Original Article

Food and Physical Activity Environments and their Impacts on Diabesity in South India Adults

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Abstract

Background: Non-communicable diseases (NCDs), including diabetes and obesity, are serious global health concerns. India, impacted by rapid urbanization, has seen a shift in dietary habits and physical activity (PA) patterns, contributing to the rise of "diabesity" (the coexistence of diabetes and obesity). The evolving food environment—with a surge in processed foods and fast-food outlets—and limited spaces for PA have discouraged active healthy lifestyles, placing a strain on healthcare resources. **Objective:** This study examined the association of food and PA environments with diabesity among adults in urban Chennai. **Materials and Methods:** This cross-sectional study included 1138 adults across two electoral wards in Chennai, selected using multistage sampling. Diabesity prevalence was assessed using anthropometric (e.g., body mass index (BMI) and waist circumference) and biochemical (e.g., fasting plasma glucose, HbA1, or current use of diabetes medication) measurements; environmental influences were assessed using the Retail Food Environment Index (RFEI) and proximity to spaces for PA. Reduced rank regression (RRR) was used to identify lifestyle-environment patterns. **Results:** Diabesity prevalence was 32.5%, with higher rates observed among females, older adults, and physically inactive individuals. Multivariable analysis confirmed age, RFEI, and distance to space for PA as independent risk factor while PA was protective. RRR revealed two patterns, with "Passive Lifestyle and Unfavorable Environment" showing the highest diabesity risk. **Conclusion:** The findings highlight the need for urban planning and public health strategies to promote healthier food environments and increased PA opportunities to mitigate the burden of diabesity in urban Chennai.

Keywords: Built environment, diabesity, environmental determinants, food environment, physical activity environment

Introduction

Diabesity, the coexistence of diabetes and obesity, highlights the strong connection between these two conditions, both of which have a profound impact on global public health.[1] Obesity is one of the most significant risk factors for type 2 diabetes, and together, they contribute to a growing epidemic, particularly in urbanized and developed regions of the world.[2-4] Environmental factors, such as limited availability of healthy food options, inadequate spaces for physical activity (PA), and health behaviors like unhealthy diets, physical inactivity, and sedentary behaviors, play a crucial role in the rise of diabesity.[5-8] Food environment refers to the accessibility and availability of healthy food choices versus those dominated by processed and fast-food, unhealthy food options within a neighborhood, which can influence dietary behaviors and overall health outcomes. The spaces for PA are defined as the built or natural environments that promote or impede PA, including access to parks, green spaces, sidewalks,

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recreational facilities, and walkable neighborhoods. Both exposures are assessed in terms of their proximity and ease of use, which can either encourage or constrain residents' ability to engage in healthy behaviors.

Chennai, the capital of Tamil Nadu, has witnessed a considerable increase in the prevalence of diabesity, with recent research indicating a rate of 34.3%.[9] Chennai was chosen as a representative city for South India due to its rapid urbanization and associated lifestyle transitions. Like many growing metropolitan areas, Chennai has experienced significant changes in its built environment, including urban sprawl, limited access to green spaces, and a growing reliance on processed and fast foods. These factors, coupled with increasingly sedentary lifestyles, have led to diabesity becoming a critical public health concern among adults.[10,11] Understanding the role of these environmental and lifestyle changes in driving diabesity is crucial for developing effective intervention strategies.

Despite global awareness of diabesity as a twin epidemic, there is limited research examining the specific influence of the built environment and lifestyle patterns in Chennai.[12,13] This study aims to explore key environmental factors, such as access to spaces for PA, food environments, and lifestyle factors like PA, diet, and socioeconomic status, that contribute to diabesity among adults in Chennai.

Materials and Methods

This cross-sectional study examined the relationship between the built environment (food environment and spaces for PA), lifestyle factors and diabesity among adults in urban Chennai, using environmental and health data.

The research is part of the wider National Institute of Health Research – Global Health Research Unit (NIHR-GHRU) South Asia Biobank project conducted across five sites in South Asia.[14] This article reports only the Chennai data. A door-to-door survey was conducted using multistage sampling. Two wards (Mandaveli and Mylapore) were randomly selected from the 200 corporation wards in Chennai, and within each ward, five census enumeration blocks (CEBs) were chosen using systematic random sampling technique.

