
5.	Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES) and Intergovernmental Panel on Climate Change (IPCC), 2021.	Growth of human populations and their increasing wealth forecasts a sharp decline in global biodiversity in the future.

Author(s) and title		Main findings
6.	Perrings and Halkos, 2015. Agriculture and the threat to biodiversity in sub-Saharan Africa.	There is a positive and generally significant correlation between numbers of threatened species and both population and per capita gross national income.
7.	Secretariat of the Convention on Biological Diversity, 2020. *Global Biodiversity Outlook 5*.	Unsustainable population growth is helping drive rapid biodiversity loss.
	Human population and defaunation	
1.	Ahmed et al, 2014. Road networks predict human influence on Amazonian bird communities.	Road building leads to significant deleterious effects on birds, in part through encouraging regional population growth.
2.	Ament et al, 2019. Compatibility between agendas for improving human development and wildlife conservation outside protected areas: Insights from 20 years of data.	Human population growth decreases bird and mammal abundance in lower income countries.
3.	Beebee, 2022. *Impacts of Human Population on Wildlife: A British Perspective*.	The reasons usually given for wildlife loss in Britain are real but secondary to a single, primary cause: the attempt to accommodate more people.
4.	Berger et al, 2020. Disassembled food webs and messy projections: modern ungulate communities in the face of unabating human population growth.	Human population growth has exterminated numerous ungulate and carnivore species and irrevocably changed ecological communities throughout the world.
5.	Boitani and Linnell, 2015. Bringing large mammals back: large carnivores in Europe.	As rural populations have declined, carnivores have naturally recolonized many former agricultural areas in Europe.
6.	Cardillo et al, 2004. Human population density and extinction risk in the world's carnivores.	Higher levels of exposure to human populations increase the extinction risk to carnivores.
7.	Ceballos, 2017. Biological annihilation via the ongoing sixth mass extinction signaled by vertebrate population losses and declines.	The ultimate drivers of rapid global biodiversity loss are human overpopulation and overconsumption.
8.	Ceballos et al, 2020. Vertebrates on the brink as indicators of biological annihilation and the sixth mass extinction.	The acceleration of the extinction crisis is certain because of the still fast growth in human numbers and consumption rates.

Author(s) and title		Main findings
9.	Chapron et al, 2014. Recovery of large carnivores in Europe's modern human-dominated landscapes.	As rural populations have declined, carnivores have naturally recolonized many former agricultural areas in Europe.
10.	Cheetah Conservation Fund, 2018. The importance of human reproductive health and rights for cheetah conservation.	Limiting human population growth is key to cheetah conservation in Namibia, where more than 90% of cheetahs live outside protected areas.
11.	Colsaet et al, 2018. What drives land take and urban land expansion? A systematic review.	Population growth is positively correlated with wildlife habitat loss at both national and global levels.
12.	Deinet et al, 2013. Wildlife comeback in Europe: The recovery of selected mammal and bird species: final report to Rewilding Europe.	Between 1960 and 2010, a 28% decline in rural populations facilitated the recovery of many European mammal and bird species.
13.	Estrada et al, 2017. Impending extinction crisis of the world's primates: why primates matter.	Human population growth is a major contributor to primate declines around the world, driving increased hunting, deforestation, habitat fragmentation and other direct causes of primate loss.
14.	Gagné et al, 2016. The effect of human population size on the breeding bird diversity of urban regions.	Increasing human population size drives habitat loss, fragmentation, and disturbance, and decreases both breeding bird species richness and abundance.
15.	Harcourt and Parks, 2003. Threatened primates experience high human densities: adding an index of threat to the IUCN Red List criteria.	Higher human population densities increase the threat of extinction for primates.
16.	Marques et al, 2019. Increasing impacts of land use on biodiversity and carbon sequestration driven by population and economic growth.	Between 2000 and 2011, demographic and economic growth decreased global bird diversity, despite a reduction in land-use impacts per unit of GDP.
17.	McKee et al, 2013. Human population density and growth validated as extinction threats to mammal and bird species.	Increased human population density increases the risk of extinction for birds and mammals.
18.	Olden et al, 2006. Forecasting faunal and floral homogenization associated with human population geography in North America.	Increased human population size leads to more homogenized natural communities, across all taxonomic groups.

Author(s) and title		Main findings
19.	Prates and Perez, 2021. Late Pleistocene South American megafaunal extinctions associated with rise of fishtail points and human population.	Human population increase and associated hunting pressure drove late Pleistocene extinctions in South America.
20.	Ripple et al, 2015. Collapse of the world's largest herbivores.	Human population growth drives the habitat loss and overhunting decimating large herbivore populations throughout the world.
21.	Smil, 2011. Harvesting the biosphere: the human impact.	Wild vertebrate biomass is vanishingly small, having been largely replaced by human and domesticated animal biomass.
22.	Stanford, 2012. *Planet Without Apes*.	Rapid population growth has played an important role in driving Africa's commercial bushmeat trade and the extirpation of chimpanzees and gorillas from large areas.
23.	Sterling et al, 2006. *Vietnam: A Natural History*.	Overhunting, driven partly by rising populations, has led to "empty forest syndrome" throughout Vietnam.
24.	Tucker et al, 2018. Moving in the Anthropocene: global reductions in terrestrial mammalian movements.	Increased human population density interferes with feeding, mating, and migration of wild mammals.
25.	Visconti et al, 2011. Future hotspots of terrestrial mammal loss.	Expected growth in human populations and consumption in biodiversity hotspots threatens future mammal loss despite conservation efforts.
26.	World Wildlife Fund, 2022. *Living Planet Report 2022*.	Global vertebrate populations have declined 69% since 1970, driven by increased human numbers and economic activity, particularly the expansion of agriculture.
27.	Young et al, 2016. Patterns, causes, and consequences of anthropocene defaunation.	Stabilizing the human population and decreasing overconsumption are essential to halt current rapid decreases in animal populations.
	Human population and general biodiversity loss	
1.	Abegão, 2019. Where the wild things were is where humans are now: an overview.	The requirements of an expanding human population are strongly linked to wildlife depletion and the increasing difficulties facing biodiversity conservation efforts.

Author(s) and title		Main findings
2.	Abell et al, 2011. Indicators for assessing threats to freshwater biodiversity from humans and human-shaped landscapes.	Areas with high human population numbers typically coincide with degraded aquatic ecosystems.
3.	Bradshaw and Di Minin, 2019. Socio-economic predictors of environmental performance among African nations.	Increasing population density is strongly correlated with greater environmental degradation in Africa, suggesting that reducing population growth is necessary to preserve African biodiversity going forward.
4.	Bradshaw et al, 2021. Underestimating the challenges of avoiding a ghastly future.	Excessive human numbers and overconsumption are driving a sixth mass extinction of Earth's biological species.
5.	Burgess et al, 2007. Correlations among species distributions, human density and human infrastructure across the high biodiversity tropical mountains of Africa.	High rural population densities threaten biodiversity hotspots in Africa.
6.	Cincotta and Gorenflo. 2011. *Human Population: Its Influences on Biological Diversity*.	Human population density has a powerful negative influence on the viability of populations for the vast majority of other species.
7.	Cunningham and Beazley, 2018. Changes in human population density and protected areas in terrestrial global biodiversity hotspots, 1995–2015.	Average human population densities in global biodiversity hotspots increased by 36% between 1995 and 2015, double the global average, threatening conservation goals.
8.	Dasgupta, 2021. *The Economics of Biodiversity: The Dasgupta Review*.	Lowering future human numbers can directly reduce demands on the natural world and reduce extinction rates.
9.	Driscoll et al, 2018. A biodiversity-crisis hierarchy to evaluate and refine conservation indicators.	Human population size and resource consumption per capita are the fundamental drivers of biodiversity loss.
10.	Dumont, 2012. Estimated impact of global population growth on future wilderness extent.	Wilderness areas around the world are threatened by the environmental impacts of the growing global human population.
11.	Gorenflo, 2011. Human demography and conservation in the Apache Highlands ecoregion, US-Mexico borderlands.	Beyond a human population density of 10 persons per km^2, high biodiversity is unlikely in the apache highlands region.

