The relationship between residential altitude and stunting: evidence from >26,000 children living in highlands and lowlands of Ethiopia

Short title: Residential altitude and child growth

Shimels Hussien Mohammed1*, Tesfa Dejenie Habtewold2, Debelo Dugasa Abdi3, Shahab Alizadeh4, Bagher Larijanī5, Ahmad Esmaillzadeh1,6,7*

1Department of Community Nutrition, School of Nutritional Sciences and Dietetics, Tehran University of Medical Sciences, Tehran, Iran.
2Department of Epidemiology, University of Groningen, Groningen, the Netherlands.
3Department of Occupational Health Engineering, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran.
4Department of Clinical Nutrition, School of Nutritional Sciences and Dietetics, Tehran University of Medical Sciences, Tehran, Iran.
5Endocrinology and Metabolism Research Center, Endocrinology and Metabolism Clinical Sciences Institute, Tehran University of Medical Sciences, Tehran, Iran.
6Obesity and Eating Habits Research Center, Endocrinology and Metabolism Molecular Cellular Sciences Institute, Tehran University of Medical Sciences, Tehran, Iran.
7Food Security Research Center, Department of Community Nutrition, Isfahan University of Medical Sciences, Isfahan, Iran.

*Corresponding authors: Shimels Hussien Mohammed (shimelsh@gmail.com); Ahmad Esmaillzadeh (a.emaillzadeh@gmail.com)
Abstract

Little information is known about the influence of altitude on child growth in Ethiopia, where most people live at highlands. We investigated the relation of residential altitude with growth faltering (stunting) of infants and young children in Ethiopia. We also examined whether the altitude-growth relationship was independent of the influence of the dietary and non-dietary determinants of growth. We used the data of 26,976 under-5 children included in the Ethiopian demographic and health surveys, conducted from 2005 to 2016. The samples were recruited following a two-stage cluster sampling strategy. Stunting was defined by height-for-age < -2 Z-scores. The relationship between residential altitude and stunting was examined by running multiple logistic regression analysis, controlling the effect of covariate dietary and non-dietary variables. The residential altitude of the study participants ranged from -116 to 4,500 meters above sea level (masl). There was a significant and progressive increase in the prevalence and odds of stunting with increasing altitude ($P<0.001$), irrespective of the dietary and non-dietary predictors of stunting. The prevalence of stunting was lowest at lowlands (39%) and highest at highlands (47%). Compared to altitude < 1000 masl, the odds of stunting was 1.41 times higher at altitude $\geq 2500$ masl (OR=1.41, 95%CI=1.16, 1.71) and 1.29 times higher at altitude 2000-2499 masl (OR=1.29, 95%CI=1.11, 1.49). Children living at highlands might be at a higher risk of poor growth. Further studies are warranted to understand the mechanism behind the observed altitude-stunting link and identify strategies to compensate for the growth faltering effect of living at highlands.

**Keywords:** Child growth: Stunting: Nutritional status: Residential altitude
Introduction

Child stunting is still a major public health nutrition problem in developing countries. Height-for-age measures the linear growth status of children. It is also widely considered as the best anthropometric indicator for assessing the overall health and wellbeing of children\(^{(1, 2)}\). Stunting is defined when a child fails to achieve a height appropriate for its age; i.e., when a child’s length-for-age (for children younger than 2 years) or height-for-age (for children older than 2 years) is below two standard units (<-2 Z-scores,) from the reference\(^{(3)}\). In 2018, 18% of under-5 children were stunted globally\(^{(4)}\). Children become stunted often as a consequence of chronic malnutrition\(^{(2, 5, 6)}\). However, epidemiological studies have shown that stunting is more prevalent at highlands than at lowlands. This altitudinal variation in stunting has been demonstrated by studies done in Tibet, Peru, Bolivia, Switzerland, and Argentina\(^{(7-12)}\). The effect of altitude is not limited to only the growth of children. It also negatively, or positively, influences other health and nutritional outcomes\(^{(13)}\). The rise of hemoglobin concentration with increasing altitude is an established phenomenon\(^{(14-16)}\). Child morbidity and mortality rates also vary by residential altitude\(^{(13, 17, 18)}\).

