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Assessing type-2 diabetes risk based on the Indian diabetes risk score among adults aged 45 and above in India

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Millions of Indian adults are pre-diabetic with a greater risk of developing type-2 diabetes mellitus (T2DM). We conducted this study to assess the prevalence of type-2 diabetes risk among non-diabetic adults aged 45 years and above and identify the correlates for diabetes risk. We conducted a secondary analysis of Longitudinal Ageing Study in India (LASI) wave 1 data. A sample of 51,315 non-diabetic adults was extracted from LASI data and analysed. Type-2 diabetes risk was assessed based on the Indian Diabetes Risk Score (IDRS) by using four risk factor variables [i.e., (1) age of the respondent, (2) waist circumference, (3) family history of diabetes, and (4) physical activity]. A diabetes risk score of ≥ 60 was considered a high risk for diabetes. Descriptive statistics and multivariate analysis were conducted to assess the prevalence and correlates of diabetes risk respectively. About 41.2% had a high risk of diabetes. Among major Indian states, Kerala leads with 64.4% of its adults 45 years and above at high risk of diabetes. Obese level BMI (AOR 4.17; 95% CI 3.59–4.84), High cholesterol (AOR 1.51; 95% CI 1.22–1.87), History of heart disease and stroke (AOR 1.85; 95% CI 1.60–2.13), and males (AOR 1.25; 95% CI 1.16–1.34) had positive odds for high risk of diabetes. Individuals from scheduled tribes (AOR 0.85; 95% CI 0.76–0.96) had lower odds of diabetes risk. Obese individuals with a history of heart disease/stroke had a significantly higher (AOR 5.30; 95% CI 4.39–6.41) risk for diabetes. The findings suggest that it is essential to establish population-level interventions to tackle the modifiable risk factors for diabetes. Educational programs on diet and physical activity, creation of public spaces conducive to physical activity, promotion of fruit and vegetable intake, and discouragement of processed and ultra-processed diets can directly address inadequate physical activity and obesity, the two primary modifiable risk factors for type-2 diabetes. Additionally, strengthening health systems for early screening and management of diabetes and pre-diabetes is needed to prevent the diabetes epidemic.

Keywords Body mass index, Diabetes, Indian diabetes risk score, Longitudinal ageing study in India, Obesity

Diabetes is a chronic disease contributing to high mortality and morbidity, particularly in low and middle-income countries[1]. Over the years, the diabetes prevalence has been increasing in India. The age-adjusted prevalence of diabetes is expected to increase from 9% in 2011 to 10.8% by 2045[2]. Moreover, more than half of the diabetic individuals in India are undiagnosed[3]. A recent study reported that there are 101 million individuals with diabetes and 136 million individuals with prediabetes in India[4]. In 2019, India had an age-standardized incidence of diabetes at 317.02 per 100,000 population and a mortality of 27.35 deaths per 100,000 population[5].

The risk of diabetes can be either due to modifiable risk factors, non-modifiable ones, or both. Studies on the epidemiology of type-2 diabetes in India identified that genetics, family history, age, ethnicity, unhealthy diet, physical inactivity, use of tobacco and alcohol, high body mass index, raised blood sugar, and blood lipid levels are major risk factors for diabetes[3]. Further, it has been found that high blood pressure, heart disease, and stroke are associated with diabetes[6,7]. While it is known that individuals with diabetes have an elevated risk of heart disease and stroke, the associations between diabetes risk among non-diabetic individuals, and cardiovascular events like heart disease and stroke are less explored. Individuals presenting these risk factors can be at a higher or lower risk of diabetes with respect to the combination of these risk factors. Despite its higher prevalence, the

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majority of diabetes cases in India are undiagnosed primarily due to long latent periods, lack of awareness, and the need for equipment/laboratory approaches for diagnosis.

The Indian Diabetes Risk Score (IDRS) is a non-invasive approach for screening type-2 diabetes risk, and was developed by the Madras Diabetes Research Foundation (MDRF)[8,9]. It evaluates an individual's risk of developing type-2 diabetes through a comprehensive scoring across four major risk factors namely (1) age, (2) family history, (3) waist circumference, and (4) physical activity. Given the simplicity involved, IDRS is considered to be a cost-effective means to screen for potential diabetes risk at the population level[10–12]. The WHO Consulting Group Criteria were used to construct the Receiver Operating Characteristic [ROC] curves to find the optimum value for the simplified IDRS and a value of 0.69 (95% CI 0.66–0.73) was shown as the area under the curve (AUC)[8,13]. Various studies conducted in different regions of India have validated the IDRS for the prediction of conditions like prediabetes [AUC of 0.83 (95% CI 0.77–0.88)], and undiagnosed diabetes among adults in the community settings (significance at <0.01)[14,15]. Another multi-centric nationwide study also reported an AUC of 0.76 (95% CI 0.76–0.76) and a significance of $p<0.0001$ for the IDRS[16]. Similarly, in 2011, Sharma, et al. and in 2023 Halder, et al. also reported similar AUC values for the prediction of T2DM[17,18].

The cut-off at an IDRS value of ≥ 60 gave an optimum sensitivity and specificity of 72.5% and 60.1% respectively to identify the risk of type-2 diabetes[8]. With the same cut-off value of IDRS ≥ 60, other studies across India later reported IDRS to have a high sensitivity of up to 98.3%[10,11,19], and clinically significant association for glucose intolerance in multiple settings[20]. Further, a recent large-scale study of 113,043 participants reported that 96.1% of newly diagnosed diabetic cases, and 91.3% of prediabetes cases were screened as moderate/high risk for type-2 diabetes by IDRS[21].

While standardised approaches such as the Glucose Tolerance Test, and HbA1c are useful to clinically diagnose diabetes and pre-diabetes, undertaking these tests at a mass scale is a logistical challenge. Moreover, the utilization of diabetes screening services provided under the comprehensive primary healthcare model through health and wellness centres (HWC) in India is seemingly low. In Kerala, which has the highest prevalence of diabetes among Indian states[22], from June 2020 to December 2023, less than 11% of footfalls to HWCs were diabetes screening. Moreover, in 24 of the 36 states and union territories, less than a third of individuals with diabetes are aware of their disease status[22]. Treatment and control levels also remain low with only 22% of the diabetic cases being on treatment and around 7% achieving control[22]. Identification of high-risk individuals, prevention, early screening, and treatment initiation are key to controlling diabetes at a population level. However, screening and diagnosis are also critical bottlenecks in the diabetes care continuum[23].

