




# BMJ Open Contribution of economic and nutritional context to overweight/obesity dynamics in Indian women from 1998 to 2016: a multilevel analysis of national survey data

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## ABSTRACT

**Background** Overweight/obesity increased dramatically among Indian women since 2000. We evaluated the independent contributions of economic and nutrition context to the changing distribution of overweight/obesity among women from 1998 to 2016 across India.

**Methods** Individual-level data from 473 912 ever married Indian women aged 18–49 in the National Family Health Surveys (1998–1999, 2005–2006, 2015–2016) were merged with year-matched state-level economic and nutrition context indicators. Cross-classified generalised linear mixed models were estimated to quantify associations of contextual characteristics with overweight/obesity (body mass index  $\geq 25$  kg/m<sup>2</sup>) across survey rounds.

**Results** Between 1998 and 2016, age-standardised prevalence of overweight/obesity increased from 13.9% to 27.5% nationally at an annual growth rate of 0.8%. After accounting for a woman's age, parity and social class, the adjusted OR (aOR) for overweight/obesity was 2.02 times higher for every unit of state log per capita gross domestic product (GDP) (95% credible interval (CrI) 2.00 to 2.03). Yet, the association of state GDP with overweight/obesity generally decreased over survey round. Women in states with higher per capita daily oil (aOR 1.02 per gram; 95% CrI 1.01 to 1.03) and sugar (aOR 1.05 per gram; 95% CrI 1.04 to 1.05) consumption were more likely to be overweight/obese, while women in states with higher cereal consumption were less likely to be overweight/obese (aOR 0.93 per 10 gram; 95% CrI 0.93 to 0.93).

**Conclusions** Indicators of state economic development and nutrition transition were independently associated with a woman's likelihood of being overweight/obese. The impact of state wealth waned over survey round, suggesting that risks for overweight/obesity may be increasingly shaped by individual factors as economic development expands in India.

## INTRODUCTION

High body mass index (BMI) is the fastest growing contributor to death and disability in India.<sup>1</sup> While India has lagged behind

## Strengths and limitations of this study

- We explore the annual rate of change in age standardised prevalence between 1999 and 2015 across various sociodemographic categories.
- We use a Bayesian cross-classified modelling framework to study the economic and nutritional contextual factors associated with overweight/obesity.
- We consider contextual factors after accounting for individual-level and household-level characteristics from serial cross-sectional surveys using multilevel model.
- Serial cross-sectional data precludes inference regarding development of overweight/obesity in women over their life course.
- Lack of contextual data at district and subdistrict levels prohibit further granular analysis of impact of contextual factors.

other nations in the nutrition transition from underweight to overweight/obesity, the country may experience the largest growth in overweight/obesity among the poor by 2040.<sup>2–3</sup> Indian women in particular have been impacted by overweight/obesity. Overweight/obesity has nearly tripled since 1998 among rural women, and the prevalence of overweight/obesity is higher among women compared with men throughout adulthood in both urban and rural settings.<sup>4–5</sup> The rise in overweight/obesity among women has also drawn concern because of its implications for potential metabolic risks to the children of overweight/obese pregnant women.<sup>6</sup>

At the individual level, aside from innate biological factors, excess weight is a result of energy imbalance from energy intake exceeding energy expenditure.<sup>7</sup> While literature documents the higher prevalence of overweight/

obesity among socioeconomically advantaged women, our understanding of whether and how individual-level risks are augmented by the environment in which women reside is limited.<sup>4 8–14</sup> In particular, economic development and food environment are contextual forces that influence population-level energy balance. In low-to-middle income countries (LMICs), economic development is associated with decreased physical activity from mechanised labour and transportation, as well as higher purchasing power to acquire nutrient-dense foods.<sup>3 15 16</sup> With sustained economic growth, families are able to afford diets that are more aspirational to conform to consumption behaviours of socioeconomically advantaged groups, introducing an assortment of more energy-dense foods to the food baskets, with high fat and sugar content.<sup>17</sup> Understanding the role of the economic and nutrition context in the distribution of overweight/obesity among women may improve our ability to prevent overweight/obesity and address-related health burdens.

Drawing on nationally representative data collected at three time points between 1998 and 2016 in all states of India, we examined the contribution of multiple indicators of economic and nutrition context to overweight/obesity among women. We evaluated the hypothesis that economic and nutritional context influence overweight/obesity above and beyond individual socio-demographic factors, and that these contextual factors are drivers in changes in the distribution of overweight/obesity over time.

## METHODS

### Data sources

We constructed a data set from multiple nationally representative data sources collected in or near 1998–1999, 2005–2006 and 2015–2016 with state and individual-level data to enable a multilevel analysis of population-level overweight/obesity among women of reproductive age across a 15-year period in India.

