Spatial assessment of the gender bias in child mortality at the district level in India, 1991-2011

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Introduction

As observed with many indicators, there is substantial local variation in sex ratios in mortality in India, reflecting the varying extent of daughter-neglect across subnational areas. Enormous rural-urban, inter-state, but also district-level differentials are observed when estimating excess female child mortality (Murthi et al. 1995; Guilmoto et al. 2018). The female disadvantage in survival has been consistently larger in the states from the northern and central parts of the country. The southern states have much lower child mortality rates and there is also less evidence of sex discrimination. According to Guilmoto et al. (2018), four northern states only account for two-thirds of the excess female deaths (Uttar Pradesh, Bihar, Rajasthan and Madhya Pradesh).

A large body of the demographic and epidemiologic literature has been devoted to identifying socio-cultural determinants of daughter neglect, and capturing spatial variations (Arokiasamy, 2004; Bhattacharya, 2006; Guilmoto et al., 2018; Murthi et al. 1995; Ram et al., 2013). Because censuses allow mapping sex-specific mortality at the district level (the basic administrative unit in India), this has been the most extensively used source to shed light on the issue. For each district, summary birth histories (the total number of children ever born and surviving reported by women classified by 5-year age groups) can be converted into life table survivorship probabilities, using Brass's method (Hill, 2013). In this study, we also use summary birth histories to obtain sex-specific mortality rates and extract district-level covariates from the 1991 and 2011 census data. However, we examine subnational variations in the female disadvantage from a new angle, adding a level of modelling sophistication by allowing the relationships between the independent variables and excess female mortality to vary by district. Based on the 1991 and 2011 census, we resort to geographically weighted regression (GWR) to analyze the possible heterogeneity in the associations between female disadvantage and a range of socio-economic factors that have been investigated in the literature.

Data and methods

Estimating sex ratios in under-five mortality

The Registrar General of India conducts Census in India every ten years. This study is based on the 1991 and 2011 censuses, aggregated at the district level. All women of childbearing age were asked to report on the total number of children ever born and children surviving. We computed the proportion dead of children born to women in each 5-year age group, in all districts, separately for boys and girls. These proportions were then converted in under-five mortality rates using the standard indirect method (Hill, 2013). The method resorts to coefficients obtained from model age patterns of mortality and fertility to map the proportion dead of children from each age group of mother to a corresponding estimate of a life table probability of dying by exact ages of childhood. The method also calculates the number of years before the census date to which the estimates refer. All the age-specific estimates are converted in under-five mortality rates using again a model life table. We used here the South Asian model life tables and regression coefficients available in United Nations (1982). Some district boundaries have changed between 1991 and 2011. For this study, however, the districts in 1991 were considered as the reference, and districts that had been separated in recent years were merged into the original district. In total, we retained 449 districts. We excluded districts from Jammu and Kashmir because the census had not been conducted in these districts in 1991. We also excluded the districts of Lakshadweep, Andaman and Nicobar Islands due to the difficulty in defining spatial neighbours for these islands calculate the bandwidth in the GWR. Only 1% of the population in 1991 and 2011 was excluded from this analysis. When reporting on regional differences, we distinguish between the six quasi-official regions of India (Central, East, North, Northeast, South, Western) (Appendix 2).

Assessing the female disadvantage in mortality

When comparing sex ratios of mortality across districts to measure to extent of female disadvantage, we need to account for the level of under-five mortality in each district, because, as indicated earlier, shifts in disease patterns that go along the mortality decline will alter the sex ratios. To do so, an expected relation should be defined between U5MR and sex ratios.

Hill and Upchurch (1995) provided estimates of the expected female-male ratio for under-five mortality for various estimates of male under-five mortality ($U5MR^{m}$), by intervals of 25 deaths per thousands. To obtain values of this ratio for any value of the male U5MR, we fitted the locally weighted regression (loess) on data from the Human Mortality Database (2018), for the same set of countries and periods as used in Hill and Upchurch (1995).. Further, U5MR ratio for required male U5MR for a district was obtained by approximating the predicted U5MR ratio for males in standard population. The index of female disadvantage is expressed as the observed female-to-male ratio for a specific district minus this ratio for in the standard for the level of under-five mortality observed in males in the data:

$$I_i = \left(\frac{U5MR_f}{U5MR_m}\right) - \left(\left(\frac{U5MR_f}{U5MR_m}\right)^s \mid U5MR_m\right)$$

