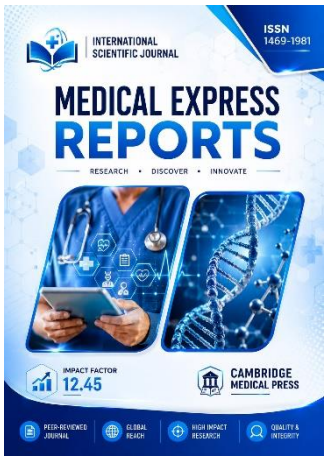
MEDICAL EXPRESS REPORTS
IMPACT FACTOR:12.45 ISSN:1469-1981



ASSESSING PHYSICAL DEVELOPMENT, SEXUAL MATURATION AND RELATED HEALTH INDICATORS OF SCHOOL-AGE GIRLS IN ENVIRONMENTAL HEALTH STUDIES

Elmurodova Dilafruz
basic doctoral student, Research Institute of Sanitation, Hygiene and Occupational Diseases of the Ministry of Health of the Republic of Uzbekistan,
E-mail: dilya7362514@gmail.com
ORCID: 0009-0009-3655-7189

ARTICLE INFO:

Received:17.11.2026
Revised: 18.11.2026
Accepted:19.11.2026

KEY WORDS:

school-age girls; physical development; puberty; Tanner stages; menarche; anemia; spirometry; air pollution; research methods.

ABSTRACT

Studies of the health effects of air pollution in industrial towns often include school-age girls, but the indicators used to describe their growth, puberty and health differ from study to study, which makes the results difficult to compare.

Aim. To summarize the currently recommended methods for assessing physical development, sexual maturation, hemoglobin and iron status, and respiratory function in school-age girls, and to show how they can be applied in a comparative hygienic study of an exposed and a control area.

Materials and methods. Narrative methodological review of international guidelines (WHO, ATS/ERS, Global Lung Function Initiative, CDC, CIOMS, World Medical Association) and validation studies published from 1969 to 2026, identified through PubMed, Google Scholar and official websites.

Results. For physical development, the WHO 2007 growth reference (height-for-age and BMI-for-age z-scores) allows international comparison, while regional standards remain useful as secondary indicators. Tanner staging by a trained female examiner is the reference method for sexual maturation; self-assessment with drawings is acceptable mainly for separating pre-pubertal from pubertal girls. Age at menarche is best recorded by the status-quo method combined with

short-term recall. Anaemia should be defined by the WHO 2024 haemoglobin cut-offs with adjustment for elevation from 500 m above sea level, and iron deficiency by ferritin interpreted together with inflammation markers. Spirometry should follow the ATS/ERS 2019 standard and be interpreted as GLI z-scores; the ISAAC questionnaire is suitable for respiratory symptoms. Exposure should be described by monitoring data and, where possible, by blood lead.

1. Introduction

Children are regarded as one of the groups most susceptible to air pollution, and international air quality guidance pays special attention to them [1]. In girls, the school years cover the pubertal growth spurt, the onset of breast development and menarche, so environmental factors acting in this period may be reflected in several health indicators at once. Differences between boys and girls in exposure and in biological response are also documented, and sex- and gender-sensitive analysis is recommended in air pollution epidemiology [2].

The town of Almalyk in the Tashkent region, a centre of non-ferrous metallurgy, illustrates the need for such studies. According to state monitoring data, the air pollution index rose from 3.68–4.30 in 2011–2018 to 7.13 in 2024, and the annual mean dust concentration in 2024 was 2.3 times the maximum permissible concentration [3]. Earlier studies in ecologically unfavourable regions of Uzbekistan reported changes in the growth of children and a shift in the timing of puberty compared with previous decades [4].

However, the results of such studies can be compared only if the same indicators, measurement procedures and reference values are used. Studies in the CIS region often rely on regional standards and clinical methods, while international studies use WHO references and standardised protocols, and the two approaches are rarely discussed together.

The **aim** of this review was to summarise the recommended methods for assessing physical development, sexual maturation, haemoglobin and iron status, and respiratory function of school-age girls (7–17 years), together with exposure assessment and ethical requirements, and to propose a practical set of indicators for a comparative hygienic study of an exposed and a control area.