	Author(s) and title	Main findings
12.	Haberl et al, 2014. Human appropriation of net primary production: patterns, trends, and planetary boundaries.	Economic growth and population growth result in increasing human appropriation of net primary production, driving biodiversity loss.
13.	Hughes, 2017. Understanding the drivers of Southeast Asian biodiversity loss.	While urbanization often is claimed to take pressure off rural areas, it increases deforestation, pollution and the spread of invasive species, hastening biodiversity loss.
14.	Kolankiewicz et al, 2022. *From Sea to Sprawling Sea: Quantifying the Loss of Open Space in America*.	Areas in the United States with rapidly growing populations had higher rates of habitat loss than areas with more slowly growing populations.
15.	Kraussman et al, 2013. Global human appropriation of net primary production doubled in the 20th century.	Population growth helped drive increased appropriation of global net primary production in the 20^{th} century and will continue to do so during the 21^{st}.
16.	Lavides et al, 2020. Patterns of coral-reef finfish species disappearances inferred from fishers' knowledge in global epicentre of marine shore fish diversity.	High Filipino population growth is depleting fish stocks and putting huge pressure on coral reefs.
17.	McDonald et al, 2020. Research gaps in knowledge of the impact of urban growth on biodiversity.	Population growth is set to drive further urban growth, leading to direct and indirect biodiversity losses worldwide.
18.	McKee, 2003. *Sparing Nature - The Conflict between Human Population Growth and Earth's Biodiversity*.	Every day, there is a net gain of more than 200,000 people on the planet, leading to the extinction of countless plant and animal species.
19.	McKee, 2009. Contemporary mass extinction and the human population imperative.	The global pattern of biodiversity loss is clearly linked to the growth of humanity's population size and density, and losses of plant and animal species will continue if this growth continues.
20.	McKee et al, 2004. Forecasting global biodiversity threats associated with human population growth.	Multiple regression analysis reveals that two predictor variables--human population density and species richness--account for 88% of the variability in threatened bird and mammal species across 114 continental nations.

Author(s) and title		Main findings
21.	McKinney, 2001. Effects of human population, area, and time on non-native plant and fish diversity in the United States.	Higher human numbers increase the numbers of invasive plant and fish species, through both planned and inadvertent non-native species introductions.
22.	Oueslati et al, 2015. Determinants of urban sprawl in European cities.	Increased population size leads to habitat loss in urban areas in Europe.
23.	Paradis, 2018. Nonlinear relationship between biodiversity and human population density: evidence from Southeast Asia.	Human population pressure on biodiversity increased between 1990 and 2000 throughout Southeast Asia.
24.	Pereira et al, 2020. Global trends in biodiversity and ecosystem services from 1900 to 2050.	A growing population and global economy have increased human demands for land and resources, causing habitat conversion and loss through a variety of proximate causes.
25.	Pimm, 2014. The biodiversity of species and their rates of extinction, distribution, and protection.	Large human populations and their continued growth are driving global biodiversity loss.
26.	Rees, 2023. The human eco-predicament: overshoot and the population conundrum.	Increasing human numbers on a finite planet necessarily competitively displaces wild species.
27.	Sánchez-Bayoa and Wyckhuysb, 2019. Worldwide decline of the entomofauna: A review of its drivers.	One-third of the world’s insect species are threatened with extinction due primarily to population-driven agricultural intensification.
28.	Seto, 2011. A meta-analysis of global urban land expansion.	A direct correlation exists between increased population densities and loss of species and natural areas to development.
29.	Seto, 2012. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools.	If current trends in population density continue, by 2030 urban land cover will nearly triple compared to 2000, resulting in considerable losses in key biodiversity hotspots.
30.	Simkin et al, 2022. Biodiversity impacts and conservation implications of urban land expansion projected to 2050.	Population-driven urbanization is expected to be an increasingly prominent driver of biodiversity loss over the next 30 years.
31.	Vincent, 2008. Reconciling fisheries with conservation on coral reefs: the world as an onion.	Unconstrained human demands, whether from overconsumption or overpopulation, threaten to overwhelm coral reef conservation and management efforts.

Author(s) and title		Main findings
32.	Waldron et al, 2017. Reductions in global biodiversity loss predicted from conservation spending.	Population growth and economic growth reliably predict biodiversity loss, while conservation investments can reduce these losses.
33.	Weber and Sciubba, 2018. The effect of population growth on the environment: evidence from European regions.	Higher population growth rates lead to increased habitat loss at the regional level in Europe.
34.	Williams, 2013. Humans and biodiversity: Population and demographic trends in the hotspots.	Global biodiversity hotspots have rapidly growing human populations, boding ill for their ability to preserve biodiversity long-term.
35.	Wilson, E.O. 2010. *The Diversity of Life*.	Population growth drives species extinctions in synergy with other factors in the "HIPPO" causal model of biodiversity loss.
36.	Wilting et al, 2017. Quantifying biodiversity losses due to human Consumption: a global-scale footprint analysis.	Population and per capita consumption largely determine national contributions to global biodiversity loss.
37.	Wood et al, 2000. The root causes of biodiversity loss.	Increased population density has been a major cause of biodiversity loss in numerous countries on all inhabited continents.

Population and Climate Change

It is well-established that human population growth is a leading cause of increased emissions of greenhouse gasses and hence global climate change (IPCC, 2022). Climate change, in turn, is one of five major direct drivers of global biodiversity loss. Many conservation biologists believe that the harmful impact of climate change on biodiversity loss will grow in coming decades. The literature on this topic is extensive. We list in table 2 a dozen recent studies that provide a good introduction.

Table 2: Population effect on climate change - evidence from select literature.

Author(s) and title		Main findings
1.	Bongaarts and O'Neill, 2018. Global warming policy: is population left out in the cold?	The potential carbon emissions reductions of reducing global population growth are large, with significant co-benefits for women's rights and economic development in poorer countries.