A positive value of $I_i$indicates a female disadvantage, because the ratio of female to male mortality is higher than expected given the overall level of male under-five mortality. A negative value indicates a female advantage, relative to that expected based on male under-five mortality. Hill and Upchurch (1995) note that it is impossible to be certain that this standard reflects the situation that would be expected if gender inequalities were due solely to genetic or biological variations, as some discrimination may also have occurred against girls in the countries covered by this standard. They also note that the distribution of causes of death that prevailed at the time in these countries could be very different from that prevailing in countries for which female disadvantage is being analyzed. These limitations are shared with our study. However, this index has the advantage of standardizing for the level of mortality when comparing countries or subnational areas, and Costa et al. (2017) have shown, by applying this approach at the national level, that the rankings of countries obtained in this way are very close to those obtained if the relationship between sex ratio and mortality are captured from the broader experience of all countries in the world, without seeking to develop a discrimination-free standard.

Exploring variations in the associations between explanatory variables and the female disadvantage

The set of explanatory variables considered in this study are captured at the district level and constructed from the two sets of census data. Many of these variables are similar to those used in Bhattacharya (2006)'s analysis. Total fertility rate for each district was estimated using the P/F ratio method proposed by Brass (United Nations, 1983) and included to control for fertility levels. Population density per square kilometre is also included to control for the demographic characteristics of the population. Social variations are reflected in the percentage of the district's population reported as Muslim, the percentage of the population belonging to scheduled castes, and the percentage of the population belonging to scheduled tribes. Scheduled tribes and castes are officially designated groups of disadvantaged people, comprising respectively 8.6 and 16.6% of the population in the 2011 censuses. The economic condition of households in each district is measured from the percentage of non-agricultural workers, urbanization and the percentage of households with access to electricity. The percentage of households with sanitation facilities and the percentage of villages with access to medical facilities are used to reflect the health environment of each district. Gender inequality, a key determinant of female disadvantage in under-five mortality in the existing literature, is captured through the ratio of male/female literacy rate and the ratio of male/female workers. Other key indicators of socio-economic status (such as income per capita, poverty rate), health infrastructure (medical staff, health expenditure per capita), or environmental exposure were not available at the district level from the censuses and were not used in this study. Other than the mentioned variables, several other variables such as solid fuel use, access to pucca roads etc. capturing each of these dimensions were initially considered in the analysis. However, due to higher multicollinearity estimates, those variables were excluded from the final analysis.

Local indicators of spatial autocorrelation (LISA) statistics were first used to identify 'hot spots', that is, local clusters of districts presenting atypical values of the index of female disadvantage (Anselin and Bera, 1998). Spatial dependence in the district-level estimates of each indicator was assessed using Moran's I Index (Global) value. Computation of spatial autocorrelation requires constructing a matrix, known as spatial weights neighbourhood matrix (W), to quantify the spatial proximity for each observational unit (district). In this analysis, contiguity based weights (queen) with all first order neighbours were considered in generating the spatial weights neighbourhood matrix. We then applied OLS models to obtain coefficient estimates at the global level. OLS models also helped identify the covariates to be retained before moving on to the GWR. Multicollinearity was assessed through variance inflation factor (VIF) values while deploying OLS models. This final list of selected variables was retained for both the OLS and GWR analyses. To explore the varying relationships between the index of female disadvantage and socioeconomic predictors, we used geographically weighted regression models. The bandwidth size was determined based on minimum Akaike Information Criterion (AIC). The main advantage of using GWR modelling is that researchers can map the local coefficients as well as R^2 and better identify spatial heterogeneities (Wang and Chi, 2017).

Following Fotheringham, Brunsdon, and Charlton (2003), the basic equation of the GWR model is expressed as:

$$y_i = \beta_{0i}(u_i, v_i) + \sum_{n=1}^{k} \beta_{ni}(u_i, v_i) x_{ni} + \varepsilon_i \qquad (1)$$

