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BMJ Nutrition, Prevention & Health

Geographical altitude and stunting among children aged under 5 years in India

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To cite: Phad SB, Siddiqui LA, Khan KA, *et al*. Geographical altitude and stunting among children aged under 5 years in India. *BMJ Nutrition, Prevention & Health* 2024;**7**:e000895. doi:10.1136/bmjnph-2024-000895

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Received 20 February 2024
Accepted 29 February 2024
Published Online First 25 April 2024

ABSTRACT

Introduction Previous studies have found positive associations between higher geographical altitude and increased risk of stunting in children under 5 years old, but little evidence exists on this relationship in the Indian context specifically. Chronic exposure to high altitudes can impair food security, healthcare access, oxygen delivery and nutrient absorption, potentially increasing malnutrition.
Objective To investigate the association between geographical altitude and stunting among children aged under 5 years in India.
Methods Using data from the 2015–2016 National Family Health Survey, logistic regression was conducted to estimate the relationship between altitude and stunting, adjusting for child, maternal and household characteristics. The analysis included over 167 555 children under 5 years old.
Results Children at higher altitudes had a significantly greater risk of stunting. Those at >2000+ metres had 40% higher adjusted odds of stunting than children below 1000 metres. The altitude–stunting association was stronger among rural children.
Conclusions This study provides robust evidence that higher geographical altitude is an important risk factor for stunting among young children in India, especially those in rural areas. Targeted interventions to improve food security, healthcare access and nutrition in high-altitude regions could help to mitigate the higher burden of stunting in these areas.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Stunting remains highly prevalent among chldren aged under 5 in India, reflecting chronic undernutrition.
⇒ Prior research in other world regions has found that higher altitude might increase the risk of stunting, but limited evidence exists in the Indian context.

WHAT THIS STUDY ADDS

⇒ This national analysis of over 167 000 Indian children demonstrates that living at higher altitudes above 2000 m corresponds to a 40% greater likelihood of being stunted.
⇒ The altitude–stunting relationship was stronger among rural children, highlighting geographical inequities.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Findings indicate that altitude is an important risk factor for child stunting in India, which should be considered in nutrition research and surveillance.
⇒ Targeted interventions in higher-altitude areas, including food supplements, health services and agricultural investments, might help to address stunting.
⇒ Prioritising nutritional programmes in hilly and mountainous regions could help to reduce geographical inequities in stunting.

INTRODUCTION

Childhood stunting, defined as low height-for-age, remains a major public health challenge in India.[1] Over one-third of children under 5 years old are stunted, reflecting chronic undernutrition.[2] Although national trends show some decline in stunting rates due to programmes like the Integrated Child Development Services, National Nutrition Policy, the mid-day meal scheme and the National Food Security Act, progress has been uneven and stunting burdens remain unacceptably high.[3–7] Further targeted explorations are essential to address stunted growth, which can impair cognitive development, increase infection risks and have long-term health consequences.

Several studies from high-altitude regions in other countries like Ethiopia, Argentina, Peru and Tibet have found that living at higher elevations is associated with increased risk of stunting and other forms of child undernutrition.[8–13] For instance, an analysis in Tibet by Li *et al*[13] found that children at 3000 m had 60% higher odds of stunting compared with those at 1500 m. In Ethiopia, children in higher altitudes showed a higher risk of stunted growth, with prevalence peaking at 47% in the highlands compared with 39% in the lowlands.

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Chronic exposure to high-altitude environments can impair growth through interlinked physiological and socioeconomic pathways. Biologically, high-altitude hypoxia can reduce appetite, restrict oxygen delivery to tissues and limit nutrient absorption.[14] Agriculturally, food insecurity tends to be greater at higher elevations where crop yields are lower and the climate is harsher. Healthcare access also declines at higher altitudes, constraining maternal and child health services.[15–17] It is also possible that children living at higher altitudes are more likely to be exposed to environmental toxins, such as lead and mercury, which can also have a negative impact on growth and development.[18]

However, there is limited evidence on the association between residential altitude and stunting specifically in the Indian context. India's large geographic and cultural diversity means that findings from other world regions might not directly apply. India's diverse terrain includes the Himalayas (3000–8000 m), peninsular plateau (600–900 m) and coastal plains. As one of few countries with substantial populations living at over 2500 m, research exploring effects of altitude can provide important insights.