The IDRS enables to reliably estimate potential diabetes risk at the population level. While various studies have investigated diabetes risk in India, they are limited by their focus to select regions or groups of states. Also, the older age population is rapidly rising in India, and very limited literature exists concerning diabetes risk among adults aged 45 years and above. Previous studies recommended employing diverse population-based studies to assess the risk of diabetes and generalize the findings related to IDRS[24–26]. There is scant evidence employing population-based representative samples to report diabetes risk in India. We conducted this study with the following objectives.

1. To estimate the prevalence & distribution of high-risk for type-2 diabetes using diabetes risk scores among non-diabetic individuals aged 45 years and above in India.
2. To identify the role of selected demographic, environmental, and lifestyle factors in influencing the high risk of type-2 diabetes among non-diabetic individuals aged 45 years and above.

Methods

Study design and sample description

The Longitudinal Ageing Study in India (LASI) Wave 1 was the first study conducted between 2017 and 2018 as part of a panel survey. We have reused data from LASI Wave 1 to carry out the cross-sectional analysis. LASI Wave 1 (2017-18) was conducted to study ageing in India as a joint initiative of the International Institute for Population Sciences (IIPS), Harvard T.H. Chan School of Public Health, Boston, and the University of Southern California[27]. The data was obtained from the IIPS through a formal request.

The LASI sample consisted of 72,250 participants, sampled through a multistage stratified area probability cluster sampling design providing a representative sample of adults aged 45 years and above across India. In each state, the sampling process involved three stages (sub-districts, villages, and households) in rural areas, and four stages (sub-districts, urban wards, census enumeration blocks, and households) in urban areas. Households were the ultimate sampling units. From each sampled household, all the individuals aged 45 years and above and their spouses irrespective of age were sampled. A detailed account of the LASI survey methodology is provided in the survey reports, and supporting documents[28].

We conducted this study among a sub-sample of non-diabetic individuals aged 45 years and above extracted from the larger LASI sample. By applying age (45 years and above), and self-reported diabetes status as a criterion we extracted a sample of 57,133 non-diabetic individuals, aged 45 years and above. Further, we curated the data for missing data in the key variables (i.e., age, family history of diabetes, physical activity, and waist circumference) used to compute the dependent variable (i.e., diabetes risk score) and excluded the cases with missing data across any one of these variables. After cleaning for the missing data, the final sample comprised was of 51,315 non-diabetic adults representing 35 states and union territories of India.

Study variables

Dependent variables

The Indian Diabetes Risk Score was computed as a composite index of the four variables namely the modifiable risk factors of (1) physical activity, (2) waist circumference, and non-modifiable risk factors of (3) age and (4) family history of diabetes[20].

Physical activity was computed based on the existing variables capturing self-reported physical activity. Respondents were categorized to be undertaking regular vigorous physical activity, regular moderate physical activity, or regular mild physical activity based on the self-reported items from the LASI survey. The vigorous physical activity involved activities requiring physical strain resulting in cardiovascular activity and sweating (such as running, jogging, swimming, heavy lifting, farm work, etc.). Moderate physical activity involved activities like cleaning the house, washing clothes by hand, fetching water/wood, gardening, bicycling, walking at a moderate pace, etc. To compute regular mild physical activity, we used the self-reported item of respondent's involvement in activities like yoga, asana, pranayama, and meditation every day of the week[29]. An individual was categorized to undertake regular vigorous/moderate/mild physical activity if he/she reported undertaking the aforementioned activities every day.

LASI survey measured waist circumference in centimetres (cm) employing standard protocols using Gulick tape. The waist circumference variable was used for computational purposes of IDRS scores. Waist circumference was computed for males and females separately to indicate low (females < 80 cm, males < 90 cm), moderate (females 80.00–89.99 cm, males 90.00–99.99 cm), and high (females > 90 cm, males > 100 cm) risk levels. The non-modifiable risk factors i.e., age, and family history were also computed from within the existing variables within the LASI survey. The age of the respondent was categorized as 45 to 49 years, and 50 years and above. Family history of diabetes was categorized as (1) no history of diabetes in parents, (2) one parent is diabetic, and (3) both parents are diabetic. The detailed outline of variable transformation, and computation of four IDRS variables, and their corresponding scores is given in supplementary file 1.

The diabetes risk score was computed as a composite index of the four IDRS variables with a score ranging between 20 and 100. The score was further categorized as low risk (score of up to 30), moderate risk (score between 30 and 50), and high risk of diabetes (score of 60 and above)[20]. Additionally, considering the age group of our sample (i.e., 45 years and above) we further dichotomized diabetes risk to high risk (score of 60 and above), and low to moderate risk (score of below 60). The dichotomous categorization of the IDRS score was warranted as the IDRS score for high-risk diabetes was reported to be a more sensitive indicator for diabetes in previous studies[11,21,24].

Independent variables

We have included selected socio-demographic, environmental, lifestyle, and health-related factors as independent variables, identified based on prior literature on diabetes epidemiology and risk. The socio-demographic variables consist of sex, place of residence, wealth index, highest education level, and caste. Environmental factors include living arrangements, while lifestyle factors cover tobacco and alcohol consumption. Individual health-related variables encompass body mass index (BMI), blood pressure, high cholesterol levels, and history of heart disease or stroke.

The socio-demographic and environmental variables are analysed in their original form. Tobacco consumption status (categorized as lifetime abstainer, current user, or past user) was derived from variables on current and past tobacco use in both smoking and smokeless forms. Alcohol consumption status was recoded to indicate less frequent consumption (0–3 days per month), frequent consumption (> 4 days per month), and lifetime abstainer.

BMI was calculated from height and weight measurements. Blood pressure was derived based on the average of the last two systolic and diastolic blood pressure readings collected in the LASI survey. High cholesterol levels was a binary variable based on responses to a self-reported item "ever diagnosed with high cholesterol". History of heart disease or stroke was combined from two separate self-reported variables: one indicating a diagnosis of chronic heart disease and the other indicating a diagnosis of stroke.