where y_i refers to the index of female disadvantage in the district *i*, (u_i, v_i) denotes the coordinates of the centroid of district *i*, β_{0i} is the local intercept for the district i, and β_{ni} is the local coefficient for predictor *n* for district *i*. In GWR models, the regression coefficients were estimated for each district independently by applying district-specific weighting schemes. There are as many 'local' regression models as there are observations (Wheeler and Tiefelsdorf, 2005). The vector of local coefficients is estimated as: $\beta_i = (X'W_iX)^{-1}X'W_iY$ (2) where X is the matrix of independent variables and Y is the vector of dependent variables. The estimator in equation (2) is a weighted least squares estimator where the weights vary according to the location point of *i*. There are a variety of weighting schemes available for researchers (Fotheringham et al., 2003). We chose the Gaussian weights and their bi-square variations, which are the most commonly used options. Thus in equation (2), W_i is an n×n diagonal matrix with the j-th diagonal element equal to $[1 - (d_{ij}/b)^2]^2$ if $d_{ij} < b$ and zero otherwise. d_{ij} refers to the Euclidean distance between location *i*, where the parameters are estimated, and a specific point in space *j* at which data is observed (Fotheringham et al., 2003). The parameter b is the bandwidth size (i.e., the distance between each observation and its neighbouring locations specified by the spatial weights). Finally, we tested for non-stationarity of the local parameter estimates estimated from GWR analysis by conducting a non-stationarity test developed by Leung, Mei, and Zhang (2000).

Results

Figure 1 presents the index of female disadvantage in mortality and the LISA clusters from the 1991 and 2011 censuses. The index of female disadvantage in 1991, averaged across the 499 districts, was 0.29, with a range varying from -0.15 to 0.89. There was a clear divide in the extent of female disadvantage, with more than 43% of the districts in the North (Punjab, Haryana, Himachal Pradesh, Uttarakhand, Delhi) showing values higher than 0.3. Further, more than 60% districts in the Central (Rajasthan, Uttar Pradesh, Madhya Pradesh and Chhattisgarh) and East (Bihar, Jharkhand, West Bengal) have estimate for more than 0.30. In other words, the female-to-male ratio was more than 30% higher than expected based on the level of male under-five mortality in these districts around 1986-1987. The mean value of the female disadvantage was maximum in East 0.42 in 1991, followed by Central (0.35), North (0.29), West (0.24), South (0.23), and finally the North-east region (0.18). The LISA cluster map based on the 1991 census shows significant geographical clustering with high values of this index (high-high clusters) in the three pockets of districts located in the northern part of India. On the other hand, the map shows a few cold spots with substantially lower values of female disadvantage in southern India and a few districts from northeastern and northern India. The area showing extreme values of the female disadvantage (>0.3) is greatly reduced in 2011, and the average of this index has declined to 0.16 (with IQR -0.58-0.74). 22 clusters now show lower-than expected sex ratios. However, the most striking finding from these maps is that, despite the decline in the female disadvantage, there has been only modest changes in the LISA maps, with respectively 55 and 46 districts falling in "high-high" clusters in 1991 and 2011, and 46 and 32 districts falling in low-low districts.

Figure 1: Index of female disadvantage in India and significant LISA clusters (1991 and 2011 censuses).

