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Built environment correlates of overweight and obesity among adults in Chennai, India

Deepti Adlakha^{a*}, Ross C. Brownson^{b, c}, J. Aaron Hipp^d

^a School of Natural and Built Environment, Queen's University Belfast, United Kingdom

^b Prevention Research Center in St. Louis, Brown School at Washington University in St. Louis, Missouri, United States of America

^c Division of Public Health Sciences, Alvin J. Siteman Cancer Center, School of Medicine, Washington University in St. Louis, Missouri, United States of America

^d Department of Parks, Recreation, and Tourism Management, Center for Geospatial Analytics, North Carolina State University, Raleigh, North Carolina, United States of America

*Corresponding author

Email: d.adlakha@qub.ac.uk

Abstract

Overweight and obesity are steadily rising in South Asia, the world's most populous region. Recent estimates suggest that two out of every five South Asian adults are either overweight or obese. India, a low- and middle-income country in South Asia is experiencing an obesity epidemic. Built environment features may profoundly influence physical activity and counter the risk from overweight and obesity. This cross-sectional study investigated built environment correlates of overweight and obesity among adults (N=370, 47.2% female, mean age=37.9 years) in Chennai, India. Participants from low-socioeconomic status households were more likely to be overweight/obese (odds ratio [OR]=1.8, 95% confidence interval [CI]=1.1-2.9) than participants from high- socioeconomic status households. Driving to work predicted a three-fold increase in overweight or obesity compared to active commuting (OR=2.9, 95%CI=1.3-6.4). Household car ownership was linked with an increased likelihood of overweight or obesity (OR=1.5, 95%CI=0.7-3.2). Low walkability neighbourhoods significantly predicted an increase in odds of overweight or obesity (OR=1.8, 95%CI=1.1-2.8). By 2030, Indian cities are projected to add 250 million people accompanied by a 9.9% annual motor vehicle growth rate, with substantial health and socioeconomic implications. As car ownership increases across Southern Asia, there is an urgent need to develop interventions to promote physical activity.

1 Introduction

2 The increasing prevalence of overweight and obesity continues to be a major public health
3 concern globally.¹ According to recent global estimates, more than 1.9 billion adults aged 18
4 years and older were overweight in 2016, and of these, over 650 million adults were obese.²
5 Obesity and overweight are risk factors for a range of health problems, including cardiovascular
6 disease, stroke, type-2 diabetes, hypertension, and some cancers.³⁻⁵ South Asia, the world's most
7 densely populated geographical region that is home to one-quarter of the world's population
8 (nearly 1.9 billion), is facing an obesity crisis with recent estimates suggesting that two out of
9 every five adults in the region are either overweight or obese.⁶ Once considered a high-income
10 country problem, overweight and obesity are now on the rise in low- and middle-income
11 countries, particularly in urban settings, even as they continue to struggle with a burden of
12 infectious disease.⁷⁻⁹

13
14 India, a low- and middle-income country located in South Asia and the second-most populous
15 country in the world is witnessing an obesity epidemic where the prevalence of overweight and
16 obesity along with other non-communicable diseases has been rising steadily.¹⁰ The Chennai
17 Urban-Rural Epidemiology Study determined that the age-standardized prevalence of
18 generalized obesity in an adult population was 45.9% (95% CI: 43.9–47.9).¹¹ In another study,
19 the prevalence of obesity among an urban adult population was 55.5% (95% CI: 47.2–63.4),
20 indicating a high burden of disease.¹² A comparative study across three Indian states found the
21 prevalence of generalized obesity ranged from 11.8% to 33.6%.¹³ A comparison of two major
22 studies conducted by the National Family Health Survey in 1998–1999 and in 2005–2006
23 highlighted that the prevalence of obesity among Indian women elevated from 10.6% to
24 12.6%.¹⁴

25
26 The pace at which obesity prevalence has grown at the population level across the globe points
27 to social and environmental causes. This sum of influences that the surroundings, opportunities,
28 or prevailing conditions of life have on promoting weight gain and obesity in individuals or
29 populations characterises certain environments as more 'obesogenic' than others. Obesogenic
30 environments are characterised by increasing urbanization, use of mechanized transport,
31 increased television viewing, adoption of less physically active lifestyles, and rise in sedentary
32 (sitting) time.¹⁵ Calls to address the global epidemic of obesity by the World Health
33 Organization have recommended increasing physical activity as a key strategy, highlighting the
34 role of the built environment to support physical activity as a central focus area.¹⁶
35 Neighbourhoods that are activity-friendly depend upon an appropriate integration of land-use
36 and transportation infrastructure, including higher residential densities, and street connectivity.¹⁷
37 The availability of pedestrian, bicycling, and transit infrastructure such as sidewalks, crosswalks,
38 bicycle lanes, and access to public transport services (e.g., bus rapid transit, light rail) has been
39 linked with increased levels of transport-related physical activity.¹⁸

40
41 A number of studies from Australasia, Europe, North America, and South America have
42 documented positive associations between walkable, mixed-use, transit-accessible
43 neighbourhoods and individuals' levels of physical activity and healthy weight status compared
44 with those living in automobile-dependent neighbourhoods.¹⁷ Findings from existing studies do
45 not lend themselves easily to generalization in other parts of the world, particularly the South
46 Asia region that is home to over 24 percent of the world's population and at high risk of
47 developing obesity.^{19, 20} Although these studies show a consistent correlation between
48 neighbourhood built environment and the prevalence of obesity in developed countries, these
49 relationships have not been examined in India. The objective of the current study was to
50 examine built environment correlates of overweight and obesity among adults in the city of
51 Chennai, India.