Participants were identified through household listings within the selected CEBs. Eligible individuals were confirmed during household visits conducted before data collection, and the Participant Information Sheet (PIS) was provided to all potential participants. During the household visit, participants were instructed to fast overnight (for at least 8 h) before blood collection. All data collection procedures, including interviews, anthropometric measurements, and venous blood sampling, were conducted in a single-day screening at the participant's household or designated site. Participants were selected via consecutive sampling which involves selecting all eligible participants sequentially until the target sample size was met. Since prevalence data on diabesity in Tamil Nadu were not available in the public domain, the expected prevalence was assumed to be 50% to yield the maximum sample size. Based on Cochran's formula, a sample size of 1067 was estimated. Allowing 5% oversampling to account for non-response, a sample size of 1121 was derived. In total, 1138 adults were recruited across the two wards. Eligible participants were adults aged 18 and older who had lived in the Chennai study area for more than 12 months and provided informed consent. Individuals with severe mental illness, major illnesses or pregnancy, were excluded. Full details of the methodology are published elsewhere.[15] The data were collected between December 2021and February 2022.

Ethical considerations

The Institutional Ethics Committee of the Madras Diabetes Research Foundation reviewed and approved the study protocol (Ref no: MDRF/NCT/06012018). All participants were provided with written informed consent forms, which outlined the objectives and purpose of the study. Participation was voluntary, and no incentives were offered. Upon completion of the study, participants received a health report detailing their current health status, along with tailored advice on health-related practices. To ensure confidentiality, each participant was assigned a unique identification number, and personal information was not disclosed to any third parties.

Data collection and measurements

Health and lifestyle questionnaire

Data were collected using the World Health Organization's (WHO) STEP wise Non-Communicable Disease (NCD) risk factor surveillance questionnaire, covering demographic and socioeconomic status, medical history—particularly family history of diabetes and heart disease—and behaviors like smoking, alcohol consumption, and fruit/vegetable intake. Field investigators facilitated pretested questionnaire in the community.[16]

Anthropometric and biochemical measurements

Obesity was assessed using body mass index (BMI) and waist circumference (WC), while diabetes was diagnosed through fasting plasma glucose (FPG) and HbA1c levels. Trained technicians collected blood samples, performed measurements, and ensured equipment calibration on-site. Height (SECA Model 213), weight and BMI (Omron BF511), and WC (non-stretchable tape) were measured following standard protocols. Obesity was defined as either abdominal obesity (AO) (WC ≥ 90 cm in males and ≥ 80 cm in females), or generalized obesity (GO) (BMI ≥ 27.5 kg/m^2).[17] FPG was measured on-site using the Jana Care AINA mini-glucose meter, with samples transported to a laboratory for HbA1c testing using the Bio-Rad Variant

II Turbo Machine. The cold chain was maintained during the transport. Diabetes was defined as individuals with FPG ≥ 126 mg/dL or HbA1c levels ≥ 6.5% (48 mmol/mol) or individuals taking diabetes medication.[18,19] Diabesity referred to co-occurring obesity and diabetes.

Physical activity assessment

The study employed the WHO's STEP Global PA Questionnaire (GPAQ) to assess participants' PA levels and patterns.[20] This validated tool has proven reliability across nine populations, including Asian Indians. It gathers data on PA in four domains: work-related activities, commuting, household tasks, and recreational activities.[21] Field investigators administered the questionnaire, and participants responses were converted into metabolic equivalents of task (METs).

METs are an index used to compare working and resting metabolic rates, serving as a measure of energy expenditure, with one MET representing the energy burned while sitting quietly, equivalent to 1 kcal/kg/h.[19] MET scores were calculated based on guidelines, with moderate activities assigned four METs and vigorous activities eight METs. Individuals were considered active if they engage in 150 min of moderate-intensity or 75 min of vigorous-intensity PA per week, totaling at least 600 MET-minutes. PA was categorized as low (<600 MET-minutes), moderate (600–1200 MET-minutes), and high (>1200 MET-minutes). The moderately active and highly active categories were combined into a single "active" group, defined as participants with 600 or more MET-minutes.[22]

Environmental factors

Environmental measures

Diabetogenic environment was operationally defined as a set of environmental and lifestyle factors that promote the development of both obesity and type 2 diabetes. It encompassed reduced opportunities for PA, unhealthy dietary patterns, high exposure to energy-dense foods, and limited access to health-promoting spaces, all of which contribute to metabolic dysfunction and an increased risk of diabesity. To assess the built environment (BE) in terms of food environment and spaces for PA, this study employed a comprehensive questionnaire adapted from International Network for Food and Obesity/NCDs Research, Monitoring and Action Support,[23] and Johns Hopkins University's Maryland Food Systems Map.[24] Field investigators facilitated the digital version of the questionnaire using the KoBo Tool app which also enabled real-time collection of global positioning system (GPS) coordinates for participants' households, spaces for PA, and nearby food outlets. As a quality measure the collected coordinates were cross-referenced using both the KoBo Toolbox and Google Maps. Geolocation data served as the primary data point and field visits were conducted at various times of the day, particularly in the mornings and afternoons, to account for temporal variations such as the presence of mobile food carts and vegetable vendors.[9,15]