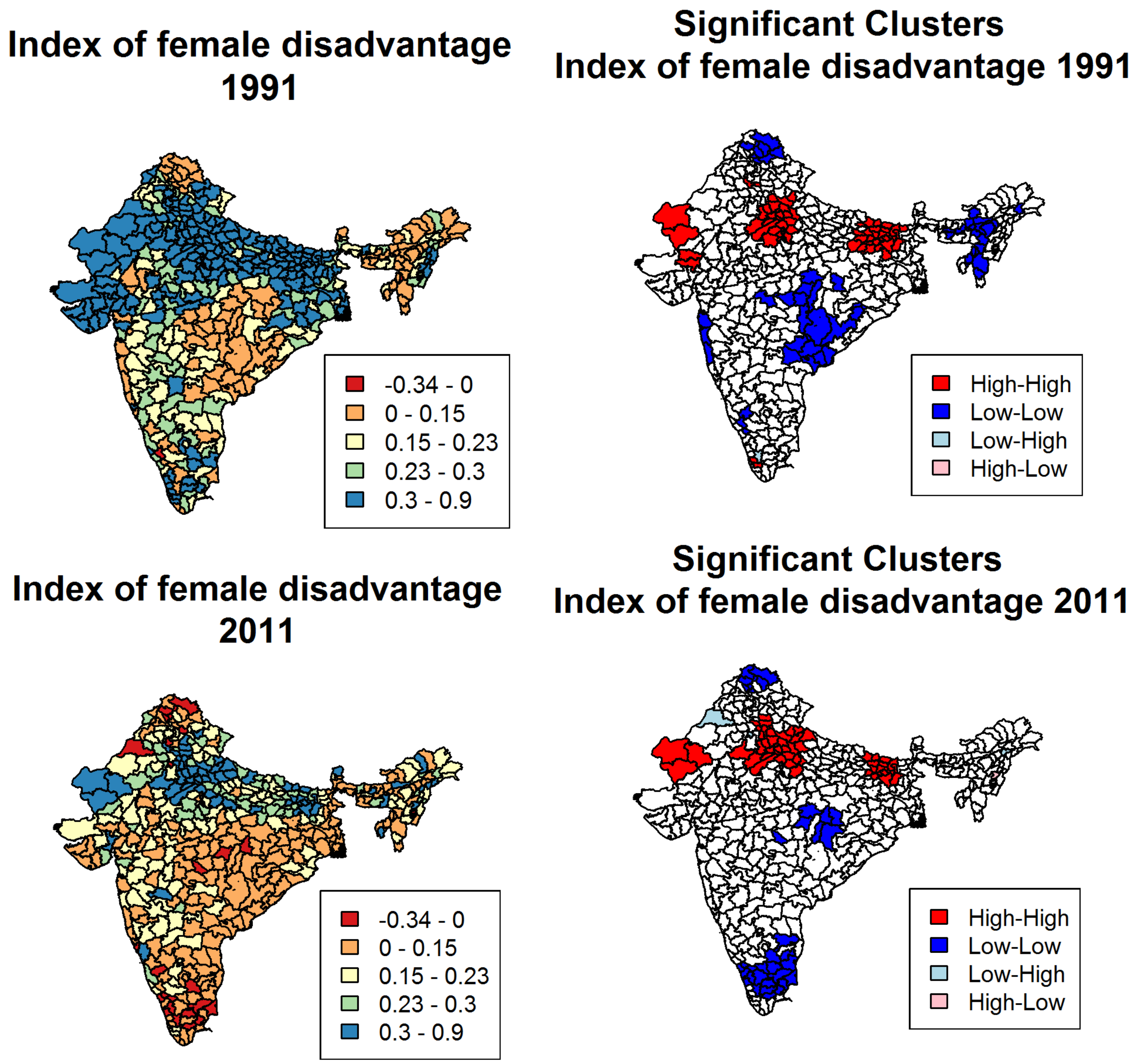


Table 1 shows that the Moran's I index value was significant for each of the explanatory variables used in this study, indicating a significant spatial autocorrelation in both censuses. Coefficients from the OLS model (Table 2) show the expected relationships between the district-level index of female disadvantage and the demographic, socioeconomic and health-related factors. These relationships are also consistent over time. According to estimates from both censuses, districts with high fertility face significantly higher female disadvantage. This magnitude of this relationship was much stronger in the recent census (2011). The percentage of the population belonging to scheduled castes or tribes is negatively associated with female disadvantage, as is the percentage of the population reported as Muslim. By contrast, access to a medical facilities (1991: β=0.0013, $p<0.001$; 2011: β=0.0005, $p<0.05$) or sanitation (2011: β=0.0013, $p<0.001$) was significantly and positively related with the index of female disadvantage in child mortality. However, increased access to electricity, which is a strong indicator of economic condition of the district, was negatively associated with the index in both periods. An increase of one percent of households with electricity in the district is associated with a reduction of the female disadvantage by 0.0014 points in 1991 and 0.0005 points in 2011. Gender inequality in literacy and work force participation also contribute significantly to explain the variation in gender bias in mortality in both census. Finally, the proportion of non-agricultural workers was significantly negatively associated with the index of female disadvantage only in the 2011 census while population density was significantly associated only in 1991. Under-five mortality is not included among the covariates, since it is already controlled in the index.

Table 1. Moran's I global index for variables in this study, 1991-2011.

Censuses	1991	2011
Index of female disadvantage	0.6356***	0.4101***
TFR	0.7243***	0.7668***
Population density	0.0494*	0.0667**
% of the population in scheduled castes	0.6511***	0.6743***
% of the population in scheduled tribes	0.6302***	0.6313***
% of the population identified as Muslim	0.5375***	0.5475***
Non-agricultural workers	0.3746***	0.4330***
Urbanization	0.1264***	0.3253***
Access to electricity	0.6397***	0.7683***
Access to sanitation	0.3838***	0.6975***
Access to medical facility	0.5994***	0.4474***
Male-female literacy ratio	0.6499***	0.6919***
Male-female workers 15-59 ratio	0.7286***	0.6583***