Ethiopia bears one of the largest global stunting burdens, with 38% of under-5 children being stunted in 2016. Besides, there is a wide geographical variation in the prevalence of stunting in Ethiopia\(^{(19)}\). Altitude in Ethiopia ranges from as low as -125 meters below sea level (mbsl) in the Afar region to as high as 4600 meters above sea level (masl) in the Amhara region. Most people in Ethiopia live at highlands, ~70 million people currently living at altitude >2000 masl\(^{(20)}\). Despite the geographical feature of Ethiopia is suitable to study the influence of altitude on health, only limited studies have been done in the country on the influence of altitude on children’s growth\(^{(21)}\). Whether the growth pattern of Ethiopian children varies by residential altitude remains largely unknown. Thus, in this study, we aimed to assess the relationship between residential altitude and the growth status of under-5 children in Ethiopia. We determined the prevalence of stunting at different altitudes and the association of altitude with stunting. We also investigated whether the altitude-stunting link was influenced by the dietary and non-dietary predictors of growth.
Methods

Study population and data source
We used the data of a nationally representative sample of under-5 children, included in the Ethiopian demographic and health surveys (EDHS), conducted in 2005, 2011, and 2016. The surveys were conducted by the United States Agency for International Development (USAID) and ICF International in collaboration with the Ministry of Health of Ethiopia. USAID, through its international DHS Program, has also been conducting similar surveys in over 90 low- and middle-income countries since 1984. In each survey, data were collected on a wide range of variables of public health importance, including on the status and determinants of child health and nutritional status indicators\(^ {22}\). All the datasets used in this study are publicly available on the website of the international DHS program: [https://www.dhsprogram.com/data/available-datasets.cfm](https://www.dhsprogram.com/data/available-datasets.cfm).

Sampling strategy and sample size
The samples of the study were obtained following a two-stage cluster sampling strategy. The primary and secondary sampling units of the surveys were census enumeration areas (EAs) and households, respectively. In each survey, an average of 645 EAs was randomly selected from the list of all EAs in the country. Then, a fixed number of 28 households per cluster, i.e. 28 households/EAs, was randomly selected from the selected EAs. Thus, a total of 18 060 households were included in each survey. All under-5 children found in the selected households were eligible for inclusion in the surveys and data were collected on various variables, including anthropometric measures. The data collection was done by trained interviewers and using the DHS questionnaire that was standardized across the 90 DHS member countries\(^ {19}\). In the three datasets, we found a total of 26 976 under-5 children, with complete information on the variables of interest for this study.

Variables
Outcome variable
The primary outcome variable was stunting, which indicates that a child fails to achieve the height appropriate to its age\(^ {23}\). In all DHS surveys, the length and height of children were measured (in cm). Length (only for children <2 years of age) was measured in a recumbent...
position and height (for those ≥2 years of age) was measured in a standing position. The length and height measuring tools were produced under UNICEF supervision\(^{(19)}\). Using the anthropometric, sex and age data, height-for-age (HFA) Z-scores for children ≥2 years of age and length-for-age (LFA) for those <2 years of age were calculated, based on the World Health Organization (WHO) 2006 child growth standards. Stunting was defined when the child’s HFA or LFA was more than two standard deviations below the standard (≤-2 Z-scores)\(^{(3)}\). Because of its more familiarity in the literature, in this report, we used HFA to refer to both HFA and LFA.

**Exposure variable**

Residential altitude was the primary exposure variable of interest in this study and measured using global positioning system (GPS) which provides records of both elevation and location of places. There is no uniform altitude classification approach in the literature. We followed the most commonly used approach and categorized the residential altitudes into five groups: <1000, 1000-1499, 1500-1999, 2000-2499, and ≥2500 masl.

**Covariates**

In addition to the main exposure and outcome variables, we included other variables with the potential to influence the altitude-stunting relationship. The variables were selected based on theoretical relevance, reports of previous studies, and availability in the datasets used. These include child factors (age, sex, birth size, breastfeeding, and dietary practices), maternal factors (educational status and antenatal care utilization), and household factors (source of water supply, type of toilet facility, and household wealth statuses). A detailed description of the definition and measurement of the covariates is presented below.