Food environment

The Retail Food Environment Index (RFEI) was employed to link local food environments with diabetes and obesity outcomes.[25] Geolocation data were used to measure the density of these establishments within a 400 m radius of each participant's residence, considering participants household as centroid using ArcMap 10.7.1. Food establishments were categorized into four types: (1) Fast-Food Outlets: Quick-service restaurants offering processed, calorie-dense meals, often unhealthy. (2) Supermarkets/Grocery Stores: Large stores providing a wide range of foods, including fresh produce, considered healthier options. (3) Convenience Stores: Small shops selling mostly processed, packaged goods with limited healthy options. (4) Produce Vendors: healthy produce vendors, including temporary markets, mobile carts selling fruits and vegetables and vendors selling natural foods like rice, eggs, and pulses seen as healthier due to their focus on unprocessed items. Despite offering both healthy and unhealthy items, supermarkets were classified as healthy due to their wider availability of healthier options compared to fast-food outlets or corner stores.

The RFEI is a metric used to assess the balance of food options in a given area. It is calculated by comparing the number of unhealthy food outlets, such as fast-food restaurants and convenience stores, to the number of healthier options, like grocery stores and produce vendors.[25]

$$\text{RFEI} = \frac{\text{number of fast food outlets} + \text{number of convenience stores}}{\text{number of supermarkets \& grocery store} + \text{number of produce vendors}}$$

A higher RFEI indicates a greater prevalence of unhealthy food options relative to healthier ones.

The 400 m RFEI scores were merged with individual health data to assess the link between diabesity and the local food environment.

Physical activity environment

Spaces for PA included recreation centers, public parks, health hubs designed specifically for the elderly to encourage active exercise, sports-oriented clubs, playgrounds for children, and fitness gyms.

Using geolocation data, the network distance between each participants' households and all identified spaces for PA was measured. The average distance to spaces for PA was calculated for each participant. Geolocation data were merged with health data to assess the relationship

between diabesity and the PA environment. Geospatial analyses were performed using ArcGIS 10.7.1.

Statistical analysis

Descriptive statistics summarized participant characteristics. Group comparisons used Student's *t*-test for comparing continuous variables (age, AO, GO, HbA1c, FPG and availability of types of food environment, and RFEI) and the chi-square test for categorial variables. Univariate logistic regression identified variables individually associated with diabesity, followed by multivariable logistic regression to determine their independent effects on diabesity while adjusting for confounders. Before inclusion in the multivariable logistic regression model, multicollinearity among independent variables was assessed using the variance inflation factor (VIF), and no significant collinearity was observed (all VIF values <2).

To explore the combined influence of lifestyle and environmental factors on diabesity, reduced rank regression (RRR), a dimensionality reduction technique, was employed. In this study, both the predictor and response were continuous. Predictor included fruit intake, vegetable intake, family income, PA (METs), RFEI, and distance to PA areas. Responses were diabetes, obesity, and diabesity [Figure 1]. Analyses were conducted using SAS 9.3 (SAS Institute Inc., Cary, NC, USA). RRR computed pattern scores from eigenvalues/eigenvectors