This analysis aims to address a critical evidence gap by investigating associations between residential altitude and stunting risk among young children across India. The present study is analysing national data to assess whether higher altitude (>2000 m vs <1000 m) is associated with greater stunting risk among Indian children aged under 5 years, especially in rural areas. We focused on young children as the period from conception to 2 years is most critical for linear growth faltering.[4]

Demonstrating an altitude–stunting link can highlight areas where targeted nutrition programmes and social protection schemes are most needed to tackle India's persistently high stunting burden. Effective interventions in high-altitude areas might include supplementary child nutrition programmes, investments in health facilities and assistance to expand agricultural production. It might also help to anticipate the impact of future climate change, as warmer temperatures could enable cropping and settlements at higher elevations. Our findings will aid policymakers in geographically prioritising interventions to improve child nutrition nationwide.

In this nationally representative analysis, we estimated the relationship between residential altitude and the prevalence of stunting among children aged under 5 years in India. We hypothesised that higher altitude would correlate with a higher stunting risk based on potential impacts on food security, healthcare access, oxygen availability and climate.

DATA AND METHODS

This analysis used data from the 2015–2016 National Family Health Survey (NFHS-4), a nationally representative household survey of India.[19] The survey followed a stratified multistage sampling design, with selection of primary sampling units (PSUs) and households. The first stage of the sampling design included selection of PSUs—that is, villages in rural areas and census enumeration blocks in urban areas, using probability proportional to population size. The second stage involved the random selection of 22 households from each PSU. The analysis included a total of 167 555 children under 5 years old. The final selection of children is presented in figure 1.

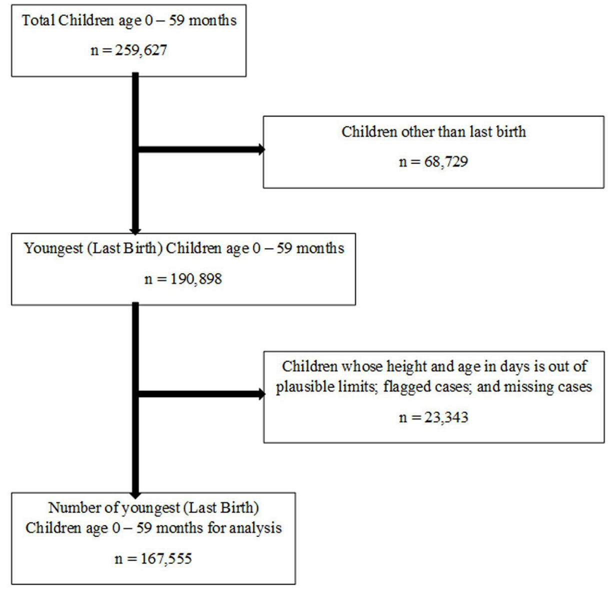

Figure 1 The process describing the final sample size.

Altitude of residence for each child was obtained from GPS data and categorised into <1000 m, 1000–1999 m and ≥2000 m groups. GPS uses trilateration to calculate position in three dimensions—latitude, longitude and altitude. The NFHS collected the data in the same way with the GPS devices for each of the PSUs selected. The invigilators carried GPS devices to record the exact altitude of all the surveyed PSUs. The outcome was stunting, defined as height-for-age z-score <−2SD based on WHO standards.

Descriptive analyses calculated the prevalence of stunting for the total sample and by background characteristics. Bivariate analysis used X^2 tests to assess associations between stunting and altitude group. Multivariable logistic regression models estimated the ORs for stunting by altitude category, adjusting for child, maternal and household factors. Regression models accounted for the survey design and sampling weights. We used Stata software for all statistical analyses, including logistic regression. The logistic regression model used is as follows:

$$\mathrm{Log}(\mathrm{p}/(1-\mathrm{p})) = \beta_0 + \beta_1 \mathrm{X}_1 + \beta_2 \times \beta_2 + \ldots + \beta_n \mathrm{X}_n$$

where

- p is the probability of the dependent variable (stunting) being 1.
- β0 is the intercept.
- β1, β2,…, βn are the coefficients of the independent variables X1,X2,…,Xn respectively.