Individual-level data were from the National Family Health Surveys of India (NFHS) conducted in 1998–1999 (NFHS-2), 2005–2006 (NFHS-3) and 2015–2016 (NFHS-4), designed to be representative at the state and national levels.<sup>18–20</sup> While the 2019–2020 NFHS survey has been fielded, data are currently not available. Hence this analysis was restricted to NFHS-2 to NFHS-4. These surveys employed a multi-stage stratified sampling scheme and were designed to be representative at the state and national levels. Strata were defined by urban–rural setting and the primary sampling units (PSU) were villages in the rural stratum and wards in the urban stratum. See online supplemental figure 1 and online supplemental note 1 for detailed description of sample exclusions.

Measures of economic and nutritional context were obtained from external data sources at the state level which allowed us to capture contextual measures that are not available in NFHS. The choice of state as the second level of analysis was pragmatically driven as district-level identifiers (for NFHS 3), and economic and nutrition indicators were not available at lower levels.

State-level contextual measures were derived from four data sources at time periods that were contemporaneous with NFHS rounds. State per-capita gross domestic product (GDP) data were obtained from the Ministry of Statistics and Programme Implementation for 1999–2000, 2004–2005 and 2015–2016. Literacy projections were obtained for 1998–1999, 2005–2006 and 2015–2016 from the Census of India.<sup>21</sup> The National Survey Sample Office Employment-Unemployment surveys and Consumer Expenditure surveys provided information on occupation and food consumption in 1999–2000 (round 55), 2004–2005 (round 61) and 2011–2012 (round 68). Both surveys use multistage stratified sampling to select households and are representative at the state and national levels.

### Overweight/obesity

Overweight/obesity was measured using directly assessed weight and height at the time of survey. BMI  $\geq 25$  kg/m<sup>2</sup> was classified as overweight/obese based on WHO international classification.<sup>22</sup> BMI  $< 25$  kg/m<sup>2</sup> was treated as the reference category for all analysis. In analyses that define overweight/obesity using a BMI  $\geq 23$  kg/m<sup>2</sup>, which has been documented as a threshold of excess diabetes risk in South Asians, we observed similar associations of contextual factors and overweight/obesity across NFHS rounds (data not shown). Therefore, we applied the internationally accepted definition of BMI  $\geq 25$  kg/m<sup>2</sup> to define overweight/obesity in this study.

### Individual sociodemographic characteristics

Age (18–25; 25–35; 35–49 years), parity (0, 1, 2 and 3 or higher) and highest educational qualification (no formal education; primary (up to fourth class); secondary (up to 10th class); or greater than secondary (11th class and higher)) were self-reported. Social caste was categorised based on constitutionally recognised groups: Scheduled Caste and Scheduled Tribe, Other Backward Castes and General.<sup>23–25</sup> Relative socioeconomic position of each woman within her state and survey period was classified using quintiles of a household wealth index derived from 25 household assets common across the three NFHS rounds.<sup>4</sup> Residence of each woman was classified as urban or rural by PSU.

### State-level contextual variables

We considered three measures of socioeconomic environment (online supplemental note 2) that capture aggregate wealth, education and occupation—GDP per capita, literacy rate and employed adults engaged in sedentary occupation. As measures of food environment (online supplemental note 3), we computed the state-level median daily per capita intake (in grams) of cereals, sugars and oils from food expenditure data.

A composite economic and nutrition score was derived from state-level economic and nutrition contextual indicators, respectively. The composite scores were computed from round-level principal component analyses. The first principal component was used to study the association of

collective economic and nutrition environments in overweight/obesity outcomes.

### Statistical analysis

States were based on state boundaries defined in NFHS-2 (1998–1999). We computed the age-standardised prevalence of overweight/obesity across strata of socio-demographic characteristics at each survey round. Age-standardised prevalence was calculated as marginal mean estimated from logistic regression models of overweight/obesity with each subgroup as a covariate while adjusting for age. We calculate the annualised rate of change (as percentage points) at the state level as the slope of the linear regression of marginal mean on year. We used NFHS sample weights, scaled to represent the population of women 18–49 years for each survey, for prevalence estimation.<sup>26</sup> Association between prevalence and state-level contextual indicators were examined using Pearson's correlation coefficients.