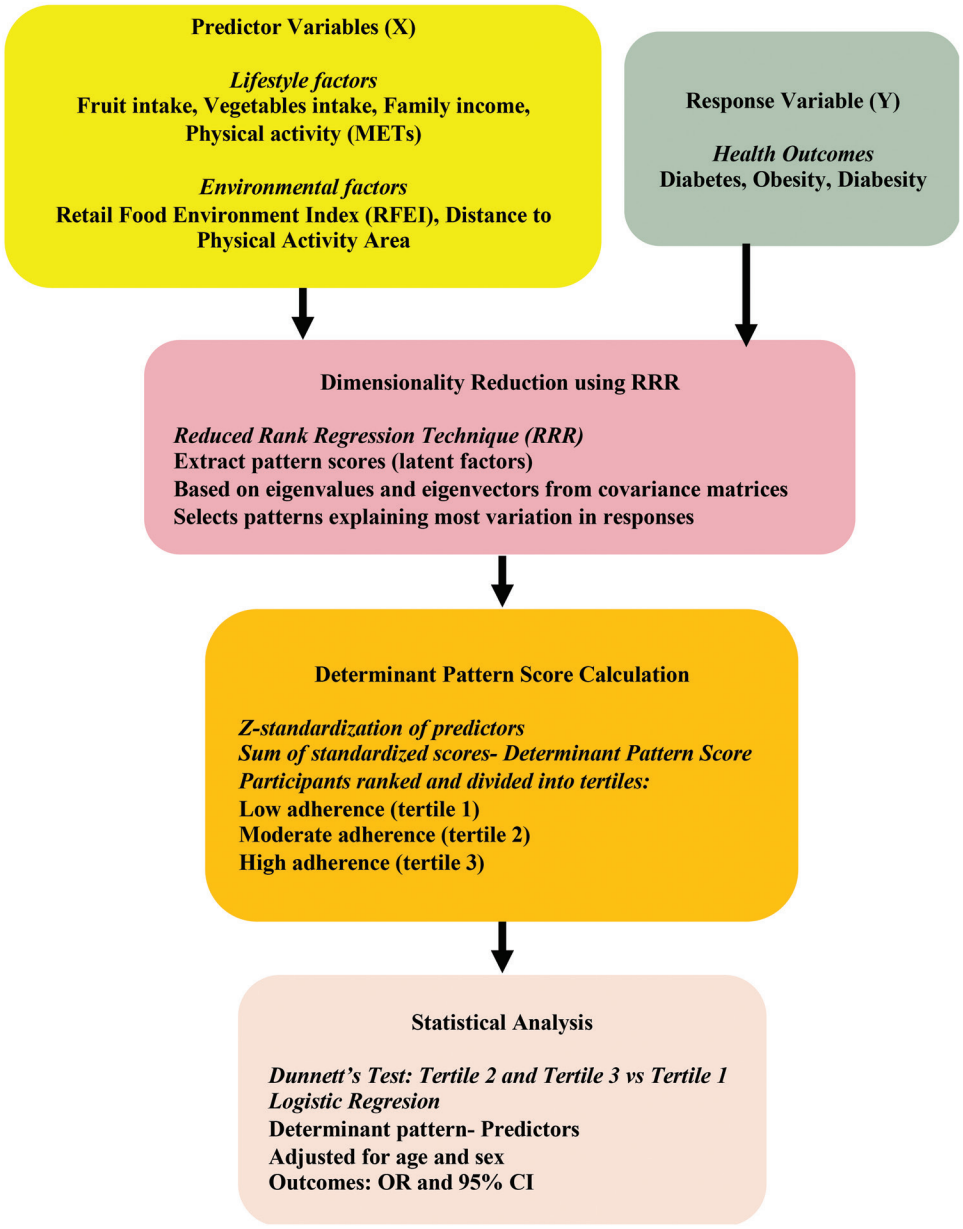


Figure 1: Conceptual framework of reduced rank regression (RRR) identifying determinant patterns of lifestyle and environmental factors associated with diabesity

of predictor-response covariance matrices; only the highest eigenvalues were retained to capture the strongest associations.

RRR modeled relationships across multiple variables, identifying a determinant model of diabesity. The determinant score was calculated by summing the z-standardized values (mean = 0, standard deviation = 1) of environmental and lifestyle variables. Participants were ranked and categorized into tertiles: low, moderate, and high adherence. Health outcomes were compared across tertiles. P-values were two-sided, with significance at 5%.

Dunnett's test compared the second and third tertiles with the first. Regression analysis evaluated the risk of diabetes, obesity, and diabesity using determinant scores, adjusting odds ratios for age and sex with 95% confidence intervals.

Results

The study enrolled 1138 participants (60% female), aged 18 and older from the two selected wards of Chennai area. The average age of participants was 51 ± 13 years. The overall prevalence of diabetes, obesity, and diabesity was 43%, 69.7%, and 32.5%, respectively. The mean (± standard deviation) values were 89 ± 11cm for abdominal obesity, 26 ± 5 kg/m^2 for general obesity, 119 ± 54 mg/dL for FPG, and 6.3 ± 1.6% for HbA1c. Most participants (59.3%) had a monthly family income between INR 10,000–20,000 (equivalent to 115–230 USD), 46.6% had less than primary education, and 38.2% were unemployed. Smoking and alcohol consumption were reported by 4.7% and 9%, respectively. Sedentary lifestyle with little PA was common (64.1%), with 67.6% consuming fewer than two servings of fruits and 84% consuming fewer than three servings of vegetables daily. Only 2.5% met the recommended intake of five daily servings (equivalent to 400 g/day or 5 servings of 80 g each) of fruits and vegetables.