(a) Age: measured in months and categorized into three groups: <12, 12-23, and >23 months.
(b) Sex: boys and girls.
(c) Birth size: assessed by the subjective reporting of the mother of the size of the child at the time of birth and categorized into three groups: low, average and large birth sizes.
(d) Early initiation of breastfeeding: assessed by whether the child was breastfed within the first hour after birth and dichotomized into yes and no.
(e) Duration of breastfeeding: measured by the number of months the child was breastfed.
(f) Dietary practice: data on dietary practice were collected by 24 hours dietary recall method, following the multiple pass approach. Besides, the frequency of complementary food feeding
was collected. The food items collected by the 24 hours recall method were reduced into seven groups: (i) grains, tubers, and roots, (ii) meat, (iii) milk, (iv) egg, (v) vitamin-A rich fruits and vegetables, (vi) other fruits and vegetables, and (vii) nuts and legumes. Following the WHO infant and young child feeding practice guidelines\textsuperscript{(23)}, the dietary recall data were used to develop dietary diversity and meal frequency scores, which were further used to assess whether the child’s feeding fulfilled the minimum dietary diversity and minimum meal frequency. The minimum dietary diversity was assessed by whether the child’s diet was composed of at least four of the seven food groups mentioned above and dichotomized into yes (≥4) and no (<4)\textsuperscript{(23)}. The minimum meal frequency was assessed by whether the child was fed at least three times in the last 24 hours and dichotomized into yes (≥3) and no (<3) for breastfeeding children. For non-breastfeeding children, the frequency of feeding should be at least four times a day\textsuperscript{(23)}.

(g) History of morbidity: assessed by whether the child had any one of fever, diarrhea, or cough in the last two weeks prior to the data collection date and dichotomized into yes and no.

(h) Antenatal care: assessed by the number of antenatal care visits attended by the mother during the pregnancy of the indexed child and categorized into three groups: none, 1-3 visits, and ≥4 visits.

(i) Maternal stature: the height of the mother, measured objectively in cm and categorized into three groups: <150.0 cm (short stature), 150.0–154.9 cm, and ≥155.0 cm (tall stature, reference group). The height categories were adapted from similar earlier studies\textsuperscript{(24, 25)}.

(j) Maternal weight: the weight of the mother, measured objectively in kg and categorized into three groups: <50 kg, 50-59.9 kg, and ≥ 60 kg (reference group).

(k) Maternal education status: assessed by the highest education level completed by the mother of the child and categorized into illiterate/none, primary, and secondary and above.

(l) Household water sources: assessed by the type of water source used by the household and dichotomized into improved and unimproved. As per the WHO guideline, piped water and protected wells were classified as improved water sources; and springs, lakes, ponds, unprotected wells, rivers, and dams as unimproved sources.

(m) Household toilet facility: assessed by the type of toilet facility used by the household and dichotomized into improved and unimproved. Flush toilets or ventilated improved pit (VIP)
latrines were classified as improved toilet facilities and traditional pit latrines as unimproved facilities.

(n) Household wealth category: assessed by developing household wealth index, using the assets variables in the dataset and following the method of principal component analysis. The wealth index was used to classify the households into quantiles of wealth categories: poorest, poorer, middle, richer, and richest.

(o) Residence place: assessed by the dejure place of residence and dichotomized into urban and rural.

(p) Survey time: the year in which the data were collected. The surveys were conducted in the years 2005, 2011, and 2016.

Statistical analysis
In all analyses, the complex design of the surveys was taken into consideration; such that, all estimates provided in this work were based on the weighted sample and taking into account the stratification and the sampling schemes used in recruiting the study participants. The sample weighting was done to ensure no region is over-represented or under-represented so that the sample resembles the actual population distribution of the country. The samples were obtained following a cluster sampling strategy. Adjustment for the cluster study design was done using the census enumeration areas as primary sampling units (clusters) and the regions (sub-national and urban-rural divisions) as strata. Descriptive statistics, like frequency distribution of stunting by residential altitude and covariates, were estimated and presented. To test the relation of residential altitude with stunting, first Chi-square test of association was run, then multivariable logistic regression analysis was run controlling for the effect of dietary and non-dietary covariates. The covariates included in the multivariable regression analysis were selected based on theoretical relevance and statistical significance. Variables that demonstrated $P<0.25$ during the bi-variable analyses, i.e. between the covariates and stunting, were also included in the multivariable model. All data analyses were conducted using STATA 16, with statistical significance determined at $P<0.05$.

