Blood pressure levels among tribal populations of India: a multi-center cross-sectional study

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Abstract

Background: This study aims to report the variability in blood pressure levels among tribal populations inhabiting different geographical regions of India. Further, it reports the association of some socio-demographic, behavioral, and anthropometric variables on blood pressure levels.

Material and methods: This population-based cross-sectional study was conducted in tribal-dominated districts from six Indian states located in different geographies. Blood pressure, anthropometric, behavioral, and socio-demographic data were collected from 8,724 adults. Univariate and multivariable regression models were used to examine the association of various factors with blood pressure levels.

Results: The mean systolic (SBP) and diastolic blood pressure (DBP) levels show a significant gender difference, with men having higher levels. Both SBP and DBP exhibit an increasing trend with age, and variations exist among states. Mean levels among participants not on antihypertensive medication are slightly higher than the total participants, and approximately 11% of men and 8.56% of women are on antihypertensive drugs. Multiple regression analysis indicates gender, age, waist-hip ratio, BMI, tribe type, and village type are highly significant ($p < 0.001$) in both SBP and DBP levels. State of residence is highly significant ($p < 0.000$) in DBP only. Alcohol consumption ($p < 0.000$) is significant for SBP but not for DBP. Association with smoking, smokeless tobacco use, and extra salt consumption are not significant.

Conclusion: Hypertension, thereby blood pressure levels, are on the rise among Indian tribal populations due to association with obesity and other preventable factors. Acculturation is an underlying factor, emphasizing the impact on diverse populations, including lower socioeconomic strata like tribal communities.

Key words: blood pressure; hypertension; indigenous; tribes; risk factors

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Introduction

Blood pressure is a dynamic physiological parameter characterized by continuous fluctuations occurring over the lifespan, ranging from seconds to years [1]. Elevated blood pressure is the foremost global risk factor for cardiovascular diseases [2]. Without intervention, individuals with elevated blood pressure are at risk of developing hypertension [3]. In 2010, a staggering 31% of the world's adult population, equating to 1.39 billion people, suffered from hypertension [4]. Globally, elevated blood pressure constitutes the primary risk factor for both mortality and morbidity [5]. It accounts for 7% of global disability-adjusted life years and was responsible for 9.4 million deaths in 2010 [6].

Nevertheless, due to population growth and aging, the number of individuals with uncontrolled hypertension surged from 605 to 978 million [7]. Consequently, high blood pressure escalated from being the fourth-ranked risk factor for disease burden in 1990 to becoming the primary risk factor in 2010 [6]. In most individuals, SBP increases steadily with age, attributed to the growing stiffness of large arteries, prolonged plaque buildup, and an increased incidence of cardiac and vascular disease [3]. Regional disparities underscore the worldwide disease burden associated with elevated blood pressure [8]. Many studies focusing on the origins of geographic disparities in hypertension have primarily explored particular hypotheses, such as the influence of acculturation and dietary factors. These studies often opt for extreme social settings to accentuate differences. In contrast, initiatives like the World Health Organization's Monitoring Trends and Determinants in Cardiovascular Disease (WHO MONICA) project comprehensively outlined coronary risk profiles across populations and tracked the trends [9].

Various factors can influence blood pressure, including medical and environmental conditions like lifestyle and dietary choices [10]. In developing countries, substantial shifts in these factors are occurring, offering a valuable opportunity to gain insights into the determinants of blood pressure at the population level [11]. Factors contributing to the rising blood pressure levels, especially in developing countries like India, are swift shifts in lifestyle practices, urbanization, and social development [12]. Numerous epidemiological studies spanning diverse populations have highlighted a notable link between certain anthropometric indicators and blood pressure [13–19]. In many of these studies, anthropometric indicators like body mass index (BMI) and body fat have been commonly employed to investigate the association between adiposity and cardiovascular risk [17, 20–23].

Moreover, an elevated BMI, alcohol consumption, improper dietary habits, and a sedentary way of life stand as the primary factors contributing to the heightened prevalence of hypertension in India [24]. Notably, there has been a limited focus on comprehensively investigating the key factors influencing the overall and individual prevalence rates of hypertension [25]. Nevertheless, there has been a notable shift in the burden of cardiovascular disease from wealthier and more educated segments of the population to those with lower socioeconomic status [26]. The transition toward rising blood pressure levels and higher prevalence of hypertension have been observed among individuals with limited incomes in several developing nations [27–32].