Among individuals with diabesity, the average age was 53 ± 12 years, with 69.2% being physically inactive and 67.3% female. These individuals had significantly higher exposure to convenience stores (26 ± 9 vs. 24 ± 10) and fast-food outlets (77 ± 22 vs. 73 ± 24) compared to those without diabesity. The RFEI score, representing the ratio of fast-food outlets and convenience stores to grocery stores and produce vendors, was higher among individuals with diabesity (1.9 ± 0.3 vs. 1.8 ± 0.3). The average RFEI within a 400 m buffer was 1.9, indicating approximately two fast-food outlets and convenience stores for every grocery store or produce vendor. Among those with diabesity, 54.6% lived in areas with an RFEI greater than 1.9, and 56.2% lived more than 1.1 km from spaces for PA, showing a significant association between higher RFEI, reduced access to PA area and diabesity [Table 1].

In the univariate analysis [Table 2], increasing age was significantly associated with a higher risk of diabesity, with the odds ratio peaking (OR = 6.3, 95% CI: 2.4–16.1) for individuals aged 50–59 years. However, the risk was slightly lower for those >60 years (OR = 5.7, 95%

Table 1: Demographic, biochemical, anthropometric, and environmental parameters of the study population

	Overall	Without diabesity	With diabesity	*P* value*
***N* (%)**	1138	768 (67.5)	370 (32.5)	
Age (years)	51 ± 13	50 ± 14	53 ± 12	**<0.01**
Female, *n* (%)	683 (60)	434 (56.5)	249 (67.3)	**<0.01**
Current smoker, *n* (%)	54 (4.7)	37 (4.8)	17 (4.6)	0.440
Current alcohol user, *n* (%)	102 (9)	69 (9)	33 (8.9)	0.478
Family Income (INR), n (%)				
<10, 000	284 (25)	187 (24.4)	97 (26.2)	0.256
10,000–20,000	675 (59.3)	463 (60.3)	212 (57.3)	0.167
>20,000	179 (15.7)	118 (15.4)	61 (16.5)	0.317
Education, n (%)				
Less than primary school	530 (46.6)	363 (47.3)	167 (45.1)	0.243
Primary school completed	252 (22.1)	165 (21.5)	87 (23.5)	0.223
Secondary and high school completed	260 (22.8)	171 (22.3)	89 (24.1)	0.249
College completed	96 (8.4)	69 (9)	27 (7.3)	0.167
Occupation, n (%)				
Public and private sector employees	371 (32.6)	262 (34.1)	109 (29.5)	0.052
Self employed	332 (29.2)	228 (29.7)	104 (28.1)	0.289
Unemployed	435 (38.2)	278 (36.2)	157 (42.4)	**0.021**
Physically inactive, *n* (%)	729 (64.1)	473 (61.6)	256 (69.2)	**0.006**

Table 1: Continued

	Overall	Without diabesity	With diabesity	*P* value*
Diet				
Fruits and vegetables combined (5 servings/day)	29 (2.5)	22 (2.9)	7 (1.9)	0.159
Anthropometric measurement (Mean ± SD)				
Abdominal obesity	89 ± 11	87 ± 11	94 ± 9	**0.001**
Generalized obesity	26 ± 5	25 ± 5	28 ± 4	**<0.001**
Bio-clinical measurements (Mean ± SD)				
HbA1c (%)	6.3 ± 1.6	5.8 ± 1.2	7.3 ± 2.0	**<0.001**
FPG (mg/dL)	119 ± 54	102 ± 39	154 ± 64	**<0.001**
Access to physical activity area > 1.1 km, *n* (%)	565 (49.6)	357 (46.5)	208 (56.2)	**0.001**
Availability of food environment (Mean ± SD)				
Fast-food outlets	74 ± 24	73 ± 24	77 ± 22	**0.002**
Convenience stores	25 ± 9	24 ± 10	26 ± 9	**0.011**
Grocery stores	42 ± 12	41 ± 12	42 ± 11	0.122
Produce vendors	12 ± 5	12 ± 5	12 ± 5	0.052
RFEI (Mean ± SD)	1.9 ± 0.3	1.8 ± 0.3	1.9 ± 0.3	**0.015**
RFEI ≥ 1.9, *n* (%)	553 (48.6)	351 (45.7)	202 (54.6)	**0.002**