Ethical Consideration
The study protocols of the surveys included in this analysis were approved by the Institutional Review Boards of Ethiopian Public Health Institute and ICF International to ensure the survey
procedure and tools complied with the Ethiopian protocol for study participants handling and the United States of America Department of Health and Human Services regulations for the protection of human subjects. The data analyzed in this study are publicly available on the website of the International DHS program (Georgia, Atlanta): https://www.dhsprogram.com/data/available-datasets.cfm. We obtained approval to use the EDHS datasets from the International DHS Program, through a project entitled ‘trends and determinants of malnutrition in Ethiopia’.

Result

The final analysis consisted of a total sample of 26,976 under-5 children, whose mean age (in months) was 28.9 (SD=17.5). Almost three-fifths of the samples were in the age group 24-59 months. Most of the study participants (68%) were living at altitude <2000 masl, 23% at 2000-2499 masl, and 9% at ≥2500 masl. The average stunting (HFA <-2 Z-scores) prevalence for the whole period (2005-2016) was 42%. The year-specific stunting prevalence rates were 48%, 44%, and 38% in 2005, 2011, and 2016, respectively. More information on the distribution of stunting as well as other covariates by different categories of altitudes is presented in Table 1.

The results of the bi-variable analyses on the relation of altitude with stunting as well as with other covariates are presented in Table 1. The prevalence of stunting among the lowlanders (altitude <1000 masl) and the highlanders (altitude >2500 masl) was 39% and 47%, respectively. Figure 1 shows the prevalence of stunting by categories of residential altitude. The prevalence of stunting increased progressively with increasing altitude. The statistical significance of the altitude-stunting link was examined by Chi-square test of association, which showed that residential altitude was significantly associated with stunting (P<0.001). Maternal height and weight were also significantly lower in the highlands than in the lowlands (P<0.001). As shown in Table 1, some of the determinants of stunting also varied by altitude. There was a significantly longer duration of breastfeeding at highlands, compared to lowlands (P<0.001. The frequency of child complementary feeding was also significantly higher at highlands than at lowlands (P<0.001). Other variables that varied significantly by altitude were dietary diversity, birth size, water source, toilet facility, history of infection, maternal educational status, and household wealth statuses (P<0.05). Child sex (P=0.098) and age (P=0.520) did not vary significantly by
residential altitude. These results are, however, less informative for they were not based on adjusted analyses and the possibility of confounding by third factors needs to be ruled out.

To rule out whether the altitude-stunting link was confounded by a third variable, multiple logistic regression analysis was run adjusting for the dietary and non-dietary factors (covariates) which also varied by altitude. The covariates included in the model are shown in Table 2. Altitude demonstrated an independent and significant link with stunting ($P$-for-trend <0.001) after adjusting for the dietary and non-dietary determinants of stunting. There was a progressive increment in the odds of stunting with increasing residential altitude. The odds of stunting at altitude $\geq 2500$ masl was 41% higher than the odds of stunting at altitude $<1000$ masl (AOR=1.41, 95%CI=1.16, 1.71, $P<0.001$). The odds of stunting at altitude 2000-2499 masl was 29% higher than the odds of stunting at altitude $<1,000$ masl (AOR=1.29, 95%CI=1.11, 1.49, $P<0.001$). The odds of stunting at altitudes 1500-1999 and 1000-1499 masl was not significantly different from the odds of stunting at altitude $<1000$ masl ($P>0.05$). Though not the primary aim of this study, history of childhood illness, dietary diversity, meal frequency, breastfeeding duration, birth size, maternal educational status, maternal stature, maternal weight, survey year, and household wealth category were also found significantly associated with stunting ($P<0.05$).