Author(s) and title		Main findings
2.	Das Gupta, 2013. Population, Poverty, and Climate Change.	Lowering fertility rates in the developing world could greatly aid their climate adaptation efforts, as well as contribute to climate change mitigation.
3.	Dodson et al, 2020. Population growth and climate change: addressing the overlooked threat multiplier.	Demographic trends will play a large role in determining the magnitude of climate disruption in the 21st century and how well societies adapt to it.
4.	Hickey, 2016. Population engineering and the fight against climate change.	The threats posed by climate change justify policies to reduce human populations, including incentivizing small families.
5.	Intergovernmental Panel on Climate Change (IPCC), 2022. *Climate Change 2022: Mitigation of Climate Change*.	Over the past three decades, population growth and economic growth have been the fundamental drivers of increased greenhouse gas emissions.
6.	Mitchell, 2012. Technology is not enough: climate change, population, affluence, and consumption.	To meet the challenge of climate change, humanity will have to address our excessive numbers and economic demands.
7.	O'Neill et al, 2015. Plausible reductions in future population growth and implications for the environment.	Limiting population growth can play a substantial role in mitigating global climate change.
8.	O'Sullivan, 2018. Synergy between population policy, climate adaptation and mitigation.	Voluntary family planning programs could significantly reduce global greenhouse gas emissions and increase the adaptability of poorer nations for the climate change that is coming.
9.	Ripple et al, 2020. World scientists' warning of a climate emergency.	Population growth is among the most important drivers of increases in carbon emissions and nations reduce their populations to fight climate change.
10.	Ripple et al, 2021. World scientists' warning of a climate emergency 2021.	Ending population growth and gradually reducing the human population by providing voluntary family planning, improving education, and supporting women's rights is necessary to limit global climate change.
11.	Spears, 2015. Smaller human population in 2100 could importantly reduce the risk of climate catastrophe.	Limiting population growth can play a substantial role in mitigating global climate change.

Author(s) and title		Main findings
12.	Wynes and Nicholas, 2017. The climate mitigation gap: education and government recommendations miss the most effective individual actions.	By more than an order of magnitude, having fewer children is the most effective action citizens in the developed world can perform to reduce their personal greenhouse gas emissions.

Biodiversity Ethics

Preserving biodiversity is not just a matter of scientific knowledge and technical and managerial problem-solving. It also rests on ethical commitments to the intrinsic value of other species and the moral discipline to limit human numbers and economic demands (IPBES, 2019). Once again, the literature on this topic is extensive. Table 3 presents key findings of a dozen recent studies that provide a good introduction.

Table 3: The ethics of biodiversity conservation - some recent work.

Author(s) and title		Main findings
1.	Borràs, 2016. New transitions from human rights to the environment to the rights of nature.	We must reject legal systems that treat the natural world solely as property to be exploited, rather than as an integral ecological partner with its own rights to exist and thrive.
2.	Bradshaw, 2018. Animal property rights.	Securing traditional property rights for wild animals could be an effective response to population growth-driven habitat loss.
3.	Cafaro, 2022. Reducing human numbers and the size of our economies is necessary to avoid a mass extinction and share Earth justly with other species.	The moral case for reducing excessive human numbers rests on duties to avoid exterminating other species or seriously harming future human generations.
4.	Cafaro, and O'Sullivan, 2019. How should ecological citizens think about immigration?	Sharing Earth justly with other species demands that overpopulated countries, such as the United Kingdom and the United States, reduce current fertility and immigration levels.
5.	Chapron et al, 2019. A rights revolution for nature: introduction of legal rights for nature could protect natural systems from destruction.	Securing legal rights to exist and flourish can level the playing field between people and other species, slowing biodiversity loss.

Author(s) and title		Main findings
6.	Donaldson and Kymlicka, 2011. *Zoopolis: A Political Theory of Animal Rights*.	Because wild animals have a right to the habitats they occupy, human beings should not increase their numbers to levels which make securing that habitat impossible.
7.	Hedberg, 2020. *The Environmental Impact of Overpopulation*.	If we extend moral consideration to other species, the incentives to reduce our numbers increase significantly.
8.	Pope Francis. 2015. *Laudato Si': On Care for Our Common Home*.	If we approach nature with awe and wonder, then we will preserve biodiversity and refuse to turn reality into an object simply to be used and controlled.
9.	Rolston, 2020. Wonderland Earth in the Anthropocene Epoch.	Humans should right-size our population in order to share Earth fairly with other species.
10.	Staples and Cafaro, 2012. For a species right to exist.	Nonhuman species have a right against untimely anthropogenic extinction, grounded in their intrinsic value and their beauty, complexity, and unique genealogies.
11.	Washington et al, 2018. Foregrounding ecojustice in conservation.	Justice demands a fair distribution of Earth's limited habitat among people and nonhuman species, which in turn demands people curb our numbers.
12.	Wienhues, 2020. *Ecological Justice and the Extinction Crisis: Giving Living Beings Their Due*.	All living beings are morally considerable, hence human numbers and economic demands must be limited as part of a compromise between human and nonhuman demands on the natural world.

Conclusions and Recommendations

We find it heartening to see all the good work done in recent years on population and biodiversity. Our first recommendation would be for redoubled work on this subject (Noss et al, 2012; Yi and Borzée, 2021). If these studies are right regarding the importance of human numbers in determining conservation success, this topic deserves even more attention. The work described here provides a solid foundation to build on.

Second, one especially deserving research area is population and ecological restoration (Navarro, 2014). Much of the evidence for the importance of population in opening up rewilding opportunities is anecdotal (Rewilding Europe, 2021) and more rigorous quantification is needed. The same holds for the impact of population on reducing human demands on restored areas and on protected areas generally (DeSilvey and Bartolini, 2018). Land managers and conservation biologists know this impact is important. We need to know just how important, and how demographic trends open up or close down biodiversity conservation opportunities.

Third, with a critical mass of studies documenting the impact of population growth and population density on biodiversity loss, in many places for many taxa, there appears to be an opportunity to generalise this work and explain the fundamental causes of biodiversity loss in a more rigorous manner (Wilson, 2010). Just as atmospheric scientists have developed the Kaya identity to explain and predict changes in regional and global CO_2 emissions, conservation biologists should also develop and test models explaining and predicting biodiversity losses and gains (Cafaro et al, 2022). These models, like Kaya identity, will need to make a prominent place for changes in population and per capita consumption (McKee et al, 2004; Driscoll et al, 2018). However, which other fundamental technical, managerial, or biological factors need to be in the mix remains to be determined (Weber and Sciubba, 2018; Bradshaw and Di Minin, 2019). Developing rigorous quantitative models can make a real contribution to guiding and informing conservation policy going forward and help our societies face their environmental choices more honestly.

Fourth, we need to apply what we have learned about the impact of excessive human numbers and excessive per capita economic demands to conservation policy (Ripple et al, 2017; Ripple et al, 2020). Most conservation biologists believe that greatly increasing the amount of land and seas protected in PAs is necessary to preserve the remaining biodiversity on Earth (Dinerstein et al, 2019; Locke et al, 2019). However, the role of population reduction in achieving the goals of Half Earth or similar programmes remains largely unexplored (important exceptions are Crist et al, 2021; Crist et al, 2022). Similarly, the role of population growth in closing off conservation options, particularly at the national level where most substantial PA designations occur, is not yet fully understood (Liu et al, 1999; Symes et al, 2016; Qiu et al, 2018). How much of Germany or India, Mexico or New Zealand, would have to be set aside to preserve viable populations of their remaining native wildlife and how large a human population would be compatible with this goal need to be explored. Every conservation biologist should know how many people his or her country can support while also supporting viable populations of all its native species.