Data cleaning and analysis

The data cleaning phase involved data transformation, computing of the dependent variable, and recording of the independent variables. Prior to the analysis, sample weights provided in the LASI dataset were applied to ensure the representativeness of the sample and minimize the over/under-representation of any groups/geographies. The results were presented as weighted percentages, coefficients, and test statistics.

We analysed the data employing univariate, bivariate, and multivariate approaches. In the univariate analysis, categorical variables were analysed using weighted percentages, while continuous variables were described using mean and standard deviation. The prevalence of the diabetes risk levels, along with its components (age, waist circumference, family history of diabetes, and physical activity), was assessed through weighted percentages. IDRS scores were reported with their means and standard deviations. The state-wise prevalence of high-risk for type-2 diabetes was illustrated using a choropleth map.

In the bivariate analysis, cross-tabulations were employed to descriptively analyse the variations in the diabetes risk score and the prevalence of high diabetes risk (IDRS ≥ 60) across the independent variables.

We conducted multivariate analysis employing binary logistic regression. Diabetes risk with responses (1) High risk of type-2 diabetes, and (2) Low risk of type-2 diabetes computed based on IDRS was the dependent variable in the regression model. The independent variables identified through the review of the literature and the LASI survey questionnaire were included in the model. Variance inflation factor (VIF) was computed to assess for multicollinearity. The mean VIF of all the variables in the model was 2.44 indicating that independent variables in the regression model are not highly correlated. Unadjusted odds ratios and adjusted odds ratios

(AOR) and their 95% confidence intervals were computed. To assess the discriminative ability, we computed the ROC curve for the logistic regression model and calculated the area under the ROC curve.

Further, interaction terms were used to develop logistic regression models for investigating the interaction effects of BMI with socio-economic variables (wealth index, caste, and education level), and health status variables (high blood pressure, history of heart disease or stroke) in influencing the type-2 diabetes risk. This analysis provided adjusted odds ratios (AOR) for type-2 diabetes risk, factoring in interactions between individual BMI categories and other independent variables (e.g., the odds of type-2 diabetes risk among overweight individuals from poorer households). These findings highlighted the prominence of BMI as a crucial explanatory variable in influencing type-2 diabetes risk.

A p-value of <0.05 was considered to be statistically significant. Data cleaning and analysis were performed using Statistical Package for Social Sciences version 27 and STATA version 13. ROC curves were developed using STATA version 13, and maps were developed using Microsoft Excel.

Ethical considerations

The study utilized publicly available deidentified secondary data and did not involve direct interaction with human participants. No personally identifiable information (PII) such as a name, personal address, national ID, bank account information, employee identification, email, mobile number, etc., was collected. The original LASI survey, which provided the data for this study, received approval from the Ethical Committee (EC) of the Indian Council for Medical Research. As part of the survey, informed consent was obtained from all the participants. The privacy and confidentiality of the participants were protected by delinking the study findings with any identifiable information of individual participants. The data used was obtained in deidentified form through a formal application to the LASI nodal agency, thereby no additional EC approval was obtained.

Results

We analysed the data of 51,315 non-diabetic adults aged 45 years and above representing 35 states and union territories of India. The average age was 59.85 years, with females accounting for 54.1% of the study sample and males accounting for 45.9%. More than half of the study sample (52.8%) reported never attending school. An outline of the study variables is provided in Table 1.

Prevalence of type-2 diabetes risk

Four out of five were aged 50 years and above, and close to a third reported undertaking no regular physical activity. 41.2% had a high risk of diabetes (i.e., the Indian diabetes risk score of ≥ 60). Table 2 outlines the distribution of the sample with respect to four risk factors of type-2 diabetes, and IDRS risk categories.

Among the Indian states, Mizoram (85.7%) had the highest prevalence of high risk for diabetes. Among states with sizable populations (i.e., > 30 million) Kerala (64.4%), Haryana (60.2%), and Telangana (56.7%) have more than half of their population above 45 years at high risk of type-2 diabetes. The state-wide prevalence of high-risk diabetes is given in Fig. 1.

Factors associated with type-2 diabetes risk

Diabetes risk scores varied substantially with various health and socio-economic factors. Obese individuals had the highest average IDRS score (62.9 (± 13.3)), followed by overweight individuals (58.1 (± 14.5)), individuals with a history of heart disease & stroke (56.3 (± 15.3)), and urban residents (53.5 (± 15.5)). The variations in IDRS scores across the independent variables are given in Table 3.

Obese individuals had 4.17 (95% CI 3.59–4.84) times higher odds of having a high risk of type-2 diabetes compared to those who are underweight. Similarly, individuals with a history of heart disease and stroke have 1.85 (95% CI 1.60–2.13) odds of having a high risk for diabetes. While individuals belonging to scheduled tribes had lower odds of high risk of diabetes (AOR = 0.85, 95% CI = 0.76–0.96) compared to scheduled castes, those who belong to other caste groups had higher odds (AOR = 1.23, 95% CI = 1.13–1.35). Similar significant associations were observed with the sex of the respondent, place of residence, wealth index, highest education level, living arrangements, tobacco use, alcohol use, high cholesterol, and high blood pressure (see Table 4).

The logistic regression model had an AUC-ROC value of 0.6629 suggesting a low to moderate level of discriminative ability (see Fig. 2). The model had a sensitivity of 41.88%, specificity of 80.60%, positive predictive value (PPV) of 62.07%, negative predictive value (NPV) of 64.65%, and correctly classified percentage of 63.90% for predicting the individuals to be at high risk of type-2 diabetes (i.e., IDRS value of ≥ 60).

Further, we also assessed the interaction effects of body mass index (BMI) with other significant selected independent variables namely (1) wealth index, (2) caste, (3) education level, (4) high blood pressure, and (5) heart disease or stroke, in influencing the high risk to diabetes. It was found that the BMI status of (1) overweight, and (2) obese was associated with significantly higher odds of high risk of diabetes across all the independent variable groups (see Table 5).

