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Intergenerational transitions in age at menarche: insights from Chandauli district, Uttar Pradesh, India

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Abstract

Background Menarche, a milestone in a woman's reproductive journey, is influenced by various factors such as lifestyle and dietary habits. Recent studies have corroborated this claim and prompted further investigation. This study explores the connection between menarche timing with lifestyle and dietary habits among three generations of women from the Sakaldiha block of Chandauli district and presents valuable insights into the role of diet and lifestyle in this crucial reproductive event.

Methods The study is based on primary data collected using multistage stratified random sampling. A comparative analysis of the mean age at menarche across independent variables has been conducted using the one-way analysis of variance (ANOVA) technique. Additionally, a multiple regression model has been developed to investigate the association between menarcheal age and various dietary, lifestyle and socio-economic factors among 400 respondents.

Results The average age of menarche for respondents was 14.29 years (95% CI: 14.12, 14.45), which has decreased by 1.66 years from 14.89 years (95% CI: 14.63, 15.15) in women over 40 years of age to 13.23 years (95% CI: 12.97, 13.49) in the < 20 years age group. The study additionally found that dietary and lifestyle factors had an impact on the age of menarche, with those who regularly consumed junk food, occasionally ate meat/fish or eggs, completely avoided curd or buttermilk and engaged in non-resting leisure activities experiencing an earlier onset of menarche.

Conclusion The study shows that diet and lifestyle affect age at menarche, with current generations experiencing an earlier onset of menstruation. The effect of socioeconomic status remains inconclusive.

Keywords Menarche, Diet, Lifestyle, Age, Decline

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Background

The first menstrual cycle that occurs during adolescence is menarche. Pubertal maturation comprises two interrelated yet distinct processes: adrenarche, which marks the return of adrenal androgen production (occurring around ages 6–8), and gonadarche, which follows a few years later and signifies the reactivation of the hypothalamic-pituitary-gonadal (HPG) axis [1]. Females experience three significant events throughout puberty: the onset of puberty, peak height velocity (PHV), and the emergence of menstruation, which typically takes place about six months after PHV and is considered a later occurrence in puberty [2]. Although most other changes occur gradually over time, girls experience a significant milestone in their puberty journey with the sudden and noticeable event of menarche [3]. For many women, this is a momentous occasion that symbolizes the transition from childhood to adulthood and holds great significance in the lives of young girls [4].

The age at menarche (AAM) among women varies worldwide [5–7]. The number is lower in more industrialized nations [8]. In India, there are spatiotemporal variations observed in menarcheal age among its population [9–13]. Apart from the variations in menarcheal age; the decline in AAM has also been documented [8, 13]. In developing countries, half of the variations in AAM have been attributed to genetic and heritable factors [5].

Numerous factors have been identified as influencing AAM, with genetic and environmental factors being regarded as the most significant [2]. Diet [14–16] and lifestyle including physical activity [8, 14, 17] have also been considered as factors affecting AAM. Both early [18–22] and late menarche [20] have been linked to health consequences. Early menarche denotes the commencement of menarche prior to the age of 12, although some experts set the threshold at 10 or 11 years [23]. Late menarche is characterized by the onset of menarche occurring at or after the age of 15 years [24]. Early menarche is associated with type 2 diabetes [18], cardiovascular risks [19, 20], breast cancer [25] and psychosocial issues [21, 22]. Conversely, late menarche is linked to impaired cognitive function [26], lower bone mineral density [27, 28], and elevated risk of fractures [27, 28] and cardiovascular problems [20]. Certain health implications, including cardiovascular risks, adult oligomenorrhea and decreased fecundability, have been observed in both early and late menarche [20, 29, 30]. Goal 3 of the Sustainable Development Goals (SDG) emphasises ensuring healthy lives and the promotion of well-being for individuals of all ages. However, the declining menarcheal age may pose future obstacles to achieving this objective as the timing of menarche and menopause is utilised as an indicator of a woman's reproductive health [31]. Besides, the physical and mental well-being of women is intricately linked to their reproductive health [32].

Environmental factors such as nutrition, psychosocial variables and endocrine-disrupting chemicals (EDCs) are recognised as strong determinants of menarcheal age [5]. Globalisation and rapid economic shifts have contributed to changes in dietary patterns and eating behaviours in India [33]. The nation has experienced a swift evolution in its dietary habits following the green revolution, with economic transformation and technology influencing lifestyle-related trends. The widespread availability of ultra-processed and junk food in the market has introduced a new facet to this concern. These nutrient-deficient, ultra-processed foods, combined with diminishing dietary diversity, may lead to future complications. Additionally, precocious puberty (early onset of puberty) has been linked to diets rich in desserts, snacks, soft drinks, and fried foods, without adjusting for socioeconomic factors [34] along with childhood BMI [35]. In addition to dietary shifts, physical inactivity has been a pressing concern in recent years. A decade-old study found that only 10% of the Indian population engage in recreational physical activity [36]. Previous research has also linked precocious puberty with screen time [37]. Moreover, elevated air pollution levels are associated with an earlier age at menarche and an increased risk of menstruation onset before the age of 11 [38]. The convergence of genetic, physical, environmental and cultural factors is elevating the risk of early menarche among young girls in India. Therefore, In the Indian context early menarche and precocious puberty are problematic because menarcheal characteristics reflect broader societal and cultural changes [8], environmental influences [38, 39] and personal repercussions; premature maturation has both physical, mental and emotional ramifications [18–22, 25, 29, 30].