Fifth, conservationists need to ramp up our population advocacy (Attenborough, 2011; Washington et al, 2018). There is still much to learn, but the evidence is clear that reducing human numbers is one key to preserving the remaining biodiversity of Earth and dealing adequately with the whole suite of environmental problems that threaten humanity (Ceballos et al, 2015; Rewilding Charter Working Group, 2020). Reducing human numbers (and the size of our economies) is necessary to avoid a mass extinction and share Earth fairly with other species (Mora and Sale, 2011; Cafaro, 2022). We should advocate for universal access to contraception, greater educational opportunities for girls and young women, comprehensive sex education, government promotion of small family size, and other policies to reduce human fertility and promote smaller national populations (Crist, 2019; Engelman and Johnson, 2019).

Many biodiversity advocates focus on minimising the negative effects of people on biodiversity. These efforts are valuable and should continue, but the evidence presented here clearly shows that to succeed in preserving the remaining biodiversity on Earth, we must also reduce human numbers.

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Appendix Table: Population effects on biodiversity by geographical area.

	Author(s) and title	Key findings
		North and South America
1.	Ahmed et al, 2014. Road networks predict human influence on Amazonian bird communities	Road building leads to significant deleterious effects on birds, in part through encouraging regional population growth.
2.	Cafaro and Crist, 2012. *Life on the Brink: Environmentalists Confront Overpopulation*.	Population policies involve a choice about whether to share the earth with other species or whether to continue to crowd them off the landscape.
3.	Foreman and Carroll, 2014. *Man Swarm: How Overpopulation is Killing the Wild World*.	Human overpopulation is the main driver of biodiversity loss and species extinction in the United States and globally.
4.	Gorenflo, 2011. Human demography and conservation in the Apache Highlands ecoregion, US-Mexico borderlands.	Beyond a human population density of 10 persons per km^2, high biodiversity is unlikely in the Apache highlands region.
5.	Kolankiewicz, 2012. Overpopulation versus biodiversity: how a plethora of people produces a paucity of wildlife.	In both tropical and temperate regions, human population increase leads to decreases in native biodiversity.
6.	Kolankiewicz et al, 2022. *From Sea to Sprawling Sea: Quantifying the Loss of Open Space in America*.	Areas in the United States with rapidly growing populations had higher rates of habitat loss than areas with more slowly growing populations.
7.	Laurance et al, 2002. Predictors of deforestation in the Brazilian Amazon.	Highways and population growth played a critical role in Amazonian Forest destruction in the last four decades of the twentieth century.
8.	López-Carr and Burgdorfer, 2013. Deforestation drivers: population, migration, and tropical land use. Environment.	Frontier colonization by small holder farmer migrants may be the main proximate cause of deforestation in Latin America, exceeding forest conversion caused by commercial logging and industrial agriculture.
9.	Lu and Bilsborrow, 2011. A cross-cultural analysis of human impacts on the rainforest environment in Ecuador.	In all cases, for all ethnicities, rapidly growing populations and sedentarization ensure that biodiversity loss and other environmental impacts continue to grow.
10.	McKinney, 2001. Effects of human population, area, and time on non-native plant and fish diversity in the United States.	Higher human numbers increase the numbers of invasive plant and fish species, through both planned and inadvertent non-native species introductions.

Author(s) and title		Key findings
11.	Olden et al, 2006. Forecasting faunal and floral homogenization associated with human population geography in North America.	Increased human population size leads to more homogenized natural communities, across all taxonomic groups.
12.	Parks and Harcourt, 2002. Reserve size, local human density, and mammalian extinctions in US protected areas.	In the western United States, extirpation rates of large mammals within national parks increased with human population density outside park boundaries.
13.	Prates and Ivan Perez, 2021. Late Pleistocene South American megafaunal extinctions associated with rise of fishtail points and human population.	Human population increase and associated hunting pressure drove late Pleistocene extinctions in South America.
14.	Radeloff et al, 2015. Housing growth in and near United States protected areas limits their conservation value.	Housing growth poses the main threat to protected areas in the United States, directly linking population growth to biodiversity loss.
15.	Wade and Theobald, 2010. Residential development encroachment on U.S. protected areas.	Population growth-driven housing development is reducing biological connectivity around protected areas in the United States.
		Europe
1.	Beebee, 2022. *Impacts of Human Population on Wildlife: A British Perspective*.	The reasons usually given for wildlife loss in Britain are real but secondary to a single, primary cause: the attempt to accommodate more people.
2.	Boitani and Linnell, 2015. Bringing large mammals back: large carnivores in Europe.	As rural populations have declined, carnivores have naturally recolonized many former agricultural areas in Europe.
3.	Cafaro and Götmark, 2019. The potential environmental impacts of EU immigration policy: future population numbers, greenhouse gas emissions and biodiversity.	Population reductions have facilitated major ecological restoration projects in Europe and could help European nations meet their targets for increasing protected area acreage in the future.
4.	Chapron et al, 2014. Recovery of large carnivores in Europe's modern human-dominated landscapes.	As rural populations have declined, carnivores have naturally recolonized many former agricultural areas in Europe.
5.	Deinet et al, 2013. Wildlife comeback in Europe: the recovery of selected mammal and bird species: final report to Rewilding Europe.	Between 1960 and 2010, a 28% decline in rural populations facilitated the recovery of many European mammal and bird species.

Author(s) and title		Key findings
6.	DeSilvey and Bartolini, 2018. Where horses run free? Autonomy, temporality and rewilding in the Côa Valley, Portugal.	Creation of new protected areas has been facilitated by rural population decreases.
7.	Keenleyside and Tucker, 2010. Farmland abandonment in the EU: an assessment of trends and prospects.	Europe's rural population decline, and its extensive abandonment of less productive farmland have helped restore many formerly rare biological species.
8.	Navarro, 2014. *Rewilding Abandoned Landscapes in Europe: Biodiversity Impact and Contribution to Human Well-being*.	Nations with decreasing populations have opportunities to expand rewilding efforts and transform marginal agricultural lands into more valuable national parks and protected areas.
9.	Navarro and Pereira, 2015. Rewilding abandoned landscapes in Europe.	Decreasing human populations reduce hunting pressures on European natural areas.
10.	Oueslati et al, 2015. Determinants of urban sprawl in European cities.	Increased population size leads to habitat loss in urban areas in Europe.
11.	Pereira and Navarro, 2015. *Rewilding European Landscapes*.	Biodiversity restoration projects in Europe often depend on population decrease and land abandonment to succeed.
12.	Perino et al, 2019. Rewilding complex systems.	Evacuation of the entire local population from the Chernobyl Radiation and Ecological Biosphere Reserve has led to one of the most successful rewilding experiments in recent history.
13.	Rewilding Europe, 2021. Our rewilding areas.	Major ecological restoration cites in Europe correspond closely to areas experiencing declining populations and reduced agricultural activity.
14.	Schnitzler, 2014. Towards a new European wilderness: embracing unmanaged forest growth and the decolonisation of nature.	Accepting depopulation and the spontaneous rewilding of former agricultural lands can help preserve Europe's biodiversity
15.	Weber and Sciubba, 2018. The effect of population growth on the environment: evidence from European regions.	Higher population growth rates lead to increased habitat loss at the regional level in Europe.
16.	World Wildlife Fund, 2020. Bringing life to the lower Danube – a real success story for WWF in Ukraine.	Dike removal, species reintroductions and other ecological restoration activities have been facilitated by population decline and agricultural abandonment.

