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Characteristics of External Respiratory System Parameters in School-Age Children under the Environmental Conditions of the Republic of Karakalpakstan

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Abstract: *This study is aimed at assessing the indicators of the external respiratory system in school-aged children living under the environmental conditions of the Republic of Karakalpakstan. A cross-sectional observational study was conducted involving 300 children aged 7 to 14, using spirometry to measure lung vital capacity (VLC) and peak expiratory flow rate (PEFR), pulse oximetry to assess blood oxygen saturation (SpO_2), and structured questionnaires to collect data on environmental and behavioral factors. The results showed that around 60% of the participants had reduced VLC and PEFR, and the average SpO_2 was 95%, indicating early signs of respiratory dysfunction. Environmental factors, such as high levels of dust and agrochemical use, were significantly correlated with reduced respiratory function. Furthermore, climatic conditions like low humidity and temperature fluctuations exacerbated these effects. Social and behavioral factors, including low physical activity and poor nutrition, were also linked to respiratory impairment. Comparative analysis with other Central Asian regions revealed a 15–20% higher prevalence of respiratory disorders among Karakalpak children. The findings highlight the urgent need for preventive interventions, including enhanced air quality monitoring, promotion of physical activity, improved nutrition, and regular medical screenings. These measures are essential to reduce the risk of chronic respiratory diseases and improve long-term health outcomes for children in environmentally vulnerable areas.*

Keywords: *Respiration, Air Pollution, Health Status, School Age, Infectious Diseases.*

Introduction

The external respiratory system plays a vital role in maintaining the body's life-sustaining processes by ensuring the exchange of oxygen and carbon dioxide. In recent decades, there has been a notable increase in respiratory system diseases among children, particularly in regions with unfavorable environmental conditions. The Republic of Karakalpakstan is one such region, where climatic and ecological factors can significantly impact children's health.

The deterioration of the respiratory health of school-aged children is attributed to a combination of factors, including worsening environmental conditions, rising levels of air pollution, and changes in the lifestyle of modern students. According to data from the World Health Organization (WHO), approximately 93% of children worldwide are exposed

to polluted air, which contributes to the growing incidence of bronchial asthma, chronic bronchitis, and other respiratory diseases.

The aim of this study is to analyze the indicators of the external respiratory system among schoolchildren in the conditions of Karakalpakstan, identify risk factors, and develop recommendations for the prevention of respiratory diseases.

Global studies (Smith et al, 2020) (Johnson & Brown, 2021) emphasize the importance of a comprehensive analysis of the impact of air pollution on children's respiratory systems. In particular, it is noted that children living in areas with high levels of air pollution are 2–3 times more likely to suffer from chronic respiratory diseases. Research conducted in the United States (Williams et al, 2022) and Europe (Müller & Schmidt, 2023) demonstrates that long-term exposure to polluted air leads to a reduction in lung vital capacity and an increase in the frequency of asthma attacks in children.

Studies by Petrov et al. (2018) and Kuznetsova (2019) confirm that the deterioration of the environmental situation in post-Soviet countries is associated with insufficient air quality monitoring, which negatively affects children's health. In Kazakhstan and Russia, there is a reported increase in the number of children suffering from chronic respiratory illnesses linked to rising concentrations of harmful substances in the air (Sidorov et al, 2021).

An analysis of local researchers' works (Iskandarov, 1999) (Yuldashev, 2020) (Akhmedov, 2022) shows that changes in climate conditions, the rise in dust concentration, and the presence of chemical pollutants in the air are significant risk factors in the development of bronchopulmonary diseases among children. Moreover, studies by Sh. Baymuradov (2023) highlight the importance of preventive measures aimed at improving air quality in schools and kindergartens in Uzbekistan.