It has been argued that while many studies have investigated the association between the age of menarche and factors such as nutritional status, BMI, residence region, socio-economic status, and geographical location, very few have explored the relationship between menarche and environmental changes and lifestyle patterns [8]. Furthermore, the majority of current research on this topic comes from foreign countries and investigations into the relationship between menarcheal age and its salient risk factors including diet and lifestyle within the Indian context remain insufficiently examined. Over the past few decades, there has been a significant shift in our way of life, including changes in traditional and cultural practices such as food habits, leisure activities, sleep and work patterns, lifestyle choices, habits, and the adoption of modern lifestyles which can be attributed to the rapid increase in population, heightened physiological stress, and the speedy urbanization and industrialisation

of society [8]. A major gap persists in comprehending the interaction of dietary and lifestyle factors in rapidly globalising regions. Limited research has investigated the combined effects of changing dietary patterns and reduced physical activity on the onset of menarche. This intersectional focus is crucial for thoroughly addressing public health issues associated with early menarche and its long-term consequences, especially in developing nations undergoing rapid socio-economic and environmental changes. To fill this gap, the current research aims to assess the impact of diet, lifestyle and socioeconomic status on AAM. It also estimates the trend in menarcheal age over three generations. Additionally, it records the alterations in dietary practices and lifestyle-related factors across generations, along with the underlying reasons for these changes.

Methods

The primary data for this study, which utilises a mixed-method approach, was collected from the Sakaldiha block of the Chandauli district in eastern Uttar Pradesh. The selected geographic unit of analysis provides a micro-regional framework. Sakaldiha Block is located within Chandauli district, which has been included in the Aspirational District Programmes launched in 2018, aimed at swiftly and effectively transforming the least developed districts in the nation [40]. The Programme concentrates on five principal socio-economic themes, including Health and Nutrition [40]. A cross-sectional study of post-menarcheal females was conducted in 26 villages within the block from March to June, 2022 (Fig. 1). Semi-structured questionnaires were utilised for the interviews, and a sample size of 400 was calculated using Taro Yamane's formula:

$$n = N/K + N(e)2$$

where, N = Study Population (104637).

K = Constant (1).

e = degree of error (0.05).

n = sample size.

= 104,637/1 + 104,637(0.05)2 = 399.99 = 400.

The study population was taken as 104,367 [41], which is the female population of Sakaldiha block after deducting under 5 female population. The constant was kept at 1 and 0.05 was the margin of error. In order to accomplish the study's objectives, it was imperative to gather data that spanned across multiple generations. To ascertain generational transition in menarcheal age, three age groups were selected: less than 20 years (<20), 20 to 40 years and more than 40 years (>40). Random samples were drawn from each Nyay Panchayat (NP) prioritising close relationships. A multistage stratified random sampling design for sample selection was used. Initially, a list of NPs and Gram Panchayat within each NP was obtained from the Block Development Office. A voter list from the gram panchayat office was used to identify the list of eligible respondents in the surveyed villages. Secondly, villages were stratified into strata based on marital status, reproductive status (pre-menopausal and post-menopausal) and social groups (caste/clan or religious-based communities). Finally, 10–15 sampled respondents were randomly selected from each village. This approach allowed the capture of the sample from diverse socioeconomic backgrounds in the study area, thus minimizing the scope of any bias in the sample selection. To determine the age at which menarche occurred, researchers used a recall method in which post-menarcheal females or their mothers were asked to recall the age at which the females first began menstruating [2]. During the study, respondents were queried about their attainment of menarche, and those who responded affirmatively were prompted to recall their age at menarche. To minimize the impact of recall bias, participants were prompted to share important memories related to their menarche experiences.

Dietary pattern and leisure activity

Dietary pattern and habits were recorded to explore how they were connected with AAM and generational shifts in dietary practices. Respondents were asked to recall their food consumption over the past seven days, including any items that were outside their usual diet, which were later excluded. Then, a list was presented to them and they were asked about the most frequently consumed food items. The most commonly consumed foods were sorted into seven categories: lentils/legumes, vegetables, milk, curd and buttermilk, meat/fish or eggs, junk/fast food, and cereals. The frequency of intake was divided into four groups: daily, frequent (3–4 times a week), occasional (once a week), and never. Junk food, which has little or no nutritional value, was placed in a separate category, including fast food, highly processed packaged food, and aerated drinks. For children under 15 years old, their family members were consulted to verify their food intake at home. The researcher also inquired about portion sizes. Older respondents were initially asked to recount their dietary habits during adolescence, which were used for statistical analysis. They were subsequently requested to detail their present dietary habits, which have been recorded as observations. They were also given clear instructions to limit their responses to their recreational pursuits and hobbies during their adolescence. Respondents were interviewed on different aspects of diet such as favourite snacks; disliked food items and frequently eaten vegetables and their answers have been recorded as observations.