Our primary outcome was individual-level overweight/obesity among women assessed in NFHS. Overweight/obesity was modelled as a function of individual-level socio-demographic characteristics and state-level contextual factors as higher-level variables. A four level (individual, PSU, state and survey year) multilevel model approach was adopted to deal with the hierarchical, clustered structure of the data, as well as to understand the individual

and state level contextual factors on individual-level overweight/obesity status of women. A cross-classified Bayesian generalised linear mixed models (GLMM) with logistic link function were used to estimate the association of contextual variables with overweight/obesity with and without adjustment for contextual characteristics. We checked the assumptions for cross-classified nature of the data, namely homogeneity of variance and normality of residuals. The 4-level primary GLMM with individual covariates and random intercepts was specified as

$$\text{logit}(E[O_{iprs}]) = (\beta_0 + w_{0psr} + u_{0s} + v_{0r}) + \sum_{m=1}^M \beta_m \times X_{m,iprs}$$

$$w_{0psr} \sim N(0, \omega^2) \quad u_{0s} \sim N(0, \tau^2) \quad v_{0r} \sim N(0, \theta^2)$$

where overweight/obesity status  $O$  for the  $i$ th individual in  $p$ th PSU cross-classified within  $s$ th state and  $r$ th NFHS survey year (online supplemental figure 2) was modelled as a function of  $M$  individual-level covariates ( $\mathbf{X}$ ).

We used a cross-classified nesting structure to appropriately reflect the hierarchical nature of the data, in which each woman resided in a PSU (rural village or urban ward) cross-classified under a given state and round (online supplemental note 4 and 5).<sup>27</sup> We estimated the variance partition coefficient (VPC) across the different levels for the null model (no covariates) using a simulated Intra class correlation (ICC) (online supplemental

**Table 1** Sociodemographic characteristics of Indian women ages 18–49 years from 1998–1999 to 2015–2016

Characteristic		1998–1999 (n=55 926)	2005–2006 (n=60 911)	2015–2016 (n=357 075)	P value
Educational attainment	No education or less than class 1	26 747 (51.3%)	23 737 (47.1%)	136 425 (36.4%)	<0.001
	Primary (class 1–4)	9987 (17.9%)	9865 (16.2%)	54 037 (14.8%)	
	Secondary (class 5–7)	13 644 (22.4%)	22 007 (30.8%)	138 102 (39.7%)	
	Higher (class eight or higher)	5566 (8.4%)	5302 (6.0%)	28 511 (9.2%)	
Wealth Index (Round state-specific)	1	9832 (17.0%)	10 777 (16.8%)	67 932 (18.1%)	<0.001
	2	10 883 (18.9%)	12 886 (20.1%)	73 486 (19.6%)	
	3	12 206 (21.2%)	12 301 (19.2%)	79 578 (21.2%)	
	4	11 701 (20.3%)	13 737 (21.5%)	75 275 (20.1%)	
	5	13 041 (22.6%)	14 259 (22.3%)	78 467 (20.9%)	
Age category (years)	18–25	7547 (14.6%)	7338 (13.3%)	39 261 (11.5%)	<0.001
	26–35	21 522 (39.2%)	23 215 (38.6%)	128 301 (36.8%)	
	36–49	26 048 (46.2%)	29 609 (48.0%)	186 010 (51.7%)	
Parity	0	34 025 (60.8%)	40 988 (66.8%)	249 043 (70.5%)	<0.001
	1	14 048 (25.0%)	13 488 (22.1%)	74 081 (20.3%)	
	2	5628 (10.0%)	4861 (8.3%)	26 194 (7.2%)	
	3	2243 (4.2%)	1574 (2.8%)	7757 (2.1%)	
Caste	Scheduled caste or scheduled tribe	15 054 (25.6%)	17 330 (25.8%)	127 741 (29.5%)	<0.001
	Other backwards class	16 525 (34.1%)	20 596 (40.8%)	149 009 (45.7%)	
	General	24 365 (40.3%)	22 985 (33.4%)	80 325 (24.8%)	
Residence	Urban	19 541 (29.5%)	28 412 (34.1%)	105 048 (35.3%)	<0.001
	Rural	36 403 (70.5%)	32 499 (65.9%)	252 027 (64.7%)	

Data Source: National Family Health Survey Rounds 2–4. All values account for the complex survey design and are represented as n (%). P value for change in individual characteristic across survey years by  $\chi^2$  test.

**Table 2** Distribution of state-level contextual indicators

State indicators	1998–1999	2005–2006	2015–2016	P value
	Mean±SD	Mean±SD	Mean±SD	
<b>Economic context</b>				
Per capita GDP (rupees)*	20 201±9227	24 026±10 392	42 897±19 817	<0.001
Literacy rate (%)*	57.4±13.1	68.5±10.2	76.8±8.4	<0.001
Sedentary occupation (%)†	29.1±10.8	25.4±8.7	31.3±12.4	0.147
<b>Nutritional context</b>				
Median per capita oil consumption (gram)‡	7.3±2.2	6.8±2.2	8.6±2.7	0.022
Median per capita sugar consumption (gram)‡	10.5±4.6	9.8±4.2	10.1±4.2	0.813
Median per capita cereal consumption (gram)‡	132.2±28.0	129.2±27.2	127.1±24.1	0.780

P value tests the statistical significance of change over round based on t-test.