Materials and methods. This is a narrative methodological review. International guidelines and technical statements (WHO, ATS/ERS, Global Lung Function Initiative, US CDC, CIOMS, World Medical Association) and validation studies were identified through PubMed, Google Scholar and the official websites of these organisations, using combinations of the terms "school-age children", "girls", "growth reference", "Tanner stage", "self-assessment", "menarche", "haemoglobin cut-off", "ferritin", "spirometry reference equations", "ISAAC" and "blood lead". Publications from 1969 to 2026 in English and Russian were considered. Priority was given to current guidelines and to studies that compared methods directly.

2. Physical development

Measurements. The basic anthropometric indicators are standing height and body weight; in the CIS hygienic tradition, chest circumference is usually added. Height is measured with a

stadiometer to the nearest 0.1 cm, without shoes, heels together and the head in the Frankfurt plane; weight is measured with a calibrated electronic scale to the nearest 0.1 kg in light clothing. Measurements should be taken in the morning, by the same trained staff in both study areas, with the instruments checked every day. Repeating the measurements in a subsample allows the technical error of measurement to be estimated and reported.

Age must be calculated exactly from the dates of birth and examination (decimal age) and not as completed years, because during adolescence a difference of a few months noticeably changes the expected height and body mass.

WHO 2007 growth reference. For children and adolescents aged 5–19 years, WHO published a growth reference that joins smoothly with the WHO Child Growth Standards at 5 years and with the adult body mass index (BMI) cut-offs at 19 years: at 19 years the +1 SD value of BMI for girls is 25.0 kg/m², equal to the adult overweight cut-off, and the +2 SD value is close to the obesity cut-off [5]. The main indicators are height-for-age and BMI-for-age z-scores; weight-for-age is given only up to 10 years, because during the pubertal growth spurt it does not distinguish height from body mass [5]. The usual classification is: stunting, height-for-age below −2 SD; thinness, BMI-for-age below −2 SD; overweight, BMI-for-age above +1 SD; obesity, BMI-for-age above +2 SD. The z-scores can be calculated with the free WHO AnthroPlus software or the corresponding macros for statistical packages [6].

Regional standards. In Uzbekistan and other CIS countries physical development is traditionally assessed with regional standards: regression scales of body weight and chest circumference by height, or centile tables, with harmonious and disharmonious development defined by sigma deviations. Their advantage is that they describe the local population. Their limitations are that many of them were developed decades ago and may be outdated because of the secular trend, the methods of construction differ between regions, and results expressed in this way cannot be compared directly with international data.

Practical recommendation. In a comparative study, WHO z-scores should be the main indicators, because they use one reference for both groups and allow comparison with the international literature. Regional standards can be added as secondary indicators for comparison with national data. In either case, the key comparison is between the exposed and the control group measured with the same protocol. The analysis should also take sexual maturation into account, because girls of the same age but at different pubertal stages differ considerably in height and body mass.

3. Sexual maturation

Tanner stages. The reference method is the five-stage scale of Marshall and Tanner for breast development (B1–B5) and pubic hair (P1–P5) [7]. In their longitudinal study of British girls, breast stage 2 was reached on average at 11.15 years and menarche at 13.47 years, with wide individual variation [7]. Breast and pubic hair stages should be recorded separately, because they do not always progress together. The examination should be performed by a trained female

physician in a private room; in girls with a high BMI, gentle palpation may be needed to distinguish glandular tissue from fat. Examiners in both study areas should be trained together, and inter-observer agreement should be checked on a subsample.