Note : *p<0.05, **p<0.01, ***p<0.001

Table 2: OLS regression estimates of index of female disadvantage, 1991-2011

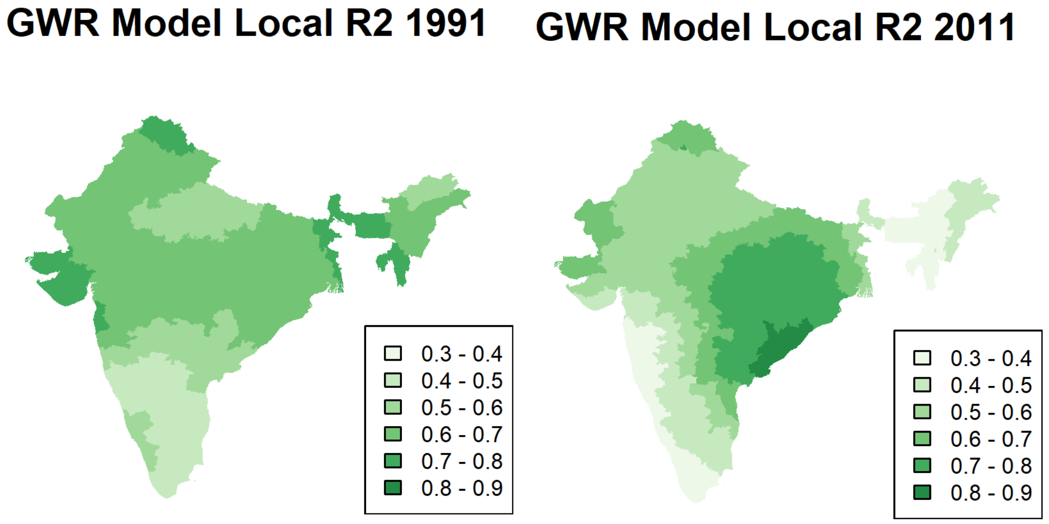
Censuses	1991			2011		
	β		vif	β		vif
(Intercept)	0.2131	**		-0.2738	**	
TFR	0.0179		2.1786	0.0638	***	3.1670
Population density	0.0000	*	1.4759	0.0000		1.5138
% of the population in scheduled castes	-0.0026	*	1.9264	-0.0009		2.0399
% of the population in scheduled tribes	-0.0023	***	2.4756	-0.0002		2.7020
% of the population identified as Muslim	-0.0028	***	1.5710	-0.0014	**	1.7358
Non-agricultural workers	-0.0012	.	3.4382	-0.0013	**	3.5886
Urbanization	0.0009		2.2398	0.0007		3.2772
Access to electricity	-0.0014	***	2.1996	-0.0005		3.5611
Access to sanitation	0.0002		1.8835	0.0013	***	3.3147
Access to medical facility	0.0013	***	1.2765	0.0005	*	1.4171

Male-female literacy ratio	0.0484	**	2.0538	0.1566	**	2.6755
Male-female workers 15-59 ratio	0.0052	***	1.5429	0.0110	**	1.9656
AICc	-479.3236			-723.6448		
Adjusted R^2	0.3289			0.3130		

Note :*p<0.05, **p<0.01, ***p<0.001

Figure 2 shows the GWR local R^2 for both censuses. These maps suggest that the GWR models perform better when explaining the variations in gender bias in the Northern, Central and Eastern parts of the country, and perform worse in the Southern part (and Northeastern in 2011). The Southern region (especially in states such as Kerala, Karnataka or Tamil Nadu), is where the female disadvantage declined the fastest between the 1991 and 2011 censuses, and a large "cold spot" appeared in 2011 (Figure 2), making it difficult to explain small variations based on our limited set of explanatory variables. Other characteristics of these districts should be measured to make sense of this variation. Despite this, the fact that the non-stationarity test results was significant for each of the explanatory variable suggests that all the covariates should be treated as local covariates (in both census years), and that the GWR regression is a clear improvement above the standard OLS.

Figure 2. Local R^2 for GWR regression.