Methods

Study Area

This study recruited a diverse sample of participants (N=370) from Chennai city (164.5 sq. miles, population=7.09 million), capital of the state of Tamil Nadu in southern India. Tamil Nadu is the most urbanized state in India with 48.4% of the population living in urban areas²¹ and has the highest number of diabetic cases, a majority of them reported in Chennai.²² The city has also seen a 24-fold increase in motorized vehicles in the last 10 years with private automobiles now constituting 55% of daily all-person trips.²³ For administrative purposes, the Chennai metropolitan area is divided into 155 smaller subdivisions called wards, which were the primary unit of sampling in this study. Wards the smallest geographic areas for which the Census Bureau of India publishes demographic information (compare to US census tracts).²⁴ The Institutional Review Board of (removed for peer review) approved all study procedures.

Sampling and Recruitment

Study protocols were based on the recommendations of the International Physical activity and the Environment Network (IPEN; www.ipenproject.org).²⁵ Participants were recruited through purposive sampling from wards stratified by walkability and socioeconomic status, to maximize variance and enhance the representativeness of the sample as low-income populations tend to be underrepresented in studies of this nature.^{26, 27}

Inclusion and exclusion criteria were based on IPEN protocol and studies conducted in Africa, Brazil and China.²⁸⁻³² Eligibility criteria for participants included: (i) current residents of Chennai; (ii) residents for at least 6 months; (iii) 18–65 years of age; (iv) able to answer questions in English or Tamil; (v) not having any disability that prevented independent walking; and (vi) no visible signs of cognitive impairment. One individual per household was recruited to ensure independence of observations. Sample size was determined using a moderate-to-large effect size (effect size [d=] 0.75), which is greater than what has been used previously IPEN studies in low- and middle-income country contexts such as Africa, Brazil, and China.²⁸⁻³²

Measures

Neighbourhood Walkability

The Neighbourhood Environment Walkability Scale—India (NEWS-India) was used to assess built environment features of participants' home neighbourhoods. NEWS-India consists of 91 items grouped into the following subscales: (a) residential density, (b) land use mix-diversity, (c) land use mix-access, (d) street connectivity, (e) infrastructure for walking/bicycling, (f) aesthetics, (g) traffic safety, and (h) safety from crime. Four-point Likert-type scale responses for all items ranging from 1 (strongly agree) to 4 (strongly disagree) were combined as “agree” (strongly agree, agree) and “disagree” (disagree, strongly disagree). NEWS-India items were positively scored to ensure that a higher score represented an activity-supportive neighbourhood.³³ Test-retest reliability of NEWS-India has been previously established, with intra-class correlation coefficients higher than 0.75, indicating excellent reliability.²⁵

Physical Activity

Two modules of the International Physical Activity Questionnaire-Long Form (IPAQ-LF) were used to measure participants' leisure and travel physical activity.³⁴ IPAQ-LF is a self-report measure that captures the frequency and duration of walking, moderate-intensity, and vigorous-intensity physical activity. It has been tested internationally with reliability (Spearman's rho ~0.8) and criterion validity (median rho ~0.3) comparable to other self-reported validation studies.³⁵ Following World Health Organization recommendations, adults aged 18–64 years should engage in 150 minutes of moderate-intensity aerobic activity in a week to incur health benefits. In the context of daily, family, and community activities, this can include leisure time

activity (e.g., walking, dancing, gardening, hiking, swimming) or transportation (e.g., walking, bicycling).³⁶

Weight Status (BMI)

Self-reported height and weight data was elicited from participants. Body mass index (BMI) was calculated as body weight divided by the square of height (kg/m^2). The World Health Organization principal cutoff points for BMI were used to create the categories: underweight ($< 18.5 \text{ kg}/\text{m}^2$), normal weight ($18.5\text{--}24.99 \text{ kg}/\text{m}^2$), overweight ($25\text{--}24.99 \text{ kg}/\text{m}^2$), and obese ($\geq 30 \text{ kg}/\text{m}^2$).³⁷

Demographic Variables

Self-reported data on participants' age, gender, marital status, educational level, employment status, and household socioeconomic status was recorded using validated scales.³⁸ Household socioeconomic status was measured using a validated composite scale developed for India. This scale measures three variables, namely, education, occupation of the head of the household, and income of the family.³⁹

Data Analysis

Multiple logistic regression models were used to examine the factors associated with overweight or obesity. Models were adjusted for age, gender, household socioeconomic status, and motor vehicle ownership to control for the confounding effects of these variables as shown in similar studies conducted in low- and middle-income countries.⁴⁰ Analysis was conducted using the Statistical Package for the Social Sciences (SPSS) v.25.⁴¹

Results

Descriptive characteristics of the sample population are presented in Table 1. The mean age of the sample was 37.9 years. The majority of participants were women (54.2%), married (61.2%), employed (62.5%), with a graduate or professional degree (49.7%). Nearly half (48.2%) of the participants reported earning less than 600 US Dollars (approximately 36,017 Indian rupees) per month.