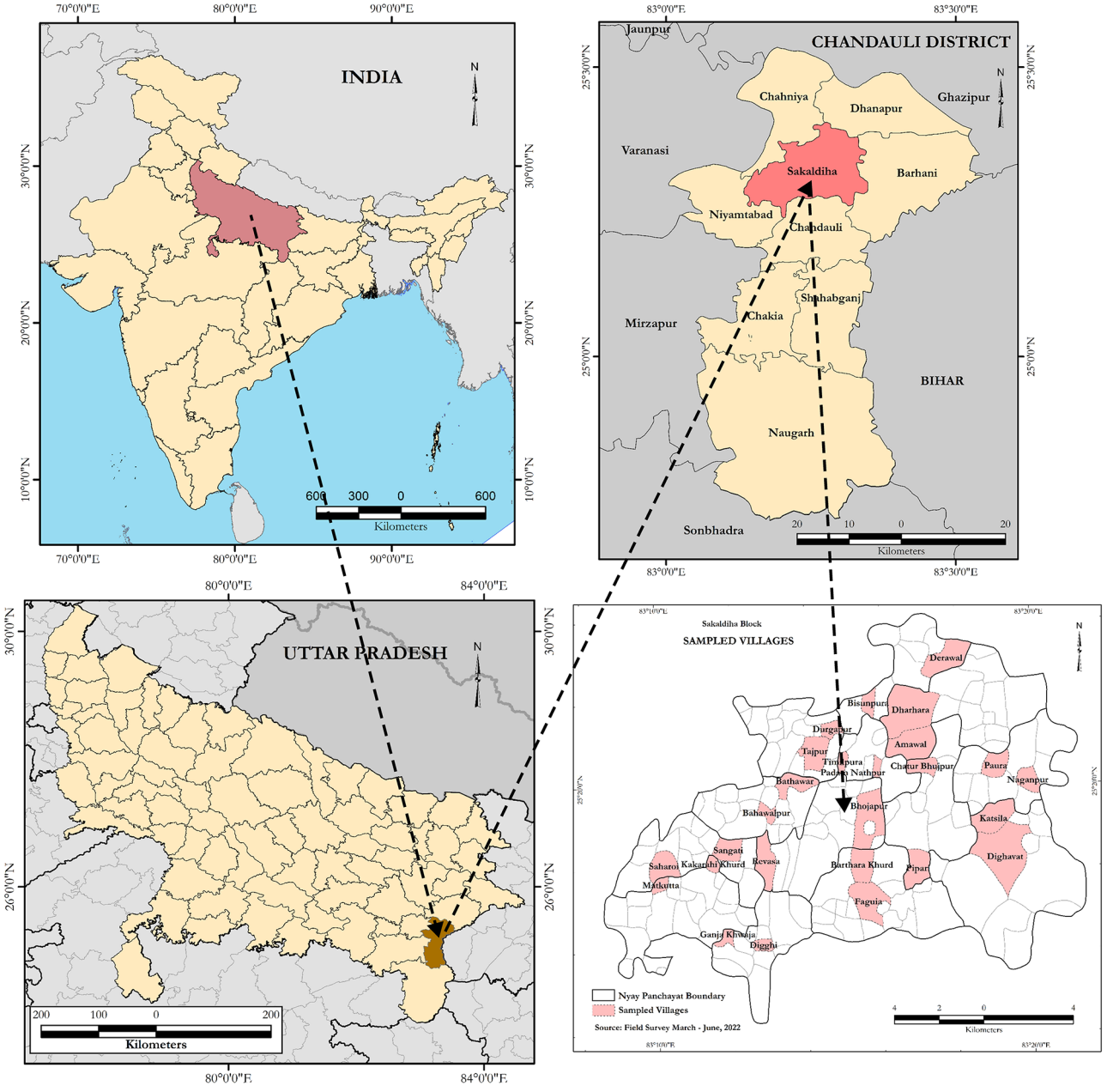

Fig. 1 Location and Extent of Sakaldiha Block and Location of Sampled Villages

Household wealth status

This study determined the household wealth by considering the assets, amenities, and occupations of the households, rather than relying on participants' disclosure of their monthly income in rupees through a traditional income probing method for accurately assessing their economic situation. Thus, to determine the proxy wealth status of the households, the surveyed individuals were categorised according to a range of variables related to sources of wealth such as nature of occupation, ownership of household assets and amenities, including land ownership, type of housing, toilet facilities, animal husbandry, family size, water source for domestic use, separate cooking area, tools and consumer goods such as mobile phones, television, refrigerator, mode of transportation and tractor. The obtained scores were aggregated to calculate household wealth scores. Individuals in the sample were then assigned the score of the household they resided in. The aggregated score of the wealth score varied from 10 to 32 and was classified into four categories: Upper, Upper Middle, Lower Middle, and Lower, following the modified Kuppuswamy Socioeconomic Scale [42, 43].

Table 1 Mean age at menarche across Age groups

Age Groups (Years)	Mean (Years)	*N*	95% CI	
< 20	13.23	108	12.97	13.49
20–40	14.49	156	14.24	14.74
> 40	14.89	136	14.63	15.15
Total	14.29	400	14.12	14.45

Note: CI is confidence interval

F = 39.094, df = 2, p = 0.000

Statistical analysis

The data was entered and analysed through the utilization of SPSS version 26. To compare the mean AAM across age groups, different food groups, leisure activities and household wealth statuses, a one-way ANOVA was conducted. The study results showed statistical significance with a p-value of 0.05 or less and a confidence interval of 95%. Additionally, the menarcheal age was analysed through a multiple linear regression analysis [44],

$$\hat{Y} = b_0 + b_1X_1 + b_2X_2 + \ldots + +b_pX_p$$

where, $\hat{Y}$ = predicted or expected value of the dependent variable

X_1 through X_p = p distinct independent or predictor variables.
b_0=value of Y when all of the independent variables (X_1 through X_p) are equal to zero b_1 through b_p = estimated regression coefficients.