Author(s) and title		Key findings
		Africa
1.	Bradshaw and Di Minin, 2019. Socio-economic predictors of environmental performance among African nations.	Increasing population density is strongly correlated with greater environmental degradation in Africa, suggesting that reducing population growth is necessary to preserve African biodiversity going forward.
2.	Brashares et al, 2002. Human demography and reserve size predict wildlife extinction in West Africa.	Human population and reserve size accounted for 98 per cent of the observed variation in extinction rates between wildlife reserves in West Africa.
3.	Brink and Eva, 2009. Monitoring 25 years of land cover change dynamics in Africa: a sample based remote sensing approach.	A high rate of population increase contributes to deforestation and loss of other natural areas in Africa
4.	Burgess et al, 2007. Correlations among species distributions, human density and human infrastructure across the high biodiversity tropical mountains of Africa.	High rural population densities threaten biodiversity hotspots in Africa.
5.	Cheetah Conservation Fund, 2018. The importance of human reproductive health and rights for cheetah conservation.	Limiting human population growth is key to cheetah conservation in Namibia, where more than 90% of cheetahs live outside protected areas.
6.	Estes et al, 2012. Land-cover change and human population trends in the greater Serengeti ecosystem from 1984–2003.	Agricultural conversion of natural habitats to agriculture was greatest in areas with the highest rates of human population growth.
7.	Fentahun and Gashaw, 2014. Population growth and land resources degradation in Bantneka watershed, southern Ethiopia.	There is a strong correlation between human population growth and deforestation and reductions in wildlife populations.
8.	Gorenflo et al, 2011. Exploring the association between people and deforestation in Madagascar.	Human population size is positively correlated with deforestation and species extirpation in Madagascar, although certain activities greatly increase human impacts.
9.	Guerbois et al, 2013. Insights for integrated conservation from attitudes of people toward protected areas near Hwange National Park, Zimbabwe.	Migration and rapid population growth into adjacent areas decreased local support for protecting biodiversity in an African national park.

	Author(s) and title	Key findings
10.	Maja and Ayano, 2021. The Impact of population growth on natural resources and farmers' capacity to adapt to climate change in low-income countries.	Addressing rapid population growth is a crucial step in curbing biodiversity loss, particularly in Sub-Saharan Africa.
11.	Ngwira and Watanabe, 2019. An analysis of the causes of deforestation in Malawi: a case of mwazisi.	The expansion of subsistence agriculture to meet the food needs of a burgeoning population has been one of the main causes of deforestation in Malawi.
12.	Perrings and Halkos, 2015. Agriculture and the threat to biodiversity in sub-saharan Africa.	There is a positive and generally significant correlation between numbers of threatened species and both population and per capita gross national income.
13.	Potapov et al, 2012. Quantifying forest cover loss in Democratic Republic of the Congo, 2000–2010, with Landsat ETM+ data.	Within Congo, forest loss is higher in areas with growing human populations, higher human population densities, and greater mining activity.
14.	Robson and Rakotozafy, 2015. The freedom to choose: integrating community-based reproductive health services with locally led marine conservation initiatives in southwest Madagascar.	Through integrating community-based reproductive health services and marine conservation initiatives, more than 800 unintended pregnancies were averted, and a community-managed marine protected area was created.
15.	Sisay and Gitima, 2020. Forest cover change in Ethiopia: extent, driving factors, environmental implication and management strategies, systematic review.	Forest loss in Ethiopia is closely linked to ongoing population growth.
16.	Spear et al, 2013. Human population density explains alien species richness in protected areas.	Human population density surrounding parks was a significant and strong predictor of numbers of alien and invasive species across plants and animals.
17.	Stanford, 2012. *Planet Without Apes*.	Rapid population growth has played an important role in driving Africa's commercial bushmeat trade and the extirpation of chimpanzees and gorillas from large areas.
18.	Veldhuis et al, 2019. Cross-boundary human impacts compromise the Serengeti-Mara ecosystem.	Regional population growth increases human impacts on biodiversity both within and outside important protected areas.

	Author(s) and title	Key findings
		Asia, Australia, and Oceania
1.	Hughes, 2017. Understanding the drivers of Southeast Asian biodiversity loss.	While urbanization often is claimed to take pressure off rural areas, it increases deforestation, pollution and the spread of invasive species, hastening biodiversity loss.
2.	Krishnadas et al, 2018. Parks protect forest cover in a tropical biodiversity hotspot, but high human population densities can limit success.	In India's Western Ghats, the habitat value of protected areas declined precipitously as local human population densities increased.
3.	Matanle, 2017. Towards an Asia-Pacific depopulation dividend in the 21st century: regional growth and shrinkage in Japan and New Zealand.	Rural population decrease in the Asia-Pacific region is creating opportunities to preserve biodiversity and revive traditional cultural activities.
4.	Paradis, 2018. Nonlinear relationship between biodiversity and human population density: evidence from Southeast Asia.	Human population pressure on biodiversity increased between 1990 and 2000 throughout Southeast Asia.
5.	Qiu et al, 2018. Human pressures on natural reserves in Yunnan Province and management implications.	Reducing human population density and encouraging residents' outmigration can help preserve biodiversity in Yunnan, China.
6.	Shahabuddin and Rao, 2010. Do community-conserved areas effectively conserve biological diversity? Global insights and the Indian context.	Population growth may undermine biodiversity protection under customary management institutions, while declining populations help preserve stable forest cover.
7.	Sterling et al, 2006. *Vietnam: A Natural History*.	Overhunting, driven partly by rising populations, has led to "empty forest syndrome" throughout Vietnam.
8.	Vincent, 2008. Reconciling fisheries with conservation on coral reefs: the world as an onion.	Unconstrained human demands, whether from overconsumption or overpopulation, threaten to overwhelm coral reef conservation and management efforts.
9.	Yi and Borzée, 2021. Human population and efficient conservation: are humans playing ostriches and rabbits?	Current societies need to reject outmoded taboos against discussing overpopulation, which is the main cause of biodiversity loss and other global environmental problems.

	Author(s) and title	Key findings
		Global and inter-regional
1.	Abegão, 2019. Where the wild things were is where humans are now: an overview.	The requirements of an expanding human population are strongly linked to wildlife depletion and the increasing difficulties facing biodiversity conservation efforts.
2.	Abell et al, 2011. Indicators for assessing threats to freshwater biodiversity from humans and human-shaped landscapes.	Areas with high human population numbers typically coincide with degraded aquatic ecosystems.
3.	Albert et al, 2021. Scientists' warning to humanity on the freshwater biodiversity crisis.	The rapid rise of human populations and associated food production is increasing pressures on freshwater resources in many regions of the world, driving a rapid loss of freshwater biodiversity.
4.	Ament et al, 2019. Compatibility between agendas for improving human development and wildlife conservation outside protected areas: Insights from 20 years of data.	Human population growth decreases bird and mammal abundance in lower income countries.
5.	Berger et al, 2020. Disassembled food webs and messy projections: modern ungulate communities in the face of unabating human population growth.	Human population growth has exterminated numerous ungulate and carnivore species and irrevocably changed ecological communities throughout the world.
6.	Cardillo et al, 2004. Human population density and extinction risk in the world's carnivores.	Higher levels of exposure to human populations increase the extinction risk to carnivores.
7.	Ceballos et al, 2020. Vertebrates on the brink as indicators of biological annihilation and the sixth mass extinction.	The acceleration of the extinction crisis is certain because of the still fast growth in human numbers and consumption rates.
8.	Cincotta and Gorenflo. 2011. *Human Population: Its Influences on Biological Diversity*.	Human population density has a powerful negative influence on the viability of populations for the vast majority of other species.
9.	Colsaet et al, 2018. What drives land take and urban land expansion? A systematic review.	Population growth is positively correlated with wildlife habitat loss at both national and global levels.
10.	Corlett, 2016. The role of rewilding in landscape design for conservation.	Rural population decreases have facilitated the creation of new protected areas.