Globally, there are an estimated 370 million indigenous people residing in more than 90 countries. While they comprise just 5% of the world's population, they represent approximately 15% of people living in extreme poverty [33]. India's indigenous communities, known officially as scheduled tribes and numbering 104 million, represent approximately 8.6% of the country's population [34]. For clarity, they will be referred to as "tribal" hereafter in this paper. India is home to 705 tribes, each diverse in terms of geography, culture, social organization, lifestyle, and level of integration into mainstream Indian society. Among these tribes, 75 have been designated as particularly vulnerable tribal groups (PVTG), characterized by pre-agricultural technology, stagnant or declining populations, meager literacy rates, and subsistence-level economies. Most of these tribal communities reside in remote forest areas within hilly terrains. These communities face poor health outcomes and exhibit limited health-care-seeking behavior [35]. The challenges they encounter can be attributed to their inhabitation of remote and difficult hilly areas, low socioeconomic status, inadequate infrastructure, including roads, and limited access to essential services such as clean water, sanitation, and healthcare.

Initially, studies indicated that hypertension was not prevalent among tribal communities in India. However, over time, its prevalence has shown significant variation, rising to as high as 30% [32]. Much attention has been directed towards diet in the context of this shift, underscoring the nutritional transformation experienced by tribal populations due to changing economies and lifestyles [36]. Research exploring this transformation has highlighted how blood pressure levels among tribal populations have been influenced by changed food patterns and other habits like tobacco and alcohol use [37]. The objective of our study is to document the diversity in blood pressure levels among tribal populations residing in various geographical regions across India. Additionally, our study investigates the association between certain socio-demographic, behavioral, and anthropometric factors and blood pressure levels.

Material and methods

Context and study design

This cross-sectional survey, including measuring blood pressure levels, was part of the formative research conducted prior to implementation research to enhance non-communicable disease care through the primary health care system. This research was conducted to assess blood pressure levels in tribal populations residing in tribal-dominated areas across six Indian states, viz., Himachal Pradesh, Karnataka, Ladakh, Odisha, Meghalaya, and Tamil Nadu.

Area and people

This study encompasses six districts across India, each with its distinct characteristics. Chamba District, situated in Himachal Pradesh, in northern India, is largely inhabited by the Gaddi tribe, with agriculture serving as the primary livelihood source and tribes making up 26.1% of the district population. Kargil District, located in Ladakh, a northern union territory, is dominated by the Puriga and Balti tribes of Tibetan origin, with tribal people constituting 86.89% of the total population. Chamarajanagar District, positioned in Karnataka, a southern state, has an 11.78% tribal population, primarily consisting of the Jenukuruba, Kadukuruba, and Soliga tribes. East Khasi Hills, found in Meghalaya, a northeastern state, is predominantly inhabited by the Khasi tribe, known for their agricultural way of life and matrilineal society, with tribes making up 80.1% of the total population. Sundargarh District, located in Odisha, an eastern state, is home to tribes like Oraon, Munda, Kisan, Khadia, and Bhuinya, constituting 22.85% of the district's population. Nilgiri District, situated in Tamil Nadu, in the southern part of India, is part of the Western Ghats and home to tribes like the Paniya, Bettakurumba, Mullakurumba, and Kattunayakan, making up 4.46% of the district population.

Study design and sample surveyed

For this study, a cluster random sampling method was used. The study was conducted in tribal villages. In multi-ethnic villages, only tribal households were included. Individuals were required to be at least 20 years of age and belong to a tribal community to qualify for participation in the study. The required sample size was calculated according to the formula [38].

This study adopted the quasi-experimental design; hence, two areas — implementation and control areas — were included in each district. Considering the utilization of government healthcare service (p) of 27.5% (estimated for the tribal population, using all India data of India Human Development Survey (IHDS-2) [39], with a 95% confidence level and 80% power, the initial sample size would be 686 for each arm. However, due to the design effect of 2.0, resulting from cluster sampling, the revised sample size is 1372. Factoring in a 10% non-response rate, the final sample size for each arm is 1509. Consequently, the total sample size is 1509 per district. Within each district, four primary health center (PHC) areas were chosen, and from each PHC area, approximately 377 households were selected. These households were sampled from villages with primary/community health centers (CHCs/PHCs) and sub-health centers (SHCs) and villages without health facilities (HFs). Altogether, a total of 8724 households from six districts were included.

Data collection

Trained nurses used an electronic sphygmomanometer to measure blood pressure following blood pressure measurement guidelines. SBP and diastolic blood pressure (DBP) were recorded based on the appearance and disappearance of Korotkoff sounds, respectively [40]. Before blood pressure measurement, participants were seated for at least 5 minutes. At least two blood pressure readings were taken and recorded with a minimum of 1 minute between the readings. Before measuring blood pressure, participants were required to sit quietly for at least 5 minutes. It was ensured that they hadn't engaged in vigorous physical activity, smoked, chewed tobacco, consumed beverages like tea or coffee, etc., in the preceding 30 minutes, and had not eaten lunch or snacks for at least 1 hour. Blood pressure was measured between 8 am and 6 pm. This timeframe was chosen because conducting the entire survey solely in the morning hours was not feasible, and scheduling the meetings of study participants was a challenge.