The outcome variable was Age at Menarche, and the independent variables were the age of respondents (continuous), Intake frequency of Lentils/Legumes, Junk/Fast food, Meat/Fish or Eggs, Vegetables, Milk, Curd, and Buttermilk, Leisure time activities and Household wealth status. The figures and graphs were generated using MS Excel version 2016 and mapping was done using ArcGIS Desktop 10.7.

Results

Characteristics of respondents

Age of respondents

The overall mean age of the sample is 33.92 years (95% CI: 32.33, 35.52). The average age of participants in the < 20 age group was 16.00 years, while in the 20–40 age group, it was 29.80 years. Similarly, in the > 40 age group, the average age was 52.89 years.

Age at menarche

Table 1 showcases the distribution of age at menarche across various age groups. The data reveals that the average age at menarche (AAM) was 14.29 years (95% CI: 14.12, 14.45). Importantly, the range of AAM reported was between 11 and 20 years. In addition, the AAM illustrated a declining trend among the younger demographic. The descriptive analysis reveals that respondents in the youngest age group (< 20 years) experienced menarche at an average age of approximately 13.23 years (95% CI: 12.97, 13.49). However, as the age of the respondents increased, the average age at menarche also increased. It reached its peak at around 14.89 years (95% CI: 14.63, 15.15) for those in the > 40 years age group, and then slightly decreased to 14.49 years (95% CI: 14.24, 14.74) for the 20 to 40 years age group. This indicates a difference of 1.66 years between the oldest and youngest age groups.

Figure 2 indicates a clear trend of decreasing average AAM over time. This implies that younger respondents generally experience menarche earlier in life compared to older respondents. However, the difference between age groups is gradual until the 20–40 years group, after

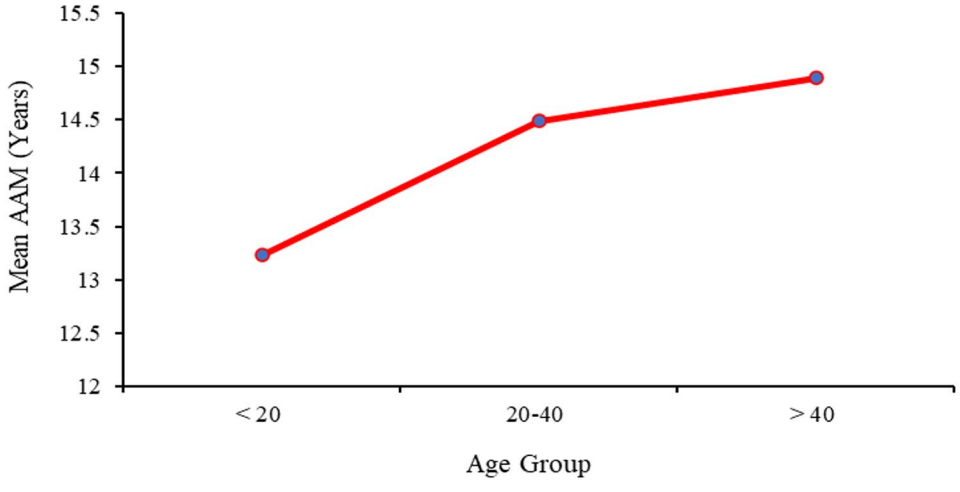

Fig. 2 Age-wise Distribution of Age at Menarche

which there is an abrupt decrease in AAM for the <20 years group (Fig. 2).

Dietary pattern

All the participants included in the study reported daily consumption of cereals (wheat and rice). Table 2 presents a descriptive analysis of mean AAM across different food items among the sampled population. Respondents who consumed lentils daily had a higher age at menarche than those who consumed it frequently, although the difference wasn't statistically significant ($p=0.438$). The consumption of junk/fast food is associated with a significant difference in the AAM ($p=0.000$). Respondents who consumed junk/fast food frequently had a lower mean AAM compared to those who consumed it occasionally or never consumed it. Meat/fish, or egg consumption resulted in minor differences in AAM, and the result was statistically insignificant ($p=0.171$). Daily and frequent consumption of vegetables resulted in statistically insignificant higher age at menarche as compared to those who consumed it occasionally/weekly ($p=0.078$). Mean AAM significantly varied among different frequencies of milk intake ($p=0.018$). The mean age at menarche (AAM) was found to be highest among individuals who frequently consumed milk in contrast to those who drank it daily and those who never consumed it. In addition, frequent consumption of curd and buttermilk was found to be associated with a higher AAM, in comparison to those who never consume it, although the differences were not statistically significant ($p=0.076$).

Lifestyle pattern

The influence of lifestyle patterns on AAM was also examined. Findings from Table 3 suggest that mean AAM was lowest among those respondents who were studying in their free time, using a cell phone, and watching television. Whereas, it was highest among those who spent their free time resting/sleeping, walking, and engaging with friends and relatives, moreover, these results were statistically significant ($p=0.000$).

Figure 3 shows the average menarcheal age across different leisure activities (Fig. 3).