Self-assessment. Because physical examination may be sensitive for adolescents and their parents, many epidemiological studies use self-assessment with Tanner drawings or photographs. Its accuracy is moderate. In a Danish study, only 44.9% of girls assessed their breast stage correctly (kappa 0.28); girls tended to underestimate their stage, and the authors concluded that self-assessment is sufficiently accurate mainly for distinguishing pre-pubertal from pubertal children [8]. In a school-based survey of 927 Thai girls, agreement with a paediatrician was 60.8% for breast stage (kappa 0.50) and 78% for pubic hair (kappa 0.68) [9]. When validity was judged against reproductive hormone levels rather than against the physician, self-assessed breast and pubic hair stages of Mexican girls performed at least as well as physician assessment [10]. Non-pictorial questionnaires such as the Pubertal Development Scale avoid images altogether, but they give an overall pubertal score rather than Tanner stages [11].

Age at menarche. Age at menarche is the most widely used single marker of female puberty, and two approaches are available. In the status-quo method each girl is asked only whether menstruation has started (yes or no), and the median age at menarche in the group is estimated by probit or logistic regression; this method has no recall error. In the retrospective method the girl reports the date of her first menstruation. Recall is reliable shortly after the event, and even after about 30 years the recalled and originally recorded ages correlated closely ($r = 0.79$) [12]. In a school study both approaches can be combined: the status-quo method gives the median age in each area, and the recalled dates are used for girls who have already reached menarche. Questions on cycle regularity and painful periods can be added, but these characteristics are remembered less accurately than the age at menarche [12].

Practical recommendation. For girls aged 7–17 years in an exposed and a control area, Tanner staging by a trained female examiner is preferable when consent is given. Self-assessment can be offered to girls who decline examination; the method used should be recorded for each girl and taken into account in the analysis. Results should be presented as the proportion of girls at each stage by age group and, if the sample allows, as median ages at breast stage 2 and at menarche.

4. Haemoglobin and iron status

Anaemia is one of the most frequent health problems of adolescent girls, and environmental factors can contribute to it: lead, for example, inhibits enzymes of haem synthesis [13]. Haemoglobin is therefore a useful indicator in hygienic studies, provided it is measured and interpreted in a standard way.

Cut-offs. The WHO 2024 guideline defines anaemia as a haemoglobin concentration below 115 g/L in children aged 5–11 years, below 120 g/L at 12–14 years, and below 120 g/L in non-pregnant girls and women aged 15 years and older; the guideline also gives cut-offs for mild, moderate and severe anaemia [14].

Adjustment for elevation. An important change in the 2024 guideline is that measured haemoglobin must be adjusted for the elevation of the place of residence starting from 500 m above sea level, instead of 1000 m as before [14]. The adjustment (g/L) equals $0.0056384 \times A + 0.0000003 \times A^2$, where A is the elevation in metres, and it is subtracted from the measured value before the cut-offs are applied; it is about 3 g/L at 500 m and about 6 g/L at 1000 m. Settlements of the Tashkent region lie at different elevations, and foothill and mountain districts are higher than the industrial towns of the valley. The elevation of every school or settlement should therefore be recorded and the adjustment applied to both the exposed and the control group. This is especially important when the control area lies higher than the exposed town: without adjustment, the naturally higher haemoglobin of girls living at higher elevation may be mistaken for a protective effect of clean air, or the prevalence of anaemia may be underestimated. The guideline also requires adjustment for smoking, which is rarely relevant at school age but should be asked about in older girls.

Blood sampling. Haemoglobin measured in single drops of capillary blood is more variable than in venous blood [15]. Venous sampling with an automated haematology analyser is therefore preferable. If portable photometers are used, the same type of device and the same sampling technique must be used in both areas, and the devices should be checked daily with control material.

Iron status. Haemoglobin alone does not show the cause of anaemia. Serum ferritin is the recommended indicator of iron stores: in apparently healthy individuals aged 5 years and older, ferritin below 15 µg/L indicates iron deficiency, while in the presence of infection or inflammation the cut-off is below 70 µg/L [16]. WHO recommends measuring two inflammation markers, C-reactive protein and alpha-1-acid glycoprotein, together with ferritin [16]. In an industrial town, it is reasonable to analyse haemoglobin and ferritin together with blood lead where it is measured (Section 6), so that iron deficiency and exposure to metals can be considered side by side.