Table 1. Characteristics of the study population

Descriptive Characteristics	Statistic
Age (in years), mean (SD)	37.9 (15.3)
Gender, n (%)	
Female	199 (53.8)
Male	166 (44.9)
Missing	5 (1.4)
Marital Status, n (%)	
Married	226 (61.1)
Not married	143 (38.6)
Missing	1 (0.3)
Educational Level, n (%)	
Uneducated	48 (13.0)
Primary–middle school	57 (15.4)
High school or diploma	79 (21.4)
Graduate or professional	184 (49.7)

Missing	2 (0.5)
---------	---------

Employment Status, n (%)

Unemployed	134 (36.2)
Blue collar	112 (30.3)
White collar	111 (30.0)
Missing	13 (3.5)

Monthly Family Income [in US Dollars] n (%)

≤80	74 (20.0)
81–200	43 (11.6)
201–549	24 (6.5)
≥550	152 (41.1)
Missing	77 (20.8)

Household Socioeconomic Status *, n (%)

Low	213 (57.6)
High	157 (42.4)

Note: 1 US Dollar = approximately 65.69 Indian Rupees (average currency exchange rate, January–April 2015)

*Socioeconomic status classification and cut-off values are from a validated composite scale developed for India. The scale measures three variables—education, occupation of the head of the household, and income of the family—that are relevant to the Indian context.³⁹

Anthropometric characteristics of participants by gender and income are presented in Table 2. Compared to high-socioeconomic status households, a higher number of participants from low-socioeconomic status households were overweight (n=54, 25.4%) and obese (n=31, 14.6%). Women were more likely to be obese (n=31, 15.6%) than men.

Table 2. Anthropometric characteristics of participants by gender and income

Body Mass Index (BMI) Categories ¹ n (%)	Overall	Gender		Household Income	
		Male	Female	Low	High
Underweight	35 (9.5)	8 (4.8)	27 (13.6)	9 (4.2)	26 (16.6)
Normal weight	177 (47.8)	92 (55.4)	84 (42.2)	107 (50.2)	70 (44.6)
Overweight	77 (20.8)	37 (22.3)	39 (19.6)	54 (25.4)	23 (14.6)
Obese	47 (12.7)	15 (9.0)	31 (15.6)	31 (14.6)	16 (10.2)
Missing	34 (9.2)	14 (8.4)	18 (9.0)	12 (5.6)	22 (14.0)

¹The World Health Organization principal cut-off points for BMI were used to create the categories: underweight (<18.5 kg/m²), normal weight (18.5–24.99 kg/m²), overweight (25–24.99 kg/m²), and obese (≥30 kg/m²).³⁷

Table 3 shows BMI, moderate-to-vigorous physical activity and sedentary levels across walkability categories. Moderate-to-vigorous physical activity was higher in neighbourhoods with higher residential density (Mean=254.8 min/week, SD=350.4 min/week), land-use mix diversity (Mean=251.8 min/week, SD=486.1 min/week), street connectivity (Mean=231.6 min/week, SD=318.9 min/week) and safety from traffic (Mean=256.2 min/week, SD=448.4 min/week). Numbers of overweight or obese participants were lower in neighbourhoods with higher residential density (n=54, 29.7%), land-use mix diversity (n=22, 25.0%), walking and cycling infrastructure (n=19, 28.4%) and safety from traffic (n=32, 28.3%).

Table 3. BMI, moderate-to-vigorous physical activity and sedentary levels observed at walkability categories

Neighbourhood Walkability Characteristics¹	Body Mass Index (BMI) ² Mean (SD)	Overweight or Obese n (%)	Weekly MVPA³ in minutes Mean (SD)	Weekly Sitting Time in minutes Mean (SD)
Residential Density				
Low	25.5 (5.8)	70 (37.2%)	203.0 (355.4)	379.5 (269.7)
High	23.7 (5.4)	54 (29.7%)	254.8 (350.4)	366.2 (252.5)
Land-use Mix Diversity				
Low	24.9 (5.2)	102 (36.2%)	221.3 (302.8)	404.5 (266.9)
High	23.5 (6.7)	22 (25.0%)	251.8 (486.1)	270.4 (212.3)
Land-use Mix Access				
Low	24.3 (7.2)	28 (29.8%)	261.2 (456.6)	358.7 (246.8)
High	24.7 (5.0)	96 (34.8%)	217.6 (312.4)	377.8 (266.1)
Street Connectivity				
Low	23.7 (5.8)	21 (25.0%)	216.4 (462.5)	222.7 (196.7)
High	24.8 (5.6)	103 (36.0%)	231.6 (318.9)	415.6 (261.7)
Walking and Bicycling Infrastructure				
Low	24.7 (5.8)	105 (34.7%)	235.0 (368.3)	367.5 (260.5)
High	23.8 (5.1)	19 (28.4%)	196.3 (270.7)	398.1 (264.6)
Aesthetics				
Low	24.5 (5.7)	96 (33.8%)	253.9 (380.0)	370.6 (255.0)
High	24.6 (5.7)	28 (32.6%)	126.0 (185.3)	381.1 (282.9)
Safety from Traffic				
Low	24.8 (5.5)	92 (35.9%)	216.8 (305.9)	371.1 (256.4)
High	24.0 (6.0)	32 (28.3%)	256.2 (448.4)	378.4 (273.8)
Safety from Crime				
Low	23.9 (5.4)	62 (30.5%)	247.0 (397.5)	322.3 (231.5)
High	25.5 (5.9)	62 (37.9%)	207.4 (291.6)	434.5 (282.8)

