Spatial characteristics of the sex ratio shift in India

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This study examines the temporal process and spatial characteristics of prenatal sex selection, identified as a major cause of female population deficit in India. In comparison with China, the authors outline the intensity of female mortality surplus resulting from prenatal sex selection and draw parallels between the value of excess mortality resulting from malnutrition and prenatal selection. Regional differences in early childhood (0–6 years) sex ratios and spatial regularities in the districts in India within the normal and skewed ranges are also presented. A correlation is confirmed between the extent of intrauterine sex selection induced by social constraints and its main determinants, such as patriarchal family structure, fertility decline, and, indirectly, religious affiliation. Regional variations in the deterioration and improvement of the feminity rate in the sex ratio transition process based on the 1991, 2001 and 2011 census data are interpreted as well. Based on the trends in child sex ratios from 1991 to 2011, Indian districts have been classified into five statistical clusters. In the absence of current population census data, building upon the trends in sex ratio shifts, a mathematics-based scenario has been generated, indicating probable district wise 0–6 sex ratio values.

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Introduction

One of the most serious social challenges today is the disparity between societal positions of women and men. This is most evident in employment, economic, political, educational and family positions, as well as in women's disadvantages in access to financial resources and opportunities for personal fulfilment. These disparities give rise to serious anomalies that threaten the very existence of a sustainable society.

The rapid pace of socio-economic development we are witnessing in Asia is reducing gender inequalities in income distribution, enhancing women's status in the labour market and community, and changing the institutional environment that negatively discriminates against them. Although this trend is expected to improve their life prospects, large numbers of women are still not reaping the social benefits of societal and economic reforms.

In fact, in some places the demographic corollaries of this material development have also emerged in recent decades, resulting in a new kind of discrimination against women. Since the early 1990s, the proportion of girls in the child population has been falling sharply in some countries, most noticeably in China and India. This phenomenon, brought about by the intensive spread of prenatal sex selection, generated by the expansion of intrauterine sex identification, is responsible for the growing female population deficit, placing an ever-growing burden on these societies. This form of male preference is forcing the states concerned, at least in the medium term, into social determinisms which will entail enormous financial sacrifices and moral hardships (Zagyi 2018, 2021).

This study presents the spatial aspects of the above-mentioned demographic process, that is, the sex ratio shift resulting from prenatal sex selection, which is extremely diverse in terms of its causes and consequences.

Examination methods

The results of the study are based on a synthesis of the literature and the independent processing of data from reliable statistical collections that are relevant to the topic and widely recognised among professionals.

Among the latter, special mention must be made of the source databases summarising the results of the 1991, 2001 and 2011 censuses (Census 1991, Census 2001, Census 2011a–e), whose data, available at the district level, allow for a thorough analysis of the wealth and demographic situation of society, and therefore serve as the primary statistical source for demographic geography analyses.

Also of great help in the preparation of this work were the surveys carried out on demographic and population trends, health status, and the social situation of the population between the two censuses: data available from the National Family Health Survey (NFHS 2007, 2017, 2022) and the Sample Registration System (SRS 2013).

Data processing was conducted using Microsoft Excel in the preparation phase and when calculating variables derived from the raw data. Data tables were then processed in R programming language (R Core Team 2023) version 4.3.2. We also used the 'variable' and 'observation' terms according to their meaning in R.

In order to verify the mathematical relationships between the data series from the above sources, correlation tests were carried out in several cases, using the correlation function *cor()* of R language (Becker et al. 1988) with pairwise complete observations using the Pearson correlation coefficient. Correlation analysis was essential in the process of selecting variables to be incorporated in later cluster analyses.

When creating maps or checking spatial distribution visually in some cases it is imperative to carefully select the groups or categories. When creating maps for feminity rate values we set 15 categories using the equal count (quantile) method, where each class will have the same number of elements. For cluster analysis, the optimal number of clusters was selected, using multiple methods, since no single method is universal. Average silhouette width, total within-sum of square and gap statistics were all checked for each clustering, running the *fviz_nbclust()* function of the *factoextra* R package (Charrad et al. 2014). Cluster stability was also checked with the 'cluster wise cluster stability assessment by resampling' method, using the *clusterboot()* function with 100 resampling runs and *pamkCBI* clustering method (Hennig 2007).

The clusters themselves were finally created with the *pamk()* function setting the number of clusters manually derived from the methods mentioned above. The applied 'partitioning around medoids' process (Kaufman–Rousseeuw 1990) abbreviated as PAM has an advantage of automatically setting one observation as the 'centre' of each cluster instead a theoretically calculated variable value. A 'medoid' is easier to understand and interpret since it is an existing observation in the sample matching a real-life entity, which is always a given district in our case. On the other hand, medoids have no spatial attribute, meaning that the medoid could be a representative 'centre' in the theoretical space of observation values only but not in geographical terms. This could be interpreted as an *n* dimension space where *n* is the number of observed variables. When a medoid is located inside or near the centre of a contiguous spatial area of its own cluster, it is either a mere coincidence or it represents a deeper interrelation, which is outside the scope of this paper.

In the early phase of the research, we also compared PAM and k-means methods on a key scenario, using feminity index (FI) changes in the first (1991–2001) and second period (2001–2011) of our timeline (see Table 1).

Table 1

Clustering method comparison of medoid and cluster centre values of PAM and k-means clustering applying MacQueen algorithm of R's kmeans() function

PAM cluster medoid districts	Normalized values of FI change from PAM clustering on the medoids		Normalized values of FI change of cluster centres from k-means clustering on the cluster closest to each PAM cluster	
	1991–2001	2001–2011	1991–2001	2001–2011
North & Middle Andaman	0.5860264	0.5324863	0.5717009	0.5218326
Panchkula	0.3040510	0.6463213	0.2369854	0.7394728
Jalaun	0.4947360	0.4825679	0.4258161	0.5253436
Mau	0.5866860	0.4098876	0.5894243	0.3967141
Sidhi	0.4758059	0.3031238	0.4383253	0.2929425

Value differences of normalized cluster centres compared to the paired medoid values are not bigger than differences between different k-means algorithms available in the k-means() R function (see MacQueen's, Hartigan–Wong's, Lloyd's algorithms for k-means). With this test we checked that the rarely used PAM method leads to comparable clusters when applied on our database.

To ensure repeatability, all calculations were coded in an R source code program, with the random seed explicitly set before each function call when using generated random number sequences. The simple features package of R (Pebesma 2018) was used to generate geographical maps of India during the calculations. The maps are partly the result of editing work done in ArcGIS version 9.2 and QGIS 3.36 based on the authors' own data input.

Since census districts changed significantly over the study period (Kumar–Somanathan 2009), the otherwise available 1991 feminity index data were superimposed on the 2011 districts to ensure comparability. When matching the feminity index values from 1991 onto the 2011 districts, various scenarios were identified, as summarised in Table 2.

Table 2

District matching versions regarding feminity index values from 1991 onto 2011

Scenario	Example 1991 data	Example 2001 district	Example district
Name change	Old name, FI: 976	New name, FI 976	Kamarajar'91 – Virudhunagar'11 in Tamil Nadu
Divided into many parts	Old district, FI: 976	New part 1, FI: 976 New part 2, FI: 976 New part 3, FI: 976	Delhi
It is the same when a district loses areas, but the remnant goes on with the same or changed name	District losing area, FI: 855	District remnant, FI: 855	
Merger from two or more	District A, FI: 800 District B, FI: 1000 District C, FI: 800	In sources[a)] population percentage or mergers from each source was given: source A: 60% source B: 20% source C: 20% Using percentages as weight for 2011 it results as follows: 800*0.6+1000*0.2+800*0.2 = FI 840	Gandhinagar/Gujarat'11 composed from: Gandhinagar'91: 37.96% Ahmedabad'91: 19.89% Kheda'91: 1.07% Mahasana'91: 41.08% = 100.00%

a) Kumar–Somanathan (2009).

This procedure has allowed us to directly examine changes over time not only by geographic location but also by numerical methods, facilitating the use of only one map having the 2011 district borders throughout the research.

When calculating possible future values for 2024, R language *lm(), poly() and predict(),* functions (R Core Team 2023) were utilized implementing linear models using orthogonal polynomials of degree 1 to 2 over the specified set of data. Although these methods are suitable for extrapolation or estimation of future values in some cases, having a minimal time series of three elements for each census year, our estimation should not be treated as a stable or well-founded forecast with acceptable probability.

The extent and causes of female population deficit

The emergence of the male surplus, identified as a real and growing social problem and as a challenging demographic trend of our times, together with its supposed causes in the background and the extent of the female population deficit, was pointed out by Amartya Sen (1989, 1990) over a quarter of a century ago. As the fundamental cause of the male population excess was observed mainly in Asian countries, he cited women's declining life prospects due to adverse social discrimination – existential marginalisation, weak community (family) bargaining power – and estimated the number of missing women at more than 100 million in the 1990 base year.

This topic has led to recent attempts to calculate a population deficit of 92–102 million people, not significantly changing the originally estimated shortage (Klasen 1994, Klasen–Wink 2002, 2003, Kulkarni 2007), which, by refining their methodology and taking into account additional influencing factors (e.g., natural sex ratios at birth, and mortality differentials), have also set the direction for a new calculation methodology for determining female population deficit.

Bongaarts–Guilmoto (2015) provide a synthesis of this research. In addition to time-series data on the magnitude of the total female population loss since 1970 and the total female population loss projected up to 2050, the authors identify two main factors responsible for female population deficit: prenatal sex selection and negative discrimination against those already born. They also quantify female mortality surplus as a result of each factor.