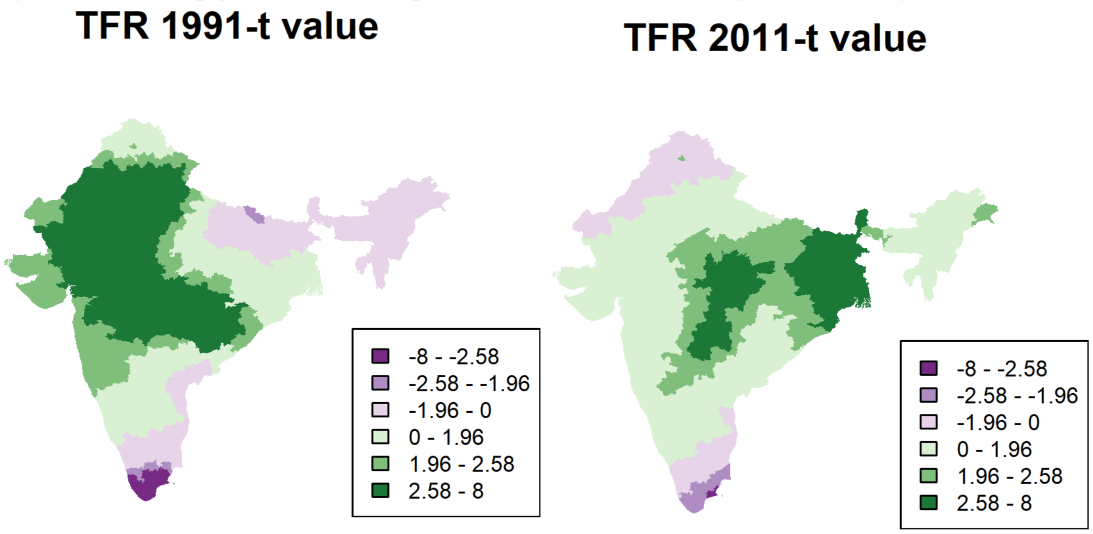


Maps of the t-values for each covariate (Figure 4) help understand how the relationship between the covariates and gender bias has varied across space and time. The positive relationship between high fertility and girls' disadvantage in survival is most evident in North and Central districts of India, in 1991 and Central and East India in 2011, while it is not significant in Southern and North-East India. In a previous analysis based on the National Family Health Survey of India (1992-93), using information on the rank of children in families, the association between high fertility and gender bias was also very strong in the Northern region, while excess female child mortality did not rise systematically with family size in other regions (Arokiasamy, 2004). Population density has a positive and statistically significant effect on the female disadvantage, but this effect is mainly concentrated in East and North-East India. The number of districts showing high and positive values for population density has greatly reduced from 1991 to 2011, to be clustered in fewer districts in Andhra Pradesh and Odisha in 2011. This explains why the OLS coefficient is no longer significant in 2011. The percentage of the population belonging to scheduled castes was significantly related to lower female disadvantage in about 22% of the districts in 1991 census, and this negative association was particularly strong in North India. However, this negative association was no longer significant in 2011, and only a small area showed positive coefficients, significant at the 95% level in 18(4%) districts of South India. The OLS coefficient has been greatly reduced (from -0.0026 to -0.0009) between the two censuses and is no longer significant in 2011. It is interesting to note that the geographical patterns differ when considering scheduled tribes and castes. More than 80% of districts had t-values associated with scheduled tribes indicating a significant and negative association in 1991 (< -1.96), and these districts were spread all over the country. By contrast, in 2011, the area with t-values lower than 1.96

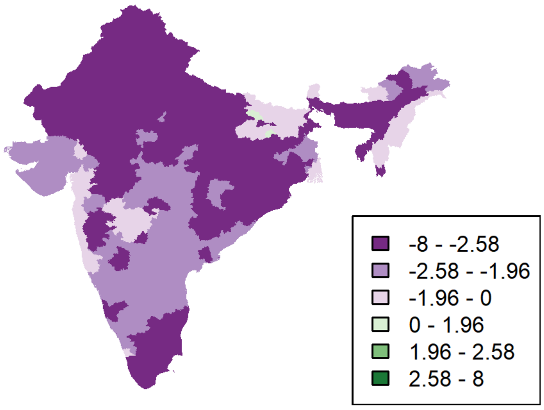
had been reduced to 40% of the districts mostly from Central, East and North India. Similarly, the percentage of the population being Muslim was significantly and negatively associated with female disadvantage in 286(64%) districts in North, Central and East India in the 1991 census. However, 20 years later, this protective effect has been reduced to 174(39%) districts. In 57(13%) districts in the South India, coefficients become positively associated with female disadvantage in 2011. This finding implies that the relationship between female disadvantage and the proportion of Muslims in the population could be place-specific.