Note: ¹All subscales were positively scored to ensure that a higher score denoted a more activity-friendly neighbourhood. All subscales were dichotomized. Residential density was dichotomized into low (weighted mean ≤ 545) and high (weighted mean > 545) densities. Land use mix-diversity was dichotomized into ≤ 10 min or ≥ 10 min walking distance. Four-point Likert-type scale response options for all other subscales (land use mix-access, street connectivity, walking and bicycling infrastructure, aesthetics, safety from traffic, and safety from crime) ranging from 1 (strongly agree) to 4 (strongly disagree) were combined as “agree” (strongly agree, agree) and “disagree” (disagree, strongly disagree)

²SD=Standard Deviation

³MVPA = Moderate-to-Vigorous Physical Activity

Participants from households of low-socioeconomic status were more likely to be overweight/obese (OR=1.8, 95% CI=1.1-2.9) than participants from households of high-socioeconomic status. Active commuting was associated with reduced likelihood of overweight or obesity compared to driving to work (OR=2.9, 95%CI=1.3-6.4), but this relationship did not remain significant in adjusted models (aOR=2.6, 95%CI=0.7-9.3). Household car ownership was associated with an increase in the likelihood of overweight or obesity (aOR=1.5, 95%CI=0.7-3.2) although this relationship was not significant. In unadjusted models, a low walkability neighbourhood significantly predicted an increase in odds of overweight or obesity (OR=1.8, 95%CI=1.1-2.8), but this was not significant in adjusted models (OR=1.7, 95%CI=0.9-2.9).

Table 4. Factors associated with overweight or obesity

Factor	OR	95% CI	p-value	B value	Pseudo R ²	aOR*	95% CI	p-value	B value	Pseudo R ²
Age (Ref: 18-35 years)										
>35 years	3.0	1.9-4.7	0.000	1.1	0.1	n/a	n/a	n/a	n/a	n/a
Gender (Ref: Female)										
Male	1.2	0.8-1.9	0.4	0.2	0.0	n/a	n/a	n/a	n/a	n/a
Household socio-economic status (Ref: High)										
Low	1.8	1.1-2.9	0.01	0.6	0.0	n/a	n/a	n/a	n/a	n/a
Household car/motor vehicle ownership (Ref: No)										
Yes	1.5	0.7-3.2	0.3	0.4	0.0	n/a	n/a	n/a	n/a	n/a
Distance to work (Ref: Distance <= 10km)										
Distance > 10km	1.1	0.6-2.1	0.8	0.1	0.0	0.7	0.4-1.5	0.4	-0.3	0.2
Use public transit to commute to work (Ref: Yes)										
Car Driving	1.1	0.6-2.3	0.7	0.1	0.0	0.7	0.3-1.8	0.5	-0.3	0.2
Actively commute to work (Ref: Yes)										
Car Driving	2.9	1.3-6.4	0.008	1.1	0.1	2.6	0.7-9.3	0.1	1.0	0.2
Public transit stops within 10-minute walk (Ref: Yes)										
No transit stop	0.5	0.3-0.9	0.01	-0.6	0.0	0.6	0.3-1.3	0.2	-0.4	0.2

Meeting physical activity recommendations¹ (Ref: Yes)										
No	1.1	0.7-1.8	0.7	0.1	0.0	0.9	0.5-1.7	0.8	-0.1	0.2
Time spent sitting weekly (Ref: Low, ≤ 60 minutes/day)										
High	1.2	0.8-1.9	0.5	0.2	0.0	1.2	0.7-2.0	0.6	0.1	0.2
Neighbourhood walkability score (Ref: High)										
Low	1.8	1.1-2.8	0.01	0.6	0.0	1.7	0.9-2.9	0.07	0.5	0.2

Note: Note: OR=Unadjusted Odds Ratios, aOR=Adjusted Odds Ratios, CI=Confidence Interval

¹At least 150 minutes of physical activity per week based on global recommendations for physical activity among adults established by the World Health Organization

*Adjusted for age, gender, household socioeconomic status, and household car ownership

Discussion

This study is one of the first to explore neighbourhood environment correlates of obesity and overweight among urban residents in India. Impacts of the physical and social environment on obesity and overweight have been examined in recent epidemiological literature, however there is a paucity of research on the environmental correlates of obesity from South Asia, despite a significant portion of the obesity disease burden being concentrated in the region.⁴²⁻⁴⁵ We found that walkable neighbourhoods were associated with higher levels of physical activity and lower odds of obesity/overweight. Residents living in neighbourhoods with a diversity of destinations, availability of walking and bicycling facilities were more likely to meet physical activity recommendations. Active commuting was associated with lower odds of being overweight or obese. These results raise the possibility that built environment attributes found to facilitate active commuting in higher-income countries do not fully generalize to low- and middle-income countries. Findings from this study in urban India emphasize the need for more high-quality epidemiologic studies from low- and middle-income countries.

In our analyses, driving to work predicted a three-fold increase in overweight or obesity compared to active commuting in unadjusted models, but this relationship did not remain significant in adjusted models. Previous studies have highlighted that active commuting could reduce the detrimental effect of obesity and could potentially decrease the risk of premature mortality.^{46, 47} Research has also shown that residents in walkable, activity-friendly neighbourhoods, such as well-connected streets, tree-shaded sidewalks, pleasant aesthetic features, and transit access have higher levels of active commuting and a lower prevalence of obesity.¹⁷ Active commuting is specifically associated with improved physical fitness, weight control, reduced cardiovascular risk, and lower obesity.⁴⁷ Despite these benefits, urban India is witnessing inadequate development of public transport infrastructure, hazardous conditions for walking and bicycling, and a mass adoption of private motorized vehicles.^{21, 48-50}

Previous research from India has highlighted that urban living is associated with lower transport physical activity and increasingly sedentary lifestyles.⁵¹ All of these factors are likely contributing to declining levels of active commuting and a rise in population prevalence of overweight, obesity, and related non-communicable diseases in India. This is important given that India's urban planning models lack suitable policies to manage growth,⁵² which has resulted

1 in urban sprawl and traffic congestion, made worse by inadequate quality and safety of public
2 transport and non-motorised transport infrastructure.⁵³ As Indian cities expand and car
3 ownership increases, pedestrians are being marginalised and their safety is likely being put at
4 risk.