This puts the number of missing women in the total female population in 2010 at 125.6 million, of which China and India account for 62.3 million and 43.3 million, respectively, a combined share of 84%, which is extremely high even in relation to their demographic weight.

The problem is further exacerbated by both traditional social factors and the growing practice of prenatal sex selection. Traditional factors such as less careful care for girls and financial struggles for women who are divorced or widowed reduce women's chances of survival. Since the 1980s, prenatal sex selection, enabled by early-stage sex determination, has added a new layer of discrimination, contributing to excess female mortality.

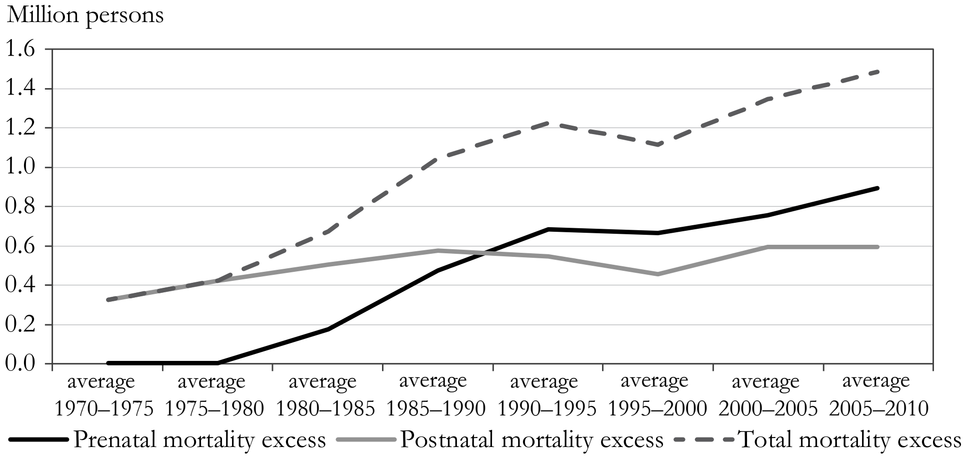
The two countries most involved in creating female under-representation have followed different paths in this process. In China, which started from a much lower level but played a more dynamic role, the population deficit has increased over the last forty years from 6.9% in 1970 to 9.5%: from 27.2 million to 62.3 million, with the postnatal surplus mortality, which rose only moderately and then stagnated. It was exceeded by the value of prenatal mortality surplus, which has been growing rapidly since the first half of the 1990s (see Figure 1).

In India, the trend is partly the opposite. The initial approximately three-fold postnatal mortality surplus declined sharply from the early 1990s, while the rate of the shortfall of female births, which also showed a marked but somewhat more moderate increase from the 1980s, stabilised and only surpassed the postnatal mortality surplus after 2005 (see Figure 2).

As a result, the overall female population deficit, which increased from 21.8 million to 43.3 million in absolute terms, decreased from 8.2% to 7.4% in relative terms. An age cohort-specific analysis of postnatal excess mortality showed that it is predominant in China mainly in cohorts older than 30 years and in India among children under 5 years. Taking into consideration the life expectancy at birth of Indian women over the period 2005–2010, a figure abnormal in comparison with the expected natural mortality rate of 119 boys/100 girls for children under 5 years of age was found: 88 boys/100 girls (UNFPA 2012).

Figure 1

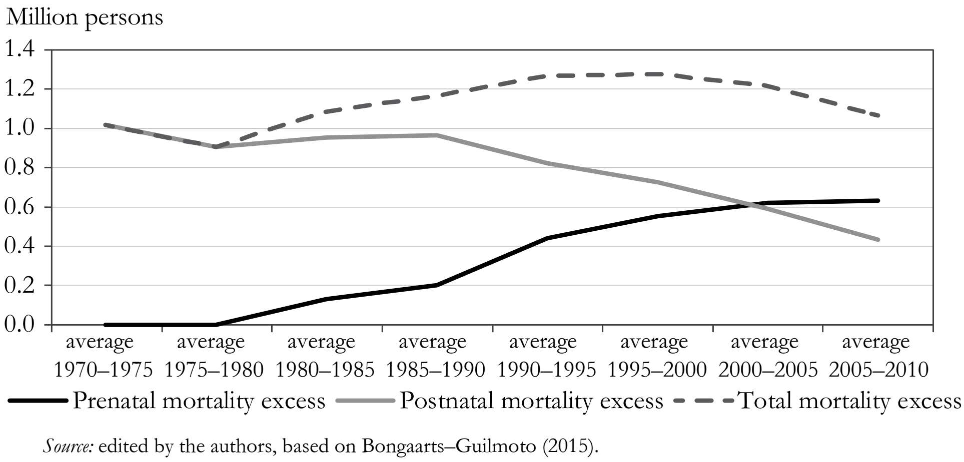
China's female population mortality surplus expressed as a five-year period average



Source: edited by the authors, based on Bongaarts–Guilmoto (2015).

Figure 2

India's female population mortality surplus expressed as a five-year period average

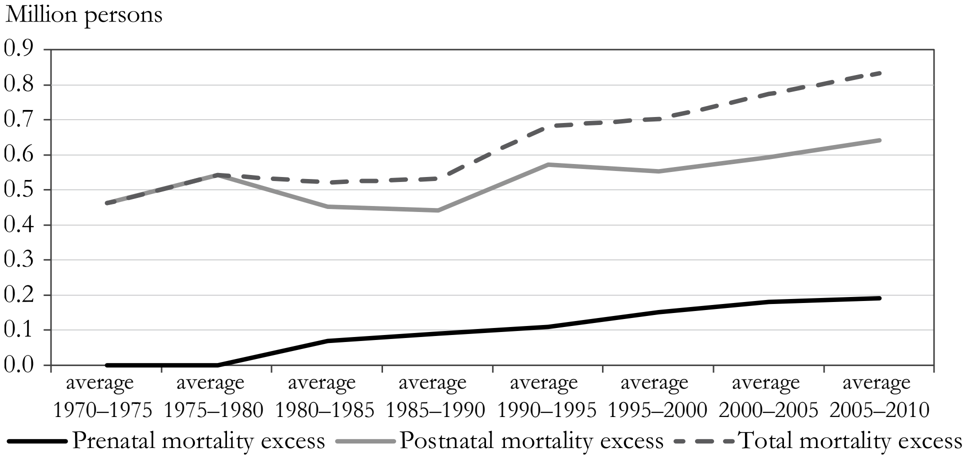


Source: edited by the authors, based on Bongaarts–Guilmoto (2015).

The rest of the world, with a more moderate growth rate compared to China and India, saw a 20 million (16%) female deficit in 2010, compared to 12.1 million in 1970, under half of this shared by just three countries: Pakistan, Bangladesh, and Nigeria. It is also clear that the role of sex-based prenatal selection in the development and growth of the female deficit has always been smaller due to the lower socio-economic development of these three countries and has not even approached the mortality surplus induced by traditional discriminatory instruments (see Figure 3). Until today, intrauterine sex selection has been most widespread (in addition to China and India) in the Caucasus countries and Vietnam, which otherwise only account for a small share of the global population deficit (Guilmoto 2009).

Figure 3

Five-year period average excess mortality of the female population in the rest of the world (excluding China and India)



Source: edited by the authors, based on Bongaarts–Guilmoto (2015).

The above figures alone suggest that social discrimination against women and the resulting mortality surplus can be seen in the same context as the effects of overpopulation, which has become a global problem, with the consequences of population growth exceeding the rate of economic development: mortality surplus caused by food supply problems, security risks, and environmental damage.

Societal factors impacting prenatal sex selection and spatial implications of sex ratio shift in India

In the following, an attempt is made to verify the links between motivational factors of male preference, patriarchal family structure, fertility decline and religious affiliation, and the sex ratio skewedness resulting from the spread of prenatal sex selection, and to show their spatial implications. This includes a summary of the comparison of these motivational factors as indicators of the extent of socio-economic constraints and the data series containing regional values of sex ratios for children 0–6 years old (feminity indices in thousands of units, as adapted to the Indian statistical data processing system) recorded in the 2011 census. Fortunately, most factors influencing or counteracting sex ratio bias can in most cases be interpreted as population groups for which the census database contains a feminity index. Thus, its values can be used to directly theorise about the role of the indicator in sex preference.

India also shows extreme variation in terms of territorial disparities, seen in the size and population of the states and union territories that make up the top tier of administrative units. As some of these are vast in population and size, and therefore the territorial disparities even within a state can be significant, with the fault lines often not following the boundaries of member states, it is certainly justified to include data for the 640 districts that existed at the time of the 2011 Census, corresponding to the next level of territorial division. The inclusion of the age group 0–6 years as a reference is justified by the lack of sufficiently detailed (district-level) records on the distribution of secondary (at birth) sex ratios. Along with the impact of prenatal sex discrimination, we can demonstrate the influence of the trend of girls' mortality rates, which are higher than those of boys, and contradict biological trends.

Spatial patterns of sex ratios in early childhood

Before analysing the actual impact of the motivational factors of female dispreference on femininity rates, let us look at the spatial pattern in the values of the latter at district level and regularities that can be detected in it, based on the 2011 census data (see in Appendix Figure A4).

A characteristic feature of the spatial pattern of sex ratios is a clear distinction between the parts of the country with normal and those with more or less skewed figures. The region to the southeast of the Goa–Sikkim line[1] (see in Figure A4 the E–G axis), whose unitary block appears to be in the phase of breaking up. The exclave formed by the northeastern districts of Ladakh and Himachal Pradesh have districts with mostly balanced sex composition. The northern, northwestern part of the country, by contrast, almost invariably has districts with abnormal sex composition.