Other indicators show important changes over time and across space. For example, the coefficient associated with urbanization was positive in the OLS models, but the GWR models suggest that urbanization increases the female disadvantage mainly in North and Central India (2011) and East India (1991), while it has a negative effect in districts in South India. Access to electricity clearly emerges as one of the most significant factors reducing gender bias in 2011. The negatively association was observed in East India (Bihar, Jharkhand, West Bengal, Orissa) in 1991 and expanded even to Central India (Madhya Pradesh, Rajasthan and Gujarat) in 2011.
Finally, the spatial distribution of coefficients associated with the two variables related to gender inequalities in schooling or workforce participation is more evident. Gender inequality in literacy was associated positively with the index of female disadvantage in the North (Punjab, Haryana and Uttarakhand) and in the central region (Madhya Pradesh) in 1991. More recently, this effect has spread to the neighboring states in the north (Uttar Pradesh) and central part (Rajasthan). Similarly, gender inequality in work force participation was associated significantly and positively to female disadvantage in approximately half of the districts in India in 1991, which lied in the North and Central part of India. However, this was reduced to the one-fourth of districts and more constrained to the northern region of India in 2011. Quite surprisingly, we observed few districts in the south where this association was significant and negative in 2011.

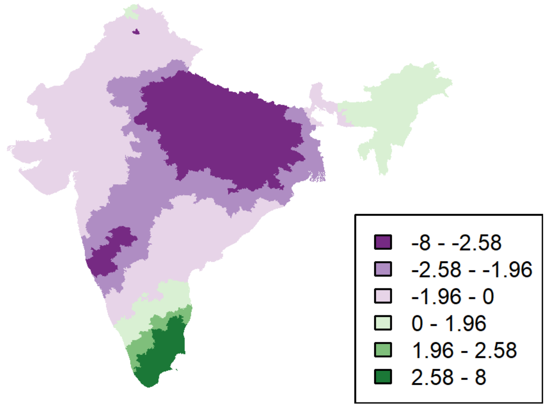
Fig 3. t values map for selected independent variable estimated from GWR regression, 1991-2011.