5
6 Studies have suggested that variations in physical activity and obesity prevalence may be driven
7 by income or education, although patterns might differ across countries. Previous studies on
8 associations between socioeconomic status and obesity concluded that obesity was essentially a
9 disease of the socioeconomic elite in low- and middle-income countries, in contrast to the
10 situation in developed countries where obesity was more common among the poor than among
11 the rich.⁵⁴ However, recent research has shown that the burden of obesity is shifting toward the
12 poor in developing societies.⁵⁵ Findings from this study confirmed this trend with participants
13 from low-socioeconomic status households more likely to be overweight or obese. There are
14 multiple individual and environmental factors that may explain why populations in
15 neighbourhoods of low-socioeconomic status are less active and bear greater obesity burdens.
16 One reason may be that parks, green spaces and playgrounds are less available to people living
17 in poor neighbourhoods, thereby limiting opportunities for physical activity.⁵⁶ Low-income
18 populations may be less able to afford indoor exercise equipment and/or memberships to gyms,
19 sports facilities, and recreation centres. Neighbourhoods with higher poverty rates also tend to
20 experience higher levels of crime and violence, which can deter physical activity.⁵⁷

21
22 Socioeconomic characteristics are associated with physical activity levels, and this is especially
23 true of car ownership. In this study, motor vehicle ownership demonstrated a strong association
24 with obesity and overweight in unadjusted models, which confirms previous research. Findings
25 from low- and middle-income countries like Mexico, Colombia, and Nigeria, have shown that
26 motor vehicle ownership is inversely associated with transport-based physical activity and a
27 predictor of obesity.⁵⁸⁻⁶⁰ Studies have shown that non-vehicle owners tend to have higher levels
28 of transport-based physical activity levels, which may be strongly driven by necessity rather than
29 choice. As automobile ownership increases across the developing world and has become the
30 primary mode of transportation, the built environment has evolved such that walking, bicycling,
31 and other forms of active travel are difficult and even hazardous.⁶¹ More research is needed to
32 understand and assess socio-economic factors and their relationship with active commuting
33 across larger geographical areas and over extended periods of time in low- and middle-income
34 country contexts in South Asia.

35 36 **Strengths and Limitations**

37 The cross-sectional study design limits causal inference and the relatively small sample from a
38 single city in India may restrict generalizability of these results. Further, the possibility of
39 residual confounding and self-selection (i.e., individuals who prefer active lifestyles may select
40 to live in areas that are more conducive to walking, bicycling, and active travel modes) are
41 limitations of this study. Self-reported measures such as IPAQ and NEWS are prone to bias from
42 social desirability, recall period, sampling approach, or selective recall.⁶²

43
44 In recent studies, researchers have independently weighed and measured participants to calculate
45 BMI and used accelerometers to track physical activity. These methods can provide objective
46 data, however, self-reported anthropometric data are commonly used to estimate prevalence of
47 obesity in population and community-based studies of this nature.⁶³ A key limitation of studies
48 in this area is a lack of consensus on the measurement of physical activity domains and types of
49 activity in each domain, reliability and validity of questionnaires to measure domain-specific
50 physical activity, and the inability to compare results across studies due to the large number of
51 measures available.⁶⁴ This study did not investigate the relationship between dietary patterns and
52 body weight, which may be a key factor contributing to the risk of overweight and obesity in

Indian populations. Studies have investigated links between consumption of high glycaemic diets and susceptibility to obesity, diabetes, and non-communicable diseases in some regions of India, however, the findings are mixed.⁶⁵ Despite the limitations, this study fills a critical gap in the scientific literature to resolve the problematic and urgent implications for population physical activity and public health in an urban South Asian context.

Conclusions

As the global burden of disease shifts from infectious diseases to non-communicable diseases in South Asia, an understanding of how environmental factors affect obesity, and how best to influence them is important for public health, health equity, and urban planning. By 2030, Indian cities are projected to be home to another 250 million people alongside a 9.9% annual growth rate in motor vehicles. The health and socio-economic implications from this heavy reliance on motorised transportation are likely to be substantial, running into tens of billions of dollars every year.^{61, 66} Similar patterns of rapid urban growth and motorised traffic are being witnessed across South Asia and potential concerns with respect to declining physical activity levels, reduced road safety, worsening air pollution, and traffic congestion. Low- and middle-income countries in South Asia have a particularly high reliance on private automobiles compared to other parts of the world, with higher rates of car usage and ownership reported in Indonesia, Cambodia, the Philippines and Vietnam.⁶⁷

As car ownership increases across South Asia, extra efforts may be needed to ensure population levels of physical activity. The documented harms of high automobile use such as lung diseases from air pollution, higher non-communicable disease risk due to the inactivity during vehicle use, and injury and death from traffic crashes, must be considered.^{68, 69} Building infrastructure that supports active commuting and equitable transit access can promote physical activity.¹⁷ City planners, public health practitioners, and elected officials need to design policies and programs that reach all members of society, especially the poor. Designing walkable communities may enable people at all income levels to travel to work, to school, and for daily needs using active transport modes. Walkable, activity-friendly neighbourhoods can also enable people with long-distance work commutes to reduce non-work automobile travel that increases non-communicable disease risk.^{17, 70} It is also important for future studies in South Asia to investigate the role of diet, nutrition, and physical activity in order to achieve the best results in preventing non-communicable diseases. Systematic attention to measuring social, cultural, and built environments could lead to improved understanding of their role in enhancing or inhibiting physical activity and the development of context-specific interventions to increase population levels of physical activity.