**Discussion**

We aimed to investigate whether residential altitude was linked to the growth status of infants and young children in Ethiopia. We found that residential altitude was significantly associated with stunting, independent of the dietary and non-dietary determinants of stunting. There was a progressive increase in the prevalence as well as the odds of stunting with increasing altitude. The highest prevalence and odds of stunting were found among those who reside at highlands (altitude $>2500$ masl). The lowest prevalence and odds of stunting were found among those who reside at lowlands (altitude $<1000$ masl).

Evidence is scarce on the influence altitude on the growth of children in Ethiopia, albeit it bears one of the largest global highland populations as well as a great variation in residential altitude$^{20}$). Other countries with a large highland population and varying residential altitude include Tibet (China), Nepal, Colombia, Bolivia, Peru, Kazakhstan, Bolivia, Argentina, Bhutan, and Switzerland$^{7, 8, 13}$. Our finding of high growth faltering at high altitude was consistent with
the findings of previous studies done in these highland countries. The risk of stunting among Tibetan children residing at highlands was two to six times higher, compared to those residing at lowlands\(^9\). In Bolivia, the prevalence of stunting was six times higher in highlands than in lowlands\(^7\,\,26\). In Argentine, the risk of stunting was twice higher in highlands than in lowlands\(^8\). Studies conducted in Nepal\(^{27}\), Switzerland\(^{11}\), and Andean nations\(^{21}\) had also shown a consistently higher risk of growth faltering among highlanders, compared to lowlanders.

Despite the evidence on the altitude-growth link is apparently consistent, the mechanism underlying the link remains largely unclear. The literature indicates that chronic exposure to hypoxia at highlands might negatively influence some phenotypic features, including children’s growth pattern\(^{13,\,21}\). Hypoxic environment influences not only physical growth, but also physiologic states like respiration, metabolism, and blood circulation rates\(^{13,\,21}\). A good example is the rise of hemoglobin concentration at highlands, a phenomenon considered as a normal adaptive response to the decrease in oxygen tension at high altitude areas\(^{14,\,15,\,28-30}\). Likewise, the slow growth rate at highlands might be in part due to the hypoxic environment, acting on its own or most probably interacting with other highland-specific ecological, sociocultural and genetic characters. Unique genes and polymorphisms have been identified among highland populations, including Ethiopians\(^{20,\,21,\,31-34}\). However, none of these hypotheses is well explored and no conclusive evidence is available on the exact mechanism through which altitude influences growth negatively.

Specific to Ethiopia, the epidemiology of stunting in the country might be in part explained by our finding of altitude-growth linkage. Ethiopia bears one of the highest global stunting burdens. In 2016, 38% of children were stunted in Ethiopia. Various stunting prevention and control measures have been instituted with the aim of meeting the WHO goal of a 40% reduction in the proportion of stunted children by 2022\(^{19,\,35}\). However, stunting reduction has been less promising in Ethiopia over the last two decades, reducing only by 7% during the period 2010-2018. In addition to the high national stunting burden, there is also a large geographical discrepancy in the prevalence of stunting in Ethiopia. The highest prevalence of stunting in Ethiopia has been in Amhara state, a mainly highland region, and the lowest prevalence has been in Somali state, a mainly lowland region\(^{19}\). This geographical variation in stunting, as well as the consistently high magnitude of stunting, might in part be explained by the fact that most Ethiopians live at highlands and consequently have a high risk of stunting.
Our finding of a significant altitude-stunting link after controlling the effect of dietary and non-dietary determinants of stunting might imply that altitude influences growth independently. Specific to Ethiopia, the main implication of this study is that the high burden of stunting, particularly in the Amhara region, might be due to the growth faltering effect of high residential altitude. However, as growth is of multiple influences and genetic factors like polymorphism were not taken into account in our analysis, our proposition of altitude influencing growth independently needs to be further corroborated by studies with better designs. Longitudinally designed and comprehensive studies might provide better information. Further studies are also warranted to know the mechanism(s) through which high altitude influences growth negatively. We are also of the opinion that the slow growth, and consequently the short stature, of children living at highlands need to be viewed as an adaptive response to the hypoxic environment like the case of hemoglobin, which is considered normal\(^{[13-15, 28-30]}\). Recently, the WHO has established a task force to investigate the validity of the existing hemoglobin cutoff points for highland communities\(^{[15, 16]}\). Likewise, it would be timely and important to investigate the suitability and validity of the WHO growth standards for highland populations and develop a mechanism to adjust for the effect of altitude during growth assessment and stunting classification. Here, worthy of note to the reader is that the altitude-stunting association should not be misunderstood and divert attention from the need for improving health and nutrition services for highland populations. The effect of altitude on growth, if a true one, could be modified by compensatory education, health, and nutrition interventions\(^{[36]}\). Thus, we recommend scaling up the implementation of nutrition-enhancing measures for all under-5 children in general, and for highland children in particular\(^{[23, 37]}\).