Among the spatial characteristics of the northwestern part of the country showing a sex ratio deviance, dividing the area into two distinct parts is the axis running from Khambhat Bay to the Indo-Gangetic Plain, roughly along the Vindhya Range, and therefore referred to as the Vindhya line on the authors' own initiative (see in Figure A4 the D–F axis), connecting relatively balanced (normal or slightly skewed) sex ratio districts. Within each of these, a formally distinct core area of high masculinity can be identified, consisting of districts with predominantly lower than 870 feminity ratio

[1] The term Goa–Sikkim line or axis applied to the relevant topographic fault line was introduced into the literature by the authors in their previous publications.

and above average socio-economic development (Wilhelm et al. 2010, Wilhelm 2011, Zagyi et al. 2021). The northern core area is formed by a region including a significant part of the states of Punjab and Haryana, fanning out between the Gwalior–Srinagar and Gwalior–Bikaner axes (see in Figure A4 the C–A and C–B axes). The southern core area is formed by the districts of the western part of the state of Maharashtra around the Aurangabad–Jalna centre (see the ellipse in Figure A4 between the D–F and E–F axes). These centres are joined by clusters of districts of triangular or concentric shape, following the shapes of the centres, showing an improvement first in the 870–909 and then in the 910–939 feminity value range.

The relationship between social constraints and sex selection

The relationship between patriarchal family structure and sex ratio skewedness

Patriarchal social structure is difficult to grasp statistically, and the relationship between the sex ratio shift in favour of boys and men can only be investigated indirectly, by including indirect indicators of the presence or absence of a male-centred family model, which also sets the limits of this experiment.

Research on the Indian traces of matriarchy (matrilinearity) reveals that it is found, albeit sporadically today, among the South Indian[2] and tribal populations (Ehrenfels 1953, Jeffrey 2004), considered to be the indigenous peoples of the subcontinent. On this basis, we have reason to posit that male preference, which is much less common among them, will have a smaller influence on the extent of sex ratio shift. In addition to the regional picture of the district-level variation in sex ratios described above, this expectation is confirmed by the fact that, in contrast to the 919 feminity index for the total population aged 0–6 years, its values for the population of the scheduled tribes and South Indians are 957 and 946, respectively, falling within the range of the normal excess of male births (962–943 girls/1000 boys) (Census 2011a). All of this suggests indirectly but with a high degree of certainty that patriarchal family structure as a social constraint is a principal determinant of gender-biased sex selection in India.

The relationship between fertility and sex ratio

When discussing the relationship between prenatal sex selection and population fertility rates, the logical claim is made that the socio-economic constraints on patriarchal communities, manifested in boy or male preference, are strong. Consequently, the degree of intolerance to the birth of girls is further increased when the fertility of the population is reduced either by natural demographic processes or artificial, administrative interventions (Guilmoto 2009, Kulkarni 2019).

To verify the existence of a link between this demographic phenomenon and sex ratios, and to establish its true magnitude for India and to illustrate its spatial

[2] The term of South India or South Indian is used for refering to the five states of Dravidian language family (Andhra Pradesh, Telangana, Tamil Nadu, Kerala and Karnataka) or to their population.

implications, we can show its strength by inferring the correlation coefficient between the 2011 feminity indices and total fertility rates for the 0–6 age groups in the country's districts. The former data are available from the census database, whereas the latter can only be obtained indirectly by taking into account crude birth rates calculated from the size of the population aged under seven, infant and child mortality rates, and the number of women in reproductive age. The detailed calculation methodology is published by Guilmoto–Rajan (2013), who provide in the annex to their publication the fertility rates for all but one member state at the time of the previous census. As the age group population figures recorded during the census for Jammu & Kashmir are presumed not to reflect the real situation, the data obtained are not suitable for calculating further population indicators. From this state, only the fertility rates of the three southernmost Hindu-majority districts of Kathua, Jammu, and Samba are known (Guilmoto–Rajan 2013).

As a first correlation test, due to the omitted districts of Jammu & Kashmir, the corresponding data for 621 administrative units were compared instead of 640 for the whole country. It was predicted with a high degree of certainty that no significant correlation between these two variables would be found in this reference range. This is simply because, as can be seen from the graph showing regional differences in fertility rates, the low fertility areas coincide to a significant extent with parts of the country south-east of the Goa–Sikkim line. As recorded earlier, they are largely unaffected by the male preference constraint due to the high proportion and dominance of tribal and South Indian populations, where fertility decline is unlikely to induce a sex ratio shift (see in Appendix Figure A1). The expectation was confirmed by the correlation coefficient obtained from these two data series, whose sign is still just positive, but its value is practically zero: 0.014.

In light of the above, it seemed appropriate to limit the contextual analysis to the districts northwest of the Goa–Sikkim line. They are strongly patriarchal and include the Indo-Aryan cultural core area. In doing so, the territorial scope of the data range consisting of 334 elements (districts) was extended to the eastern–southeastern borders of Maharashtra, Madhya Pradesh, Uttar Pradesh, and Bihar, in line with the internal borders of the member states that most closely approximate the aforementioned socio-cultural dividing line. The latter state, bisected by the Goa–Sikkim axis, is included in its entirety, as it forms an integral part of the region in cultural terms and because of the negligible presence of the scheduled tribes (1.3%). In line with their preliminary hypothesis, the authors were able to confirm the existence of a moderate correlation between the variables, indicated by the correlation coefficient of +0.34. This relatively low value suggests two things: that this type of demographic constraint has only a marginal effect on the sex ratio shift process and that additional confounding factors sway the correlation.

As regards the mathematical methods to prove a closer link between sex ratio shift and fertility decline, it is the population share of the scheduled tribes again that can lead to a solution. To do so, we need to consider this: the higher than average proportion of tribal population with little or much less patriarchal social relations is not unique to the region southeast of the Goa–Sikkim line. There are states northwest from this axis that have a higher proportion of the scheduled tribes than the national average of 8.6%. We can demonstrate an even stronger relationship, with a coefficient of +0.53, when the data ranges excluding the feminity indices and fertility rates of the districts of these states (Jammu and Kashmir, Rajasthan, Madhya Pradesh, Gujarat, and Maharashtra) are correlated, that is, if we restrict the correlation analysis to the Indo-Gangetic Plains, which still comprises 187 districts and a population of 392 million (2011), almost a third (32.4%) of India's total population. This, in addition to the influence of fertility decline in amplifying prenatal sex selection, indirectly supports the effect of tribal social organization against female discrimination.

The relationship between religious affiliation and sex ratio shift

In India's geography of religion, we refer to the possibility of a direct sacral (Hindu) or indirect relationship based on historical traditions and occupational preferences (Sikh, Jain) between the religion of a given community and its relation to the sex composition of its child and youth population, as well as the incidence and prevalence of prenatal sex selection. We believe that there a number of factors suggest a link between these two social indicators. Still, it would be a serious mistake to generalize about religious aspects as there is no necessary and universal determinism in the application of sex selection between religious affiliation and discrimination against girls and women, even in the form of excess mortality.

Among the six religious denominations forming separate statistical groups – the Hindu, Jain and especially the Sikh – those for whom specific social motivations for intolerance of female childbearing can be identified, the feminity index for the 0–4 age group is below the national average, which is itself abnormally low (see Table 3). In their case, therefore, the practice of intrauterine sex determination and prenatal sex selection can be taken for granted.

Table 3

Feminity rates of the Indian population and the respective religious denominations in the total population and in the age group 0–29 years*

Age groups	Total population	Hindus	Muslims	Christians	Sikhs	Buddhists	Jains
Total population	943	939	951	1,023	903	965	954
0–4 years	924	919	947	960	836	933	896
5–9 years	914	910	938	960	804	934	874
10–14 years	912	908	935	968	779	933	873
15–19 years	884	873	929	987	804	908	882
20–24 years	935	929	947	1,052	917	956	949
25–29 years	975	971	988	1,071	955	971	982

* In 5-year breakdown.
Source: edited by the authors, based on Census (2011b).

Regionally, no easily identifiable traces can be found of a sex-ratio shift linked to religious denominations for Hindus and Jains, assuming a certain degree of spatial concentration and population share. In the region northwest of the Goa–Sikkim line, there is virtually no district where Hinduism is not the largest or, rarely, the second largest religious community, while there is no district where Jainism is at least the second most followed religion. Their spatial patterns are therefore not suitable for comparison with regional variations in sex ratio skewedness. The situation is different for Sikhs. It is well known that, according to their original homeland, the vast majority of them live in the state of Punjab and the border districts of neighbouring Haryana and Rajasthan, while in the rest of the country, except for Delhi, they are found in insignificant scattered patches. Thus, the extreme masculinity in the same space confirms the spatial correlation between the share of Sikhs and the female population deficit.

As far as Buddhists, Muslims, and Christians are concerned, no facts or phenomena can be identified as determinants of prenatal sex selection, either doctrinally or in terms of traditional social motivations associated with religious affiliation. This is confirmed by the 2011 feminity indices for children 0–4 years old (see Table 2), which for Buddhists are minimally below the lower limit set at 943. With some flexibility in this respect, we can say that the early childhood sex ratios for all of them can be considered normal. In the 5–19 age groups of the Buddhist and Muslim communities, we find stagnant to declining or steadily but slightly decreasing feminity rates, indicating continuously falling excess mortality of girls. However, its magnitude and intensity do not reach a level that would necessarily or predominantly indicate the prevalence of prenatal sex selection. They raise the possibility of patriarchal social relations in terms of male preference.