5. Respiratory function and symptoms

Spirometry. Lung function testing is an objective indicator of the respiratory effects of air pollution. Spirometry should follow the 2019 ATS/ERS technical standard: a daily calibration check of the spirometer, at least three acceptable forced expiratory manoeuvres, and repeatability, in children older than 6 years, of the two largest values of forced vital capacity (FVC) and forced expiratory volume in 1 s (FEV1) within 0.150 L [17]. The standard also introduces a quality grade for each test [17]; tests of insufficient quality should be excluded by the same rule in both study areas. Testing in schools requires trained staff who coach each child. Height must be measured on the same day, because it is the main determinant of the predicted values. Season, time of day and recent respiratory infections should be recorded.

Reference values. Results should be expressed as z-scores and compared with the lower limit of normal (LLN, the 5th percentile, $z = -1.645$), because the normal range of lung function

changes with age, and a fixed "80% of predicted" threshold does not take this into account [18]. The Global Lung Function Initiative (GLI-2012) equations cover the age range 3–95 years and have been endorsed by the major respiratory societies [18]. They include equations for Caucasian, African American, North East Asian and South East Asian populations and an "other/mixed" equation for groups that are not represented [18]. Since no specific equations exist for Central Asian populations, the race-neutral GLI Global (2022) equations, derived from the same data, are a reasonable choice [19]. Because one equation is applied to both groups, the comparison between the exposed and the control area remains valid even if the absolute predicted values do not fit the local population perfectly.

Respiratory symptoms. Respiratory and allergic symptoms are best collected with the core questionnaire of the International Study of Asthma and Allergies in Childhood (ISAAC). It was developed for two age groups, 6–7 years (completed by parents) and 13–14 years (completed by the children themselves), and has been used in many countries [20]. Standard questions on wheezing in the past 12 months, dry cough at night and doctor-diagnosed asthma make the results comparable with international data. The questionnaire should be translated into Uzbek and Russian with back-translation, and the same version should be used in both areas.

6. Exposure assessment, biomonitoring, study design and ethics

Exposure assessment. The exposed and control areas should be selected on the basis of measured air quality and not only on the presence of industry. Data of the state monitoring network on dust, sulphur dioxide, nitrogen dioxide, carbon monoxide and metals, and integral indices such as the air pollution index, describe the contrast between areas [3]. For interpretation, concentrations can be compared both with the national maximum permissible concentrations and with the WHO 2021 air quality guideline levels [1]. At the individual level it is useful to record school and home addresses (with distance and direction to the main emission sources), the length of residence in the area (with a minimum period defined in advance as an inclusion criterion), and household factors that also affect health: passive smoking, the fuel used for cooking and heating, and socioeconomic status.

Biomonitoring. In towns with non-ferrous metallurgy, blood lead is the most informative biomarker of exposure. It should be measured in venous blood by a validated method (graphite furnace atomic absorption spectrometry or inductively coupled plasma mass spectrometry) in a laboratory that takes part in external quality control. The US CDC blood lead reference value of 3.5 µg/dL is the 97.5th percentile of blood lead in US children aged 1–5 years; it identifies children with higher exposure than most of their peers and is not a safe level or a toxicity threshold [21]. Metal analysis of hair or nails is simpler, but external contamination makes it difficult to interpret [13], so it should be regarded as supplementary.

Design and analysis. The sample size should be calculated in advance for the main outcome. Because girls are sampled through schools, observations within a school are not independent, and multilevel models or cluster-adjusted standard errors should be used. Comparisons of growth,

haemoglobin and lung function between areas should be adjusted for age and pubertal stage and, where possible, for socioeconomic and household factors. Results should be reported with 95% confidence intervals, not only with p values.

Ethics. The protocol must be approved by an ethics committee and follow the Declaration of Helsinki [22]. For research involving minors, the permission of a parent or legal guardian and the assent of the child are required, and a child's refusal should be respected [23]. Pubertal examination requires particular care: a female examiner, a private room, the right to have a parent or the school nurse present, and the option of self-assessment instead of examination. Personal data must be coded and stored securely. Families should be informed about clinically important findings, such as anaemia or elevated blood lead, and the girls should be referred for follow-up.

The recommended set of indicators is summarised in Table 1.