The definition of hypertension used in this study followed guidelines from the seventh Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure [41]. Hypertension was defined as SBP and/or DBP equal to or greater than 140/90 mmHg. Behavioral risk factors like smoking, non-smoking tobacco use, and alcohol consumption were recorded. In addition, socio-demographic variables, viz. age, gender, education, type of tribe, and type of village, were collected using a pretested questionnaire. Particularly vulnerable tribal group (PVTG) status was determined by elucidating the tribe's name from the study participants and subsequently classifying them based on the list of PVTGs available in the public domain, whether they belong to PVTG or not. The categorization of villages is based on the presence of health facilities in the village, such as PHC/CHC villages, HSC villages, and no HF villages. The anthropometric data were also collected for height vertex, body weight, waist, and abdominal circumference measurements. We followed the anthropometric data collection recommendations outlined by Weiner and Lourie (1981) [42]. Using this data, we calculated the following indices:

$$BMI = body\ weight\ [kg]/height^2\ [mts],$$

and

$$Waist–hip\ ratio\ (WHR) = waist\ circumference\ [cms]/maximum\ hip\ circumference\ [cms].$$

Data analysis

The data were computerized and analyzed using SPSS version 26 for Windows. Continuous variables are presented as mean (standard deviation), while categorical variables are presented as numbers and percentages. ANOVA was conducted as a univariate analysis to assess the variations of SBP and DBP levels by some independent variables. t-Tests were utilized to examine these differences. Multivariable regression models were used separately for both SBP and DBP to examine the association of various factors. For these analyses, WHR was categorized as risk (≥ 0.90 for men and ≥0.85 for women) and no risk categories (< 0.90 for men and < 0.85 for women) [43]. BMI was categorized as per the classification of WHO as follows: underweight (< 18.5 kg/m^2), normal BMI (18.5–24.9 kg/m^2), overweight (25.0–29.9 kg/m^2), and obesity (30 kg/m^2) [44]. For statistical significance, a p-value lesser than 0.05 was considered.

Ethical clearance

The study protocol for each district was approved by the institutional ethical committees (IECs) of the authors' respective institutions (YCB, SR, SM, ASK, NT, NKM). All participants in the study were provided with information regarding the study's objectives, and written consent was obtained from them.

Results

Table 1 provides means and their corresponding standard deviation (SD) for SBP and DBP by age, gender, and study site. The mean (±SD) SBP of men is 127.08 ± 18.11 mm Hg; in women, it is 123.05 ± 18.66 mm Hg. The difference is significant ($p < 0.0001$). Concerning DBP, the same trend is noted with higher DBP levels among men (82.01 ± 10.82 mm Hg) than women (80.81 ± 10.39 mm Hg). And this difference was also significant ($p < 0.0001$). Both in men and women, an increasing trend of SBP and DBP is seen with age. Concerning the variations by states, the highest mean levels of SBP (132.65 ± 16.91 mm Hg) and DBP (86.61 ± 10.66 mm Hg) are reported by Himachal Pradesh, while Meghalaya reports the lowest mean SBP (116.28 ± 15.44 mm Hg) and mean DBP (77.19 ± 9.85 mm Hg).

Table 2 shows all participants' mean blood pressure levels and those on and not on any hypertension medication. The mean levels of SBP and DBP among total participants are slightly higher than those not on antihypertensive drugs. The difference is significant ($p < 0.001$) for SBP among both men and women of Ladakh, Meghalaya, and Tamil Nadu. Regarding DBP, the difference is significant ($p < 0.05$) in men and women of Tamil Nadu. A significant ($p < 0.05$) difference is also seen in women of Ladakh and Meghalaya. Almost 11% of men and 8.56% of women are on antihypertensive drugs. The mean levels are significantly higher among participants on antihypertensive medications than those with normal pressure values.

By univariate analysis, the levels of SBP and DBP were significantly associated with gender, age, state of residence, alcohol, smoking, extra salt consumption, WHR, BMI, PVTG, and type of village (Table 3). Men have higher mean SBP (127.08 ± 18.11 mm Hg) and mean DBP (81.93 ± 10.60 mm Hg), which is significant. The difference is also significant in the age group of 60+ years with high mean SBP (132.94 ± 20.91 mm Hg) and mean DBP (83.78 ± 10.90 mm Hg). Among states, Himachal Pradesh had high mean SBP (128.37 ± 18.13 mm Hg) and mean DBP (84.56 ± 10.61 mm Hg) with significant differences. Smokers are found to have high mean SBP (125.81 ± 18.36 mm Hg) and mean DBP (81.28 ± 11.38 mm Hg), and the dif-