Christians stand out among all denominations. Their sex composition does not show any anomalies as the sex ratios of children aged 0–9 indicate a normal birth excess of boys. This is in accordance with biological determination, and in the gradually ageing groups of children, in line with the regular pattern of survival of the sexes. We can see a gradual decline in the preponderance of boys: the abnormal excess of female mortality, typical of the Indian population and unique worldwide, is absent. The moderate female predominance in the total population, which is hardly different from the ideal sex distribution, is also a curiosity in India.

Of the three religious communities, in the case of Christians in particular, and to some extent Buddhists, a link can be seen between their spatial concentration and normal sex composition, although for Christians this link is indirect. Christians, who are overwhelmingly concentrated southeast of the Goa–Sikkim line and are almost exclusively represented there as the most populous or second most populous religion, typically influence feminity rates through two social factors that counteract female discrimination: their belonging to the tribal and/or to the South Indian population.

As regards the spatial aspects of the apparent link between the presence of Buddhism and balanced childhood sex ratios, we can refer to the Buddhist block comprising the northern part of Ladakh and Himachal Pradesh, with the Buddhist population concentration in the eastern part of Maharashtra state as a complementary element that is less clearly visible in the value of the feminity indices.

Interpretation of the sex ratio shift, and its implications for India

In recent years, research on the evolution of sex ratios has repeatedly suggested the possibility that in male-centred societies, sex ratios in a specific transition process first gradually become skewed and then shift towards a levelling off. The result is the re-establishment of a normal sex composition, in line with the natural excess of male births and age-structural characteristics (Chun–Das Gupta 2009, Guilmoto 2009). In our view, the sex ratio in patriarchal communities is determined by its relationship to a particular stage in a state sequence, its change over time predominantly influenced by social necessities (Wilhelm–Zagyi 2012, 2013, Wilhelm et al. 2014).

As proof of the existence of this model, the example of South Korea is often cited, a traditionally male-dominated state in East Asia, which in socio-economic development has been ahead of the two giants, China and India. There, the male surplus was already evident and much more pronounced, with the feminity index at birth reaching a nadir of 870 in 1990, and then gradually improving as the transition impacting sex ratios progressed, before returning to its natural level by now (Chun–Das Gupta 2009).

Some stages of the process are the constraints of male preference, the dominant factor in which is the patriarchal social order, the diagnostic conditions and material resources that allow for intrauterine sex identification as a possibility, and finally the legal constraints and social incentives against prenatal sex selection, according to the authors' interpretation on the existence or absence of such constraints and incentives, detailed as follows.

In the initial phase of the transition process, in a society burdened by economic, demographic, and cultural constraints on the birth and upbringing of male offspring(s), there is evidently a strong preference for boys. However, in the absence of real methods to prevent the birth of girls, the only means of discriminating against girls who are born are those of varying effectiveness but with limited overall influence on sex ratios. Legal sanctions for discrimination in this form do exist (at least in theory) at this stage already, but in practice they have no deterrent effect due to the lack of publicity and evidence. In other words, the combination of strong social constraints and the absence of effective methods of sex selection results in relatively balanced sex ratios. This phase lasted until the turn of the 1970s and 1980s.

In the second stage, the effects of the constraints are just as strong, but the continuous penetration and modernisation of technical innovations, such as the availability of prenatal sex determination devices and their accessibility to a growing part of the population, means that the sex ratio at birth is becoming increasingly skewed. It is at this stage that the anti-discrimination laws imposed by the mass introduction of prenatal sex selection are coming into force. Their impact on the sex ratio, however, remains imperceptible, given the blatantly low number of cases brought for their violation and the continuing decline in the feminisation rate. Thus, the combination of social pressures visible in male preference, the ever-modernising means and methods of prenatal sex selection, and the rise in discretionary incomes that make it possible to use them, is leading to a growing and sometimes extreme sex ratio shift. This transition is still underway in the country as a whole.

In the third phase, which we hope to see in certain areas of the country and among particular social groups, we are already witnessing the emergence of social modernisation in the western sense: a change of attitude, the rise of globalisation, the decline in the patriarchal family model, the preference for male births is declining and tolerance of female births is increasing, which, although methods of sex identification will continue to exist and may even be modernised, will lead to a gradual improvement and levelling out of the feminity rate, which has reached a negative peak. Legislative restrictions and sanctions, if they had any role to play before, are clearly losing further relevance at this stage. Thus, the weakening of social constraints on prenatal sex selection despite the availability of technical and financial means to achieve it effectively leads to a reduction in the abnormally high sex ratio gap.

In the second, but especially in the third phase, we must also consider the impact of demographic pressure resulting from the decline in natural population growth. In fact, this is a phenomenon that can be seen as a sub-system of a change in social attitudes, a shift to the western value system, but it has just the opposite effect: it encourages male births.

In the final stage, which for India as a whole is still hypothetical, valid only for the distant future and for a limited territorial and population range, the preference for boys as a consequence of known socio-economic constraints will disappear completely. Its absence will be permanent, regardless of the level of development of methods of sex identification, which in reality will remain high, and the presence or absence of restrictive legal institutions. In other words, the absence or limited presence of social constraints, combined with the high technical level of foetal or embryonic diagnosis, will result in sex ratios that are levelled off or stabilise at very close to levelling. The basic concept is that the existence of this transition can only be demonstrated in areas where patriarchal social determination is given.

The full details of the process are still to be worked out. According to the most respected researcher on the issue, the French demographer Christophe Z. Guilmoto (2009), sex ratio transition is still an assumption based on partially identified trends in the evolution of sex ratios at birth and can be considered as the overture of a heuristic discovery. The following is an attempt to point to the signs of sex ratio transition in India within the authors' own interpretation of the transition.

In communities with a male-centred cultural value pattern, one determinant of the size of the sex ratio shift, at least in terms of opportunities, is the availability of the financial means to perform prenatal sex identification and subsequent prenatal sex selection (Guilmoto 2008). This is most clearly indicated by the differences in the degree of sex ratio skewedness between higher-income urban and poorer rural populations. However, a comparison of the relevant data also shows that the social pressures that result in discrimination against girls also impact disadvantaged groups (scheduled castes, the homeless, slum dwellers). For the latter, however, the excess of girls' postnatal mortality is largely or exclusively responsible for the abnormal sex ratios (see Table 4).

Table 4

Sex ratios of those in the 0–6 age group among disadvantaged social groups in India

Denomination	Total population of India	Scheduled castes	Homeless people	Residents of urban slums
Total population	919	933	932	922[a)]
Urban population	905	922	920	–
Rural population	923	936	941	–

a) Only for urban type settlements.
Source: edited by the authors, based on Census (2011a, 2011c, 2011d).

By monitoring the sex composition of children aged 0–6 over time, further significant observations can be made. In this study, the magnitude and direction of change in the sex ratio values recorded by district in the last three censuses were compared (see in Appendix Figures A2, A3, A4).

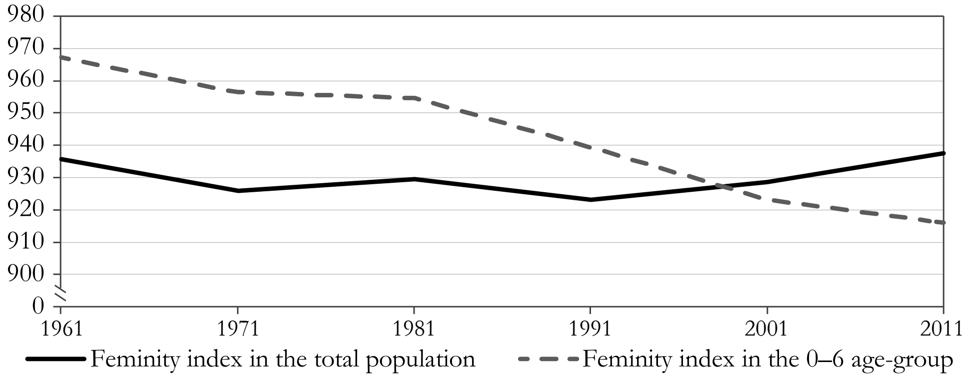
As we have assumed above in the interpretation of sex transition, it is obvious that India as a whole, and in particular the region northwest of the Goa–Sikkim line, is the scene of the social processes characteristic of the second phase of the transition. The region is not simply a case of abnormal sex ratios, except for a few districts, but also of declining feminity indices within an already skewed range of values in a large part of the territory. However, as the dynamism of the deterioration in the feminity index for the total population aged 0–6 have moderated over the last decade (see Figure 4), it also seems likely that some places show signs of moderation in masculinity among the population entering the third stage of the sex ratio transition.

Regional differences in the change in sex ratios confirm this assumption. Areas with abnormal feminity rates more than two decades ago and still deteriorating form four well-defined blocks. The largest of these is the region which first widens in a rhombus-like shape and then narrows, connecting Western Rajasthan and Central Bihar. This is followed by a group of districts south of the Vindhya line, previously identified as the central core area, by districts in the eastern part Uttarakhand state, and finally by the Mahanadi River delta region (Odisha), mostly linked by districts that have joined the sex ratio decline process in the last decade.

Finally, in line with the earlier assumptions of the study, at least two regions can be identified that in the authors' opinion entered the third phase of the sex ratio transition at the beginning of this millennium. The process, which is taking place in the northeastern part of Gujarat, concerning a relatively small area and population, is being repeated on a larger scale in the Sikh-majority Punjab–Haryana region, with the lowest feminity rate, typically less than 800 in 2001, but which has now improved significantly in this respect and is at the forefront of socio-economic development and the following of western values. The decrease in female population deficit, i.e. the start of the increase in feminity rate, which has reached its lowest point, is presumably also influenced by the growing social value of girls resulting from their deficit in the population (Diamond-Smith–Bishai 2015).