\*Ministry of Statistics and Programme Implementation, Government of India data sheets.

†National Sample Survey Employment Unemployment survey rounds 55, 61 and 68 Sch 10.0.

‡National Sample Survey Consumer Expenditure Survey Rounds 55, 61 and 68 Sch 1.0.

GDP, gross domestic product.

note 6).<sup>28</sup> We also estimated associations of contextual indicators with overweight/obesity separately by round.

All associations are reported as adjusted OR (aOR) and 95% credible intervals (CrI) conditional on random effects. These may be interpreted as the association of a given covariate for women in a typical village/ward nested within a typical state and round. Statistical analyses were conducted using R V.3.5.0, MLwiN V.3.03 using R2MLwiN V.0.8–V.5 and Stata V.16.1.

## RESULTS

The final analytical sample consisted of 473912 ever-married women aged 18–49 years residing in 26 states in 1998–1999, 2005–2006 or 2015–2016. We noted socio-demographic changes among the sample over the study period (table 1). From 1998–1999 to 2015–2016, women with no formal education declined (51%–36%), women aged 35–49 years increased (46%–51%), women who were nulliparous increased (60%–70%), and women in constitutionally protected castes decreased (40%–25%). At the state level, inflation adjusted per-capita GDP doubled, and the literacy rate rose by over one-third (table 2). The population engaged in sedentary occupations was similar over the study period. There were no changes in median per capita cereal intake or sugar intake. However, median oil intake increased from 7.3 to 8.6g. Despite large temporal variability in GDP, literacy, and oil consumption, the relative position of states remained consistent from 1998 to 2016 (rank correlation  $\geq 0.9$ ; Online supplemental table S1). Economic and nutrition indicators (except cereal intake) were positively correlated with overweight/obesity prevalence for all rounds ( $r=0.35$ – $0.80$ ; figure 1).

Between 1998–1999 and 2015–2016, age-standardised prevalence of overweight/obesity increased (13.9%–27.5%; table 3). The increase in prevalence was observed across all states with varying rates (online supplemental

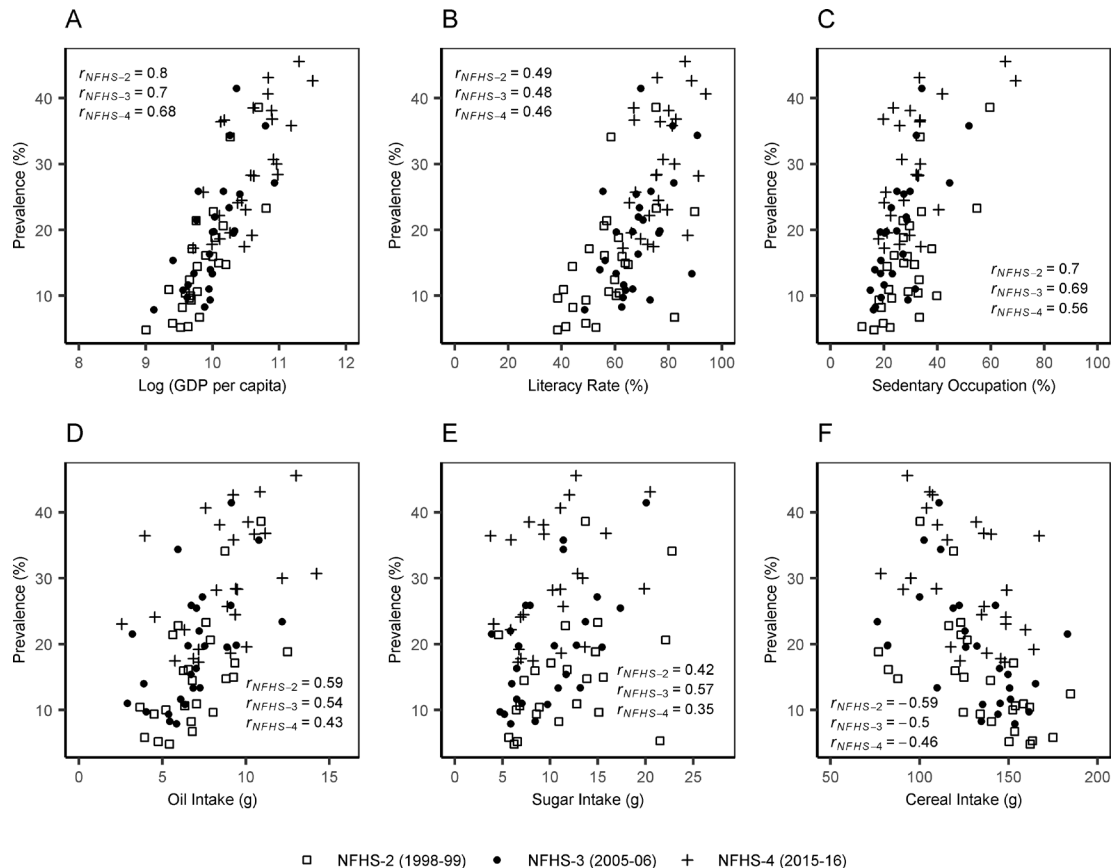
figure 3). The overall annualised increase in the prevalence of overweight/obesity was consistently higher among more socioeconomically advantaged groups (table 3).