Discussion

Based on a nationally representative sample of 51,315 non-diabetic adults aged 45 years and above we found that 41.2% had a high risk of type-2 diabetes. The ICMR-INDIAB study which covered a sample of 1,13,043 individuals aged 20 years and above reported the prevalence of high risk of diabetes to be 32.4%[21]. Our study's finding of 41.2% of the adults being at high risk of diabetes is due to our study's focus on adults aged 45 years and above. We also found state-wide variations with the states of Kerala, Jammu & Kashmir, Delhi, Haryana, Telangana, and Andhra Pradesh having over half of their adult population at a high risk of type-2 diabetes. Previous research also reported that southern and northern regions have a high prevalence of diabetes and

Study variables	Frequency (*n*)	Weighted %*	Mean (SD)
Age in completed years	51,315		59.85 (10.64)
Sex			
Female	27,632	54.1	
Male	23,683	45.9	
Place of residence			
Rural	35,190	73.1	
Urban	16,125	26.9	
Wealth Index			
Poorest	10,574	21.8	
Poorer	10,651	21.9	
Middle	10,410	20.8	
Richer	10,137	19.1	
Richest	9543	16.4	
Highest education			
Never attended schooling	25,297	52.8	
Up to primary schooling	12,588	23.0	
Middle school to higher secondary	10,957	19.5	
Diploma, graduate, and other higher qualifications	2473	4.7	
Caste			
Scheduled caste	8919	20.2	
Scheduled tribe	9579	9.3	
Other backward classes	19,129	44.7	
Others	13,688	25.8	
Living arrangements			
Living with others only	2126	4.3	
Living with children and others	9633	18.8	
Living with spouse and children	30,104	57.2	
Living with spouse and others	7606	15.9	
Living alone	1846	3.7	
Tobacco consumption status			
Lifetime abstainer	31,604	60.8	
Current user	16,982	34.4	
Past user	2729	4.8	
Alcohol consumption			
0–3 days per month (less frequent consumer)	7069	11.7	
> 4 days per month (frequent consumer)	2439	3.9	
Lifetime abstainer	41,807	84.4	
BMI			
Underweight	10,469	23.4	
Normal weight	27,308	52.5	
Overweight	10,191	18.6	
Obese	3272	5.6	
Blood Pressure			
Systolic BP ≥ 140 mmHg and/or Diastolic ≥ 90 mmHg	16,583	30.0	
Systolic BP < 140 mmHg and/or Diastolic < 90 mmHg	34,732	70.0	
Heart Disease or Stroke			
Yes	2063	4.1	
No	49,252	95.9	
High cholesterol			
Yes	1215	1.9	
No	50,100	98.1	
Family history of diabetes			
No diabetes in parents	47,502	92.7	
One of the parents is diabetic	3477	6.8	
Both parents are diabetic	336	0.5	
Physical activity			
Continued			

Study variables	Frequency (*n*)	Weighted %*	Mean (SD)
Regular vigorous physical activity	12,979	26.3	
Regular moderate physical activity	18,929	37.6	
Regular mild physical activity	1467	2.5	
No physical activity	17,940	33.6	
Waist circumference-Females	27,632		83.24 (13.31)
Waist circumference-Males	23,683		84.32 (11.86)

Table 1. Descriptive outline of study variables ($n = 51315$). SD, Standard deviation; BMI, Body Mass Index; mmHg, millimetres of mercury. *The estimates provided in the table are weighted estimates derived after applying sample weights to the study sample, weighted percentages may slightly differ from crude percentages.
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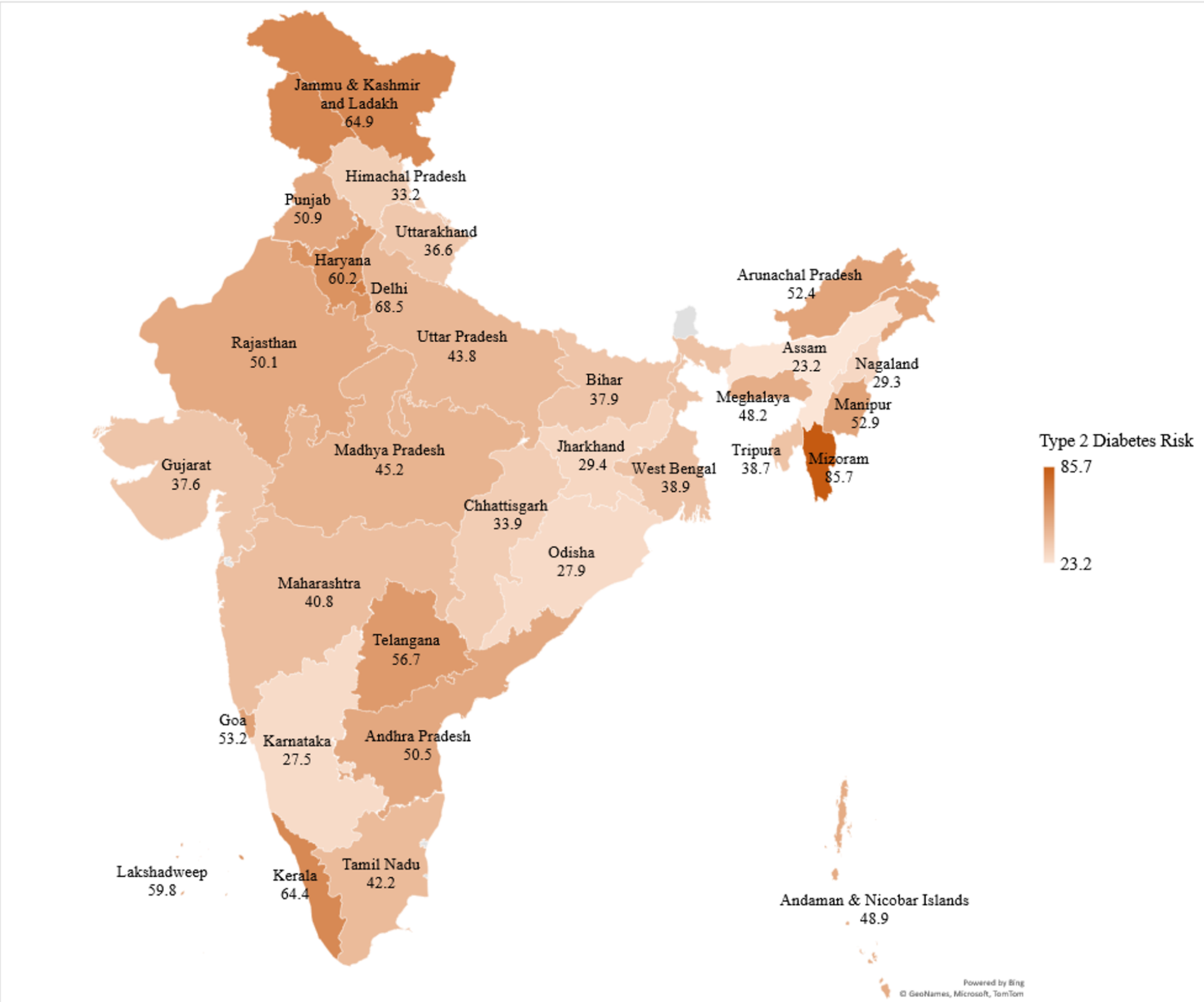
IDRS variables with scores	Percentage
Age of the respondents	
45–49 years (20)	20.1
50 years and above (30)	79.9
Family history of diabetes	
None of the parents are diabetic (0)	92.7
One parent is diabetic (10)	6.8
Both parents are diabetic (20)	0.5
Physical activity	
Regular vigorous physical activity[a] (0)	26.3
Regular moderate physical activity[b] (10)	37.6
Regular mild physical activity[c] (20)	2.5
No physical activity (30)	33.6
Waist circumference	
Females < 80 cm, Males < 90 cm (0)	54.7
Females 80.00–89.99 cm, Males 90.00–99.99 cm (10)	24.2
Females ≥ 90.00 cm, Males ≥ 100.00 cm (20)	21.0
Indian Diabetes Risk Score categories	
Low risk of type-2 Diabetes (< 30)	3.9
Moderate risk of type-2 Diabetes (30–50)	54.8
High risk of type-2 Diabetes (≥ 60)	41.2