Continuous variables are displayed as mean ± standard deviation (SD); categorical variables are shown as frequency (*n*) and percentage(%);
*P value compared to without diabesity; $P < 0.05$ considered significant

Table 2: Association of lifestyle and environmental risk factors with diabesity

Environmental and lifestyle factors	Odds ratio (95% CI)
Univariate association	
Age	
18–29	Ref
29–39	4.1 (1.5−10.8)*
40–49	5.2 (1.9−13.2)*
50–59	6.3 (2.4−16.1)*
>60	5.7 (2.2−14.7)*
Sex	
Male	Ref
Female	1.6 (1.2−2.1)*
Physical activity	
Active	Ref
Sedentary	1.4 (1.1−1.8)*
RFEI score	
<1.9	Ref
≥1.9	1.4 (1.1−1.8)*
Distance to PA areas	
0–1.1 km	Ref
>1.1 km	1.5 (1.2−1.9)*
Multivariable association	
Age	1.02 (1.01−1.03)*
Sex	1.9 (1.4−2.6)*
Physical activity	0.6 (0.5−0.8)*
RFEI score	1.5 (1.0−2.3)*
Distance to PA areas	1.4 (1.1−1.8)*

Values are based on multivariable logistic regression models adjusted for age, sex, and income. OR = Odds ratio; CI = confidence interval; diabesity is defined as the coexistence of type 2 diabetes and BMI ≥ 27.5 kg/m².
*P value <0.05 considered significant

CI: 2.2–14.7). Females had a 60% higher risk than males (OR = 1.6, 95% CI: 1.2–2.1). Sedentary individuals (OR = 1.4, 95% CI: 1.1–1.8), those with a RFEI score ≥1.9 (OR = 1.4, 95% CI: 1.1–1.8), and those living >1.1 km from PA areas (OR = 1.5, 95% CI: 1.2–1.9) were at greater risk of diabesity.

In the multivariable model for diabesity, age remained an independent risk factor (OR: 1.02, 95% CI: 1.01–1.03), along with female sex (OR = 1.9, 95% CI: 1.4–2.6), higher RFEI score (OR = 1.5, 95% CI: 1.0–2.3), and greater distance to PA areas (OR = 1.4, 95% CI: 1.1–1.8). Conversely, PA was inversely associated with diabesity, indicating a lower risk (OR = 0.6, 95% CI: 0.5–0.8).

Factor-loading analysis using RRR identified two determinant patterns [Figure 2]. RRR-1, labeled as "Passive Lifestyle with an Unfavorable Environment," was characterized by low PA (METs regression score: −0.3), greater distance from PA areas (−0.9), lower fruit (−0.2), and vegetable (−0.1) consumption, and average family income levels with high exposure to unhealthy food environments (RFEI: 0.2). This group had the highest diabesity risk due to unfavorable lifestyle and environmental factors. RRR-2, or "Moderate Lifestyle with an Inconsistent Environment," included individuals with better PA access and moderate PA levels but continued exposure to unhealthy food outlets (higher RFEI scores). This pattern reflected a mixed risk profile, with some health-promoting behaviors counterbalanced by high exposure to diabetogenic environments.

Analysis across tertiles of RRR patterns [Table 3] showed that being in the highest tertile (Tertile 3) of RRR pattern 1 was associated with increased BMI, WC, HbA1c, and

FPG, along with lower PA levels (METs) and higher exposure to unhealthy food environments compared to those in the lowest tertile (Tertile 1). These trends suggest that higher adherence to this pattern is associated with increased metabolic risk and a lifestyle conducive to diabesity. Similar patterns were observed for RRR pattern 2, though the association was less consistent across all variables. Table 4 presents the risk of developing diabetes, obesity, and diabesity based on adherence to these patterns. RRR pattern 1 showed strong association with increased odds of diabesity, obesity and diabetes across tertiles. In contrast, RRR pattern 2 was associated only with obesity, not with diabetes or diabesity.