In multilevel logistic regression analyses of the association between individual characteristics and overweight/obesity across the three time periods, we observed a strong positive association of individual-level education, wealth, and age with overweight/obesity status (online supplemental table S2). The aOR for overweight/obesity were 2.04 (95% CrI 1.99 to 2.09), 2.14 (95% CrI 2.09 to 2.21) and 3.95 (95% CrI 3.84 to 4.07) for women in the highest education, wealth and age groups, respectively, relative to reference levels of each domain. In contrast, there were inverse associations between higher parity and overweight/obesity as well as between belonging to a constitutionally protected caste and overweight/obesity. Similar associations were observed by urban and rural areas (Online supplemental table S2). The associations were of lower magnitude for rural areas. The association of individual-level covariates with overweight/obesity were not impacted by inclusion of state-level variables.

Across survey rounds, the variability (as measured by VPC) in overweight/obesity was largely at the individual level in both urban (85.8%) and rural (70.2%) areas (Online supplemental table S3; null model). Although geographical variability at the ward/village and state levels was comparable between urban and rural areas, there was more temporal heterogeneity in overweight/obesity between rounds in rural (19.5%) as compared with urban areas (5.1%). Similarly, state variability was higher in rural (6.1%) compared with urban areas (2.7%).

Independent of individual socio-demographic characteristics, composite state-level economic (aOR 1.15; 95% CrI 1.09 to 1.22) and nutrition (aOR 1.19; 95% CrI 1.16 to 1.22) scores were positively associated with prevalent overweight/obesity status in women (table 4). With





**Figure 1** Prevalence of overweight/obesity by economic and nutrition indicators. X-axis represents state wise (A) log (per capita GDP in rupees) (B) literacy rate (in %) (C) employed adults engaged in a sedentary occupation (in %) (D) median per capita oil intake (in grams) (E) median per capita sugar intake (in grams) (F) median per capita cereal intake (in grams). each point represents a state value for different rounds (white squares—NFHS-2, black circles—NFHS-3 and plus sign—NFHS-4). Sedentary occupation, and nutritional intakes were computed using survey estimation procedures as per respective NSSO rounds. The values corresponding to  $r_{NFHS-2}$ ,  $r_{NFHS-3}$  and  $r_{NFHS-4}$  represent the Pearson's correlation coefficient between the state economic and nutritional indicators and overweight/obesity prevalence by NFHS round. GDP, gross domestic product; NFHS, National Family Health Survey; NSSO, National Sample Survey Office.

respect to individual indicators, the adjusted relative odds of overweight/obesity were aOR=2.02 (95% CrI 2.00 to 2.03) for every unit of log state GDP per capita. Similarly, we observed positive associations between literacy rate (aOR 1.32; 95% CrI 1.31 to 1.34) and sedentary occupation (aOR 1.05; 95% CrI 1.02 to 1.06). Residing in a state with higher daily oil (aOR 1.02 per gram; 95% CrI 1.01 to 1.03) and sugar (aOR 1.05 per gram; 95% CrI 1.04 to 1.05) consumption was associated with greater odds of prevalent overweight/obesity. Women in states with higher cereal consumption were less likely to be overweight/obese (aOR 0.93 per 10 g; 95% CrI 0.93 to 0.93). All state-level economic and nutrition indicators were associated with overweight/obesity in both urban and rural areas, with stronger associations of log state GDP and literacy with overweight/obesity in rural areas.