Table 1. Age-wise distribution of the sample with mean ± standard deviation (SD) of systolic blood pressure (SBP) and diastolic blood pressure (DBP) levels

Population/Sex		Age group (in years)					Total sample	Age [years] (mean ± SD)
		20–29	30–39	40–49	50–59	60+		
Himachal Pradesh/Men	Number	30	71	79	94	93	367	49.08 ± 14.02
	Mean SBP ± SD	125.25 ± 14.65	127.36 ± 13.49	132.36 ± 17.11	133.46 ± 15.46	138.52 ± 19.16	132.65 ± 16.91	
	Mean DBP ± SD	82.28 ± 12.07	84.35 ± 9.47	88.19 ± 12.00	88.13 ± 9.53	86.87 ± 10.44	86.61 ± 10.66	
Himachal Pradesh/Women	Number	162	351	295	180	166	1154	43.26 ± 13.45
	Mean SBP ± SD	115.39 ± 10.06	120.56 ± 13.30	128.59 ± 17.26	135.30 ± 20.34	140.21 ± 20.29	127.01 ± 18.30	
	Mean DBP ± SD	78.69 ± 8.29	81.78 ± 9.17	85.42 ± 9.91	86.93 ± 11.33	87.58 ± 12.21	83.91 ± 10.52	
Ladakh/Men	Number	30	124	227	216	369	966	53.61 ± 13.45
	Mean SBP ± SD	121.00 ± 12.95	118.84 ± 9.88	122.29 ± 12.97	126.86 ± 15.59	131.78 ± 17.00	126.45 ± 15.64	
	Mean DBP ± SD	77.33 ± 4.49	78.18 ± 4.95	79.24 ± 6.59	81.29 ± 7.77	83.98 ± 9.79	81.31 ± 8.33	
Ladakh/Women	Number	10	87	177	201	169	644	51.85 ± 11.72
	Mean SBP ± SD	118.50 ± 8.18	118.63 ± 14.53	122.08 ± 16.59	129.47 ± 15.51	131.46 ± 16.37	126.33 ± 16.53	
	Mean DBP ± SD	79.00 ± 3.16	78.44 ± 7.00	80.45 ± 9.40	84.00 ± 11.15	84.58 ± 10.48	82.35 ± 10.18	
Karnataka/Men	Number	74	69	55	23	61	282	42.44 ± 16.14
	Mean SBP ± SD	124.56 ± 9.02	126.06 ± 15.33	127.90 ± 15.30	137.43 ± 26.51	137.97 ± 22.02	129.53 ± 17.67	
	Mean DBP ± SD	79.81 ± 7.04	83.92 ± 10.41	83.86 ± 9.25	86.43 ± 12.95	86.77 ± 11.67	83.65 ± 10.22	
Karnataka/Women	Number	410	297	185	102	188	1182	38.91 ± 14.66
	Mean SBP ± SD	112.50 ± 10.73	116.29 ± 12.00	125.57 ± 18.01	129.09 ± 19.49	134.82 ± 21.19	120.48 ± 17.31	
	Mean DBP ± SD	75.85 ± 7.84	79.14 ± 7.46	82.43 ± 9.61	83.21 ± 9.85	83.44 ± 8.96	79.55 ± 8.96	
Meghalaya/Men	Number	54	116	106	97	82	455	45.85 ± 13.74
	Mean SBP ± SD	112.77 ± 11.69	116.05 ± 10.94	116.67 ± 10.08	121.84 ± 14.93	124.07 ± 16.66	118.49 ± 13.44	
	Mean DBP ± SD	76.07 ± 10.09	75.70 ± 9.55	75.07 ± 8.25	78.51 ± 9.89	81.19 ± 10.74	77.19 ± 9.85	
Meghalaya/Women	Number	180	272	213	186	213	1064	45.12 ± 15.75
	Mean SBP ± SD	112.43 ± 15.17	111.91 ± 12.79	115.70 ± 13.08	118.65 ± 14.86	123.64 ± 18.21	116.28 ± 15.44	
	Mean DBP ± SD	76.44 ± 8.00	75.20 ± 7.89	77.71 ± 8.36	78.40 ± 9.29	79.21 ± 9.62	77.27 ± 8.73	
Odisha/Men	Number	93	157	169	99	143	661	44.92 ± 13.90
	Mean SBP ± SD	124.69 ± 12.81	125.14 ± 17.74	128.56 ± 17.39	133.09 ± 19.69	138.68 ± 23.64	130.07 ± 19.49	
	Mean DBP ± SD	80.73 ± 9.41	83.87 ± 10.53	86.04 ± 10.93	86.60 ± 10.74	85.58 ± 10.57	84.76 ± 10.66	
Odisha/Women	Number	191	192	212	87	133	815	41.71 ± 13.58
	Mean SBP ± SD	114.91 ± 13.93	120.63 ± 13.68	128.17 ± 20.62	133.47 ± 21.56	141.71 ± 27.83	126.06 ± 21.38	
	Mean DBP ± SD	77.13 ± 9.60	80.48 ± 9.09	83.88 ± 10.91	85.39 ± 11.21	85.13 ± 11.43	81.86 ± 10.77	
Tamil Nadu/Men	Number	119	168	191	123	92	693	43.35 ± 12.86
	Mean SBP ± SD	125.48 ± 20.49	127.06 ± 21.41	125.52 ± 21.12	127.87 ± 20.56	129.21 ± 22.12	126.79 ± 21.10	
	Mean DBP ± SD	80.14 ± 12.30	80.04 ± 11.95	78.76 ± 11.76	80.47 ± 11.40	81.92 ± 13.16	80.03 ± 12.04	