Table 2. Risk of type-2 diabetes based on IDRS and associated variables ($n = 51315$). IDRS, Indian Diabetes Risk Score; cm, centimetres; India-level individual sample weights were used. [a]Vigorous activities involve running, jogging, swimming, going to a health centre or gym, cycling, heavy lifting, chopping, farm work, etc. [b]Moderate activities involve cleaning the house, washing clothes by hand, fetching water/wood, drawing water from the well, gardening, bicycling, and waking at a moderate pace. [c]Mild physical activity involves yoga, meditation, asana, pranayama, or similar activities.

diabetes risk compared to other state regions[21,30]. Similarly, studies across Indian states and population groups reported a high risk of diabetes ranging between 33.4 and 74.3%[19,24,26,31].

While age and family history of diabetes are non-modifiable risk factors, they together account for a total IDRS score of up to 50, representing a moderate risk on IDRS categorisation. The modifiable risk factors of physical activity, and waist-circumference contributed substantially to diabetes risk. In our study, it was found that more than a third of adults did not undertake any form of physical activity. Evidence reported physical inactivity among the adults to be ranging between 37.6 and 54.4%[32–34]. While adults > 50 years are known to have poor physical activity status due to physical limitations, health status, and comorbidities, tailored physical activity programmes could be beneficial[34]. Moreover, inadequate physical activity can also be a major contributor to loss of muscle, bone density, and abdominal obesity which is a known risk factor for metabolic syndrome. We found that one in five (21.0%) adults had a waist circumference (WC) at high-risk levels. A recent study based on LASI data reported that 44% of adults are in high-risk categories for combined BMI-WC measures[35]. A South Indian study reported the prevalence of abdominal obesity (WC > 90 cm among males, WC > 80 cm among females) among adults as 46.6%[36]. Our findings place it at around 45.2% at the country level, concurring with earlier studies and reiterating that physical inactivity and abdominal obesity are the two most important risk factors for targeted diabetes prevention strategies.



Note: A high risk of type 2 diabetes was defined as an Indian Diabetes Risk Score of ≥ 60. The LASI Wave 1 data were collected for Jammu & Kashmir (J&K) from 2017-2018 before Ladakh became a separate administrative entity, so the combined prevalence was reported for Jammu & Kashmir and Ladakh. The data for Sikkim was not available from the LASI 2017-2018, so the area of Sikkim was marked white on the map. All the values are given in weighted percentages. State individual sample weights were used in the analysis.

Fig. 1. State-wise prevalence of high risk of type-2 diabetes among adults aged 45 years and above.

Among all the independent variables, high BMI was the most important predictor of diabetes risk. Given that waist circumference is part of the diabetes risk score, the statistical association between high BMI and high risk of diabetes is apparent. However, high BMI and obesity are known risk factors for diabetes with established pathophysiology[37]. Moreover, our findings suggest that BMI itself as well as associated with other independent factors (such as wealth, education, caste, high blood pressure, and history of heart disease/stroke) positions individuals at high risk of type-2 diabetes at the population level. This highlights the prominence of high BMI as an important target for diabetes control. The major reasons for obesity and diabetes are unhealthy diet patterns and lack of physical activity. Further, the built environment is an essential factor for the promotion of physical activity in people[38,39]. Health education on diet and physical activity requirements, and creating safe neighbourhoods conducive to physical activity can help to prevent obesity-induced diseases including diabetes. Additionally, encouraging healthy diets by promoting adequate fruit and vegetable intake, and high-quality dietary protein along with discouraging processed and ultra-processed diets can directly address obesity and diabetes in the Indian population[40].

Diabetes risk was higher among females, urban residents, and those from poorer to richest income groups. Females have a higher life expectancy and are known to have a higher prevalence of abdominal obesity, which could have contributed to diabetes risk[41]. Living in urban regions and belonging to a richer wealth index was shown to carry significant diabetes risk in previous large-scale studies[22,42,43]. Studies reported that urbanization, and wealth accumulation are associated with dietary changes, and sedentary lifestyles contributing to obesity, physical inactivity, and eventually diabetes[44,45]. When compared with scheduled castes, the individuals belonging to scheduled tribes had lower odds of a high risk of diabetes, while the individuals from the other caste groups