Our findings are subject to the limitations of cross-sectional design, including its observational nature and the possibility of unmeasured confounding. The analysis did not take into account the effect of genetic factors and duration of residence on the altitude-growth link. Thus, we could not rule out the role of genetic factors like polymorphism and duration of stay on the observed altitude-stunting link. In spite of these limitations, the study has important strengths, including the use of large and nationally representative samples, the inclusion of individuals residing at a wide range of altitudes, and the adjustment for various dietary and non-dietary determinants of stunting. The fact that the study was undertaken in a previously less
explored setup (Ethiopia) would also be a strength as it would contribute to filling the gap in the literature.

**Conclusion**

We found that residential altitude was significantly and independently associated with the growth status of infants and young children in Ethiopia. The odds of stunting in children residing at altitude >2500 masl was 41% higher than the odds of stunting in those residing at altitude <1000 masl. Living at high altitude areas might be contributing to the high burden as well as the wide regional variation of stunting in Ethiopia. Further studies are warranted to understand the mechanism behind the observed altitude-stunting link, identify strategies to compensate the growth faltering effect of high altitude, and evaluate the validity of the existing growth monitoring tools for highland communities. Meanwhile, presuming children living in highlands as more vulnerable to stunting and prioritizing them for preventive interventions stands worthy of consideration.

**Acknowledgments**

We acknowledge the International DHS Program of the United States Agency for International Development (USAID) for conducting the surveys and availing the data publicly and free of charge.

**Financial Support**

This research received no specific grant from any funding agency, commercial or not-for-profit sectors.

**Competing interests**

The authors declared no competing interests.

**Authors’ contributions**

SHM conceived and led the study. SHM extracted the dataset, analyzed the data and wrote the manuscript. AE supervised the work. TDH, AE, DDA, SA, and BL reviewed the draft and final manuscripts. All authors read and approved the final manuscript.
References