Figure 2 shows the differing associations of contextual indicators with overweight/obesity by round. The association of state GDP with overweight/obesity was positive across all rounds but declining over time. Nationally, the aOR of log per capita GDP for overweight/obesity was attenuated from 2.08 (95% CrI 1.99 to 2.18) in 1998–1999

to 1.20 (95% CrI 1.18 to 1.21) in 2015–2016. We found a similar pattern in urban and rural models. Similarly, the association of literacy, sedentary occupation, oils and sugar tended to reduce over time.

Comparing the differential impact of contextual measures, the composite state-level nutrition score yielded the best model fit based on deviance information criterion (DIC) in urban and rural areas separately (table 4). State-level literacy rate and per capita sugar yielded the best model fit with respect to individual contextual indicators.

## DISCUSSION

Between 1999 and 2015, the age-standardised prevalence of overweight/obesity more than doubled in Indian women, increasing by 0.81 percentage points each year. Independent of individual and household socio-demographic characteristics, state-level economic and nutritional contexts was associated with being overweight/obese across the 20-year period of analysis. Across the study period, we observed robust positive associations

**Table 3** Age-standardised prevalence of overweight/obesity and annualised changes in Indian women from 1998–1999 to 2015–2016

		1998–1999 (n=55 926)	2005–2006 (n=60 911)	2015–2016 (n=357 075)	Annualised change*
All India		13.9%	18.3%	27.5%	0.81%
Place of residence	Rural	9.1%	11.9%	19.0%	0.59%
	Urban	24.6%	30.5%	43.0%	1.09%
Educational attainment	No education/less than class 1	7.7%	10.3%	14.8%	0.42%
	Primary (class 1–4)	14.2%	18.4%	25.3%	0.66%
	Secondary (class 5–7)	22.4%	28.2%	36.9%	0.85%
	Higher (class eight or higher)	30.5%	37.3%	46.8%	0.96%
Wealth Index (Round state-specific)	1	3.0%	3.8%	7.1%	0.25%
	2	5.8%	7.4%	13.2%	0.45%
	3	10.5%	13.1%	22.3%	0.71%
	4	18.6%	22.6%	35.6%	1.02%
	5	30.6%	36.0%	51.4%	1.25%
Parity	0	14.3%	18.9%	28.2%	0.83%
	1	13.1%	17.4%	26.2%	0.78%
	2	12.4%	16.4%	25.0%	0.75%
	3+	11.4%	15.2%	23.3%	0.71%
Caste	General	17.7%	23.8%	35.9%	1.08%
	Scheduled caste or scheduled tribe	8.9%	12.5%	20.4%	0.68%
	Other backwards class	13.1%	17.9%	28.2%	0.90%

Temporal trends have  $p < 0.001$ .

\*Calculated as slope of regression of age-standardised prevalence on year;.

of state-level log per GDP capita, literacy rate, sedentary occupation, oil consumption and sugar consumption with individual-level overweight/obesity nationally and within urban and rural settings. Residing in states with higher cereal consumption was associated with lower odds of overweight/obesity in both urban and rural women.

There is consensus that cross-national, sub-national, and temporal variations in overweight and obesity are driven by differences in economic development and nutritional environment, as described in the literature around the nutrition and obesity transition.<sup>16 29 30</sup> Within LMIC settings, the risk of overweight and obesity are generally higher among wealthier individuals.<sup>16 29 30</sup> Across countries, obesity is more prevalent in high income countries (HIC), and over time, the difference in obesity prevalence between HICs and LMIC has diminished. Yet there is relatively limited empirical research quantifying the direct impact of specific contextual characteristics on prevalent overweight/obesity in LMICs at the national or individual level.<sup>31</sup> Our descriptive analyses begin to close this gap and lend support to the socioecological paradigm underpinning the rise of overweight and obesity in India.

Stratifying by urbanicity and survey round revealed important findings. With respect to urbanicity, we found that the impact of state wealth (measured as log per capita GDP) on overweight/obesity was larger in rural compared

with urban areas. While the relative odds of overweight/obesity were 1.39 times for every unit increase in urban areas, the relative odds of overweight/obesity were 2.16 times in rural areas across the study period. If urban is to be compared with HIC and rural with low income countries, the above finding is comparable to the higher prevalence in wealthy observed in the low income countries and among the disadvantaged populations in the higher-income countries.<sup>31</sup> With respect to survey round, our analysis indicates that the impact of contextual characteristics has generally waned over time. Nationally, the association between state-level log per capita GDP and overweight/obesity waned over time. Taken together, the larger associations of GDP and overweight/obesity in rural areas and the declining role of GDP over time may indicate that the role of contextual factors in shaping obesity risk attenuates as the prevalence of overweight/obesity increases, household wealth and purchasing power rises, and environments become more homogeneous with economic development. This hypothesis must be further evaluated using well-characterised longitudinal data with measures of environment and weight status.