Figure 4

Evolution of sex ratios in India



Sources: edited by the authors, based on Census (2011e).

Clusters on feminity index changes over 1991–2011, and possible future trends

After observing different trends in the change in the feminity index of the 0–6-year old population between 1991 and 2011, we investigated what characteristic groups emerged. The partitioning around the medoids resulted in five cluster groups (see Table 5, and in Appendix Figure A5).

The results of the cluster analysis seem to confirm our theses formulated above about the social and territorial aspects of boy preference and sex ratio transition. It is indeed possible to identify a population or regional cluster in which the feminity ratio has stagnated over a longer period, or even improved to a small extent, where, as a result of human intervention, sex ratio distortion in early childhood has not occurred (*neutral cluster*). Since this period coincides with the extensive spread of prenatal sex selection, the social constraints manifested in the intolerance of female births are not or only slightly enforced in the population of this cluster. These clusters largely coincide with areas where South Indian and tribal populations are found in greater proportions, the resistance of matriarchal and matrilineal social traditions that survive even indirectly and unconsciously against women's discrimination can indeed be identified.

Table 5

Clusters and their medoids of feminity index value changes of those in the 0–6 age group

Cluster #	Our classification	Medoid district of the cluster	Feminity index 0–6 years population change from	
			1991–2001	2001–2011
1	NEUTRAL	Andaman & Nicobar Islands UT/North & Middle Andaman	–2.75	0.41
2	RAPIDLY IMPROVING	Haryana/Panchkula	–59.34	21.44
3	HEALING	Uttar Pradesh/Jalaun	–21.08	–8.80
4	TURNING DOWN	Uttar Pradesh/Mau	–2.62	–22.22
5	FREE FALLING	Madhya Pradesh/Sidhi	–24.87	–41.94

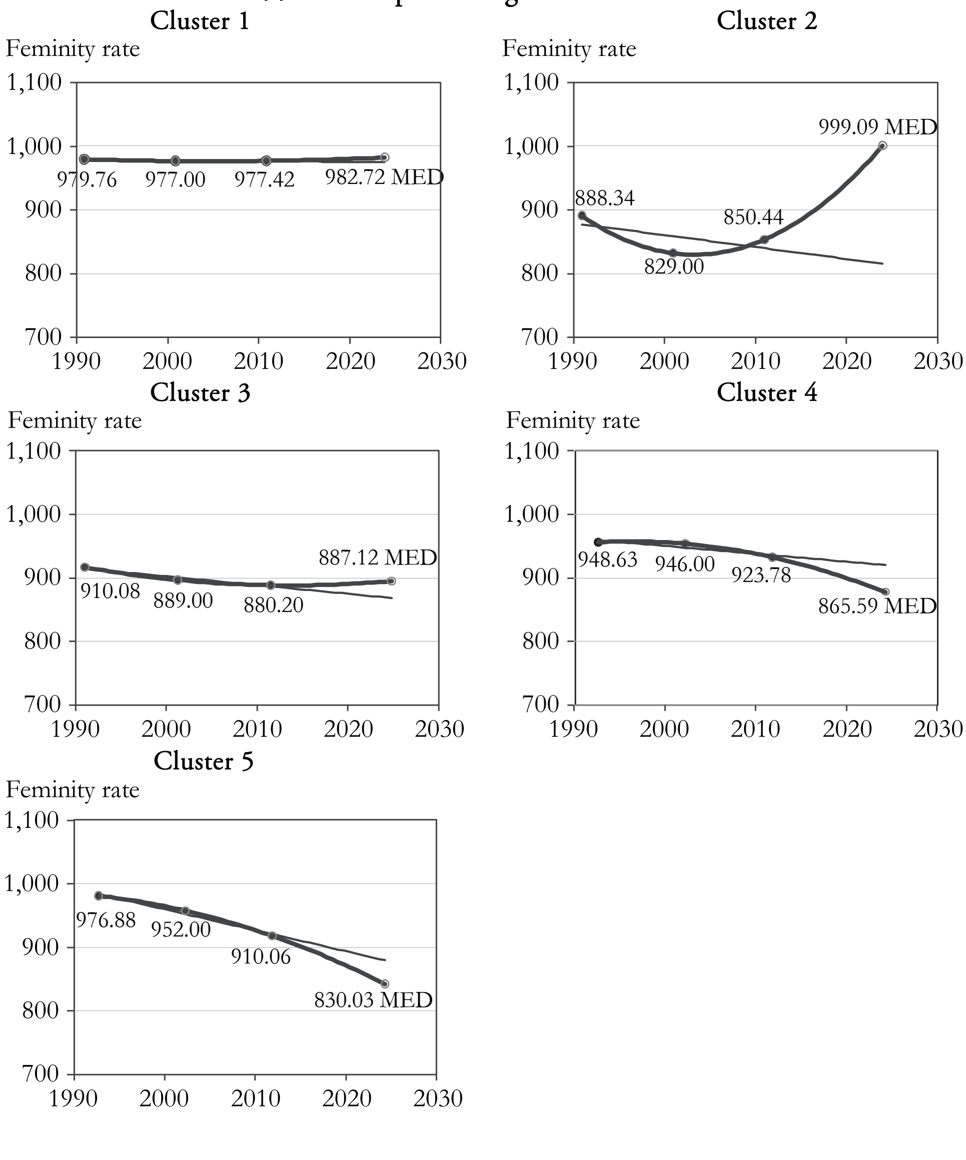
This, however, does not mean that there are no districts southeast of the Goa–Sikkim line that do not show a worsening trend in terms of changes in feminity ratio. It only means that such districts are predominantly located northwest of the given axis, while they only partially occur southeast of it. Particularly noteworthy in this regard are the districts that form a bag-like northwest–southeast direction infiltration, extending through the states of Telangana, Andhra Pradesh, and Tamil Nadu, roughly along the Hyderabad–Puducherry axis. The exact reason for this has not yet been clarified. It is almost certain that there are multi-component social reasons in the background, among which, according to our preliminary investigations, the religious factor does not play a significant role.

It is also clear that the majority of the country's population is in the second phase of the sex ratio transition, characterized by a decrease in feminity ratios, a lack of female children (ages 0–6). However, this group cannot be considered homogeneous at all, since three distinct clusters can be identified based on the degree and direction of the change in the feminity ratios in the negative value range. The largest contiguous cluster, roughly covering the area of the Hindi belt, is found in the initial, negative phase of the deterioration of the feminity ratio (*cluster turning down*), while the more radical *free falling cluster*, characterized by sex ratio distortion towards the bottom, appears in island-like blocks (Western Maharashtra, Eastern Rajasthan, Northern Uttarakhand). The third cluster, called *healing*, typical of parts of Central and South India south of the turning down cluster, represents a movement towards a healthy sex ratio composition, even though it is still in the negative value range. Finally, similarly to the falling down cluster, in smaller and larger, but decidedly contiguous areas (Punjab, Haryana, and Central Gujarat) the *rapidly improving cluster* appears, in which sex ratio composition has achieved a huge improvement from the extremely distorted state in the direction of a balanced feminity ratio. This cluster matches the third phase of the sex ratio transition.

As for future trends in cluster-specific feminity rates, we found it worth examining the data for a conservative scenario, even though the three-item time series of districts may be inadequate for traditional trend analysis. After trying several methods, we chose linear prediction based on each district's own 2001–2011 period for 0–6-year feminity index values. The calculated value for 2024 was then corrected by the second degree prediction of the cluster medoid belonging to the district over 1991–2011 (see Figure 5).

Figure 5

First and second degree models for each cluster's medoids over 1991–2011 predicting a new value for 2024



The method involved calculating the simple average of the two deltas (Δ1 and Δ2) for the 2011–2024 period where one was the change predicted from the district's linear model and the other one was the delta of the second order estimation for the medoid. The calculated delta (Δa in Appendix Figure A6) value was then added to the known 2011 data for the respective district. This solution allowed us to correct the district-specific trend for cluster-specific dynamics. The resulting values are illustrated in Appendix Figure A7, using the same 15 groups and quantile method as for Figures A2, A3 and A4.

In accordance with the results of the cluster analysis revealing the characteristics of the change in the feminity ratio of the population aged 0–6, and its spatial pattern (see in Appendix Figure A5), our district-level scenario for 2024 based on the demographic dynamics of each cluster (see in Appendix Figure A7) shows that the primary dividing line between regions characterized by balanced and more or less distorted sex ratios is still the Goa–Sikkim axis. To a large extent, districts located to the southeast of this line belong to the neutral or *healing clusters*. As a result of lack of interest in the enforcement of preferences and a relatively low level of sex ratio deterioration, in this part of the country predominantly healthy sex ratios can be pre-indicated at present.

Different degrees and directions of vibrant movements can be experienced in the areas located northwest of the above mentioned axis. The basic dynamics of the sex ratio shift is determined by the dominance of the *turning down cluster*. The almost completely compact block of districts belonging to this area covers the Hindi belt area from Rajasthan through Madhya Pradesh and Uttar Pradesh to Bihar. Since these clusters embody the state of the feminity ratio tipping from a normal situation to a negative direction for the period between 1991 and 2011, here, depending on the unique characteristics of each district, a moderate or stronger, but not extreme excess of boys reflected in the feminity ratio between 850 and 920 may be assumed. To the northwest of the main fault line, smaller and larger islands of homogeneous composition matching the *free falling cluster* show a deterioration of the sex ratio in the same direction as the former, but to a much more radical extent. Consequently, in western parts of Maharashtra state, northeastern Rajasthan, and northern parts of Uttarakhand, districts with a feminity ratio of less than 800 can be found, which indicates a significant shortage of girls aged 0–6. A process in the opposite direction and at a pace exceeding all others, reflecting the transition from the negative low point to the positive range, the return to a state with a balanced gender composition can be identified in the states of Punjab and Haryana, and to a lesser extent in the central part of the state of Gujarat, which primarily include districts belonging to the *rapidly improving cluster*. According to our scenario in 2024 typically feminity ratios above 950 can be calculated here, corresponding to the normal excess of male births.