Independent variables	IDRS score [Mean (SD)]	High risk of type-2 diabetes (%)
Sex		
Female	51.6 (15.4)	43.4
Male	47.5 (15.7)	38.7
Place of residence		
Rural	48.4 (15.5)	38.9
Urban	53.5 (15.5)	47.4
Wealth index		
Poorest	48.3 (15.3)	38.4
Poorer	48.8 (15.6)	39.3
Middle	49.9 (15.4)	41.7
Richer	50.1 (16.4)	42.8
Richest	52.3 (15.4)	45.0
Highest education		
Never attended schooling	49.6 (15.4)	41.8
Up to primary schooling	49.0 (15.9)	39.5
Middle school to higher secondary	50.4 (16.3)	41.7
Diploma, graduate, and other higher qualifications	52.6 (15.2)	41.1
Caste		
Scheduled caste	48.5 (15.3)	39.4
Scheduled tribe	45.4 (15.1)	33.7
Other backward classes	49.6 (15.6)	40.1
Others	52.5 (15.9)	47.3
Living arrangements		
Living with others only	48.9 (16.6)	42.0
Living with children and others	53.6 (15.2)	51.8
Living with spouse and children	48.3 (15.9)	37.4
Living with spouse and others	50.2 (14.8)	42.2
Living alone	50.3 (13.9)	40.7
Tobacco consumption status		
Lifetime abstainer	51.5 (15.5)	44.0
Current user	46.3 (15.4)	35.2
Past user	52.3 (15.1)	49.9
Alcohol consumption		
0–3 days per month (less frequent consumer)	45.9 (15.7)	34.5
> 4 days per month (frequent consumer)	45.5 (15.5)	35.5
Lifetime abstainer	50.5 (15.6)	42.4
BMI		
Underweight	44.5 (13.7)	35.5
Normal weight	47.7 (15.2)	35.7
Overweight	58.1 (14.5)	55.7
Obese	62.9 (13.3)	69.3
Blood Pressure		
Systolic BP ≥ 140 mmHg and/or Diastolic ≥ 90 mmHg	52.5 (15.5)	46.6
Systolic BP < 140 mmHg and/or Diastolic < 90 mmHg	48.6 (15.6)	38.9
Heart disease or stroke		
Yes	56.3 (15.3)	60.1
No	49.5 (15.6)	41.8
High cholesterol		
Yes	58.7 (14.4)	63.1
No	50.0 (15.7)	42.1

Table 3. Variations in risk of type-2 diabetes across study variables ($n = 51315$). SD, Standard Deviation; BMI, Body Mass Index; mmHg, millimetres of mercury.

Variables	Unadjusted Odds (95% CI)	*p*-value	Adjusted Odds (95% CI)	*p*-value
Sex				
Male	0.82 (0.80–0.83)	< 0.01	1.25 (1.16–1.34)	< 0.01
Female (ref)				
Place of residence				
Urban	1.52 (1.49–1.56)	< 0.01	1.21 (1.12–1.30)	< 0.01
Rural (ref)				
Wealth index				
Poorer	1.06 (1.03–1.09)	< 0.01	1.01 (0.93–1.10)	0.77
Middle	1.16 (1.13–1.19)	< 0.01	1.11 (1.01–1.21)	0.02
Richer	1.24 (1.21–1.28)	< 0.01	1.14 (1.04–1.25)	0.01
Richest	1.42 (1.37–1.4)	< 0.01	1.18 (1.07–1.31)	< 0.01
Poorest (ref)				
Highest education				
Never attended schooling	0.88 (0.84–0.92)	< 0.01	1.63 (1.37–1.94)	< 0.01
Up to primary schooling	0.84 (0.79–0.88)	< 0.01	1.33 (1.12–1.58)	< 0.01
Middle school to higher secondary	0.91 (0.87–0.96)	< 0.01	1.22 (1.03–1.45)	0.03
Diploma, graduate, and other higher qualifications (ref)				
Caste				
Scheduled tribe	0.75 (0.72–0.8)	< 0.01	0.85 (0.76–0.96)	0.01
Other backward classes	1.07 (1.04–1.09)	< 0.01	0.98 (0.91–1.06)	0.65
Others	1.42 (1.38–1.46)	< 0.01	1.23 (1.13–1.35)	< 0.01
Scheduled caste (ref)				
Living arrangements				
Living with others only	1.09 (1.03–1.17)	< 0.01	1.12 (0.91–1.38)	0.28
Living with children and others	1.55 (1.47–1.63)	< 0.01	1.54 (1.31–1.80)	< 0.01
Living with spouse and children	0.88 (0.83–0.92)	< 0.01	0.83 (0.71–0.97)	0.02
Living with spouse and others	1.06 (1.01–1.12)	0.02	1.00 (0.8–1.18)	0.96
Living alone (ref)				
Tobacco consumption status				
Current user	0.66 (0.64–0.67)	< 0.01	0.78 (0.73–0.84)	< 0.01
Past user	1.22 (1.17–1.23)	< 0.01	1.33 (1.16–1.53)	< 0.01
Lifetime abstainer (ref)				
Alcohol consumption				
0–3 days per month (less frequent consumer)	0.93 (0.88–0.98)	< 0.01	0.86 (0.74-1.00)	0.58
Lifetime abstainer	1.32 (1.26–1.39)	< 0.01	1.04 (0.90–1.19)	0.05
> 4 days per month (frequent consumer) (ref)				
BMI				
Normal weight	1.02 (0.99–1.05)	0.58	0.99 (0.92–1.07)	0.87
Overweight	2.49 (2.42–2.56)	< 0.01	2.37 (2.14–2.60)	< 0.01
Obese	4.51 (4.30–4.72)	< 0.01	4.17 (3.59–4.84)	< 0.01
Underweight (ref)				
Blood pressure				
Systolic BP ≥ 140 mmHg and/or Diastolic ≥ 90 mmHg	1.36 (1.34–1.39)	< 0.01	1.18 (1.11–1.26)	< 0.01
Systolic BP < 140 mmHg and/or Diastolic < 90 mmHg (ref)				
Heart disease or stroke				
Continued				

Variables	Unadjusted Odds (95% CI)	*p*-value	Adjusted Odds (95% CI)	*p*-value
Yes	2.10 (2.01–2.20)	< 0.01	1.85 (1.60–2.13)	< 0.01
No (ref)				
High cholesterol				
No (ref)				
Yes	2.35 (2.19–2.52)	< 0.01	1.51 (1.22–1.87)	< 0.01

Table 4. Factors associated with high risk of diabetes: results of binary logistic regression ($n = 51315$). IDRS, Indian Diabetes Risk Score; CI, Confidence Interval; BMI, Body Mass Index; State Individual Sample weights were used in the analysis; Pseudo $R^2 = 0.0614$, Hosmer-Lemeshow test: $p = 0.388$. Significance is considered at p-value < 0.05. Reference categories: Independent variables: sex-female, place of residence-rural, wealth index-poorer, highest education-diploma, graduate and other higher qualifications, caste-scheduled caste, living arrangement-living alone, tobacco consumption status-lifetime abstainer, alcohol consumption-frequent consumer, BMI-underweight, blood pressure-systolic BP < 140 mmHg and/or Diastolic < 90 mmHg, heart disease or Stroke-No. Dependent variable: risk of type 2 diabetes-low risk of type 2 diabetes (reference category), high risk of type 2 diabetes (outcome category).