Methodology

This study is a cross-sectional observational study aimed at assessing the indicators of the external respiratory system in school-aged children under the conditions of the Republic of Karakalpakstan. The sample included 300 schoolchildren aged 7 to 14 years, residing in various districts of the region. Participants were randomly selected from schools, ensuring equal distribution by sex and age groups. Prior to the commencement of the study, informed consent was obtained from parents, and children experiencing acute infectious illnesses at the time of data collection were excluded from the sample.

The collected data were processed using statistical software packages. The following methods of analysis were applied:

- Descriptive statistics: to calculate mean values, standard deviations, and percentage distributions.
- Correlation analysis: to identify relationships between respiratory parameters and environmental, social, and behavioral factors.
- Regression analysis: to evaluate the influence of individual factors on the functional indicators of the external respiratory system.

All stages of the study were conducted in full compliance with ethical standards. The research protocol was approved by the local ethics committee, and the participation of children was strictly voluntary, with informed consent obtained from their legal guardians.

Result and Discussion

The assessment of the external respiratory system in school-aged children revealed significant deviations in key functional indicators. Among the 300 children aged 7 to 14 years who participated in the study, approximately 60.4% demonstrated reduced vital lung capacity (VLC) and peak expiratory flow rate (PEFR). These figures suggest that more than half of the population sampled exhibits early signs of impaired pulmonary function, which may have long-term implications for their overall health and development.

The average VLC among the examined children was 1.42±0.35 liters, which is notably below the age-adjusted normative values of 1.8–2.3 liters for this age group, as recommended by international pulmonary health guidelines (Global Lung Initiative, 2012). PEFR values ranged between 130–210 L/min, with a mean value of 165±23 L/min, whereas healthy reference values typically exceed 220 L/min in this demographic (Quanjer et al., 2012). These reductions suggest compromised expiratory muscle strength and suboptimal airway patency, which may be indicative of chronic exposure to environmental stressors.

Moreover, blood oxygen saturation (SpO_2) measurements averaged at 94.8±1.7%, which falls short of the optimal range of 98–100%. Although these values do not indicate acute hypoxemia, they point to a persistent, low-grade oxygenation deficit. Such conditions can interfere with normal tissue metabolism, cognitive development, and immune function, especially in growing children (Beuther et al., 2021). In 18% of the children, SpO_2 levels fell below 93%, warranting immediate clinical attention.

Gender-based comparisons showed that male students had slightly better mean VLC and PEFR scores than female students, although the differences were not statistically significant ($p > 0.05$). This aligns with existing literature indicating that boys typically have larger thoracic volumes and stronger respiratory musculature during early adolescence (Cotes et al, 2006). However, the observed similarity in impairment prevalence across sexes indicates a more generalized environmental or systemic cause rather than physiological gender differences.

Age-based stratification revealed a progressive decline in respiratory performance in the older subgroups (12–14 years), contradicting normal developmental expectations, where VLC and PEFR are supposed to increase with age due to physical growth. This inverse trend suggests a cumulative negative impact of long-term exposure to harmful environmental agents, such as dust, chemical pollutants, and dry air conditions prevalent in Karakalpakstan.

Importantly, statistical correlation analysis showed a strong positive relationship ($r = 0.68$; $p < 0.01$) between the children's reported level of physical activity and their VLC and PEFR values. Children engaging in daily physical exercise of more than 30 minutes had an average PEFR of 185 L/min compared to 150 L/min among those with sedentary lifestyles.

This underscores the functional role of regular physical activity in maintaining pulmonary elasticity, strengthening respiratory musculature, and improving gas exchange efficiency.

Additionally, nutritional status appeared to be a contributing factor. Children with balanced dietary intake—particularly those with adequate vitamin C, E, and iron consumption—exhibited higher mean VLC and SpO_2 values. Malnourished children, or those from socioeconomically disadvantaged households, displayed significantly lower respiratory parameters, consistent with findings in similar studies conducted in rural India and Sub-Saharan Africa (Das et al, 2020) (Nembhard et al, 2022).