The logistic regression model estimates the log-odds of the probability of p being 1 as a linear combination of

Table 1 Distribution of sample and percentage of youngest children under age 5 years who are stunted, by background characteristics, India, National Family Health Survey 4

Background characteristic	Percentage %	Number	Percentage stunted (95% CI)
Altitude (m)			
Below 1000 m	98.4	164 874	36.1 (35.8 to 36.5)
1000–1999 m	1.4	2346	29.1 (27.7 to 30.5)
≥2000 m	0.2	335	32.5 (29.0 to 36.1)
Age of child			
<18 months	37.5	62 833	27.4 (26.9 to 27.9)
18–59 months	62.5	104 722	41.2 (40.8 to 41.7)
Sex of child			
Male	54.2	90 815	37.2 (36.7 to 37.6)
Female	45.8	76 740	34.7 (34.2 to 35.2)
Birth order and birth interval			
First birth	33.5	56 131	30.3 (29.7 to 30.9)
Second birth order and <24 months' interval	8.9	14 912	39.8 (38.6 to 41.0)
Second birth order and ≥24 months' interval	25.7	43 062	32.5 (31.9 to 33.2)
Third or higher birth order	31.9	53 450	43.9 (43.3 to 44.4)
Small or very small size at birth			
No	88.4	148 119	34.9 (34.5 to 35.3)
Yes	11.6	19 436	44.9 (43.9 to 45.8)
Mother's education			
No education	27.3	45 743	48.1 (47.5 to 48.7)
Primary	13.5	22 620	41.3 (40.4 to 42.2)
Secondary	47.3	79 254	31.4 (30.9 to 31.9)
Higher	11.9	19 938	20.6 (19.6 to 21.6)
Full exposure to media			
No	81.1	135 887	38.8 (38.4 to 39.2)
Yes	18.9	31 668	24.3 (23.4 to 25.1)
Mother's age at birth			
<25 years	54.6	91 485	36.1 (35.6 to 36.6)
25–29 years	30.0	50 267	34.8 (34.2 to 35.4)
30–49 years	15.4	25 803	38.3 (37.4 to 39.1)
Distance to health facility is a problem in getting medical help for self			
No	33.6	56 298	31.3 (30.7 to 31.9)
Yes	66.4	111 257	38.4 (38.0 to 38.9)
Four or more ANC visits			
No	48.6	81 432	41.9 (41.4 to 42.4)
Yes	51.4	86 123	30.5 (30.0 to 31.0)
Received at least two TT injections			
No	16.5	27 647	38.9 (38.0 to 39.8)
Yes	83.5	139 908	35.5 (35.1 to 35.9)
Consumed IFA tablet/syrup for 100 days			
No	69.7	116 786	38.6 (38.2 to 39.0)
Yes	30.3	50 769	30.1 (29.5 to 30.8)
Residence			
Urban	29.3	49 094	29.8 (28.9 to 30.6)

Continued

Table 1 Continued

Background characteristic	Percentage %	Number	Percentage stunted (95% CI)
Rural	70.7	118461	38.6 (38.3 to 39.0)
Religion			
Non-Hindu	21.0	35187	35.8 (35.0 to 36.6)
Hindu	79.0	132368	36.1 (35.7 to 36.5)
Caste/tribe			
Non-schedule caste/schedule tribe	68.7	115110	33.9 (33.5 to 34.4)
Schedule caste/schedule tribe	31.3	52445	40.7 (40.1 to 41.3)
Use of clean fuel for cooking			
No	65.9	110419	40.3 (39.9 to 40.7)
Yes	34.1	57136	27.7 (27.0 to 28.4)
Source of drinking water – piped water			
No	63.4	106169	38.4 (37.9 to 38.8)
Yes	36.7	61386	32.0 (31.4 to 32.7)
Improved sanitation facility			
No	59.8	100198	41.0 (40.6 to 41.5)
Yes	40.2	67357	28.6 (28.1 to 29.2)
Total	167 555		36.0 (35.7 to 36.4)

Source: Author's own calculation from fourth round of National Family Health Survey.[19]
ANC, antenatal care; IFA, iron–folic acid; TT, tetanus toxoid.

the independent variables. The log-odds are then transformed into probabilities using the logistic function:

$$p = 1/(1 + e - (\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n))$$

Patients or the public *were not* involved in the design, conduct, reporting or dissemination plans of our research.

RESULTS

The overall prevalence of stunting in the study population was 36%. The analysis shows a high prevalence of stunting among children aged 18–59 months (41%) compared with children below 18 months (27%). Stunting was more common among children of third or higher birth order (44%) versus first birth order (30%). Children born small or very small had higher stunting rates (45%) than those born average or large size (35%). Maternal education showed an inverse relationship with stunting, with prevalence declining as education level rose. Children of mothers without schooling had the highest stunting rate (48%), whereas those whose mothers had higher education had the lowest (21%). Stunting was less common when mothers had full exposure to both newspaper/magazine and television (24%).