Table 2 Mean age at menarche across frequency of intake of different food items

Food groups	*N*	Mean	Standard deviation	Standard error	95% CI	
Lentils/Legumes						
Daily	290	14.32	1.613	0.095	14.14	14.51
Frequently	110	14.18	1.704	0.162	13.86	14.50
F = 0.602, df = 1, $p=0.438$						
Junk/Fast Food						
Frequently	85	13.87	1.534	0.166	13.54	14.20
Occasionally	298	14.33	1.610	0.093	14.15	14.52
Never	17	15.53	1.940	0.471	14.53	16.53
F = 8.031, df = 2, $p=0.000$						
Meat/Fish or Eggs						
Frequently	45	14.44	1.603	0.239	13.96	14.93
Occasionally	213	14.14	1.596	0.109	13.93	14.36
Never	142	14.45	1.699	0.143	14.17	14.73
F = 1.773, df = 2, $p=0.171$						
Seasonal Vegetables						
Daily	337	14.29	1.643	0.09	14.11	14.46
Frequently	35	14.69	1.301	0.22	14.24	15.13
Occasionally	28	13.75	1.838	0.347	13.04	14.46
F = 2.564, df = 2, $p=0.078$						
Milk						
Daily	94	14.01	1.590	0.164	13.69	14.34
Frequently	76	14.75	1.745	0.2	14.35	15.15
Occasionally	96	14.38	1.630	0.166	14.04	14.71
Never	134	14.15	1.568	0.135	13.88	14.42
F = 3.387, df = 3, $p=0.018$						
Curd/Buttermilk						
Frequently	37	14.68	1.4150	0.233	14.2	15.15
Occasionally	94	14.49	1.7890	0.184	14.12	14.86
Never	269	14.16	1.6000	0.098	13.97	14.35
F = 2.592, df = 2, $p=0.076$						
Total	400	14.29	1.637	0.082	14.12	14.45

Table 3 Mean age at Menarche across different leisure activities

Leisure Time Activity	*N*	Mean	Standard Deviation	Standard Error	95% CI	
Cell phone	51	13.65	1.293	0.181	13.28	14.01
Rest / Sleeping	155	14.61	1.621	0.130	14.36	14.87
TV	82	13.88	1.753	0.194	13.49	14.26
With friends and relatives	69	14.71	1.466	0.177	14.36	15.06
Walk	11	14.82	1.888	0.569	13.55	16.09
Other Activities	21	13.95	1.627	0.355	13.21	14.69
Study	11	13.09	1.136	0.343	12.33	13.85
Total	400	14.29	1.637	0.082	14.12	14.45

F = 5.627, df = 6, $p = 0.000$

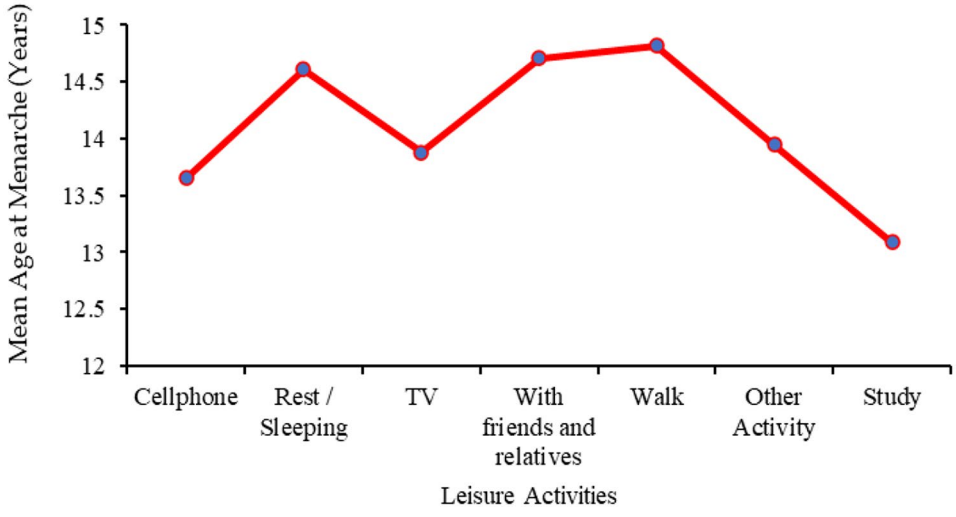

Fig. 3 Age at Menarche across different Leisure Activities

Table 4 Mean Age at Menarche across Household Wealth Status

Household Wealth Status	*N*	Mean	Standard Deviation	Standard Error	95% CI	
Upper	15	13.87	1.246	0.322	13.18	14.56
Upper Middle	153	14.40	1.718	0.139	14.12	14.67
Lower Middle	200	14.21	1.634	0.116	13.98	14.44
Lower	32	14.41	1.411	0.249	13.9	14.91
Total	400	14.29	1.637	0.082	14.12	14.45

F = 0.769, df = 3, $p = 0.152$

Household wealth status

The highest proportion of interviewed females belonged to the lower and upper-middle groups. Table 4 shows that the proportion was much lower in the poorest and richest groups. However, the mean age at menarche registers lower figures in the richest group but the difference between the respondents of the richest group with other categories was not significant ($p = 0.152$).

Predictors of menarcheal age

The results from Descriptive Analysis establish that AAM is declining among post-menarcheal women of three generations in the study area. The results also showcase variations in AAM across varying intakes of certain food items. Nevertheless, to test whether the observations are true, a multiple linear regression model has been fitted, adjusting for potential dietary, lifestyle factors and socio-economic status. Table 5 indicates that the fitted regression model has an R^2 value of 0.227 and an adjusted R^2 value of 0.182, which explains 18% of the total variation found in AAM. The results suggest a positive association between mean AAM and age of respondents as one unit of increase in age was associated with a 0.038-year rise in age at menarche. Therefore, the estimated regression parameter confirms the declining trend in AAM.