Table 1. Prevalence (%) of stunting by residential altitude and determinants of stunting (N=26 976).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Residential Altitude (in meters, above sea level)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;1000</td>
<td>1000-1499</td>
<td>1500-1999</td>
<td>2000-2499</td>
<td>≥2500</td>
<td>P*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stunting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>39.4</td>
<td>39.3</td>
<td>40.6</td>
<td>41.9</td>
<td>46.5</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>60.6</td>
<td>60.7</td>
<td>59.4</td>
<td>58.1</td>
<td>53.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boys</td>
<td>52.7</td>
<td>51.7</td>
<td>51.0</td>
<td>50.3</td>
<td>51.4</td>
<td>0.098</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Girls</td>
<td>47.3</td>
<td>48.3</td>
<td>49.0</td>
<td>49.7</td>
<td>48.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (months)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;12</td>
<td>22.0</td>
<td>21.3</td>
<td>21.5</td>
<td>21.0</td>
<td>21.8</td>
<td>0.520</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12-23</td>
<td>17.9</td>
<td>19.4</td>
<td>18.7</td>
<td>19.7</td>
<td>19.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥24</td>
<td>60.1</td>
<td>59.2</td>
<td>59.8</td>
<td>59.3</td>
<td>59.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>28.2</td>
<td>29.1</td>
<td>31.2</td>
<td>29.3</td>
<td>29.8</td>
<td>0.002</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>71.8</td>
<td>70.9</td>
<td>68.8</td>
<td>70.7</td>
<td>70.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dietary diversity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;4</td>
<td>95.4</td>
<td>93.1</td>
<td>92.1</td>
<td>92.0</td>
<td>93.8</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥4</td>
<td>4.6</td>
<td>6.9</td>
<td>7.9</td>
<td>8.0</td>
<td>6.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feeding frequency</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;3</td>
<td>70.0</td>
<td>56.5</td>
<td>53.2</td>
<td>48.1</td>
<td>51.1</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥3</td>
<td>30.0</td>
<td>43.5</td>
<td>46.8</td>
<td>51.9</td>
<td>48.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Place</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rural</td>
<td>84.6</td>
<td>81.3</td>
<td>86.7</td>
<td>78.5</td>
<td>87.0</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban</td>
<td>15.4</td>
<td>18.7</td>
<td>13.3</td>
<td>21.5</td>
<td>13.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toilet facility</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unimproved</td>
<td>89.0</td>
<td>83.6</td>
<td>89.2</td>
<td>83.5</td>
<td>89.5</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved</td>
<td>11.0</td>
<td>16.4</td>
<td>10.8</td>
<td>16.5</td>
<td>10.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water source</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unimproved</td>
<td>33.2</td>
<td>37.5</td>
<td>37.8</td>
<td>34.4</td>
<td>37.8</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved</td>
<td>66.8</td>
<td>62.5</td>
<td>62.2</td>
<td>65.6</td>
<td>62.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breastfeeding duration</td>
<td>&lt;12 months</td>
<td>12-23 months</td>
<td>≥24 months</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------------------</td>
<td>------------</td>
<td>--------------</td>
<td>------------</td>
<td>---</td>
<td>---</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>44.8</td>
<td>40.5</td>
<td>38.6</td>
<td>35.2</td>
<td>34.7</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Birth size</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small</td>
<td>35.0</td>
<td>29.0</td>
<td>25.8</td>
<td>28.0</td>
<td>29.2</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>39.6</td>
<td>40.3</td>
<td>40.7</td>
<td>42.0</td>
<td>42.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large</td>
<td>25.4</td>
<td>30.8</td>
<td>33.6</td>
<td>30.1</td>
<td>28.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maternal education</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Illiterate</td>
<td>71.9</td>
<td>73.7</td>
<td>71.2</td>
<td>63.3</td>
<td>73.4</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary</td>
<td>21.3</td>
<td>20.9</td>
<td>22.9</td>
<td>24.5</td>
<td>19.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Secondary+</td>
<td>6.8</td>
<td>5.4</td>
<td>5.9</td>
<td>12.2</td>
<td>7.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maternal stature</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;150.0 cm</td>
<td>71.4</td>
<td>65.4</td>
<td>63.2</td>
<td>60.3</td>
<td>59.6</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>150.0-154.9 cm</td>
<td>19.1</td>
<td>22.7</td>
<td>25.2</td>
<td>26.7</td>
<td>26.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥155 cm</td>
<td>9.6</td>
<td>11.9</td>
<td>11.6</td>
<td>13.0</td>
<td>13.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maternal weight</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;50 kg</td>
<td>51.6</td>
<td>49.0</td>
<td>52.1</td>
<td>53.3</td>
<td>51.1</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50-59.9 kg</td>
<td>35.0</td>
<td>39.2</td>
<td>39.7</td>
<td>38.4</td>
<td>41.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥ 60 kg</td>
<td>13.4</td>
<td>11.8</td>
<td>8.2</td>
<td>8.3</td>
<td>7.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wealth category</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poorest</td>
<td>63.5</td>
<td>36.4</td>
<td>25.5</td>
<td>15.8</td>
<td>19.6</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poorer</td>
<td>11.2</td>
<td>16.5</td>
<td>20.8</td>
<td>18.2</td>
<td>21.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle</td>
<td>7.1</td>
<td>12.9</td>
<td>19.3</td>
<td>19.0</td>
<td>21.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Richer</td>
<td>7.9</td>
<td>12.5</td>
<td>16.5</td>
<td>18.9</td>
<td>19.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Richest</td>
<td>10.4</td>
<td>21.6</td>
<td>18.0</td>
<td>28.1</td>
<td>17.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Survey year</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td>49.2</td>
<td>43.5</td>
<td>33.5</td>
<td>35.5</td>
<td>43.0</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td>34.6</td>
<td>20.7</td>
<td>37.5</td>
<td>34.2</td>
<td>27.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>29.9</td>
<td>35.7</td>
<td>29.0</td>
<td>30.4</td>
<td>16.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*P*-value derived from Chi-square test of association.
Table 2. Relation of altitude with stunting (multi-variable adjusted) (N=26,976).