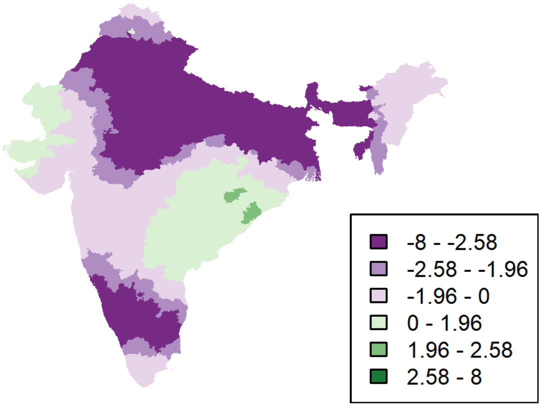
Scheduled Tribe 1991-t value



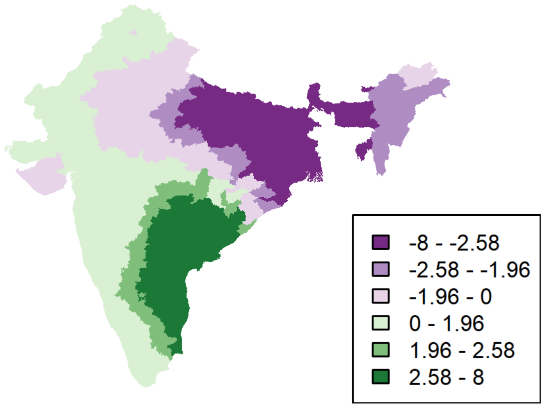
Scheduled Tribe 2011-t value



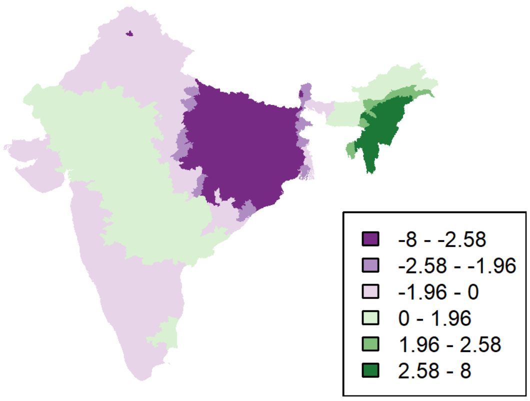
Muslim 1991-t value



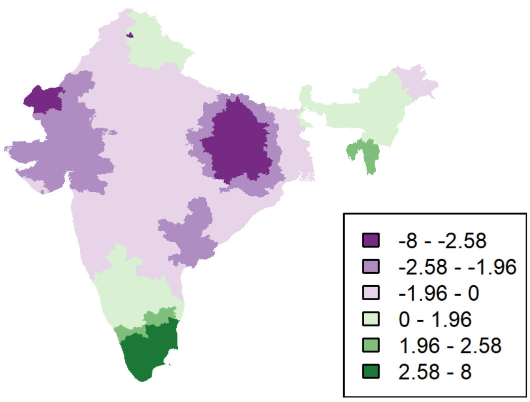
Muslim 2011-t value

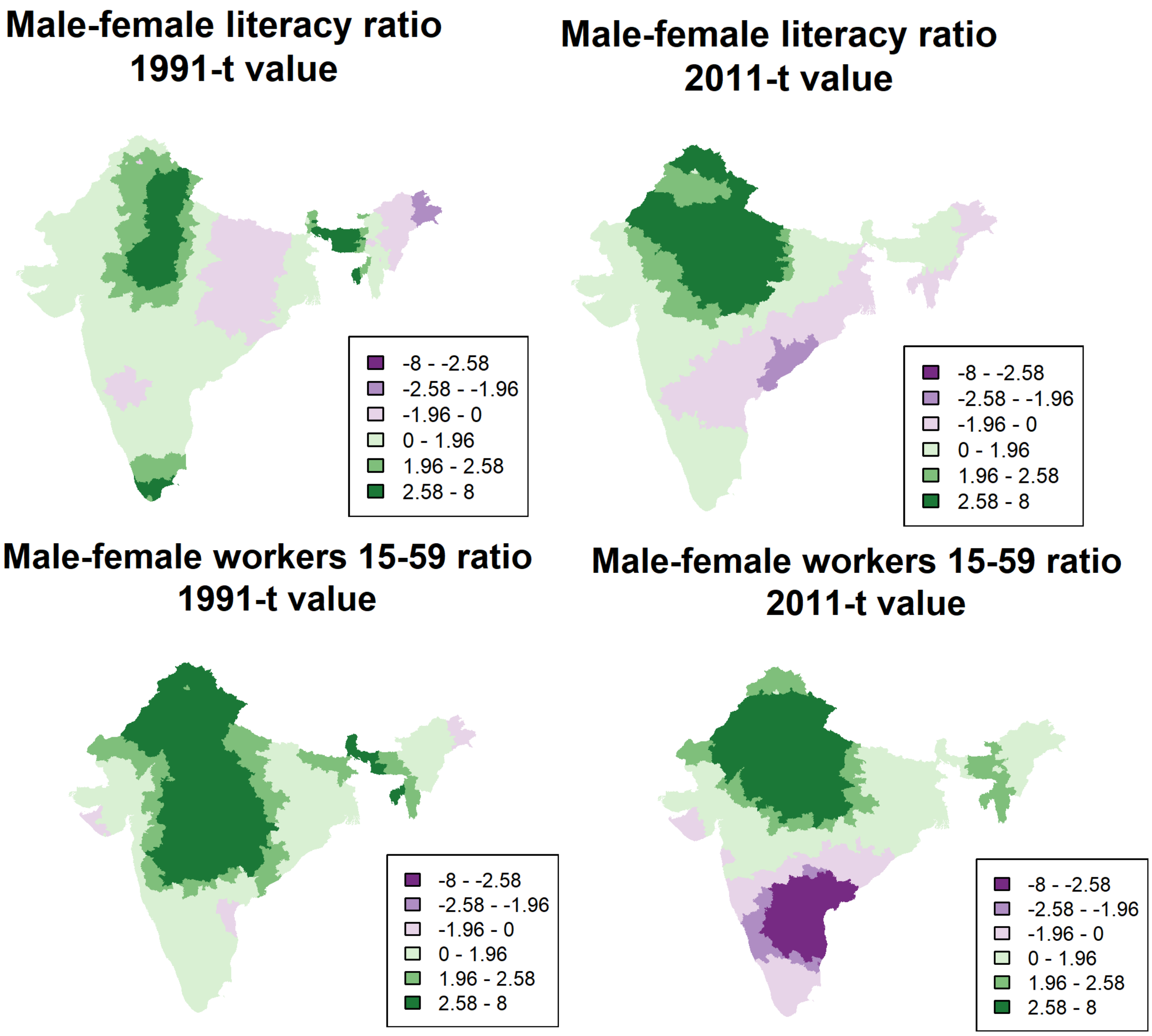


Access to electricity 1991-t value



Access to electricity 2011-t value





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