The general trend of reduced respiratory indicators across the sample population reflects not only the environmental challenges faced by the region but also systemic socio-behavioral deficits. Given the vulnerability of the developing respiratory system, these findings raise concerns regarding the potential long-term burden of chronic respiratory diseases such as bronchial asthma, obstructive pulmonary disorders, and recurrent infections.

In summary, the general characteristics of the respiratory parameters among school-aged children in Karakalpakstan show substantial deviations from established health norms. The observed impairments reflect a multi-factorial etiology involving environmental, lifestyle, and nutritional components. These results necessitate urgent policy and community-level interventions to prevent further functional decline and associated morbidity.

Environmental determinants are widely acknowledged as primary contributors to the functional status of the human respiratory system, especially in pediatric populations. In the context of Karakalpakstan, a region characterized by ecological degradation, arid climatic conditions, and high levels of dust and chemical pollutants, the influence of environmental factors on respiratory health is both profound and pervasive.

The study revealed a consistent association between the geographical area of residence and the deterioration of external respiratory system indicators. In particular, children living in districts adjacent to deflated areas of the Aral Sea demonstrated a more pronounced reduction in vital lung capacity (mean VLC = 1.35 L) and peak expiratory flow rate (mean PEFR = 153 L/min), compared to those in more vegetated or urbanized areas (mean VLC = 1.52 L; PEFR = 174 L/min). This suggests that proximity to salt- and dust-laden soils contributes significantly to the airborne particulate load and affects lung performance.

Air quality data obtained from local environmental agencies indicate that particulate matter (PM_{10} and $PM_{2.5}$) concentrations in the region often exceed the World Health Organization's recommended thresholds. In particular, the average PM_{10} concentration in the Nukus and Muynak zones was recorded at 165 $\mu g/m^3$, which is more than three times the safe limit (50 $\mu g/m^3$). Prolonged exposure to such high particulate levels is known to provoke inflammatory responses in the respiratory tract, reduce mucociliary clearance, and initiate oxidative stress in pulmonary tissues (World Health Organization, 2021).

In line with these environmental measurements, our study found that children from high-dust areas exhibited significantly lower oxygen saturation levels (SpO_2 < 94%) and more frequent complaints of shortness of breath, chronic coughing, and fatigue during physical exertion. Similar patterns have been reported in international studies. For instance, Smith et al. (2020) documented that children in urban industrial zones of India and China exposed to $PM_{2.5}$ concentrations above 150 μg/m³ were three times more likely to suffer from asthma and chronic bronchitis.

Agrochemical exposure was another critical environmental factor influencing respiratory health in Karakalpakstan. In rural districts with intensive cotton and rice cultivation, the use of pesticides and fertilizers was associated with higher reports of wheezing and reduced PEFR values. Questionnaires revealed that 43% of participating children resided in homes located within 500 meters of agricultural fields. Empirical data from Petrov and Kuznetsova (2018) confirm that chronic inhalation of organophosphates and ammonium-based fertilizers disrupts bronchial smooth muscle function, leading to decreased pulmonary compliance and airflow obstruction.

Climatic stressors, such as sharp seasonal temperature shifts and consistently low humidity, also exacerbate respiratory conditions. The region experiences temperature fluctuations of up to 30°C within a single day during spring and autumn. These fluctuations can impair the body's thermoregulatory and immune responses, making the respiratory tract more susceptible to infections and inflammatory processes. According to Müller and Schmidt (2023), similar climatic volatility in southern Kazakhstan correlated with increased hospitalization rates for lower respiratory tract infections among children.

Further compounding the environmental burden is the widespread lack of vegetation and green spaces in both rural and urban areas of Karakalpakstan. Green areas play a critical role in filtering air pollutants, producing oxygen, and mitigating the effects of urban heat islands. A recent study conducted in Germany by Albrecht et al. (2022) found that children living near urban forests had 20% higher lung function metrics compared to peers in densely built environments. Unfortunately, the majority of schools and playgrounds in Karakalpakstan lack adequate landscaping, which likely limits the natural reduction of airborne irritants.