Author(s) and title		Key findings
11.	Crist et al, 2017. The interaction of human population, food production, and biodiversity protection.	Research suggests that the scale of human population and the current pace of its growth contribute substantially to the loss of biological diversity.
12.	Cunningham and Beazley, 2018. Changes in human population density and protected areas in terrestrial global biodiversity hotspots, 1995–2015.	Average human population densities in global biodiversity hotspots increased by 36% between 1995 and 2015, double the global average, threatening conservation goals.
13.	Defries et al, 2010. Deforestation driven by urban population growth and agricultural trade in the twenty-first century.	Urban population growth is a significant driven of tropical forest loss in Africa, Asia, and Latin America.
14.	Diaz et al, 2019. Pervasive human-driven decline of life on Earth points to the need for transformative change.	The human impact on life on Earth has increased sharply since the 1970s, driven by the demands of a growing population with rising average per capita incomes.
15.	Dinerstein et al, 2017. An ecoregion-based approach to protecting half the terrestrial realm.	Current trends in rural population decrease facilitate the increased protected area acreages necessary to preserve global biodiversity.
16.	D'Odorico et al, 2018. The global food-energy-water nexus.	Human pressure on global water resources is increasing at alarming rates in response to population growth and changes in diet, leading to biodiversity losses in many parts of the world.
17.	Driscoll et al, 2018. A biodiversity-crisis hierarchy to evaluate and refine conservation indicators.	Human population size and resource consumption per capita are the fundamental drivers of biodiversity loss.
18.	Dumont, 2012. Estimated impact of global population growth on future wilderness extent.	Wilderness areas around the world are threatened by the environmental impacts of the growing global human population.
19.	Duraiappah and Naeem, 2005. *Millennium Ecosystem Assessment: Ecosystems and Human Well- Being: Biodiversity Synthesis*.	The growth of agriculture is the primary driver of habitat loss in all human-dominated landscapes, and the primary threat to biodiversity worldwide.
20.	Engelman et al, 2016. *Family Planning and Environmental Sustainability: Assessing the Science*.	Contraceptive availability benefits environmental sustainability, including biodiversity and forest protection.

Author(s) and title		Key findings
21.	Estrada et al, 2017. Impending extinction crisis of the world's primates: why primates matter.	Human population growth is a major contributor to primate declines around the world, driving increased hunting, deforestation, habitat fragmentation and other direct causes of primate loss.
22.	Guan et al, 2021. Global patterns and potential drivers of human settlements within protected areas	Human access to protected areas is a better predictor of biodiversity loss than formal level of protection.
23.	Haberl et al, 2014. Human appropriation of net primary production: patterns, trends, and planetary boundaries.	Economic growth and population growth result in increasing human appropriation of net primary production, driving biodiversity loss.
24.	Harcourt and Parks, 2003. Threatened primates experience high human densities: adding an index of threat to the IUCN Red List criteria.	Higher human population densities increase the threat of extinction for primates.
25.	Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES), 2019. *Summary for Policymakers. Global Assessment Report on Biodiversity and Ecosystem Services.*	Biodiversity loss is underpinned by demographic and economic growth, which have increased in recent decades.
26.	Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES) and Intergovernmental Panel on Climate Change (IPCC), 2021. *Co-sponsored Workshop on Biodiversity and Climate Change: Scientific Outcome*.	Growth of human populations and their increasing wealth forecasts a sharp decline in global biodiversity in the future.
27.	Jha and Bawa, 2006. Population growth, human development, and deforestation in biodiversity hotspots.	Correlation between population growth and deforestation was positive in global biodiversity hotspots, although human development may ameliorate its effects.
28.	Kehoe et al, 2017. Biodiversity at risk under future cropland expansion and intensification.	High human population density and large size are linked with biodiversity loss, so conservation biologists should study the connections between them.
29.	Laurance et al, 2014. Agricultural expansion and its impacts on tropical nature.	Population growth in the tropics threatens to detonate an "agricultural bomb" that extinguishes numerous species.
30.	Leverington et al, 2010. Management effectiveness evaluation in protected areas – a global study.	Increased human population density reduces the effectiveness of protected areas in sustaining native biodiversity.

Author(s) and title		Key findings
31.	Lidicker, 2020. A scientist's warning to humanity on human population growth.	Human-caused extinctions have reached an unprecedented rate, thanks in part to unprecedented human population growth.
32.	Lopez-Carr and Ervin, 2017. Deforestation drivers: population, migration, and tropical land use.	Review of population-health-environment programs in eight developing countries found they achieved substantial improvements in maternal and child health and biodiversity conservation.
33.	Marques et al, 2019. Increasing impacts of land use on biodiversity and carbon sequestration driven by population and economic growth.	Between 2000 and 2011, demographic and economic growth decreased global bird diversity, despite a reduction in land-use impacts per unit of GDP.
34.	McDonald et al, 2020. Research gaps in knowledge of the impact of urban growth on biodiversity.	Population growth is set to drive further urban growth, leading to direct and indirect biodiversity losses worldwide.
35.	McKee, 2003. *Sparing Nature—The Conflict between Human Population Growth and Earth's Biodiversity*.	Every day, there is a net gain of more than 200,000 people on the planet, leading to the extinction of countless plant and animal species.
36.	McKee and Chambers, 2011. Behavioral mediators of the human population effect on global biodiversity losses.	Human population density, agricultural land use and species richness are the best combined predictors of threats to mammal and bird species.
37.	McKee et al, 2004. Forecasting global biodiversity threats associated with human population growth.	Multiple regression analysis reveals that two predictor variables, human population density and species richness, account for 88% of the variability in threatened bird and mammal species across 114 continental nations.
38.	McKee et al, 2013. Human population density and growth validated as extinction threats to mammal and bird species.	Increased human population density increases the risk of extinction for birds and mammals.
39.	Molotoks et al, 2018. Global projections of future cropland expansion to 2050 and direct impacts on biodiversity and carbon storage.	Global population increase threatens biodiversity, by driving habitat loss to increase cropland.