Table 1. Age-wise distribution of the sample with mean ± standard deviation (SD) of systolic blood pressure (SBP) and diastolic blood pressure (DBP) levels

Population/Sex		Age group (in years)					Total sample	Age [years] (mean ± SD)
		20–29	30–39	40–49	50–59	60+		
Tamil Nadu/Women	Number	69	94	90	115	73	441	45.29 ± 13.60
	Mean SBP ± SD	129.10 ± 22.75	127.41 ± 21.29	123.90 ± 22.72	123.96 ± 21.76	124.06 ± 21.19	125.50 ± 21.92	
	Mean DBP ± SD	81.27 ± 13.99	81.77 ± 13.20	79.76 ± 13.59	80.08 ± 13.75	79.41 ± 12.20	81.93 ± 10.60	
Total/Men	Number	400	705	827	652	840	3424	47.57 ± 14.42
	Mean SBP ± SD	123.06 ± 15.51	123.31 ± 16.57	124.93 ± 16.89	128.57 ± 18.05	133.12 ± 19.92	127.08 ± 18.11	
	Mean DBP ± SD	79.61 ± 10.14	80.66 ± 10.34	81.15 ± 10.63	82.70 ± 10.29	84.28 ± 10.75	82.01 ± 10.82	
Total/Women	Number	1022	1293	1172	871	942	5300	43.64 ± 14.57
	Mean SBP ± SD	114.58 ± 13.81	118.14 ± 14.40	124.35 ± 18.32	127.99 ± 19.36	132.78 ± 21.77	123.05 ± 18.66	
	Mean DBP ± SD	77.04 ± 8.90	79.37 ± 9.08	82.06 ± 10.41	82.94 ± 11.47	83.34 ± 11.01	80.81 ± 10.39	

ference is significant ($p < 0.05$) for SBP but not for DBP. The risk category of WHR has the highest mean SBP (125.20 ± 18.80 mm Hg) and mean DBP (81.48 ± 10.60 mm Hg) with significant differences. Concerning BMI, the obese are found to have high mean SBP (128.95 ± 18.75 mm Hg) and mean DBP (84.32 ± 10.66 mm Hg) with significant differences. PVTGs show higher mean SBP (127.29 20.86 mm Hg) and mean DBP (82.00 ± 12.13 mm Hg) than non-PVTGs, with significant differences. Participants living in SHC villages are recorded with higher mean SBP (126.79 ± 18.70 mm Hg) and mean DBP (82.31 ± 10.27 mm Hg), and the difference is significant. The use of smokeless tobacco is found to have no significance for mean SBP, but it is significant ($p < 0.01$) for mean DBP.

Multiple regression analysis for different variables viz. gender, age, smoking, alcohol consumption, tobacco users, extra salt, WHR, BMI, PVTG, and type of village with both SBP and DBP levels are shown in Table 4. Gender, age, WHR, BMI, type of tribe, and type of village are highly significant ($p < 0.001$) for both SBP and DBP. However, state of residence is not significant for SBP but is highly significant ($p < 0.000$) for DBP. On the other hand, alcoholism is significant ($p < 0.000$) for SBP but not significant for DBP. Smoking, use of smokeless tobacco, and extra salt consumption are insignificant for both SBP and DBP. Adjusted R2 indicated that 12% and 7% of the variation in SBP and DBP levels, respectively, were explained by this model.