Table 1. Recommended set of indicators for a comparative hygienic study of school-age girls

Domain	Indicator	Method and reference	Output for analysis
Physical development	Height, weight (chest circumference)	Stadiometer, electronic scale; WHO 2007 reference [5, 6]; regional standards as secondary indicators	Height-for-age and BMI-for-age z-scores; stunting, thinness, overweight, obesity
Sexual maturation	Breast and pubic hair stage	Tanner scale, trained female examiner [7]; self-assessment as an alternative [8–10]	Proportion of girls at each stage by age; median age at breast stage 2
Sexual maturation	Menarche	Status-quo question plus recalled date [12]	Median age at menarche (probit or logit)
Haemoglobin and iron	Haemoglobin	Venous blood, haematology analyser; WHO 2024 cut-offs with elevation adjustment [14, 15]	Prevalence and severity of anaemia
Haemoglobin and iron	Ferritin, CRP, AGP	WHO 2020 guideline [16]	Prevalence of iron deficiency
Respiratory system	FEV1, FVC, FEV1/FVC	ATS/ERS 2019 standard [17]; GLI z-scores [18, 19]	z-scores; proportion below LLN
Respiratory system	Symptoms	ISAAC core questionnaire [20]	Prevalence of wheeze, night cough, asthma

Domain	Indicator	Method and reference	Output for analysis
Exposure	Ambient air quality	Monitoring data, air pollution index; WHO 2021 guideline levels [1, 3]	Exposed versus control area
Exposure	Blood lead	GF-AAS or ICP-MS with quality control; CDC reference value [21]	Geometric mean; proportion ≥ 3.5 µg/dL
Covariates	Age, socioeconomic and household factors	Standard questionnaire	Adjustment variables

7. Conclusion

Health studies of girls living near non-ferrous metallurgy enterprises need a set of indicators that are measured in the same way in the exposed and control areas and can be compared with international data. Current evidence supports the following choices: WHO 2007 z-scores for physical development, with regional standards as secondary indicators; Tanner staging by a trained female examiner, with self-assessment used mainly to separate pre-pubertal from pubertal girls; the status-quo method combined with recall for age at menarche; WHO 2024 haemoglobin cut-offs with adjustment for elevation from 500 m, and ferritin interpreted together with inflammation markers; spirometry according to the ATS/ERS 2019 standard with GLI z-scores, and the ISAAC questionnaire for symptoms; and exposure described by monitoring data and blood lead. Applying these methods will make the results of hygienic studies in Uzbekistan more reliable and comparable with studies from other countries.

References

1. World Health Organization. WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. Geneva: WHO; 2021. Available from: https://www.who.int/publications/i/item/9789240034228
2. Clougherty JE. A growing role for gender analysis in air pollution epidemiology. Environ Health Perspect. 2010;118(2):167–176. https://doi.org/10.1289/ehp.0900994
3. Elmurodova DB. Analysis of atmospheric air pollution in Almalyk city during 2011–2024 and its impact on public health. Meditsinskiy vestnik Uzbekistana. 2026;(7):210–214. (In Russian)
4. Kamilova RT, Niyazova GT, Basharova LM, et al. Influence of hygienic and medico-biological aspects in ecologically unfavourable conditions of the Republic of Karakalpakstan on the processes of growth and development of children: monograph. Moscow: Publishing House of the Academy of Natural Sciences; 2016. 93 p. ISBN 978-5-91327-381-9. (In Russian)

5. de Onis M, Onyango AW, Borghi E, et al. Development of a WHO growth reference for school-aged children and adolescents. Bull World Health Organ. 2007;85(9):660–667. https://doi.org/10.2471/BLT.07.043497

6. World Health Organization. WHO AnthroPlus for personal computers. Manual: software for assessing growth of the world's children and adolescents. Geneva: WHO; 2009. Available from: https://www.who.int/tools/growth-reference-data-for-5to19-years/application-tools

7. Marshall WA, Tanner JM. Variations in pattern of pubertal changes in girls. Arch Dis Child. 1969;44(235):291–303. https://doi.org/10.1136/adc.44.235.291