Components of antenatal care (ANC) also had an impact on stunting. Children of mothers with four or more ANC visits had lower stunting (31%) than their counterparts, as did those whose mothers had two or more tetanus toxoid injections (36%) or consumed iron–folic acid for ≥100 days (30%). Stunting was more prevalent when mothers reported distance to health facilities as an obstacle to care (38%) and among children of mothers belonging to scheduled caste or scheduled tribe (41%) versus other groups (34%).

Access to clean fuels, piped drinking water and improved sanitation also correlated with lower stunting rates (28%, 32% and 29%, respectively) (table 1).

The logistic regression analysis, adjusted for specified variables including district, showed that children at ≥2000 m altitude had higher odds of stunting than those below 1000 m (OR=1.39; 95% CI 1.11 to 1.74). Children aged 18–59 months had two times higher odds than those aged <18 months. Girls had 9% lower odds than boys. Second birth order children with <24 months' spacing (OR=1.29; 95% CI 1.21 to 1.37) and third/higher birth order children (OR=1.19; 95% CI 1.14 to 1.25) had higher odds than first borns. Small/very small birth size increased odds by 47% vs average/large birth size.

Maternal education decreased the odds of stunting, while media exposure and four or more ANC visits lowered odds. Children of scheduled caste/tribe had 21% higher odds than other groups (OR=1.21; 95% CI 1.17 to 1.26). Access to clean fuels and improved sanitation lowered odds (table 2).

DISCUSSION

Despite significant progress in reducing child stunting in India between 2005–2006 and 2015–2016, the prevalence remains high, with over one-third of children under five being stunted. To deal with the problem of stunting

Table 2 Results of multivariable logistic regression showing OR of stunting among youngest child under age 5 years, India, National Family Health Survey 4

Background characteristics	OR	(95% CI)	P value
Altitude (m)			
Below 1000 m*			
1000–1999 m	1.06	(0.92–1.22)	0.408
≥2000 m	1.39	(1.11–1.74)	0.005
Child age 18–59 months (below 18 months*)	2.04	(1.98–2.11)	0.000
Female child (male*)	0.91	(0.88–0.93)	0.000
Birth order and birth Interval			
First birth*			
Second birth order and <24 months' interval	1.29	(1.21–1.37)	0.000
Second birth order and ≥24 months' interval	1.02	(0.98–1.07)	0.298
Third or higher birth order	1.19	(1.14–1.25)	0.000
Small or very small size at birth (no*/yes)	1.47	(1.4–1.53)	0.000
Mother's education			
No education*			
Primary	0.87	(0.83–0.91)	0.000
Secondary	0.69	(0.66–0.72)	0.000
Higher	0.50	(0.47–0.54)	0.000
Full exposure to media (no*/yes)	0.89	(0.84–0.94)	0.000
Mother's age at birth			
<25 years*			
25–29 years	0.89	(0.85–0.92)	0.000
30–49 years	0.85	(0.81–0.9)	0.000
Distance to health facility is a problem in getting medical help for self (no*/yes)	1.08	(1.04–1.12)	0.000
Four or more ANC visits (no*/yes)	0.88	(0.85–0.91)	0.000
Received at least two TT injections (no*/yes)	0.99	(0.95–1.03)	0.625
Consumed IFA tablet/ syrup for 100 days (no*/yes)	0.96	(0.92–1)	0.046
Rural residence (urban*)	1.02	(0.97–1.06)	0.499
Hindu religion (no*/yes)	0.93	(0.89–0.98)	0.003
Scheduled caste/tribe (no*/yes)	1.21	(1.17–1.26)	0.000
Use of clean fuel for cooking (no*/yes)	0.84	(0.8–0.87)	0.000
Source of drinking water – piped (no*/yes)	1.05	(1.01–1.1)	0.025
Improved sanitation facility (no*/yes)	0.84	(0.81–0.87)	0.000
Constant	0.35	(0.25–0.5)	0.000

Note: Variable district is also controlled in the model, but not shown separately.
*Reference category.
ANC, antenatal care; IFA, iron–folic acid; TT, tetanus toxoid.

among children, India has taken several policy initiatives and interventions through different programmes, yet its implementation is affected by several factors. Consequently, the prevalence of stunting remains high among children under age 5 years in India. Our findings highlight key factors associated with stunting that need to be addressed through policies and programmes.

First, geographical altitude is a key factor, aligning with previous research showing higher stunting prevalence at higher altitudes.[8–13] The harsher climate and terrain at higher altitudes probably pose challenges to implementing nutrition interventions. Tailored policies and programmes are needed for higher-altitude areas, potentially involving enhancing transportation and storage of nutritious foods, nutrition education and counselling and access to healthcare. Strengthening community health worker capacity in these areas could help to deliver interventions.