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References

1. Jaacks LM, Vandevijvere S, Pan A, McGowan CJ, Wallace C, Imamura F, et al. The obesity transition: stages of the global epidemic. *The Lancet Diabetes & Endocrinology* 2019;7(3):231-240.
2. Guthold R, Stevens GA, Riley LM, Bull FC. Worldwide trends in insufficient physical activity from 2001 to 2016: a pooled analysis of 358 population-based surveys with 1.9 million participants. *The Lancet Global Health* 2018;6(10):e1077-e1086.
3. Beaglehole R, Bonita R, Horton R, Adams C, Alleyne G, Asaria P, et al. Priority actions for the non-communicable disease crisis. *The Lancet* 2011;377(9775):1438-1447.
4. Guh DP, Zhang W, Bansback N, Amarsi Z, Birmingham CL, Anis AH. The incidence of co-morbidities related to obesity and overweight: a systematic review and meta-analysis. *BMC Public Health* 2009;9:88.

- 1 5. Lauby-Secretan B, Scoccianti C, Loomis D, Grosse Y, Bianchini F, Straif K. Body
2 Fatness and Cancer--Viewpoint of the IARC Working Group. *N Engl J Med*
3 2016;375(8):794-8.
- 4 6. Helble M, Francisco K. The Upcoming Obesity Crisis in Asia and the Pacific: First
5 Cost Estimates. ADBI Working Paper 743. Tokyo: Asian Development Bank Institute.; 2017.
- 6 7. Prentice AM. The emerging epidemic of obesity in developing countries.
7 *International Journal of Epidemiology* 2006;35(1):93-99.
- 8 8. Swinburn BA, Sacks G, Hall KD, McPherson K, Finegood DT, Moodie ML, et al. The
9 global obesity pandemic: shaped by global drivers and local environments. *Lancet*
10 2011;378(9793):804-14.
- 11 9. Siddiqui ST, Kandala NB, Stranges S. Urbanisation and geographic variation of
12 overweight and obesity in India: a cross-sectional analysis of the Indian Demographic
13 Health Survey 2005-2006. *Int J Public Health* 2015;60(6):717-26.
- 14 10. Meshram, II, Vishnu Vardhana Rao M, Sudershan Rao V, Laxmaiah A, Polasa K.
15 Regional variation in the prevalence of overweight/obesity, hypertension and diabetes and
16 their correlates among the adult rural population in India. *Br J Nutr* 2016;115(7):1265-72.
- 17 11. Deepa M, Pradeepa R, Rema M, Mohan A, Deepa R, Shanthirani S, et al. The Chennai
18 Urban Rural Epidemiology Study (CURES)--study design and methodology (urban
19 component) (CURES-I). *J Assoc Physicians India* 2003;51:863-70.
- 20 12. Rautela YS, Reddy BV, Singh AK, Gupta A. The prevalence of obesity among adult
21 population and its association with food outlet density in a hilly area of Uttarakhand. *J*
22 *Family Med Prim Care* 2018;7(4):809-814.
- 23 13. Pradeepa R, Anjana RM, Joshi SR, Bhansali A, Deepa M, Joshi PP, et al. Prevalence of
24 generalized & abdominal obesity in urban & rural India--the ICMR-INDIAB Study (Phase-I)
25 [ICMR- NDIAB-3]. *Indian J Med Res* 2015;142(2):139-50.
- 26 14. Garg C, Khan SA, Ansari SH, Garg M. Prevalence of obesity in Indian women. *Obes*
27 *Rev* 2010;11(2):105-8.
- 28 15. Mackenbach JD, Rutter H, Compernelle S, Glonti K, Oppert J-M, Charreire H, et al.
29 Obesogenic environments: a systematic review of the association between the physical
30 environment and adult weight status, the SPOTLIGHT project. *BMC public health*
31 2014;14:233-233.
- 32 16. World Health Organization. Global Recommendations on Physical Activity for
33 Health; 2019.
- 34 17. Sallis JF, Cerin E, Kerr J, Adams MA, Sugiyama T, Christiansen LB, et al. Built
35 Environment, Physical Activity, and Obesity: Findings from the International Physical
36 Activity and Environment Network (IPEN) Adult Study. *Annual Review of Public Health*
37 2020;41(1):119-139.
- 38 18. Kerr J, Emond Jennifer A, Badland H, Reis R, Sarmiento O, Carlson J, et al. Perceived
39 Neighborhood Environmental Attributes Associated with Walking and Cycling for
40 Transport among Adult Residents of 17 Cities in 12 Countries: The IPEN Study.
41 *Environmental Health Perspectives* 2016;124(3):290-298.
- 42 19. Milton K, Macniven R, Bauman A. Review of the epidemiological evidence for
43 physical activity and health from low- and middle-income countries. *Global Public Health*
44 2014;9(4):369-81.
- 45 20. Elshahat S, O'Rourke M, Adlakha D. Built environment correlates of physical activity
46 in low- and middle-income countries: A systematic review. *PLOS ONE*
47 2020;15(3):e0230454.
- 48 21. Ministry of Urban Development (MOUD). Level of Urbanization. New Delhi, India:
49 Government of India; 2013.