<table>
<thead>
<tr>
<th>Variables</th>
<th>AOR (95% CI)</th>
<th>(P^*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude (masl)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;1000 Reference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000-1499 1.01 (0.80, 1.26)</td>
<td>0.933</td>
<td></td>
</tr>
<tr>
<td>1500-1999 1.03 (0.92, 1.15)</td>
<td>0.604</td>
<td></td>
</tr>
<tr>
<td>2000-2499 1.29 (1.11, 1.49)</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>≥2500 1.41 (1.16, 1.71)</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Dietary diversity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;4 1.38 (1.09, 1.75)</td>
<td>0.008</td>
<td></td>
</tr>
<tr>
<td>≥4 Reference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meal frequency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;3 1.31 (1.13, 1.50)</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>≥3 Reference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breastfeeding duration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;12 months 3.39 (2.92, 3.94)</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>12-23 months 2.85 (2.28, 3.56)</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>≥24 months Reference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Birth size</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small 1.34 (1.15, 1.56)</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Average 1.09 (0.87, 1.36)</td>
<td>0.454</td>
<td></td>
</tr>
<tr>
<td>Large Reference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infection history</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes 1.02 (0.89, 1.17)</td>
<td>0.755</td>
<td></td>
</tr>
<tr>
<td>No Reference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water source</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved Reference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unimproved 1.09 (0.95, 1.25)</td>
<td>0.234</td>
<td></td>
</tr>
<tr>
<td>Toilet facility</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved Reference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unimproved 1.58 (1.25, 1.99)</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Maternal education</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Illiterate 1.75 (1.50, 2.03)</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Primary 1.42 (1.22, 1.66)</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Secondary+ Reference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maternal height</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;150.0 cm 1.76 (1.54, 2.02)</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Maternal weight</td>
<td>AOR (CI)</td>
<td>p-value</td>
</tr>
<tr>
<td>-----------------</td>
<td>------------</td>
<td>---------</td>
</tr>
<tr>
<td>&lt;50 kg</td>
<td>1.54 (1.26, 1.88)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>50-59.9 kg</td>
<td>1.36 (1.11, 1.65)</td>
<td>0.003</td>
</tr>
<tr>
<td>≥60.0 kg</td>
<td>Reference</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Antenatal care</th>
<th>AOR (CI)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>1.31 (1.20, 1.44)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>1-3</td>
<td>1.14 (1.03, 1.25)</td>
<td>0.011</td>
</tr>
<tr>
<td>≥4</td>
<td>Reference</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Residence place</th>
<th>AOR (CI)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural</td>
<td>2.75 (2.18, 3.46)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Urban</td>
<td>Reference</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wealth category</th>
<th>AOR (CI)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poorest</td>
<td>1.68 (1.46, 1.84)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>poorer</td>
<td>1.53 (1.36, 1.71)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Middle</td>
<td>1.37 (1.21, 1.55)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Richer</td>
<td>1.32 (1.17, 1.49)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Richest</td>
<td>Reference</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Survey year</th>
<th>AOR (CI)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>1.30 (1.13, 1.50)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>2011</td>
<td>1.08 (0.98, 1.19)</td>
<td>0.129</td>
</tr>
<tr>
<td>2016</td>
<td>Reference</td>
<td></td>
</tr>
</tbody>
</table>

*P*-value derived from multiple logistic regression analysis.
AOR: adjusted odds ratio; CI: confidence interval; masl: meters above sea level.
Figure 1. Distribution of stunting by categories of altitude.