Interestingly, females who were not consuming fast food experienced a mean AAM of 1.138 years later than females who consumed it frequently. Similarly, respondents who never consumed meat/fish or eggs experienced menarche 0.073 years later than those who ate

Table 5 Factors Associated with Age at Menarche

Parameters	Coefficient	*p*-value	95% CI	
(Constant)	11.504	0.000	10.143	12.865
Age	0.038	0.000	0.025	0.050
Lentils/Legumes				
Frequently*	0.000		0.000	0.000
Daily	-0.228	0.200	-0.578	0.121
Junk/Fast Food				
Frequently*	0.000		0.000	0.000
Occasionally	0.153	0.461	-0.256	0.562
Never	1.138	0.007	0.315	1.962
Meat/Fish or Eggs				
Occasionally*	0.000		0.000	0.000
Frequently	0.634	0.014	0.129	1.138
Never	0.073	0.664	-0.259	0.405
Vegetables				
Never*	0.000		0.000	0.000
Frequently	0.104	0.796	-0.687	0.895
Daily	-0.095	0.762	-0.712	0.522
Milk				
Daily*	0.000		0.000	0.000
Frequently	0.114	0.654	-0.386	0.614
Occasionally	-0.045	0.848	-0.502	0.413
Never	0.056	0.802	-0.381	0.492
Curd/Buttermilk				
Never*	0.000		0.000	0.000
Frequently	0.628	0.026	0.075	1.181
Occasionally	0.198	0.296	-0.174	0.569
Leisure				
Studying*	0.000		0.000	
Cell phone	0.633	0.210	-0.358	1.623
Rest / Sleeping	0.977	0.045	0.023	1.931
Television	0.638	0.191	-0.319	1.595
With friends and relatives	0.821	0.116	-0.203	1.844
Walk	0.675	0.315	-0.644	1.994
Others	0.807	0.154	-0.304	1.919
Household Wealth Status				
Upper*	0.000		0.000	0.000
Upper Middle	0.624	0.129	-0.182	1.430
Lower Middle	0.533	0.195	-0.274	1.339
Lower	0.641	0.192	-0.324	1.605

R^2=0.227, Adjusted R^2=0.182, F=5.030, p=0.000

N=400

*Reference

occasionally. Notably, respondents who had curd/ buttermilk frequently experienced menarche 0.628 years later than those who never consumed any fermented dairy. The mean AAM also varied significantly among those who spent their free time resting or sleeping compared to those who were studying. Respondents who were spending their free time resting or sleeping had a mean age at menarche 0.977 years later than those who were studying (Fig. 4).

Discussion

The onset of menarche plays a crucial role in shaping a woman's outlook and beliefs about menstruation as a recurring biological process [45]. The study highlights the intergenerational transition in AAM at the block level in a predominantly rural district. Previous studies have mentioned that girls residing in rural areas achieve menarche later than their urban counterparts [46, 47]. Upon analysing AAM across age groups, a significant decrease of 1.66 years in menarcheal age in the first group, or the youngest age group compared to the third group, or the oldest age group is evident from the observations made. The findings revealed significant variations in mean AAM depending on intake of junk food and engaging in recreational activities, emphasising the necessity of addressing dietary and lifestyle factors contributing to early menarche.

Lifestyle and eating habits affect the circadian rhythm [48]. Circadian rhythm affects hormone levels [49]. There are several ramifications of disturbance in the circadian rhythm, which might also result in fluctuation in hormonal levels [48, 49], including changes in dietary habits and patterns [49]. The age of menarche is significantly impacted by lifestyle choices, in addition to genetic factors [50]. Indian doctors in Goa have observed a trend where girls are experiencing menarche as early as 8 or 9 years old, while their mothers had their first menstrual cycle around the age of 13 and 14 [50]. These findings are highly alarming both at an individual level and at the level of society, due to the discrepancy or delay between physical puberty and social puberty. In the present study, several older respondents have self-reported that contemporary adolescent girls are achieving puberty and menarche at an earlier age compared to their own experiences.

The results from this study highlighted the impact of dietary factors on the age of menarche. All respondents were able to remember their food intake with ease. Cereals were not incorporated in the regression model as all the respondents were consuming it daily with every meal. Although sugar intake was also examined, it was discovered that it varied greatly among the groups, with only a small number of participants able to specify their consumption levels. The findings indicated a striking similarity in the eating habits of the participants. Their lunches and dinners consisted primarily of whole wheat chapatis, pulses, white rice, seasonal vegetables, and meat/egg curry (for those who consumed animal protein). Other protein sources included a few varieties of lentils/legumes/pulses, soybean granules, and dairy products such as milk, curd, and buttermilk. Potatoes and onions were consumed daily and formed a greater part of daily vegetable intake in every meal. Although individuals consumed pulses on a near-daily basis, it was in low