The positive though modest association of oil and sugar and the negative association of cereals with overweight/obesity ring an alarm. The country should be cautious of rise in consumption of energy-dense foods which are

**Table 4** Association of state level characteristics with overweight/obesity in pooled data of Indian women in 1998–1999, 2005–2006 and 2015–2016

National	n=473 912	DIC
Economic measures		
Log (per capita GDP)	2.02 (2.00, 2.03)	449 741.0
Literacy rate (10%)	1.32 (1.31, 1.34)	449 326.4
Sedentary occupation (10%)	1.05 (1.02, 1.06)	449 598.9
Composite economic score	1.15 (1.09, 1.22)	449 585.9
Nutrition measures		
Oils (grams)	1.02 (1.01, 1.03)	449 557.5
Sugar (grams)	1.05 (1.04, 1.05)	449 547.8
Cereal (10 grams)	0.93 (0.93, 0.93)	449 580.5
Composite nutrition score	1.19 (1.16, 1.22)	449 395.2
Urban	n=152 998	DIC
Economic measures		
Log (per capita GDP)	1.39 (1.37, 1.41)	183 605.0
Literacy rate (%)	1.05 (1.05, 1.06)	183 583.3
Sedentary occupation (%)	1.13 (1.10, 1.15)	183 591.2
Composite economic score	1.08 (1.03, 1.15)	183 582.3
Nutrition measures		
Oils (grams)	1.05 (1.04, 1.05)	183 587.8
Sugar (grams)	1.02 (1.02, 1.03)	183 569.1
Cereal (10 g)	0.95 (0.95, 0.96)	183 586.4
Composite nutrition score	1.04 (1.02, 1.05)	183 572.7
Rural	n=320 914	DIC
Economic measures		
Log (per capita GDP)	2.16 (2.15, 2.18)	263 961.8
Literacy rate (%)	1.36 (1.35, 1.37)	263 763.2
Sedentary occupation (%)	1.06 (1.04, 1.09)	263 865.9
Composite economic score	1.1 (1.05, 1.15)	263 875.0
Nutrition measures		
Oils (grams)	1.02 (1.01, 1.02)	263 872.9
Sugar (grams)	1.04 (1.03, 1.04)	263 865.2
Cereal (10 g)	0.92 (0.91, 0.92)	263 876.4
Composite nutrition score	1.14 (1.11, 1.18)	263 815.1

Separate models were fit for each state-level variable. All values are aOR (95% CrI) estimated from logistic cross-classified random intercept model adjusted for woman's age category, educational attainment, wealth index, parity and caste. CrI, credible interval; DIC, Deviance information criterion; GDP, gross domestic product.

associated with overweight/obesity that are replacing cereals.<sup>32–35</sup> Cereal consumption may have decreased over time (table 2) to maintain balance with reduced energy

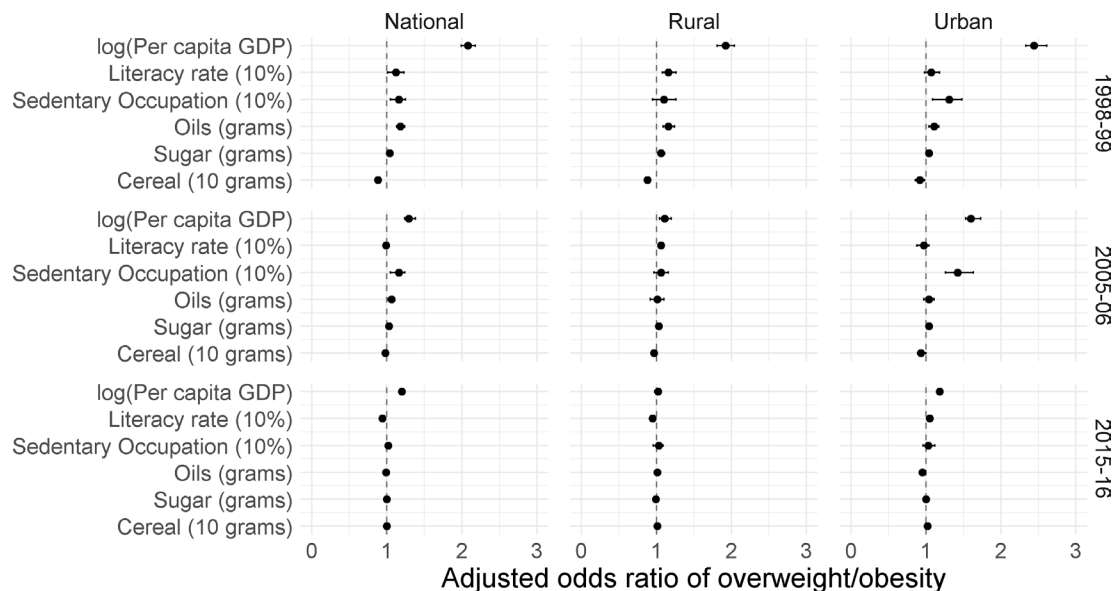
requirement of the population.<sup>36</sup> The working group on addressing consumption of high fat, salt and sugar and promotion of healthy snacks in schools of India (constituted by the Government of India) recognised the rising intake of processed foods in both rural and urban areas. The ease of availability, taste, low cost, peer pressure and aggressive marketing and advertisements were identified as reasons for this rise among children and adolescents.<sup>37</sup>