However, it is also necessary to note that although some districts had sex ratios exceeding 1,000, which means that there are more girls than boys in the examined age group, this only points to certain limitations of the mathematical model that forms the basis of our scenario. An excess of girls among 0–6-year olds could only occur in cases of extreme male mortality, given the generally prevailing normal excess of male births (which typically results in feminity ratios between 940–960).

Summary

One of the fundamental reasons for female population deficit, particularly in China and India, is prenatal sex selection, which stems from the socio-economic constraints of the patriarchal family model. The two countries have followed different trajectories since the 1980s. In China, which now plays a much more dynamic role, the value of the prenatal female mortality surplus, which has been growing rapidly to date, exceeded the postnatal mortality surplus as early as the first half of the 1990s. In India, the trend was partly the opposite, with the already much higher postnatal mortality surplus declining sharply from the early 1990s. The rate of the backlog of female births showed a somewhat more moderate increase, only after 2005 surpassing the mortality surplus of babies born and now appearing to stabilise. However, in both countries, the value of the prenatal female mortality surplus now exceeds the child mortality rate of males and females, caused by malnutrition.

A distinctive feature of the spatial pattern of sex ratios for children 0–6 years old in India is a clear distinction between the parts of the country with normal and those with more or less skewed values. In the area southeast of the Goa–Sikkim line, running northwest to southeast, and in the exclave formed by the northeastern districts of Ladakh and Himachal Pradesh, the proportions are mostly balanced. By contrast, in the north and northwest, districts show almost exclusively abnormal sex compositions.

Another spatial structural feature of the northwestern part of the country that shows a sex ratio bias is that the axis running from Khambat Bay to the Indo-Gangetic Plain, roughly along the Vindhya Range, and consisting of districts with normal or only slightly skewed sex ratios, divides the area into two distinct parts. In each, a central area of distinctly high masculinity can be identified, predominantly consisting of districts with a feminity ratio of less than 869. The northern core area consists of the region between the Gwalior–Srinagar and Gwalior–Bikaner axes, which widens out in a fan shape to include a large part of the states of Punjab and Haryana, whereas the southern core area consists of the districts of the western part of Maharashtra around the Aurangabad–Jalna centre.

In contrast to the low feminity index for the total population aged 0–6 years, this value falls within the range of the normal excess of male births among the scheduled tribes and the South Indian population. By contrast, the Indo-Aryan cultural area, based on patriarchal tradition, has a markedly high masculinity value in this age group.

The authors interpret patriarchal family structure as a social constraint, which is the dominant determinant of prenatal sex selection.

The value correlations of the feminity indices and fertility rates for the age group under study in the states and union territories northwest of the Goa–Sikkim line with tribal populations below the national average, that is, Uttar Pradesh, Bihar, Delhi, Haryana, Punjab, Chandigarh, Uttarakhand, and Himachal Pradesh, suggest a strong relationship between these two variables. This confirms the effect of fertility decline in amplifying prenatal sex selection and indirectly supports the effect of tribal social structure against female discrimination.

In India's geography of religion, we posit a direct sacral (Hindu) or indirect relationship based on historical traditions and occupational preferences (Sikh, Jain) between the religion of a community and the sex composition of its child and youth population, as well as the incidence and prevalence of prenatal sex selection. We believe that several factors suggest a link between these two social indicators, but it would be a serious mistake to generalize about religious aspects. There is no necessary and generalized determinism in the application of sex selection between religious affiliation and discrimination against girls and women, even in the form of excess mortality. This is a fact even though there is a clear practice of prenatal sex selection among Hindus, Sikhs, and Jains, whereas among Muslims, Christians, and Buddhists, the data suggest that sex selection is not prevalent. The differences in sex ratios observed in the respective religious communities are explained by the presence or absence of secondary social preferences that exist independently of religious doctrines.

Results of the cluster analysis have confirmed that India as a whole and more specifically the northern and middle parts of the country are in the second phase of the sex ratio transition, which is clearly indicated by the demographic processes reflected in the *turning down* and *free-falling clusters*. The improvement in the feminity ratio appearing in a smaller area and population circle, embodied by the *healing* and *rapidly improving clusters*, indicates that social movements characteristic of the third phase of the sex ratio transition can already be detected. The presence of the *neutral cluster* signifies that certain regions and population groups are not or only less affected by this type of demographic transition.

In light of new census data coming in the future, it will be useful to recalibrate the current basic projection model and to re-examine the correlations of changes, especially of the feminity index, with other indicators over a longer time scale.

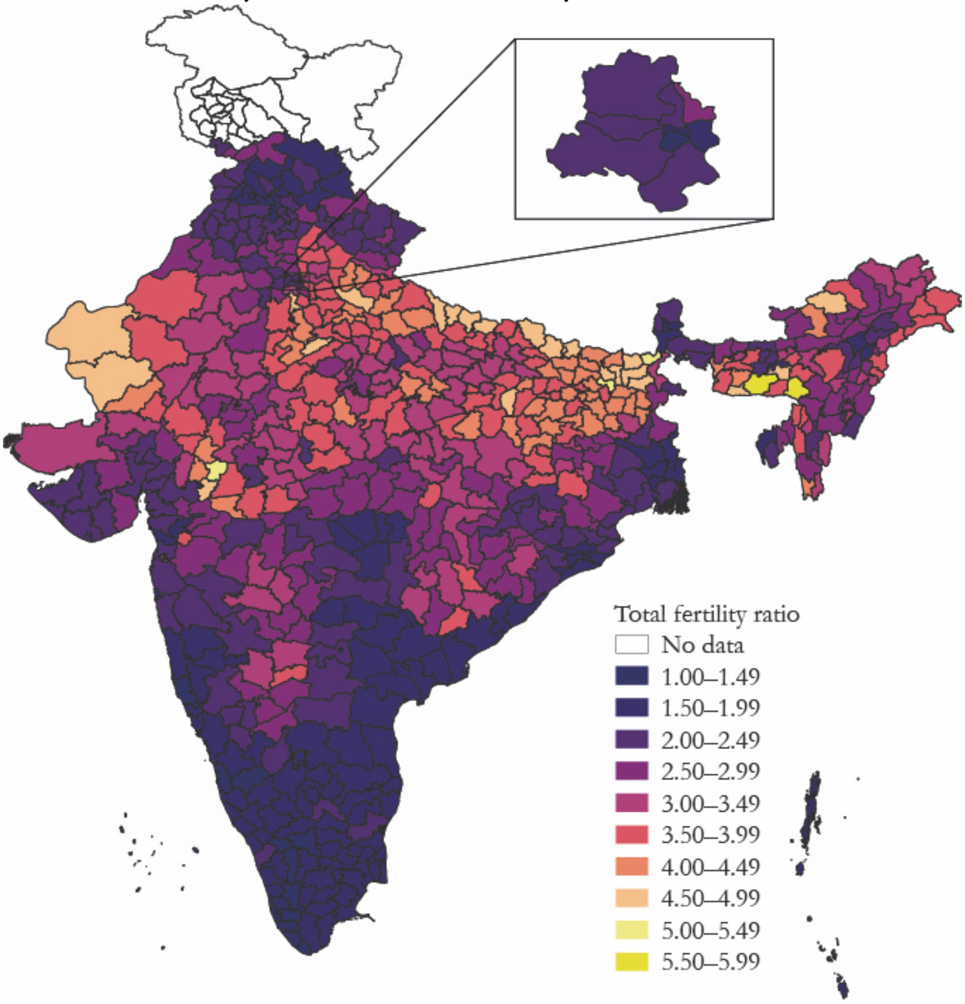
As for actionable and policy making issues relating to the deterioration of feminity ratios arising since the 1990s, both prohibitive and encouraging initiatives have been taken. Among the former are the laws prohibiting sex identification and selection (Pre-Natal Diagnostic Techniques [Regulation and Prevention of Misuse] Act, 1994; Pre-Conception & Pre-Natal Diagnostic Techniques [Prohibition of Sex Selection] Act, 2003). In addition to legal constraints, union and state governments also aim to alleviate the discrimination faced by many economically disadvantaged parents of girls and girls themselves by providing financial incentives (Balika Samridhi Yojana; Danalakshmi Plan; National Scheme of Incentives for Girls to Secondary Education; Apni Beti Apna Dhan; Ladli Lakshmi Yojana; Balri Rakshak Yojana etc.) (Sekher 2012).

Based on our previous research, we believe that existing efforts to address sex ratio imbalances have only a limited impact on mitigating the issue. While attempts to correct the unhealthy sex composition of the population – particularly among children and young adults – are commendable and not entirely ineffective, their influence on improving feminity ratios appears to be modest. This is reminiscent of the similarly limited success of past efforts to manage the demographic explosion. In our view, the observed improvements in sex ratios are more likely the result of a spontaneous shift in social attitudes. This shift can be attributed to the influence of western value systems and the increasing social value placed on girls, driven in part by their declining population (Zagyi 2018, 2021, Wilhelm–Zagyi 2012, 2013, Diamond-Smith–Bishai 2015).