Author(s) and title		Key findings
40.	Mora and Sale, 2011. Ongoing global biodiversity loss and the need to move beyond protected areas: a review of the technical and practical shortcomings of protected areas on land and sea.	The only scenarios that end ongoing biodiversity loss require concerted efforts to reduce human population growth and consumption.
41.	Morales-Hidalgo et al, 2015. Status and trends in global primary forest, protected areas, and areas designated for conservation of biodiversity from the Global Forest Resources Assessment.	A global assessment found a 1% increase in national population density and per capita GDP were associated with a 0.2% decrease in forest area.
42.	Pereira et al, 2020. Global trends in biodiversity and ecosystem services from 1900 to 2050.	A growing population and global economy have increased human demands for land and resources, causing habitat conversion and loss through a variety of proximate causes.
43.	Pimm, 2014. Global trends in biodiversity and ecosystem services from 1900 to 2050.	Large human populations and their continued growth are driving global biodiversity loss.
44.	Pyšek et al, 2020. Scientists' warning on invasive alien species.	Rising human population size is driving biological invasions around the world, reducing overall global biodiversity.
45.	Raven and Wagner, 2021. Agricultural intensification and climate change are rapidly decreasing insect biodiversity.	To limit the mass extinction of invertebrates, a lower human population and sustainable consumption levels will be necessary.
46.	Ripple et al, 2015. Collapse of the world's largest herbivores.	Human population growth drives the habitat loss and overhunting decimating large herbivore populations throughout the world.
47.	Ripple et al, 2017. World scientists' warning to humanity: A second notice.	Rapid population growth is a primary driver of biodiversity loss and other ecological threats.
48.	Sánchez-Bayoa and Wyckhuysb, 2019. Worldwide decline of the entomofauna: a review of its drivers.	One-third of the world's insect species are threatened with extinction due primarily to population-driven agricultural intensification.
49.	Scharlemann, 2005. The level of threat to restricted-range bird species can be predicted from mapped data on land use and human population.	Increasing rural populations lead to agricultural habitat conversion and loss of biodiversity.
50.	Secretariat of the Convention on Biological Diversity, 2020. *Global Biodiversity Outlook 5*.	Unsustainable population growth is helping drive rapid biodiversity loss.

Author(s) and title		Key findings
51.	Seto, 2011. A meta-analysis of global urban land expansion.	A direct correlation exists between increased population densities and loss of species and natural areas to development.
52.	Seto, 2012. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools.	If current trends in population density continue, by 2030 urban land cover will nearly triple compared to 2000, resulting in considerable losses in key biodiversity hotspots.
53.	Simkin et al, 2022. Biodiversity impacts and conservation implications of urban land expansion projected to 2050.	Population-driven urbanization is expected to be an increasingly prominent driver of biodiversity loss over the next 30 years.
54.	Smil, 2011. Harvesting the biosphere: the human impact.	Wild vertebrate biomass is vanishingly small, having been largely replaced by human and domesticated animal biomass.
55.	Symes et al, 2016. Why do we lose protected areas? Factors influencing protected area downgrading, downsizing and degazettement in the tropics and subtropics.	Increased human population densities within or near protected areas is an important cause of their being downgraded or downsized, leading to habitat loss and degradation.
56.	Tucker et al, 2018. Moving in the Anthropocene: global reductions in terrestrial mammalian movements.	Increased human population density interferes with feeding, mating, and migration of wild mammals.
57.	Visconti et al, 2011. Future hotspots of terrestrial mammal loss.	Expected growth in human populations and consumption in biodiversity hotspots threatens future mammal loss despite conservation efforts.
58.	Waldron et al, 2017. Reductions in global biodiversity loss predicted from conservation spending.	Population growth and economic growth reliably predict biodiversity loss, while conservation investments can reduce these losses.
59.	Weisman, 2007. *The World Without Us*.	Areas depopulated by war, nuclear meltdown and other anthropogenic debacles show how quickly wild nature returns when human beings leave.
60.	Whitmee et al, 2015. Safeguarding human health in the Anthropocene epoch: report of the Rockefeller Foundation–Lancet Commission on Planetary Health.	Population growth is an important driver of deforestation and biodiversity loss, particularly in tropical hotspots.

Author(s) and title		Key findings
61.	Williams, 2013. Humans and biodiversity: population and demographic trends in the hotspots.	Global biodiversity hotspots have rapidly growing human populations, boding ill for their ability to preserve biodiversity long-term.
62.	Wilson, 2016. *Half Earth: Our Planet's Fight for Life*.	Population growth has driven biodiversity loss in the Anthropocene epoch and ending population growth will be necessary to share Earth generously with other species.
63.	Wilting et al, 2017. Quantifying biodiversity losses due to human Consumption: a global-scale footprint analysis.	Population and per capita consumption largely determine national contributions to global biodiversity loss.
64.	Wittemyer et al, 2008. Accelerated human population growth at protected area edges.	Rates of deforestation are highest around protected areas where human population growth is greatest, linking population growth to habitat loss and fragmentation.
65.	Wood et al, 2000. The root causes of biodiversity loss.	Increased population density has been a major cause of biodiversity loss in numerous countries on all inhabited continents.
66.	World Wildlife Fund, 2022. *Living Planet Report 2022*.	Global vertebrate populations have declined 69% since 1970, driven by increased human numbers and economic activity, particularly the expansion of agriculture.
67.	Wright and Muller-Landau, 2006. The future of tropical forest species.	Remaining forest cover is closely correlated with human population density among countries in both the tropics and the temperate zone.
68.	Young et al, 2016. Patterns, causes, and consequences of anthropocene defaunation.	Stabilizing the human population and decreasing overconsumption are essential to halt current rapid decreases in animal populations.
		No specific geographical focus
1.	Attenborough, 2011. Impact of population growth on the planet.	More people lead to less wildlife.
2.	Barnosky et al, 2013. Scientific consensus on maintaining humanity's life support systems in the 21st century: information for policy makers.	Global population growth is driving species extinctions and human over-appropriation of the biosphere; limiting future population growth is key to reversing these trends.

Author(s) and title		Key findings
3.	Bradshaw et al, 2021. Underestimating the challenges of avoiding a ghastly future.	Excessive human numbers and overconsumption are driving a sixth mass extinction of Earth's biological species.
4.	Cafaro et al, 2022. Overpopulation is a major cause of biodiversity loss and smaller human populations are necessary to preserve what is left.	Population growth is a fundamental driver of biodiversity loss and population decrease facilitates ecological restoration efforts.
5.	Ceballos et al, 2015. Accelerated modern human-induced species losses: entering the sixth mass extinction.	Avoiding a sixth mass extinction will require rapid, greatly intensified efforts to reduce habitat loss, overexploitation, and climate change—all of which are related to human population size and growth.
6.	Ceballos et al, 2017, Biological annihilation via the ongoing sixth mass extinction signaled by vertebrate population losses and declines.	The ultimate drivers of rapid global biodiversity loss are human overpopulation and overconsumption.
7.	Crist, 2019. *Abundant Earth: Toward an Ecological Civilization*.	Justice and prudence both counsel reducing human numbers to 1 or 2 billion and sharing earth generously with other species.
8.	Crist et al, 2021. Protecting half the planet and transforming human systems are complementary goals.	To limit biodiversity losses, humanity must greatly expand protected areas, which will necessitate much smaller human populations.
9.	Crist et al, 2022. Scientists' warning on population.	Reducing the human population is necessary to address the collapse of global biodiversity and ensure long-term human wellbeing.
10.	Dasgupta, 2021. *The Economics of Biodiversity: The Dasgupta Review*.	Lowering future human numbers can directly reduce demands on the natural world and reduce extinction rates.
11.	Dinerstein et al, 2019. A global deal for nature: guiding principles, milestones, and targets.	The success of plans to boost food production while protecting biodiversity will depend on limiting human population growth.
12.	Engelman and Johnson, 2019. Removing barriers to family planning, empowering sustainable environmental conservation: a background paper and call for action.	Conservation organisations can and should build family planning into their efforts to preserve biodiversity.