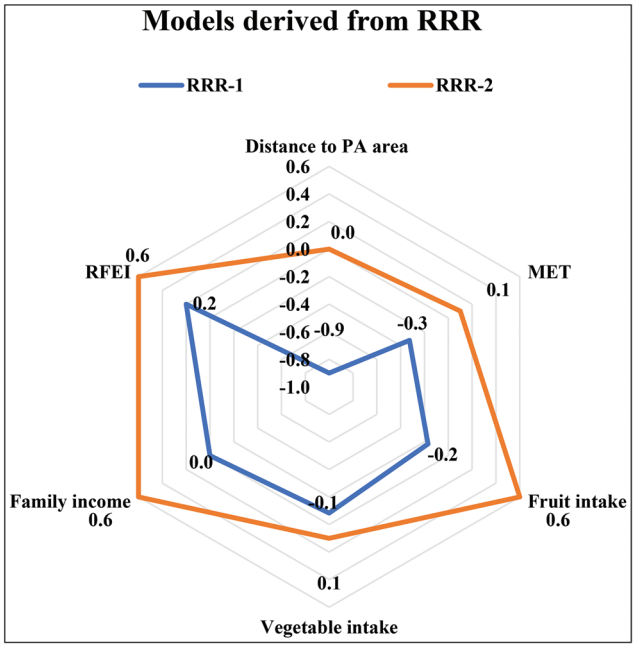


Figure 2: Spider diagram of factor-loading values for environmental and lifestyle predictors across two patterns identified by reduced rank regression (RRR)

Discussion

This study provides a comprehensive analysis of the interplay between lifestyle and environmental factors and diabesity risk, identifying distinct patterns through RRR. The findings highlight that greater exposure to unhealthy food environments and limited access to PA facilities are significantly associated with higher diabesity risk. These results reinforce previous evidence on obesogenic environments while offering a structured framework for understanding their combined impact. Importantly, the study suggests that beyond individual behaviors, broader urban planning and policy interventions are needed to mitigate these environmental contributors to diabesity.

A key strength of this study includes the use of RRR to identify key lifestyle and environmental patterns, offering valuable insights for public health interventions and urban planning. Two distinct patterns emerged: "Passive Lifestyle with an Unfavorable Environment" (RRR-1) and

Table 4: Risk for diabesity, obesity, and diabetes by reduced rank regression-derived patterns in tertiles adjusted for age and sex

		RRR-1 OR (95% CI)	RRR-2 OR (95% CI)
Diabesity	Tertile 1	Reference	Reference
	Tertile 2	2.6 (1.8–3.6)*	1.9 (0.7–1.3)
	Tertile 3	4.1 (2.9–5.8)*	1.1 (0.8–1.5)
Obesity	Tertile 1	Reference	Reference
	Tertile 2	1.5 (1.1–2.1)*	1.4 (1.0–1.9)**
	Tertile 3	1.8 (1.1–2.5)**	2.1 (1.5–2.9)*
Diabetes	Tertile 1	Reference	Reference
	Tertile 2	1.9 (1.5–2.7)*	0.9 (0.7–1.2)
	Tertile 3	3.1 (2.3–4.2)*	0.9 (0.7–1.2)

RRR = Reduced rank regression

*P value < 0.001 considered highly significant;

**P value <0.05 considered significant

Table 3: Demographic, biochemical, clinical, and environmental factors of the study population across tertiles derived by reduced rank regression (RRR)

Variables	RRR-1			RRR-2		
	Tertile 1	Tertile 2	Tertile 3	Tertile 1	Tertile 2	Tertile 3
Age (years)	51 ± 14	51 ± 13	50 ± 13	52 ± 13	50 ± 14	51 ± 13
Family income (INR)	13519 ± 11691	14192 ± 13400	136401 ± 10789	9859 ± 4851	12130 ± 6150*	19368 ± 17957*
Weight (kg)	62 ± 13	64 ± 13*	64 ± 12*	61 ± 13	63 ± 12*	66 ± 13*
BMI (kg/m^2)	26 ± 5	27 ± 5	27 ± 5	26 ± 5	26 ± 5	27 ± 5
WC (cm)	88 ± 12	90 ± 11*	90 ± 11*	88 ± 11	89 ± 11	91 ± 11*
HbA1c (%)	6.1 ± 1.5	6.3 ± 1.6**	6.6 ± 1.8*	6.4 ± 1.7	6.3 ± 1.7	6.2 ± 1.6*
FPG (mg/dL)	110 ± 48	119 ± 54*	127 ± 60*	120 ± 54	122 ± 60	115 ± 49*
METs	505 ± 433	415 ± 365*	259 ± 327*	373 ± 420	390 ± 394*	416 ± 356*
RFEI	1.7 ± 0.3	1.9 ± 0.3*	1.9 ± 0.3*	1.7 ± 0.3	1.9 ± 0.3*	2.0 ± 0.2*

BMI = Body mass index, WC = waist circumference, FPG = fasting plasma glucose, METs = metabolic equivalent of task, RFEI = Retail Food Environment Index, RRR = reduced rank regression tertile 2 and 3 were compared with Tertile 1-reference

*P value <0.05 considered significant

"Moderate Lifestyle with an Inconsistent Environment" (RRR-2), both associated with increased diabesity risk.