Appendix

Figure A1

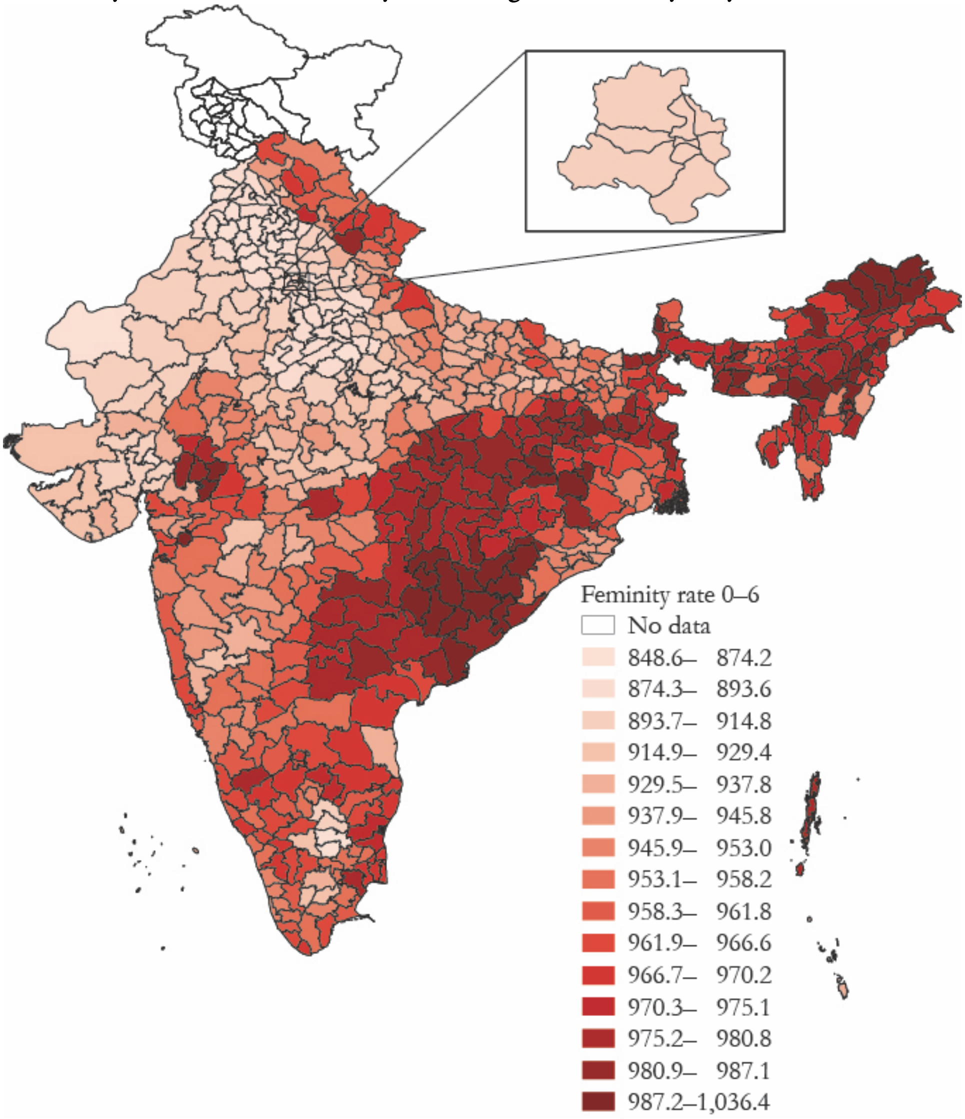
Regional differences in fertility of the Indian population by district-level total fertility rates in 2011



Source: edited by the authors, based on Guilmoto–Rajan (2013).

Figure A2

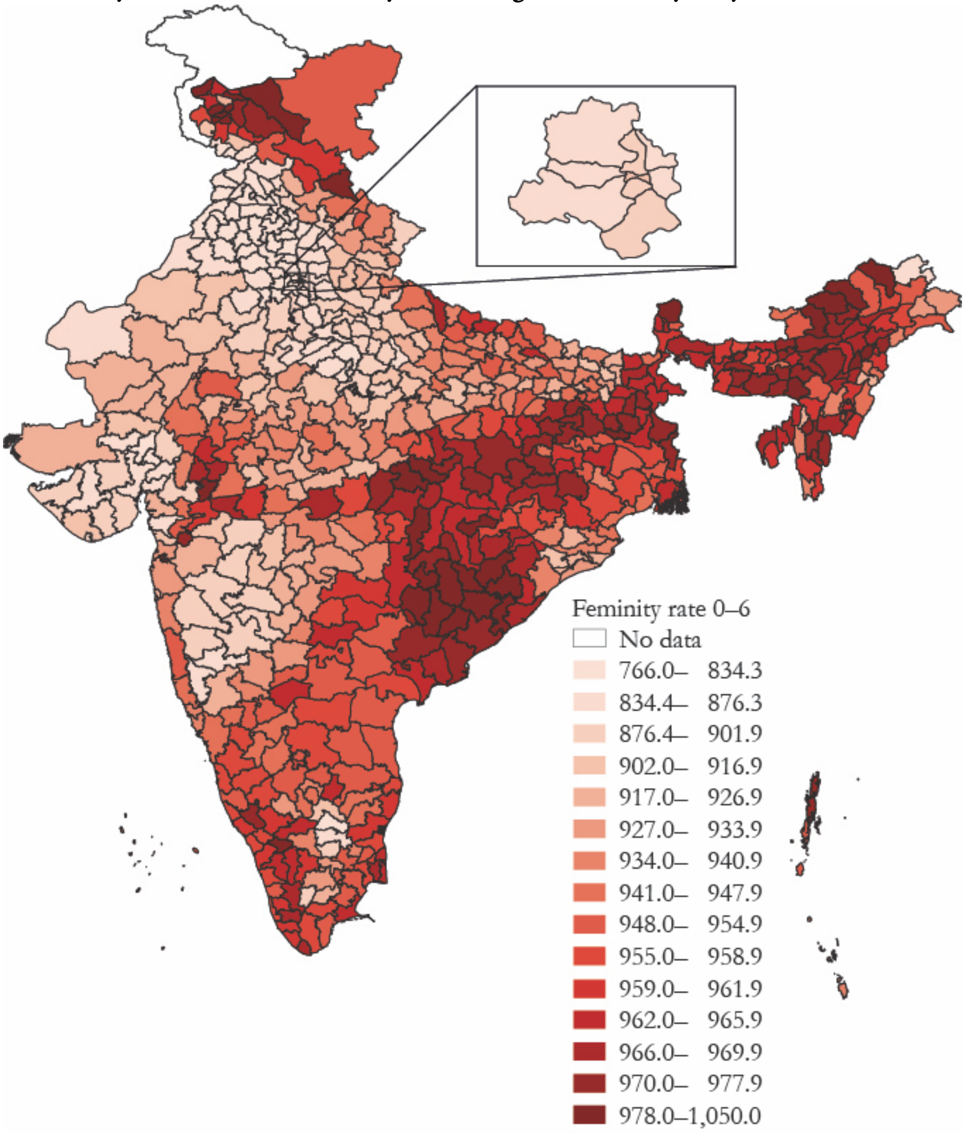
Feminity rate of children 0–6 years old (girls/1000 boys) by districts in 1991



Source: edited by the authors, based on Census (2011a).

Figure A3

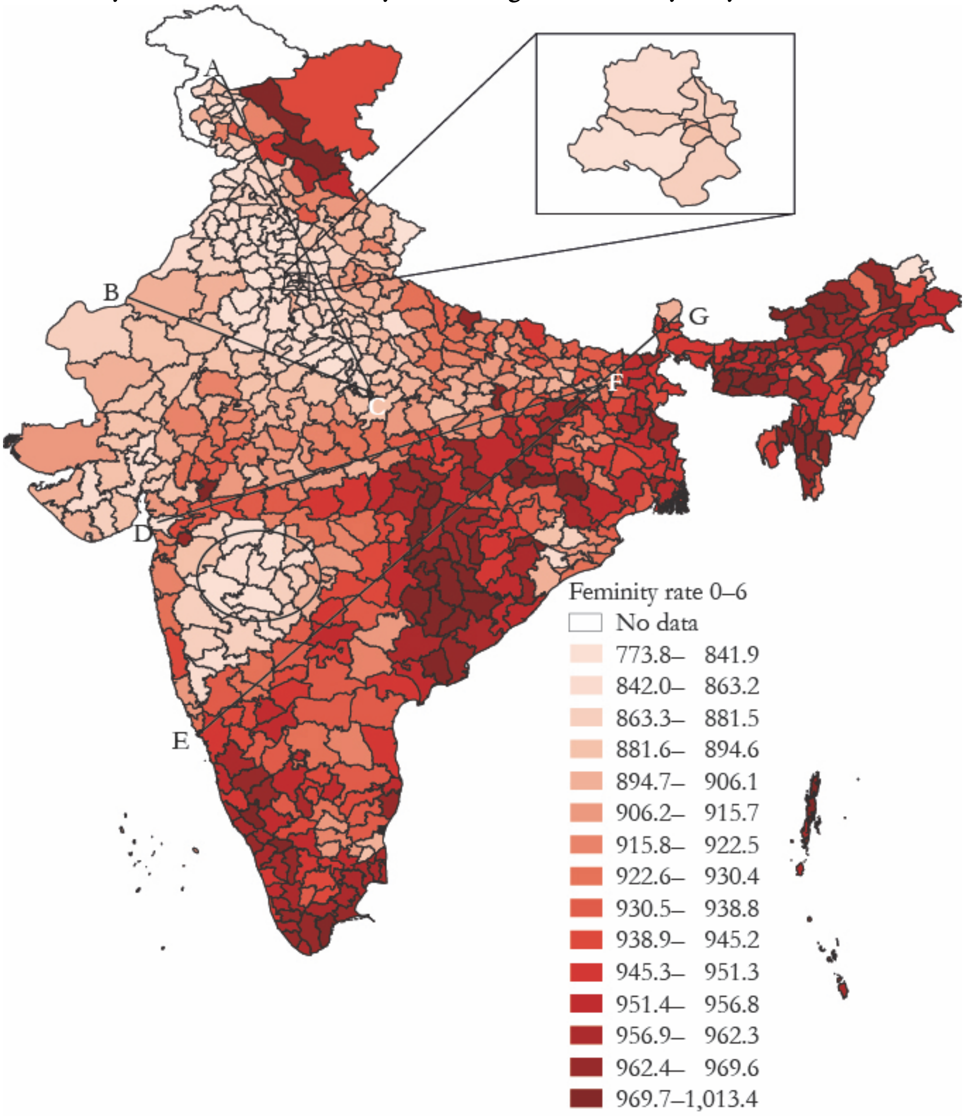
Feminity rate of children 0–6 years old (girls/1000 boys) by districts in 2001