While the annual rate of change in overweight/obesity was faster among advantaged groups, our results reiterate the finding that that overweight/obesity increased substantially across all education, wealth and caste groups.<sup>4</sup> Socioeconomically vulnerable groups may require new vigilance for emergence of obesity-related chronic disease from a public health perspective. At 65%, the lifetime risk of diabetes in women in Indian cities is among the highest in the world, and the rise of overweight/obesity in rural women may usher in similar risks.<sup>38</sup>

Our study has numerous methodological strengths. Using a Bayesian GLMM has numerous advantages from providing stable estimates incorporating the hierarchy of space and time, better convergence to point estimates and modelling a cross-classified framework. Partitioning of variance using a simulated ICC allows for fewer approximations of nesting. Additionally, our study used the best available data sources which were nationally representative avoiding the pitfall of correlated errors when computing contextual effects from the same dataset.

Our study has several limitations. The use of serial cross-sectional data does not allow us to make inferences regarding the development of incident overweight/obesity in women over their lifetimes. Furthermore, we lacked individual-level data on modifiable risk factors for obesity such as diet and physical activity, sleep, which may have changed over time. Many of these health behaviours, however, are considered mediators that link context to weight status. BMI as measure of overweight and obesity, and not waist circumference or body fat percentage may be an inadequate measure of adiposity and related health risks in South Asians.<sup>3 11</sup> Data on state-to-state migration of women were not available, and therefore, the analysis assumed that the current state of residence appropriately measured state-level contextual exposures for each woman. While contextual sources were matched closest to date of survey, lack of such data at lower geographical units (district or village) prohibit more granular analysis of the impact of contextual factors. We did not adjust for survey weights in the multilevel models due to software limitations. We analysed data on women 18–49 years and restricted our analysis to those who were non-pregnant/non-lactating, thus limiting generalisability.

Our analysis of overweight/obesity dynamics in India was constrained by several data limitations which motivate comment on several gaps and opportunities in the data infrastructure. For example, district-level identifiers across all survey around would have enabled a more granular evaluation of contextual determinants of excess weight, high quality administrative data on



**Figure 2** Associations of state-level characteristics with overweight/obesity in Indian women in 1998–1999, 2005–2006, 2015–2016. Separate models were fit for each state-level variable. All values are aOR (95% CrI) estimated from logistic cross-classified random intercept model adjusted for woman's age category, educational attainment, wealth index, parity and caste. aOR, adjusted OR, CrI, credible interval; GDP, gross domestic product.

contextual characteristics would enable rigorous evaluation of specific features of context, and longitudinal data tracking individual weight status over time would provide a basis for understanding the risk (rather than prevalence) of overweight/obesity over the past two decades. This research infrastructure gap presents policymakers, private foundations, and academic institutions with an opportunity to establish—and make public—data sources that allow investigators to prospectively study the temporal association of regional and local environment on incidence of cardiovascular disease and diabetes for decentralised decision making. For example, placing integrated data reserves such as those at TATA-NIN (<https://www.nintata.res.in>) in the public domain would substantially enhance the ability of scientists to study the complex interplays of various factors over time.

## CONCLUSION

This study identified a significant rise in overweight/obesity over the past two decades among Indian women under the age of 50, an age group that makes up over 75% of all women in India.<sup>21</sup> Based on lessons from other settings, the rise in overweight/obesity in woman signals a likely future rise in overweight/obesity among children and men.<sup>16</sup> While residing in a state with higher per capita GDP, oil and cereal consumption was associated with higher odds of overweight/obesity, the impact of these contextual risk factors may be diminishing over time. Further investigation into what may explain the apparent changing associations between contextual characteristics and overweight/obesity may provide insight on environmental characteristics that can be leveraged to halt the rise of excess weight in India. Future studies

may also consider mechanisms linking environment with weight outcomes, in particular on the relative importance of food availability and social norms around diet are driving these results.

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