22. Gupta S, Singh Z, Purty A, Kar M, Vedapriya D, Mahajan P, et al. Diabetes prevalence and its risk factors in rural area of Tamil Nadu. *Indian Journal of Community Medicine* 2010;35(3):396-399.
23. Government of Tamil Nadu. Vehicular Position in Chennai City as on 1.3.2014. Chennai, India: State Transport Authority; 2014.
24. Office of the Registrar General & Census Commissioner. Census of India. New Delhi, India: Government of India; 2011.
25. Adlakha D, Hipp JA, Brownson RC. Adaptation and Evaluation of the Neighborhood Environment Walkability Scale in India (NEWS-India). *International Journal of Environmental Research and Public Health* 2016;13(4).
26. Turrell G. Income non-reporting: implications for health inequalities research. *J Epidemiol Community Health* 2000;54(3):207-14.
27. Cerin E, Conway TL, Saelens BE, Frank LD, Sallis JF. Cross-validation of the factorial structure of the Neighborhood Environment Walkability Scale (NEWS) and its abbreviated form (NEWS-A). *International Journal of Behavioral Nutrition and Physical Activity* 2009;6(1):32.
28. Oyeyemi AL, Kasoma SS, Onywera VO, Assah F, Adedoyin RA, Conway TL, et al. NEWS for Africa: adaptation and reliability of a built environment questionnaire for physical activity in seven African countries. *Int J Behav Nutr Phys Act* 2016;13(1):33.
29. Cerin E, Conway TL, Cain KL, Kerr J, De Bourdeaudhuij I, Owen N, et al. Sharing good NEWS across the world: developing comparable scores across 12 countries for the Neighborhood Environment Walkability Scale (NEWS). *BMC Public Health* 2013;13:309.
30. Salvo D, Reis RS, Sarmiento OL, Pratt M. Overcoming the challenges of conducting physical activity and built environment research in Latin America: IPEN Latin America. *Preventive Medicine* 2014;69 Suppl:S86-S92.
31. Oyeyemi AL, Sallis JF, Deforche B, Oyeyemi AY, De Bourdeaudhuij I, Van Dyck D. Evaluation of the neighborhood environment walkability scale in Nigeria. *International Journal of Health Geographics* 2013;12:16.
32. Saelens BE, Sallis JF, Black JB, Chen D. Neighborhood-based differences in physical activity: an environment scale evaluation. *Am J Public Health* 2003;93:1552 - 1558.
33. Kerr J. Advancing science and policy through a coordinated international study of physical activity and built environments: IPEN adult methods. *J Phys Act Health* 2013;10(4):581-601.
34. IPAQ. International physical activity questionnaires. IPAQ-long: last 7 days self-administered format. In: *International physical activity questionnaires*; 2002.
35. Craig CL, Marshall AL, Sjostrom M. International physical activity questionnaire: 12-country reliability and validity. *Med Sci Sports Exerc* 2003;35(8):1381 - 1395.
36. World Health Organization. Global Recommendations on Physical Activity for Health. In: *Global Strategy on Diet, Physical Activity and Health*. Geneva: World Health Organization; 2010.
37. World Health Organization. Obesity: Preventing and Managing the Global Epidemic. WHO Technical Report Series 894 2000. Geneva, Switzerland: World Health Organization; 2000.
38. Bairwa M, Rajput M, Sachdeva S. Modified Kuppuswamy's Socioeconomic Scale: Social Researcher Should Include Updated Income Criteria, 2012. *Indian J Community Med* 2013;38(3):185-186.
39. Gururaj, Maheshwaran. Kuppuswamy's Socio-Economic Status Scale – A Revision of Income Parameter For 2014. *International Journal of Recent Trends in Science And Technology* 2014;11(1).
40. Kerr J, Emond JA, Badland H, Reis R, Sarmiento O, Carlson J, et al. Perceived Neighborhood Environmental Attributes Associated with Walking and Cycling for

1 Transport among Adult Residents of 17 Cities in 12 Countries: The IPEN Study. *Environ*
2 *Health Perspect* 2016.

3 41. IBM Corp. IBM SPSS Statistics for Windows, Version 25.0. In. Armonk, NY: IBM
4 Corp.; Released 2012.

5 42. Bassett DR, Jr., Pucher J, Buehler R, Thompson DL, Crouter SE. Walking, cycling, and
6 obesity rates in Europe, North America, and Australia. *J Phys Act Health* 2008;5(6):795-
7 814.

8 43. Bauman AE, Reis RS, Sallis JF, Wells JC, Loos RJF, Martin BW. Correlates of physical
9 activity: why are some people physically active and others not? *The Lancet*
10 2013;380(9838):258-271.

11 44. Becerra JM, Reis RS, Frank LD, Ramirez-Marrero FA, Welle B, Arriaga Cordero E, et
12 al. Transport and health: a look at three Latin American cities. *Cadernos de Saúde Pública*
13 2013;29:654-666.

14 45. Heath GW, Parra DC, Sarmiento OL, Andersen LB, Owen N, Goenka S, et al. Evidence-
15 based intervention in physical activity: lessons from around the world. *The Lancet*
16 2012;380(9838):272-281.

17 46. Gordon-Larsen P, Nelson MC, Beam K. Associations among Active Transportation,
18 Physical Activity, and Weight Status in Young Adults. *Obesity Research* 2005;13(5):868-
19 875.