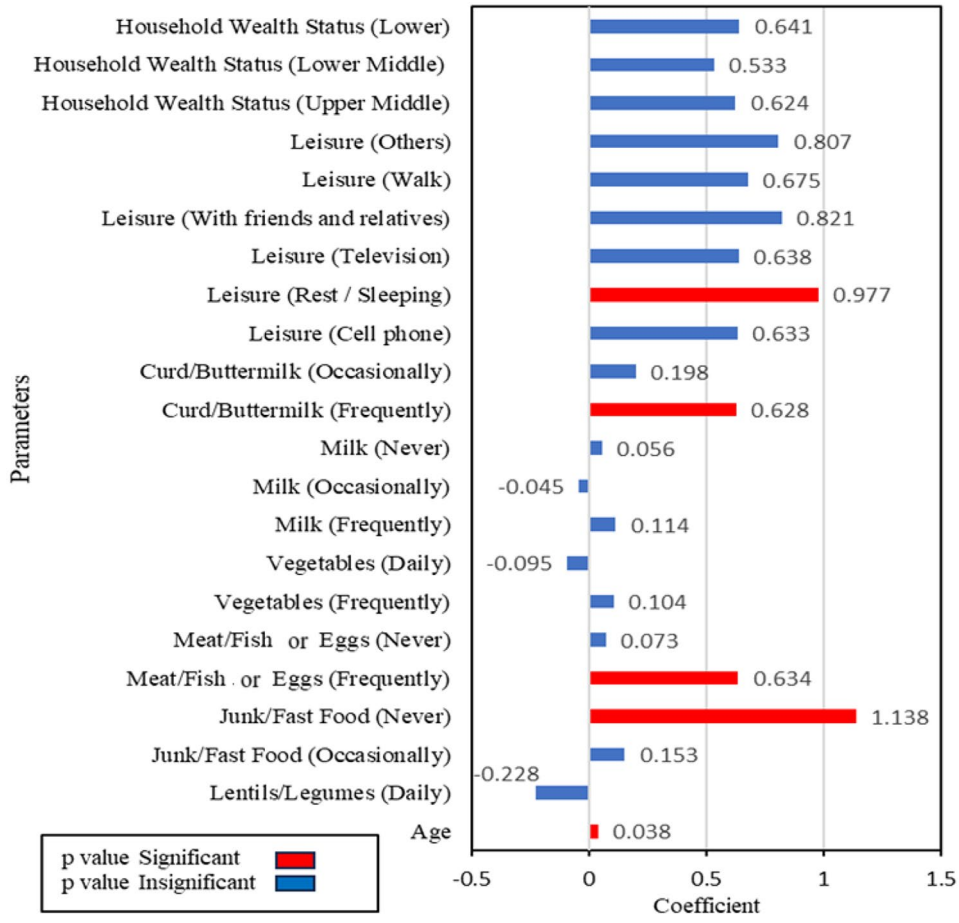

Fig. 4 Factors Associated with Age at Menarche

quantities and the proportion of dal to rice or chapati was severely imbalanced, as was the proportion of seasonal vegetables. Those of an older age reported that the reason for the decreased consumption of pulses was due to their affordability. Conversely, younger individuals reported that they did not enjoy the taste of lentil dishes and instead preferred fast food and heavily processed foods for their heightened flavours.

Fruits were only consumed during certain seasons. Groundnuts, roasted gram, and jaggery were snack items that all of the older participants consumed, but the younger generation primarily snacked on packaged food items, and their intake of these snacks varied significantly. Research suggests that the younger generation may have a preference for ultra-processed foods due to their highly addictive taste [51]. Fast foods are often designed to be more addictive as well [52]. Furthermore, studies have linked a modern diet with a decline in menarche [16] and possible circadian rhythm disruption from fast food consumption [48]. As a result, younger individuals may have a stronger desire for junk food, which they often fulfil with food items such as packaged noodles, chips, toffees, sweetened soft drinks, and fried fast-food items like dumplings, noodles, and rolls. Interestingly, older individuals reported limited access to fast food and ultra-processed foods during their childhood, resulting in a lower inclination towards these items compared to younger participants. Interviews and discussions revealed that the food choices of respondents over 50 tend to remain consistent throughout their lives, even into old age.

The results bring out the interconnection between physical activity and AAM. In rural areas, adolescent girls lead active lifestyles, often walking or cycling to school. However, many have traded outdoor activities for social media. When surveyed about leisure time activities during adolescence, older respondents reported engaging in outdoor games, spending time with loved ones, and pursuing screen-free hobbies. While many younger respondents were primarily focused on activities such as watching television and using cell phones, and in some cases, dedicating their free time to academic pursuits like studying due to academic pressure, resulting in a lack of recreational activities for rejuvenation, it is noteworthy that these respondents exhibited the lowest AAM. Among them, individuals who engaged in

studying during their leisure time exhibited the lowest AAM, which can be attributed to academic stress. These relatively minor alterations are the unavoidable consequences of societal shifts. The previous generations used leisure time for rest or to pursue their hobbies, but now it has been taken over by screens or, in some cases, excessive academic pressure. Even leisure time is dominated by continuous mental stimulation, rather than being a source of rejuvenation. Overall, the findings offer valuable insights into the transformative dietary and lifestyle changes occurring in communities located in rural settings.

The results from this study did not establish socioeconomic patterning of mean AAM. Previous studies have suggested that socioeconomic factors might play a role in the onset of menstruation [46, 53]. In our study, although mean age at menarche (AAM) was not found to be significantly associated with household wealth status in this study population, the results showed that respondents belonging to the Upper class had the lowest mean AAM. This finding is consistent with prior studies on Indian girls [13, 54], indicating that those from higher socioeconomic backgrounds tend to experience menarche earlier than those from lower socioeconomic backgrounds. Similarly, in another study from the subcontinent, Pakistani girls from the highest social class experienced menarche earlier compared to their lower-class counterparts [55].