The BE significantly influences food consumption and PA behaviors, shaping health outcomes. Individuals with greater exposure to convenience stores and fast-food outlets exhibited a higher risk of diabesity. The RFEI score in our study highlights an unequal distribution of food options, with approximately two fast-food outlets and convenience stores for every grocery store and produce vendor. This imbalance may encourage individuals to choose more easily accessible, unhealthy options. A UK study similarly found that increasing the availability of healthy options doubled the likelihood of healthier choices, while a greater number of unhealthy options tripled the chances of selecting less healthy alternatives.[26] Our findings indicate a significant public health implication, with an RFEI score ≥1.9 linked to a 1.4-fold increased risk of diabesity. These results are consistent with previous research from Sri Lanka and Bangladesh (South Asia Biobank data), which have demonstrated strong associations between fast-food density and metabolic risk.[27,28]

Our geospatial analysis used a 400 m buffer, aligning with prior work reporting most significant impacts were observed within a 400 m rage for both radial and line-based buffers, and this impact diminished as the buffer size increased.[29] Our findings show that individuals with diabesity were significantly more exposed to convenience stores and fast-food outlets. Similar trends have been reported internationally; studies from Bangladesh and Sri Lanka demonstrated that unhealthy food environments, characterized by fast-food outlets, were associated with higher risk of diabetes and obesity, with stronger effects among urban women.[27,28] Research from the Netherlands reported that greater fast-food density was positively associated with diabetes risk[30] and that study from China reported that higher obesity prevalence in rural areas with greater fast-food access.[31] These findings reinforce that unhealthy food environments contribute to metabolic risk across diverse settings, consistent with our results from urban India, and underscore the need for targeted food environment interventions. Research from Andhra Pradesh reported that a higher density of processed food vendors and limited access to fresh produce were associated with increased diabetes and obesity risk.[32]

Conversely, studies from China, Taiwan, and South Korea highlight the protective effect of green spaces and walkability on type 2 diabetes (T2DM) risk.[33-35] Our findings show that individuals living away from PA areas had a 1.5-fold higher diabesity risk. Reviews also report 21% and 10% reductions in T2DM risk with better walkability and green space access, respectively.[36] These results align with broader evidence that proximity to PA spaces boosts PA. Research articles indicating that the PA environment significantly influences individual behavior.[37,38]

Focusing on Chennai, our study offers a more integrated analysis of food environments, PA accessibility, and metabolic risk, unlike earlier work that evaluated these factors separately. This holistic approach underscores the need for integrated urban planning, especially in rapidly urbanizing South Asian settings.

Effective diabesity management must address lifestyle, socioeconomic, and environmental factors.[39-41] Regular exercise, healthy diets, and access to healthy foods and healthcare resources are essential for effective management.[40,42] Family income also significantly impacts access to both healthy foods and healthcare resources.[43,44] Environmental factors like RFEI and PA proximity also shape behavioral choices.[45,46]

Interventions should combine individual behavior change with community and policy-level strategies. Recommended actions include lifestyle programs, improved access to healthy food and PA spaces, regulation of unhealthy food outlets, and training for healthcare providers on environmental determinants. Digital health tools can also support behavior change.

Limitations include the cross-sectional design, potential self-reporting bias, and focus on one urban area, limiting generalizability. Although the Retail Food Environment Index (RFEI) and proximity to PA spaces were generated individually for each participant using GPS-based data, some residual clustering of exposures may remain among participants living in very close proximity. The study also did not assess online food delivery or use detailed dietary assessment tools. Future studies should adopt longitudinal designs and consider digital food environments to better capture evolving influences on diabesity.

Conclusion

This study highlights the significant impact of food environments and PA accessibility on diabesity risk in an urban South Asian setting. Individuals exposed to more fast-food outlets at a higher risk for diabesity; similarly, individuals living further from space for PA were at higher diabesity risk and less active, emphasizing the BE's influence on lifestyle choices and health behaviors. Addressing diabesity will require policy driven urban planning, better access to PA spaces, and community-level health interventions. Integrated strategies at the individual, community, and policy levels are essential to curb the growing burden of diabesity in rapidly urbanizing regions.

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Conflicts of interest

There are no conflicts of interest.

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