8. Rasmussen AR, Wohlfahrt-Veje C, Tefre de Renzy-Martin K, et al. Validity of self-assessment of pubertal maturation. Pediatrics. 2015;135(1):86–93. https://doi.org/10.1542/peds.2014-0793

9. Jaruratanasirikul S, Kreetapirom P, Tassanakijpanich N, Sriplung H. Reliability of pubertal maturation self-assessment in a school-based survey. J Pediatr Endocrinol Metab. 2015;28(3–4):367–374. https://doi.org/10.1515/jpem-2014-0053

10. Chavarro JE, Watkins DJ, Afeiche MC, et al. Validity of self-assessed sexual maturation against physician assessments and hormone levels. J Pediatr. 2017;186:172–178.e3. https://doi.org/10.1016/j.jpeds.2017.03.050

11. Petersen AC, Crockett L, Richards M, Boxer A. A self-report measure of pubertal status: reliability, validity, and initial norms. J Youth Adolesc. 1988;17(2):117–133. https://doi.org/10.1007/BF01537962

12. Must A, Phillips SM, Naumova EN, et al. Recall of early menstrual history and menarcheal body size: after 30 years, how well do women remember? Am J Epidemiol. 2002;155(7):672–679. https://doi.org/10.1093/aje/155.7.672

13. Agency for Toxic Substances and Disease Registry (ATSDR). Toxicological profile for lead. Atlanta, GA: U.S. Department of Health and Human Services; 2020. Available from: https://www.atsdr.cdc.gov/toxprofiles/tp13.pdf

14. World Health Organization. Guideline on haemoglobin cutoffs to define anaemia in individuals and populations. Geneva: WHO; 2024. Available from: https://www.who.int/publications/i/item/9789240088542

15. Neufeld LM, Larson LM, Kurpad A, et al. Hemoglobin concentration and anemia diagnosis in venous and capillary blood: biological basis and policy implications. Ann N Y Acad Sci. 2019;1450(1):172–189. https://doi.org/10.1111/nyas.14139

16. World Health Organization. WHO guideline on use of ferritin concentrations to assess iron status in individuals and populations. Geneva: WHO; 2020. Available from: https://www.who.int/publications/i/item/9789240000124

17. Graham BL, Steenbruggen I, Miller MR, et al. Standardization of spirometry 2019 update. An official American Thoracic Society and European Respiratory Society technical statement. Am J Respir Crit Care Med. 2019;200(8):e70–e88. https://doi.org/10.1164/rccm.201908-1590ST

18. Quanjer PH, Stanojevic S, Cole TJ, et al. Multi-ethnic reference values for spirometry for the 3–95-yr age range: the global lung function 2012 equations. Eur Respir J. 2012;40(6):1324–1343. https://doi.org/10.1183/09031936.00080312

19. Bowerman C, Bhakta NR, Brazzale D, et al. A race-neutral approach to the interpretation of lung function measurements. Am J Respir Crit Care Med. 2023;207(6):768–774. https://doi.org/10.1164/rccm.202205-0963OC

20. Asher MI, Keil U, Anderson HR, et al. International Study of Asthma and Allergies in Childhood (ISAAC): rationale and methods. Eur Respir J. 1995;8(3):483–491. https://doi.org/10.1183/09031936.95.08030483

21. Ruckart PZ, Jones RL, Courtney JG, et al. Update of the blood lead reference value — United States, 2021. MMWR Morb Mortal Wkly Rep. 2021;70(43):1509–1512. https://doi.org/10.15585/mmwr.mm7043a4

22. World Medical Association. WMA Declaration of Helsinki — ethical principles for medical research involving human participants. Amended by the 75th WMA General Assembly, Helsinki, October 2024. Available from: https://www.wma.net/policies-post/wma-declaration-of-helsinki

23. Council for International Organizations of Medical Sciences (CIOMS). International ethical guidelines for health-related research involving humans. Geneva: CIOMS; 2016. Available from: https://cioms.ch/publications/product/international-ethical-guidelines-for-health-related-research-involving-humans