Discussion

This study reports the variation in mean blood pressure levels among Indian indigenous (tribal) populations. A few studies show the variation in blood pressure levels among Indian tribal populations [45–51]. These studies, along with a review of microstudies on the prevalence of hypertension among Indian tribal populations, revealed that the prevalence of hypertension and, thereby, mean blood pressure levels are increasing among Indian tribes [32]. Modernization and acculturation appear to raise the population's mean blood pressure [52–57]. As the process of epidemiological transition unfolded, tribal populations in the country started experiencing increased pressure from chronic and cardiovascular diseases, as well as external causes of illness and death, which began to shape their disease and mortality profiles. Cardiovascular diseases are a leading cause of mortality and morbidity, caus-

Table 2. Blood pressure levels and prevalence of selected characteristics by gender and state of residence

Variable	Men							Women						
	HP	LAD	KAR	MEG	ODI	TN	All	HP	LAD	KAR	MEG	ODI	TN	All
Mean SBP ± SD [mm Hg]														
All	367	380	282	455	661	693	2838	1154	378	1182	1064	815	441	5034
Mean SBP ± SD	132.65 ± 16.91	131.03 ± 18.55	129.53 ± 17.67	118.49 ± 13.44	130.07 ± 19.49	126.79 ± 21.10	127.82 ± 18.97	127.01 ± 18.30	128.89 ± 17.64	120.48 ± 17.31	116.28 ± 15.44	126.06 ± 21.38	125.50 ± 21.92	123.06 ± 18.87
Excluding those on antihypertensive drugs	358	255	273	422	631	580	2519	1124	217	1161	969	769	363	4608
Mean SBP ± SD	132.24 ± 16.77	126.59 ± 16.52	128.82 ± 16.94	116.74 ± 11.01	129.60 ± 18.88	123.88 ± 19.13	126.11 ± 17.81	126.40 ± 17.78	123.53 ± 15.84	119.99 ± 16.78	114.06 ± 13.34	125.15 ± 20.92	121.98 ± 18.57	121.54 ± 17.90
t-test for difference	0.3277	3.0877**	0.4829	2.1000*	0.4400	2.5565*	3.3888***	0.8066	3.7006***	0.6955	3.4533***	0.8555	2.4257*	4.0490***
Mean DBP ± SD [mm Hg]														
All	367	380	282	455	661	693	2838	1154	378	1182	1064	815	441	5034
Mean DBP ± SD	86.61 ± 10.66	84.09 ± 9.78	83.65 ± 10.22	77.19 ± 9.85	84.76 ± 10.66	80.03 ± 12.04	82.43 11.18 ±	83.91 ± 10.52	83.61 ± 11.23	79.55 ± 8.96	77.27 ± 8.73	81.86 ± 10.77	80.45 ± 13.36	80.83 ± 10.49
Excluding those on antihypertensive drugs	358	255	273	422	631	580	2519	1124	217	1166	969	769	363	4608
Mean DBP ± SD	86.40 ± 10.40	82.97 ± 9.81	83.29 ± 9.95	76.06 ± 8.78	84.65 ± 10.50	78.46 ± 11.12	81.72 10.87 ±	83.71 ± 10.44	81.56 ± 11.87	79.44 ± 8.91	76.22 ± 7.85	81.40 ± 10.50	78.34 ± 11.86	80.15 ± 10.13
t-test for difference	0.2684	1.4129	0.4203	1.7882	0.1868	2.3988*	2.3504*	0.4554	2.0990*	0.2983	2.8413*	0.8600	2.3435*	3.2321**

*p < 0.05; **p < 0.01; ***p < 0.001; HP — Himachal Pradesh; LAD — Ladakh; KAR — Karnataka; MEG — Meghalaya; ODI — Odisha; TN — Tamil Nadu; SD — standard deviation, SBP — systolic blood pressure; DBP — diastolic blood pressure

Table 3. Details of univariate analysis for association of demographic, behavioural and anthropometric variables on systolic (SBP) and diastolic blood (DBP) pressure levels