Based on the findings, a community-based intervention is proposed to promote balanced nutrition and encourage the incorporation of traditional, affordable, nutrient-dense foods, which were previously staples in local diets, while aiming to diminish the reliance on fast and junk food consumption, particularly among adolescents in rural areas where such options are becoming increasingly accessible. A major transition away from conventional healthy eating practices highlights the necessity for focused interventions. Health education initiatives emphasising the advantages of whole foods and physical activity could be established in schools and community centres, targeting both adolescents and families to address generational nutritional practices, thereby promoting long-term health benefits and potentially postponing menarche to a more optimal age. Furthermore, policies that facilitate access to affordable, nutrient-dense foods in rural markets may mitigate the dietary changes associated with early menarche. To augment the efficacy of these strategies, it would be advantageous to undertake longitudinal research to monitor trends in AAM and assess the enduring effects of dietary and lifestyle alterations. These interventions may facilitate a comprehensive enhancement of adolescent health and correspond with Sustainable Development Goal 3, which seeks to guarantee health and well-being for all age groups.

Strengths and limitations

This study's strengths lie in its distinctive data covering three generations to determine the decrease in menarcheal age. It thoroughly records dietary patterns, lifestyle habits related to recreation, and socioeconomic status, as well as their effects on the average age of menarche, thereby providing valuable insights to the limited research on this subject in India. The application of a mixed-method approach yields profound insights into the alterations in dietary and lifestyle habits among a sample of women living predominantly in a rural area of the Chandauli District in Uttar Pradesh, India. Nonetheless, the study possesses certain limitations. This is a micro-level study, necessitating further investigation to fully understand the potential implications of these findings on a broader scale, across various disciplines, and for future research endeavours. The results reflect area-specific trends, as these patterns may vary in different populations. Consequently, asserting that the findings are generalisable beyond the specific population is inconclusive, as the study examines associations within a particular region and demographic, and extrapolating to other regions may be constrained by variations in dietary habits, lifestyle, socioeconomic conditions, and environmental factors. Similar studies may be conducted in different geographical or cultural contexts to identify new patterns.

Moreover, the dependence on self-reported data may result in recall bias, and the study's conclusions may not be generalised to other regions of India.

Implications

The findings underscore the necessity for an elaborate integrated strategy to tackle the declining menarcheal age in the region, encompassing agricultural, educational, and social policies. There is an immediate necessity to enhance diversity on the plate and to deter the consumption of junk food specifically among youth. Rural populations predominantly consume locally cultivated vegetables, fruits, and grains. Promoting the cultivation of fruits, vegetables, and millet can enhance agricultural diversity and variety in diets. Incorporating sports into the educational curricula and promoting non-screen recreational activities will augment engagement in physical activity, thereby addressing this issue and improving overall health.

Conclusion

The age at which girls experience menarche is decreasing in the study population. The results demonstrate a reduction of 1.66 years from the first to the third generation. Dietary and lifestyle patterns substantially affected alterations in the age of menarche. India is undergoing significant changes in dietary patterns and lifestyle preferences,

including in less urbanised and rural areas of the country. Studies suggest that these alterations can impact the onset of menarche. The compounding impact of consuming nutrient-deficient food, engaging in sedentary behaviours such as excessive screen time, and experiencing heightened academic stress may result in significant repercussions. These alterations have the potential to impact an individual's physiological and biological processes over an extended period. This study offers valuable insights into the dietary habits and lifestyle of females from three different generations at a micro-level. The findings gain significance as the age of menarche is associated with significant non-communicable health concerns. The study's findings have significant ramifications for public health and policy in India. Moreover, health initiatives emphasising the significance of a balanced traditional seasonal diet, recreational physical activity, and the reduction of screen time must be advocated, particularly during formative years.

Abbreviations

AAM	Age at Menarche
ANOVA	One-way Analysis of Variance
CI	Confidence Interval
EDCs	Endocrine-disrupting Chemicals
HPG	Hypothalamic-Pituitary-Gonadal
PHV	Peak Height Velocity
SDG	Sustainable Development Goals
NP	Nyay Panchayat

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Author contributions
Sumedha conceptualised the study, collected, curated, analysed, interpreted the data, and wrote and edited the manuscript. S.S. supervised and reviewed the work. P.K.P. interpreted, supervised and reviewed the work. All authors read and approved the final manuscript.

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Data availability
The primary data used in this study are not publicly available (to protect the privacy of the study participants).

Declarations

Ethics approval and consent to participate
Approval for the study and permission for data collection were obtained from the Department of Geography, Institute of Science, Banaras Hindu University. The study required the recollection of menarcheal age alongside dietary and lifestyle habits, without involving any clinical trials on human subjects. The procedures adhered to the standards of the Helsinki Declaration of 1964. Before the interviews', informed consent was secured from each respondent, to ensure their voluntary participation. Informed consent was obtained from a parent or legal guardian for respondents under 18 years of age, in addition to informed consent from the minors themselves. Respondents' personal data was kept confidential. Additionally, participants were thoroughly apprised of the study's objective, their entitlement to withdraw at any moment, and the protocols implemented to safeguard the confidentiality of their data.

Consent for publication
Not Applicable.

Competing interests
The authors declare no competing interests.

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