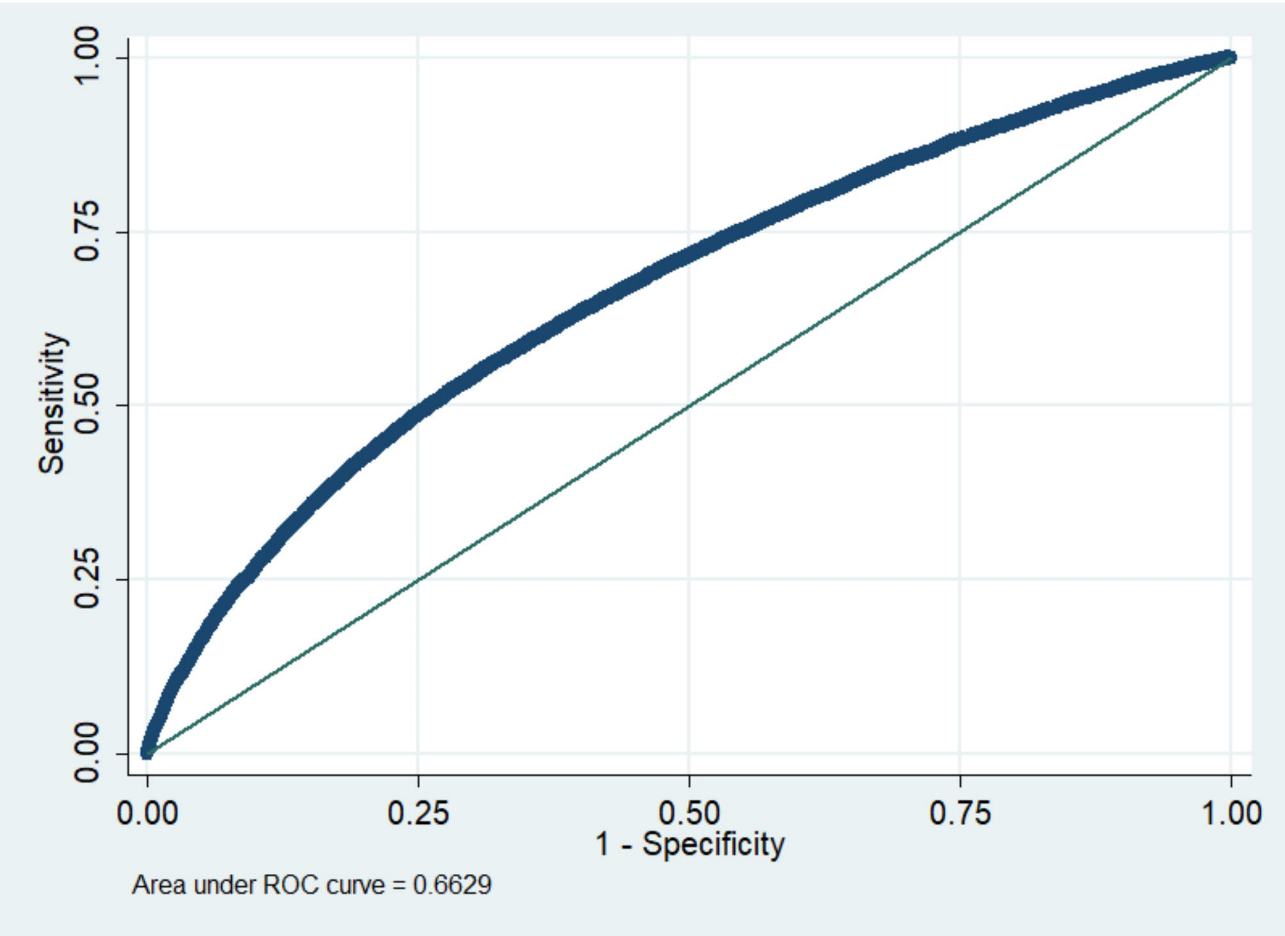


Fig. 2. AUC-ROC curve representing the model prediction ability of the logistic regression model.

had higher odds (AOR = 1.23) of a high risk of diabetes. Evidence points that Scheduled Tribes have a high percentage of poverty, under-weight, and lower mean BMI which may potentially explain the findings[46,47]. Individuals from scheduled tribes are often exposed to physically demanding jobs owing to lower educational status and may not have conclusive information on the family history of diabetes due to lower life expectancy and poor healthcare utilization[48–50]. Given that physical activity, age, and family history are key constituents of IDRS, the scores among ST communities might be lowered. However, evidence indicates that there is a high premature mortality and a very low diabetes screening in these population groups, indicating the critical need for improving the accessibility and availability of health facilities for diabetes screening[48].

BMI[a]	Wealth index[1]		Caste[2]		Education level[3]		High blood pressure[4]		Heart disease or Stroke[5]	
	Responses	AOR (95% CI)	Responses	AOR (95% CI)	Responses	AOR (95% CI)	Responses	AOR (95% CI)	Responses	AOR (95% CI)
Normal weight	Poorer	0.86 (0.83–0.89)**	ST	0.75 (0.71–0.79)**	Never attended schooling	1.02 (0.99–1.04)	Yes	1.01 (0.98–1.03)	Yes	1.73 (1.63–1.84)**
	Middle	0.91 (0.88–0.94)**	OBC	0.90 (0.88–0.92)**	Up to primary schooling	0.90 (0.87–0.93)**				
	Richer	1.03 (1.00–1.20)	Others	1.11 (1.08–1.15)**	Middle school to higher secondary	0.87 (0.84–0.90)**				
	Richest	1.16 (1.12–1.20)**								
Over-weight	Poorer	2.24 (2.13–2.36)**	ST	1.66 (1.49–1.84)**	Never attended schooling	2.26 (2.46–2.66)**	Yes	2.30 (2.22–2.39)**	Yes	4.34 (3.88–4.86)**
	Middle	2.30 (2.19–2.42)**	OBC	2.10 (2.03–2.18)**	Up to primary schooling	2.07 (1.98–2.17)**				
	Richer	2.39 (2.27–2.51)**	Others	2.76 (2.65–2.88)**	Middle school to higher secondary	2.41 (2.30–2.52)**				
	Richest	2.39 (2.28–2.51)**								
Obese	Poorer	4.41 (4.00–4.87)**	ST	2.22 (1.75–2.81)**	Never attended schooling	4.39 (4.06–4.74)**	Yes	4.31 (4.03–4.62)**	Yes	5.30 (4.39–6.41)**
	Middle	4.29 (3.88–4.74)**	OBC	3.79 (3.55–4.04)**	Up to primary schooling	4.50 (4.12–4.92)**				
	Richer	4.39 (4.01–4.80)**	Others	5.39 (5.01–5.80)**	Middle school to higher secondary	3.72 (3.46–4.01)**				
	Richest	3.63 (3.34–3.94)**								