Second, older children (18–59 months) have a significantly higher odds of being stunted than younger children, indicating a need to expand coverage and use age-targeted strategies in current programmes like Integrated Child Development Services. Possible enhancements include prioritising older children for food supplementation, micronutrient supplementation and growth monitoring. Home fortification with micronutrient powders could also help to fill nutrient gaps for this age group.

Third, higher birth order and short birth intervals are associated with higher stunting, aligning with research on birth spacing and height outcomes.[20] This highlights the importance of reproductive health initiatives to delay age at first birth, provide access to family planning and promote optimal birth spacing. Nutrition counselling during antenatal care on appropriate maternal nutrition and birth spacing could also help address this factor.

Fourth, small size at birth is a predictor of stunting, indicating a need to improve maternal nutrition and antenatal care. Expanding coverage of antenatal care, iron–folic acid supplementation and balanced energy protein supplementation could help more mothers deliver larger, healthier infants.

Limitations of the study

The study has some drawbacks. The first and foremost is that the study uses data from a cross-sectional survey. Thus, it captures a snapshot at a specific point in time, making it challenging to establish causality between altitude and stunting. Second, there may be some inaccuracy in altitude data and thus the reliability of such data is questionable. Even after adjusting for child, maternal and household characteristics, there might be unmeasured or residual confounding factors that were not considered in the analysis, which could affect the observed association between altitude and stunting. Lastly, selection bias or non-response bias might exist in survey data, where certain groups or regions might be over-represented or under-represented, affecting the generalisability of the findings.

Future scope of the study

The study findings open up a number of new avenues for future research. A longitudinal study could be undertaken to establish a causal relationship between altitude and stunting. Following up children over time in high-altitude areas, tracking their growth patterns, dietary habits and health outcomes could provide more concrete evidence. Specific regions within high-altitude regions should be explored to understand variations in stunting prevalence. Factors such as access to healthcare, dietary diversity, cultural practices and socioeconomic disparities could be studied in-depth to identify specific drivers of stunting. A comparative analysis could be undertaken to compare stunting prevalence and its determinants between high-altitude and low-altitude regions within India, which could highlight unique challenges and effective interventions specific to altitude. Future studies exploring these areas would contribute to a more comprehensive understanding of the altitude–stunting relationship, facilitate evidence-based interventions and inform policies aimed at reducing the prevalence of stunting among children in high-altitude areas, not just in India but potentially in similar contexts globally.

Conclusion

Despite progress, undernutrition and stunting remain major public health concerns for children under age 5 in India. This analysis of national survey data reveals key high-risk groups and associated factors requiring targeted policy attention. This study might help to identify potential links between altitude and nutritional factors, such as availability of certain foods, climatic conditions affecting agriculture or the impact of altitude on nutrient absorption, especially in a diverse physiographic country like India.

Children at higher geographical altitudes have significantly higher odds of stunting than those at lower altitudes, probably due to challenges in implementing nutrition interventions in these harsher terrains. Tailored policies and programmes are needed, potentially involving strengthening community health worker capacity, enhancing food storage and transportation and integrating nutrition into healthcare. More implementation research in higher altitudes could inform effective strategies.

Older children (18–59 months) are at higher risk than infants, pointing to a need for enhanced delivery of Integrated Child Development Services and prioritisation of this age group for supplementation and growth monitoring. Short birth intervals and higher birth orders also emerge as risk factors, underscoring the importance of improving access to family planning and counselling on optimal birth spacing.

Furthermore, a focus on maternal nutrition and antenatal care is essential to reduce the rate of small-for-gestational-age births associated with stunting. Expanding coverage of interventions like iron–folic acid and balanced energy protein supplementation can help more mothers deliver larger, healthier infants.

In summary, concerted efforts are needed across health and nutrition sectors to address stunting, tailored to focus on higher-risk children in vulnerable areas. A multipronged approach should combine reproductive health initiatives, women's nutrition programmes, infant and young child feeding interventions and food security measures. Continued research, monitoring and evaluation will be key to guide evidence-based policies and targeted action to ensure every Indian child has the opportunity for healthy growth and development.

Contributors Conceived and designed the research paper: SBP; analysed the data: LAS, KAK; contributed agents/materials/analysis tools: MHUR, SBP; wrote the manuscript: SBP and MHUR; refined the manuscript: LAS, KAK, RS. All authors read, reviewed and approved the final manuscript.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests None.

Patient consent for publication Not applicable.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available in a public, open access repository.

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