Author(s) and title		Key findings
13.	Gagné et al, 2016. The effect of human population size on the breeding bird diversity of urban regions.	Increasing human population size drives habitat loss, fragmentation, and disturbance, and decreases both breeding bird species richness and abundance.
14.	Ganivet, 2020. Growth in human population and consumption both need to be addressed to reach an ecologically sustainable future.	Limiting population growth and decreasing per capita consumption are both necessary to preserve global biodiversity.
15.	Hughes et al, 2023. Smaller human populations are neither a necessary nor sufficient condition for biodiversity conservation.	Human numbers have little impact on biodiversity losses and population control has no positive role to play in conservation.
16.	International Union for the Conservation of Nature (IUCN), 2020. Importance for the conservation of nature of removing barriers to rights-based voluntary family planning. Motion at IUCN World Conservation Congress.	Nations should include rights-based voluntary family planning in their national biological strategic action plans to limit the negative the impacts of human population growth on biodiversity.
17.	Kraussman et al, 2013. Global human appropriation of net primary production doubled in the 20th century.	Population growth helped drive increased appropriation of global net primary production in the 20th century and will continue to do so during the 21st.
18.	McKee, 2009. Contemporary mass extinction and the human population imperative.	The global pattern of biodiversity loss is clearly linked to the growth of humanity's population's size and density, and losses of plant and animal species will continue if this growth continues.
19.	Mora, 2014. Revisiting the environmental and socioeconomic effects of population growth: a fundamental but fading issue in modern scientific, public, and political circles.	Although tackling overpopulation will be difficult, continued neglect of this issue will decrease chances for humanity to reverse rapid biodiversity loss.
20.	Noss et al, 2012. Bolder thinking for conservation.	Accepting continued population growth and economic growth ensures conservationists will make limited headway in stemming extinction.

Author(s) and title		Key findings
21.	Pacheco et al, 2016. Conservation as the new paradigm for development.	Development planning should include judgements on how many people ecosystems can sustain without degrading ecosystem services and losing species.
22.	Rees, 2023. The human eco-predicament: overshoot and the population conundrum.	Increasing human numbers on a finite planet necessarily competitively displaces wild species.
23.	Rewilding Charter Working Group, 2020. *Global Charter for Rewilding the Earth*.	Nations should enact laws and policies to lower human numbers in order to stem plummeting wildlife populations.
24.	Rust and Kehoe, 2017. A call for conservation scientists to empirically study the effects of human population policies on biodiversity loss.	High human population density and large size are linked with biodiversity loss, so conservation biologists should study the connections between them.
25.	Shi et al, 2005. Integrating habitat status, human population pressure, and protection status into biodiversity conservation priority setting.	Areas with growing human populations should be prioritized for protection efforts since more people increase demand for land and resources and threaten natural habitats.
26.	Shragg, 2022. On the wrong track: why the Endangered Species Act isn't enough.	Population growth undermines legal efforts to protect endangered species.
27.	Wilson, E.O. 2010. *The Diversity of Life*.	Population growth drives species extinctions in synergy with other factors in the "HIPPO" causal model of biodiversity loss.

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Obituary

Chirayath M Suchindran

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Professor Chirayath M Suchindran (Suchi) died on 25th March 2023 after a long and illustrious academic career spanning over almost 50 years. Born on 11th May 1942 in Kochi, India, Professor Suchindran had his graduation at the University of Kerala in Trivandrum. Subsequently, he went to the School of Public Health at the University of North Carolina at Chapel Hill, USA in 1967 to pursue doctoral studies on a Ford Foundation scholarship under the mentorship of Professor Mindel C Sheps and, after completing his doctoral studies in 1972, he joined as a faculty at the Department of Biostatistics, of the University of North Carolina Chapel Hill where he remained very active in teaching and research in demography and statistics for more than four decades. He also served on many professional bodies including Biometrics Society, Population Association of America (PAA), and International Union for the Scientific Study of Population (IUSSP). He was also an elected fellow of the American Statistical Association and the Indian Society for Medical Statistics. At the time of his death, Professor Suchindran was a member of the Editorial Board of the Indian Journal of Population and Development. He also served as the Deputy Editor of Demography, Co-editor, Associate Editor and Advisory Board Member of Mathematical Population Studies, Associate Editor, Survey Methodology, and Member of the Editorial Board of Canadian Studies in Population, Demography India, etc. The research acumen of Professor Suchindran is reflected in his book on life table techniques and applications which he authored with Professor NK Namboodiri and more than 250 research papers that he got published in scientific journals of international repute. At the University of North Carolina at Chapel Hill, Professor Suchindran taught several courses including a course on demographic techniques in association with Professor Richard Bilsborrow and maintained a National Institute of Health-funded training grant for 25 years. He was the most passionate about guiding students to pursue their academic dreams. He also served as the Director of Graduate Admissions in the Department of Biostatistics of the University of North Carolina at Chapel Hill for many years.

I first met Professor Suchindran in 1990 when I joined the University of North Carolina at Chapel Hill to pursue my post-doctoral research on a fellowship from the Rockefeller Foundation. At the very first meeting, I was overwhelmed by the generosity and the humbleness of Professor Suchindran. I reached Chapel Hill along with my wife and two kids with only 20 Dollars in my pocket, of which I had spent 16 Dollars at the John F Kennedy Airport, New York before reaching Chapel Hill. Professor Suchindran was already at the airport to receive me and my family and, without any formality, he put 200 Dollars in my pocket and left me at a hotel which he booked for me in advance and asked me to rest with my family because we all were very tired from a long journey. Next morning, he took all the pains to come and helped me to find an accommodation for the stay and paid all expenses by himself.

During my stay of two years at the University of North Carolina at Chapel Hill, I had regular interaction with Professor Suchindran and have many memories of him. He usually sat at the Department of Biostatistics of the School of Public Health of the University, and I had my office at the Carolina Population Center (CPC), but it was never an obstacle in our lively discussions and interactions. He used to call me frequently after lunch and we had discussions on many concepts and thoughts about the subject. He used to explain each concept on a small board that was placed in his room. He always offered me tea during these discussions but he himself took only hot water.

Professor Suchindran motivated me to venture into the new world of data analysis as I was doing pure Statistics manually and happened to be a core mathematical demographer. The motivation of Professor Suchindran encouraged me to start practising data analysis using hazard and logistic models and, in the process, I learnt SAS, LIMDEP and other related statistical software packages. He was my mentor in this new field of academia as I had spent a decade in teaching and research in Statistics and Mathematical Demography. Professor Suchindran gave me ideas about how to interpret the data and to present results of data analysis. I was very much impressed with the knowledge and intelligence of Professor Suchindran over a range of academic disciplines including biostatistics, demography, and data analysis. Professor Suchindran was also instrumental in motivating and training me to give Friday seminar at the Carolina Population Centre having audiences from different academic disciplines. The Friday seminar was a mandatory requirement for all post-doctoral fellows. I found in Professor Suchindran true academician, demographer, and statistician. His teachings have helped me in pursuing my research interests throughout my academic career.

I last met Professor Suchindran in October 2019 before the COVID-19 pandemic when he visited Varanasi after retirement to pay homage to Lord Shiva. He also delivered a lecture at that time to the faculty and students of the Department of Statistics of Banaras Hindu University and interacted with the faculty and students of the Department of Statistics and gave very valuable inputs to the research scholars in pursuing their research.

The death of Professor Suchindran is an irreparable loss to the academic community the world over. I am sure, his teaching and his research will continue to guide the academic fraternity in the coming years.