Table 5. Interaction effects of body Mass Index with other independent variables in influencing diabetes risk (n = 51315). Dependent Variable: Diabetes Risk: High diabetes risk (IDRS ≥ 60); reference category = Low to moderate risk (IDRS < 50). Primary Independent Variable: (a) Body Mass Index (BMI): Normal Weight; Overweight; Obese; Underweight (ref). Second Independent Variable/s in the models: (1) Wealth Index: Poorest (ref); (2) Caste: SC (ref); (3) Education Level: Diploma, graduate and other higher qualification (ref); (4) High Blood Pressure: <140 mmHg systolic, < 90 mmHg diastolic blood pressure (ref); (5) Heart disease or Stoke: No (ref). ref = Reference Category; AOR = Adjusted Odds Ratio; CI = Confidence Interval; ST = Scheduled Tribe; OBC = Other Backward Classes; SC = Scheduled Caste. *$p \le 0.05$ value **p value ≤ 0.01.

High blood pressure, high cholesterol levels, and a history of heart disease or stroke are associated with a higher risk of diabetes. Given that hypertension, high cholesterol levels, heart disease & stroke, and type-2 diabetes share common risk factors like advancing age, and obese levels of waist circumference, an association can be expected, while it may not likely be causal[51]. Moreover, it may also be argued that given the comparatively early age of onset for hypertension, persistent elevated blood pressure may be indicative of future diabetes risk. Further research however is needed to confirm the same.

Living arrangements are associated with diabetes risk. Individuals who are living with spouse and children had lower odds of high risk of diabetes compared to those living alone. Living alone and lack of social support were known to be associated with the increased risk of type 2 diabetes[51,52]. Tobacco use interestingly is seen to have a negative association with diabetes risk as current users had lower odds of high risk of diabetes, while past users had higher odds compared to lifetime abstainers. The conflicting results could be due to the reason that tobacco quit rates increase with age and disease manifestation both of which are risk factors for diabetes[53]. Also, lifetime abstainers tend to have a significantly higher life expectancy than tobacco users, which may increase diabetes risk due to longevity[54], but significantly prevents the risk of tobacco-induced diseases.

Our study is limited by its cross-sectional design, which prevents us from establishing causal associations. The factors identified from multivariate analysis, while report being significantly associated with high risk of type-2 diabetes, must be inferred with reference to biological plausibility, and temporality. Additionally, self-reported responses for variables such as tobacco use, alcohol consumption, and family history of diabetes may be influenced by social desirability bias and recall bias. While there were 57,133 non-diabetic adults in the LASI sample, around 10% (n = 5818) were excluded due to missing data resulting a final sample size of 51,315 which may have introduced bias. Additionally, the components of IDRS could have their own limitations. Particularly, IDRS relies on measures like waist circumference and family history of diabetes. In contexts like India where lean diabetes is substantially prevalent[55] and healthcare utilization is limited, IDRS scores need to be supported by biomarkers & screening tests. Despite these limitations, this study is among the few that provide nationally representative evidence on type-2 diabetes risk in India, highlighting the urgent need for policy interventions to prevent the diabetes epidemic.

Conclusions

Our findings point that four in ten adults over 45 years of age in India are at high risk of developing type-2 diabetes. India's elderly population is growing at a rapid pace and will be one-fifth of the total population by 2050. In light of rapid demographic and epidemiological transition, the risk of type-2 diabetes in the Indian population is increasing. Our findings suggest it to be already happening as states on a higher end of demographic transition (i.e., those with higher life expectancies) have more than half of their adults at high risk of diabetes. Further, the key risk factors of obesity and physical inactivity are very high contributing to increased risk of type 2 diabetes and other non-communicable diseases. There is a need for sustained efforts at the population level to tackle the modifiable risk factors of physical inactivity, obesity, unhealthy diets, tobacco use, and alcohol consumption. Mass-scale health education campaigns on healthy eating behaviours and physical activity can reduce diabetes risk at the population level. As the risk of diabetes increases with decreasing levels of education, implementing health education campaigns to raise awareness is crucial. Targeting urban residents and individuals in the middle to highest wealth groups could significantly amplify the effectiveness of these interventions. Additionally, creating a built environment in urban areas that encourages physical activity can have a substantial impact. Further, increasing access to early screening and management of diabetes through primary healthcare facilities, and increasing community-level screening of all adults using non-invasive approaches like IDRS by community health workers can contribute to diabetes control at the individual level. Additionally, considering the limitations of IDRS as an approach, coupling diabetes risk score with cost effective screening approaches may be explored. Policymakers must integrate these findings into national health strategies to curb the growing burden of diabetes in India.

Data availability

The data for this study is publicly accessible on the website of the International Institute of Population Sciences (IIPS), Mumbai. Researchers can obtain the data by submitting a formal request to the investigators of the LASI project through the LASI data catalogue available at IIPS Data Catalogue (https://www.iipsdata.ac.in/datacatalog_detail/5).

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Author contributions
KM & PBK conceptualized the study. PBK acquired the data and developed data analysis plan. KM conducted data analysis and developed results tables and figures. KM & PBK developed the initial version of the manuscript, critically reviewed it. KM & PBK finalized and approved the manuscript.

Declarations

Competing interests
The authors declare no competing interests.

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