Variable	Number	Mean SBP ± SD	F-value	p	Mean DBP ± SD	F-value	p
Gender							
Male	3424	127.08 ± 18.11	99.458	0.000	81.93 ± 10.60	23.718	0.000
Female	5300	123.05 ± 18.66			80.81 ± 10.39		
Mean age [years]							
20–29	1422	116.96 ± 14.80	215.401	0.000	77.76 ± 9.34	87.354	0.000
30–39	1998	119.96 ± 15.40			79.83 ± 9.56		
40–49	1999	124.59 ± 17.74			81.70 ± 10.51		
50–59	1523	128.24 ± 18.81			82.84 ± 10.98		
60+	1782	132.94 ± 20.91			83.78 ± 10.90		
State of residence							
Himachal Pradesh	1521	128.37 ± 18.13	87.293	0.000	84.56 ± 10.61	94.337	0.000
Ladakh	1610	126.40 ± 16.00			81.73 ± 9.13		
Karnataka	1464	122.22 ± 17.74			80.34 ± 9.35		
Meghalaya	1519	116.94 ± 14.90			77.25 ± 9.08		
Odisha	1476	127.86 ± 20.65			83.16 ± 10.82		
Tamil Nadu	1134	126.29 ± 21.43			80.19 ± 12.57		
Smoking							
Yes	1100	125.81 ± 18.36	5.095	0.024	81.28 ± 11.38	0.008	0.927
No	7624	124.46 ± 18.57			81.25 ± 10.35		
Alcohol consumption							
Yes	2416	121.83 ± 18.44	76.596	0.000	79.82 ± 10.68	62.281	0.000
No	6308	125.70 ± 18.48			81.80 ± 10.36		
Use of smokeless tobacco							
Yes	2336	124.93 ± 19.77	0.838	0.360	80.80 ± 11.37	5.950	0.015
No	6388	124.52 ± 18.08			81.42 ± 10.14		
Extra salt consumption							
Yes	2165	122.61 ± 17.56	34.077	0.000	80.11 ± 10.48	34.152	0.000
No	6559	125.29 ± 18.82			81.63 ± 10.46		
Waist-hip ratio							
Risk	7105	125.20 ± 18.80	36.270	0.000	81.48 ± 10.60	17.54	0.000
No risk	1619	122.13 ± 17.29			80.27 ± 9.95		
Body mass index							
Underweight	1184	121.75 ± 18.36	35.335	0.000	79.66 ± 10.32	48.014	0.000
Normal	5055	123.83 ± 18.47			80.65 ± 10.31		
Overweight	1905	127.32 ± 18.25			83.05 ± 10.64		
Obese	492	128.95 ± 18.75			84.32 ± 10.66		
Particularly vulnerable tribal group							
Yes	1308	127.29 ± 20.86	31.891	0.000	82.00 ± 12.13	7.774	0.005
No	7416	124.16 ± 18.07			81.12 ± 10.16		
Type of village							
Primary/community health centre	2480	120.54 ± 17.21	89.789	0.000	79.08 ± 10.25	77.132	0.000
Sub-health centre village	3644	126.79 ± 18.70			82.31 ± 10.27		
Non-health facility village	2600	125.50 ± 19.01			81.84 ± 10.71		

SD — standard deviation

Table 4. Details of multiple regression analysis for association of demographic, behavioural and anthropometric variables on systolic (SBP) and diastolic blood pressure (DBP) levels

Variables	SBP				DBP			
	B	SE	β	p	B	SE	β	p
Constant	115.344	2.445		0.000	80.807	1.426		0.000
Sex (1 = Male; 2 = Female)	–2.480	0.421	–0.065	0.000	–0.806	0.245	–0.037	0.001
Age	0.358	0.013	0.286	0.000	0.121	0.008	0.171	0.000
Smoking (1 = Smoker; 0 = Non-smoker)	–0.819	0.623	–0.015	0.189	0.023	0.363	0.001	0.949
Alcoholism (1 = Alcoholics; 0 = Non-alcoholics)	2.008	0.535	0.048	0.000	0.287	0.312	0.012	0.358
Smokeless Tobacco (1 = Chewers; 0 = Non-chewers)	0.544	0.518	0.013	0.293	0.339	0.302	0.014	0.261
Extra salt Consumption (1 = Yes; 0 = No)	0.036	0.480	0.001	0.940	0.199	0.280	0.008	0.478
WHR (1 = Risk; 0 = No Risk)	2.083	0.507	0.044	0.000	1.092	0.296	0.040	0.000
BMI (1 = Underweight; 2 = Normal; 3 = Overweight; 4 = Obese)	2.072	0.260	0.083	0.000	1.381	0.152	0.097	0.000
PVTG (1 = Yes; 2 = No)	–2.976	0.652	–0.057	0.000	–2.151	0.380	–0.073	0.000
Type of village (1 = Non-health facility village; 2 = Sub health centre village; 3 = PHC/CHC village)	–2.633	0.294	–0.108	0.000	–1.243	0.172	–0.090	0.000
State of residence (1 = Himachal Pradesh; 2 = Ladakh; 3 = Karnataka; 4 = Meghalaya; 5 = Odisha; 6 = Tamil Nadu)	–0.152	0.159	–0.014	0.341	–0.639	0.093	–0.101	0.000

SBP adjusted R^2 = 0.122; DBP adjusted R^2 = 0.069; SE = standard error; WHR— waist-hip ratio; BMI — body mass index; PVTG — particularly vulnerable tribal group; PHC — primary health centre; CHC — community health centre

ing an estimated 17.9 million deaths worldwide each year [58]. There is evidence that most cardiovascular diseases can be prevented by treating modifiable lifestyle factors. An unhealthy diet, lack of physical activity, tobacco consumption, and excessive alcohol consumption are the primary behavioral risk factors for heart disease and stroke.