Source: edited by the authors, based on Census (2011a).

Figure A4

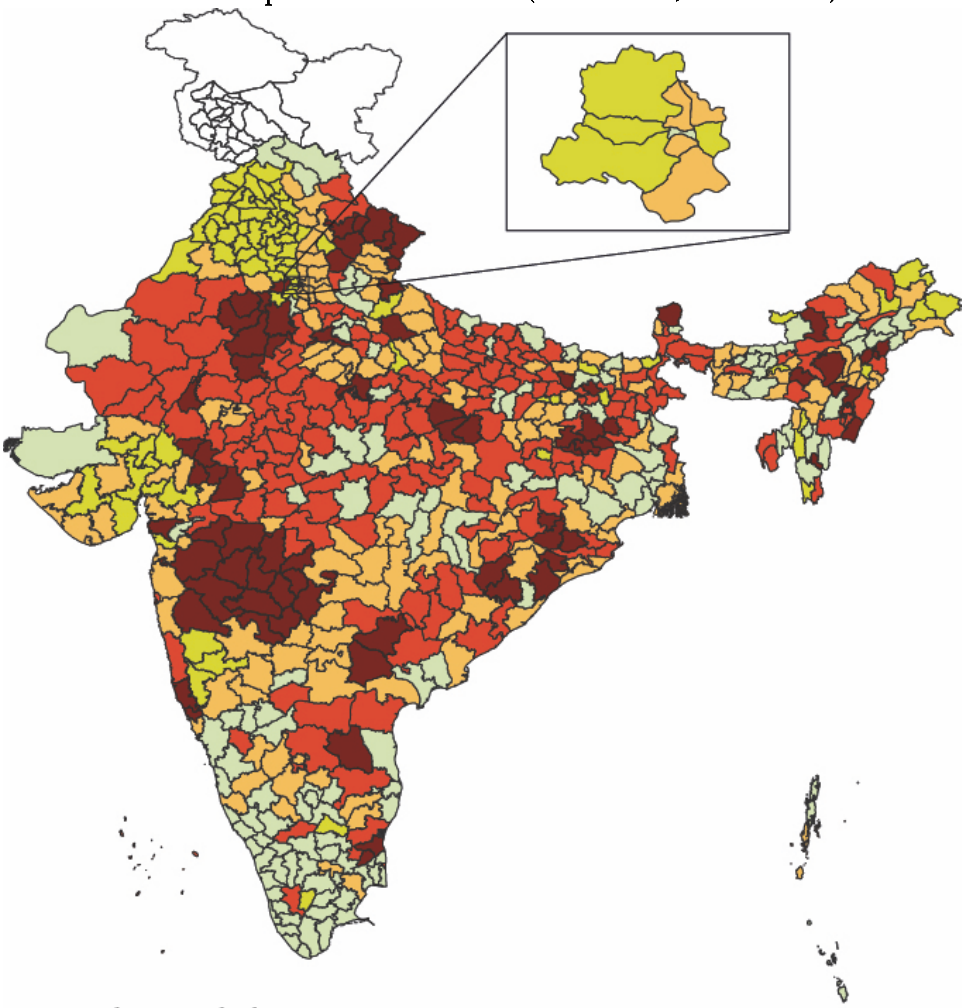
Feminity rate of children 0–6 years old (girls/1000 boys) by districts in 2011



Source: edited by the authors, based on Census (2011a).

Figure A5

Clusters on 0–6-year old population feminity index changes in the two periods under review (1991–2001, 2001–2011)



Cluster and their medoids

- 1 NEUTRAL Andaman & Nicobar Islands UT/North & Middle Andaman –2.759 0.219
- 2 RAPIDLY IMPROVING Haryana/Panchkula –59.342 21.4439
- 3 HEALING Uttar Pradesh/Jalaun –21.078 –8.800
- 4 TURNING DOWN Uttar Pradesh/Mau –2.627 –22.223
- 5 FREE FALLING Madhya Pradesh/Sidhi –24.877 –41.940
- No data

Figure A6

Example of the simple method correcting individual scenarios of districts

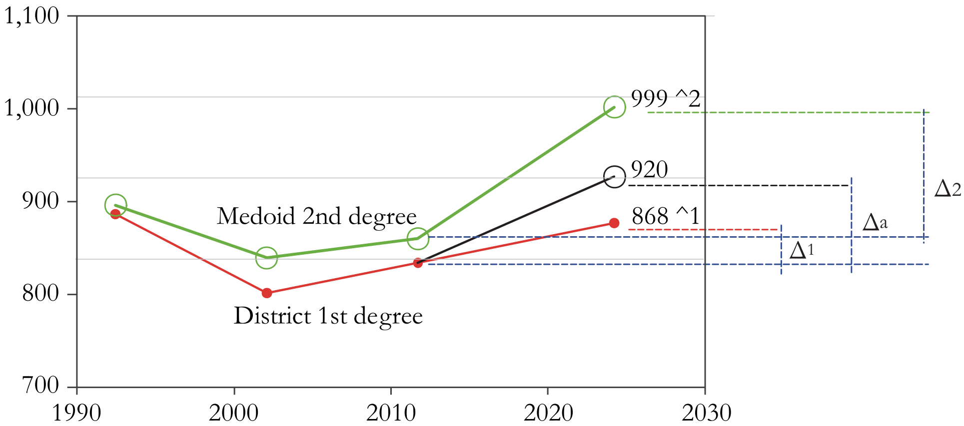
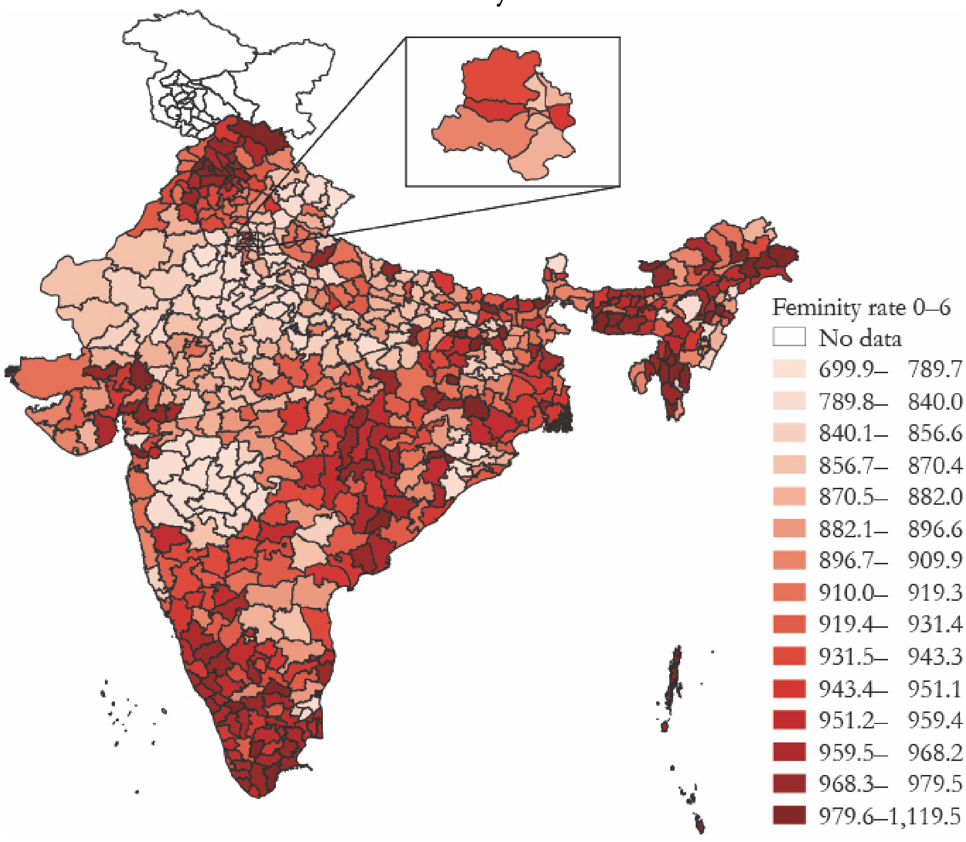


Figure A7

District wise 0–6 feminity rate scenario for 2024



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