20 47. Yang L, Hipp JA, Adlakha D, Marx CM, Tabak RG, Brownson RC. Choice of commuting
21 mode among employees: Do home neighborhood environment, worksite neighborhood
22 environment, and worksite policy and supports matter? *Journal of Transport & Health*
23 2015;2(2):212-218.

24 48. Ministry of Road Transport and Highways. Basic Road Statistics of India. In:
25 Ministry of Road Transport and Highways; 2010-2011.

26 49. Pucher J, Zr P, Mittal N, Zhu Y, Korattyswaroopam N. Urban transport trends and
27 policies in China and India: impacts of rapid economic growth. *Transport Reviews* 2007;27.

28 50. Solanki HK, Ahamed F, Gupta SK, Nongkynrih B. Road Transport in Urban India: Its
29 Implications on Health. *Indian Journal of Community Medicine : Official Publication of*
30 *Indian Association of Preventive & Social Medicine* 2016;41(1):16-22.

31 51. Adlakha D, Hipp JA, Brownson RC. Neighborhood-based differences in walkability,
32 physical activity, and weight status in India. *Journal of Transport & Health* 2016;3(4):485-
33 499.

34 52. Mohanty PK. *Cities and Public Policy: An Urban Agenda for India*. SAGE
35 Publications; 2014.

36 53. Chatterjee A, Chattopadhyay RN. *Satellite Towns in Neo-metropolitan Development*
37 *in India: Lessons from Selected Cities*. Springer Singapore; 2020.

38 54. Ogden CL, Fakhouri TH, Carroll MD, Hales CM, Fryar CD, Li J X, et al. Prevalence of
39 Obesity Among Adults, by Household Income and Education — United States, 2011–2014.
40 *MMWR Morb Mortal Wkly Rep* 2017;66:1369–1373.

41 55. Monteiro CA, Conde WL, Popkin BM. Income-specific trends in obesity in Brazil:
42 1975-2003. *American journal of public health* 2007;97(10):1808-1812.

43 56. Sallis JF, Slymen DJ, Conway TL, Frank LD, Saelens BE, Cain K, et al. Income
44 disparities in perceived neighborhood built and social environment attributes. *Health*
45 *Place* 2011;17(6):1274-83.

46 57. Rees-Punia E, Hathaway ED, Gay JL. Crime, perceived safety, and physical activity: A
47 meta-analysis. *Preventive Medicine* 2018;111:307-313.

48 58. Oyeyemi AL, Ishaku CM, Oyekola J, Wakawa HD, Lawan A, Yakubu S, et al. Patterns
49 and Associated Factors of Physical Activity among Adolescents in Nigeria. *PLoS One*
50 2016;11(2):e0150142.

59. Salvo D, Torres C, Villa U, Rivera JA, Sarmiento OL, Reis RS, et al. Accelerometer-based physical activity levels among Mexican adults and their relation with sociodemographic characteristics and BMI: a cross-sectional study. *Int J Behav Nutr Phys Act* 2015;12:79.
60. Parra DC, Lobelo F, Gomez LF, Rutt C, Schmid T, Brownson RC, et al. Household motor vehicle use and weight status among Colombian adults: are we driving our way towards obesity? *Prev Med* 2009;49(2-3):179-83.
61. Shoham DA, Dugas LR, Bovet P, Forrester TE, Lambert EV, Plange-Rhule J, et al. Association of car ownership and physical activity across the spectrum of human development: Modeling the Epidemiologic Transition Study (METS). *BMC public health* 2015;15:173-173.
62. Wood TM. Issues and Future Directions in Assessing Physical Activity: An Introduction to the Conference Proceedings. *Research Q for Exerc Sport* 2000;71(2):ii-iv.
63. Bowring AL, Peeters A, Freak-Poli R, Lim MS, Gouillou M, Hellard M. Measuring the accuracy of self-reported height and weight in a community-based sample of young people. *BMC medical research methodology* 2012;12:175-175.
64. Steele R, Mummery K. Occupational physical activity across occupational categories. *J Sci Med Sport* 2003;6(4):398-407.
65. Joy EJ, Green R, Agrawal S, Aleksandrowicz L, Bowen L, Kinra S, et al. Dietary patterns and non-communicable disease risk in Indian adults: secondary analysis of Indian Migration Study data. *Public health nutrition* 2017;20(11):1963-1972.
66. Adlakha D, Hipp JA, Sallis JF, Brownson RC. Exploring Neighborhood Environments and Active Commuting in Chennai, India. *Int J Environ Res Public Health* 2018;15(9).
67. The Organisation for Economic Co-operation and Development. *Economic Outlook for Southeast Asia, China and India 2019 Towards Smart Urban Transportation: Towards Smart Urban Transportation*. OECD Publishing; 2018.
68. Douglas MJ, Watkins SJ, Gorman DR, Higgins M. Are cars the new tobacco? *Journal of Public Health* 2011;33(2):160-169.
69. Giles-Corti B, Vernez-Moudon A, Reis R, Turrell G, Dannenberg AL, Badland H, et al. City planning and population health: a global challenge. *The Lancet* 2016;388(10062):2912-2924.
70. Vancampfort D, Smith L, Stubbs B, Swinnen N, Firth J, Schuch FB, et al. Associations between active travel and physical multi-morbidity in six low- and middle-income countries among community-dwelling older adults: A cross-sectional study. *PloS one* 2018;13(8):e0203277-e0203277.