Obesity is an alarmingly increasing global public health problem [59]. The increasing prevalence of obesity has been linked to alterations in environmental and dietary habits, coupled with the growing sedentary behaviors of individuals. Obesity and high blood pressure are representative lifestyle-related disorders; therefore, obese and hypertensive people should first undergo lifestyle modifications [60]. Obesity plays a critical role in the development of NCDs, including conditions such as diabetes, hypertension, and coronary artery diseases [61, 62]. Obesity increases blood pressure through various mechanisms [60]. High blood pressure also increases the risk of macro-vascular diseases and mortality [63, 64]. Life expectancy decreases with increasing elevated blood pressure severity [65]. Findings from the Framingham Heart Study, a prospective cohort study, demonstrated that adults who were obese at the age of 40 lost approximately 6 to 7 years of their expected lifespan. Alarmingly, for obese individuals who also smoked, the years of life lost nearly doubled [66].

Given that obesity is a preventable condition, the role of public health policymakers becomes pivotal. It is essential to address the stigma associated with obesity, as it can hinder appropriate health-care-seeking and resource utilization, early identification of complications, and the management of morbidity. Obesity has profound effects on both the physical and psychosocial aspects of an individual's quality of life, with morbidly obese individuals experiencing more significant impacts. In fact, the risk of developing chronic medical conditions is nearly doubled in morbidly obese individuals compared to those who are overweight. Blood pressure increases in parallel with body weight [67]. Among obese, the incidence of high blood pressure is 2–3 times higher than in non-obese individuals [68].

Several epidemiological studies have begun to uncover an uptick in chronic disease cases among various indigenous/tribal populations. They attribute the potential causes of increased high blood pressure to shifts in habits and lifestyles resulting from the modernization embraced by these indigenous communities. Our focus on tribal populations stems from their underrepresentation in nationally representative surveys. However, more extensive and more comprehensive studies are necessary to elucidate the full spectrum of these diseases and identify their determinants within indigenous communities. The relatively elevated blood pressure levels observed across all six study sites may be linked to the phenomenon of rising blood pressure and age-related increases associated with the modernization of the communities [69–75]. The findings align with other Indian studies, with mean blood pressure levels falling within the range reported in these studies. Among the tribal groups in our study, mean blood pressure levels are greater than those observed in other tribal communities [53,76]. Lower socioeconomic strata are associated with higher blood pressure levels and higher morbidity and mortality rates due to cardiovascular and other conditions [77].

Smoking has been extensively documented as the primary risk factor for numerous chronic diseases, including cardiovascular diseases [78]. A cohort study discovered an additive interaction between current smoking and high SBP in terms of the risk of ischemic heart disease among adult Chinese females [79]. Alcohol consumption and smoking are two prevalent and often co-occurring risk factors (of which 2 billion or 1 in 10 cardiovascular deaths worldwide are attributed to smoking [80]. Observational research consistently indicates that smoking is closely associated with blood pressure and other cardiovascular diseases [81]. WHR and BMI are good predictors of high blood pressure, along with indications combined with BMI to further improve the detected blood pressure prediction. However, the clinical importance of such improvements can be questioned. Another study suggests that waist circumference is an essential discriminatory power to capture the relationship between blood pressure and likely cardiovascular risk, as waist circumference is easy to acquire [82]. In this study, WHR and BMI are significantly associated with raising blood pressure levels.

Our study identified several notable risk factors, including smoking, alcohol consumption, extra salt intake, and BMI. These behavioral risk factors can manifest as elevated blood pressure, increased blood glucose, elevated blood lipids, and overweight or obesity in individuals. These "intermediate risk factors" are measurable in primary healthcare settings and serve as indicators of heightened risk for conditions such as heart attacks, strokes, heart failure, and other complications [58]. Both smoking and alcohol consumption were found to be significant factors and can be prevented. Our findings, in line with several other studies conducted across various regions of India, underscore the rise of blood pressure levels across diverse population segments, including those in lower socioeconomic strata. Future research endeavors should assess the prevalence and distribution of high blood pressure, hypertension, and their associated risk factors among different ethnic groups. This will provide valuable insights into blood pressure trends and cardiovascular risk factors across various ethnic groups, particularly concerning their exposure to modern lifestyles and acculturation processes.

Data availability statement

Data will be available upon reasonable request.

Ethics statement

The study protocol for each district was approved by the institutional ethical committees (IECs) of the authors' respective institutions (YCB, SR, SM, ASK, NT, NKM). All participants in the study were provided with information regarding the study's objectives, and written consent was obtained from them.

Author contributions

C.R.H: statistical analysis and writing of the first draft of the manuscript; S.K.R, S.R.M., Y.C.B., N.T., A.S.K., N.M., F.K.J.: data collection; B.V.B.: conceptualisation and designing of the study, finalisation of the manuscript, and guaranteeing the manuscript.

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Conflict of interest

The authors declare that they have no conflict of interest.

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