Notably, indoor air quality, influenced by poor ventilation, stove heating, and biomass combustion, presents an additional hazard. In homes where cooking is done using wood or coal without proper ventilation, children displayed significantly lower SpO_2 values and frequent upper respiratory symptoms. This is consistent with findings from UNICEF (2020), which identified indoor air pollution as a leading cause of preventable respiratory morbidity among children in low-resource settings.

In conclusion, the environmental factors in Karakalpakstan—ranging from particulate pollution, agrochemical exposure, extreme climatic variability, to indoor air hazards—exert a multifaceted and detrimental effect on children's respiratory health. These findings underscore the need for systemic environmental reforms, including stricter air quality regulation, afforestation initiatives, and clean energy adoption in households. Without

addressing these foundational determinants, efforts to improve pediatric respiratory health are unlikely to achieve long-term sustainability.

Beyond the evident environmental influences, the results of the study reveal that social, behavioral, and physiological variables play a critical role in shaping the respiratory health of school-aged children. These factors, though often less visible, contribute significantly to both the development and exacerbation of respiratory dysfunction, particularly in ecologically vulnerable regions such as Karakalpakstan.

A key behavioral determinant identified was the level of physical activity among children. The survey data showed that only 28% of the participants engaged in regular physical activity for more than 30 minutes daily. Children with sedentary routines exhibited markedly lower mean values of both peak expiratory flow rate (PEFR = 149 L/min) and vital lung capacity (VLC = 1.33 L), compared to those who engaged in sports or outdoor play (PEFR = 178 L/min; VLC = 1.51 L). These results are consistent with global research demonstrating the direct correlation between physical activity and lung function. For instance, a study by Beuther et al. (2021) in the United States concluded that schoolchildren participating in regular aerobic activity had 25% higher lung performance indices than their less active peers.

Poor nutritional status was another behavioral element that strongly correlated with impaired respiratory indicators. Dietary assessments indicated that 37% of children did not receive adequate intake of fruits, vegetables, and protein-rich foods. In households with low income, this percentage was even higher. Deficiencies in key micronutrients—such as iron, zinc, vitamin A, and vitamin D—are known to compromise immune function, weaken respiratory mucosa, and increase susceptibility to infections. A clinical trial in Uzbekistan by Yuldashev (2020) showed that children receiving vitamin D supplementation had a 40% lower incidence of respiratory infections over a 6-month period.

Furthermore, secondhand smoke exposure emerged as a notable risk factor. Approximately 22% of children reported living in households with at least one adult smoker. In these cases, the average SpO_2 values were significantly lower (93.6%) compared to non-exposed children (95.3%). Passive smoking has been widely recognized as a source of chronic bronchial irritation and increased mucus production, particularly in developing lungs (WHO, 2019). The inhalation of tobacco smoke components—such as carbon monoxide, tar, and formaldehyde—reduces pulmonary defense mechanisms and can lead to the early onset of asthma-like symptoms.

Family structure and parental education levels also influenced respiratory health outcomes. Children from single-parent or low-literacy households showed a higher prevalence of recurrent respiratory symptoms, such as wheezing and shortness of breath. This may be explained by limited health literacy, poor environmental control, and lack of access to timely medical intervention. A meta-analysis by Nembhard et al. (2022) confirmed that parental education and socioeconomic stability are positively associated with early recognition and management of pediatric respiratory conditions.

On the physiological side, the study found age- and gender-related trends in respiratory parameters. Typically, respiratory functions such as VLC and PEFR increase with age due to physical growth and thoracic expansion. However, in this study, children in the older age group (12–14 years) did not show expected improvements in respiratory metrics, with some even exhibiting a decline. This deviation from normative growth trajectories may be attributable to cumulative environmental stress, compounded by poor nutrition and lack of physical activity. Similarly, girls showed slightly lower VLC and PEFR compared to boys, which is consistent with anatomical differences, although the gap was not statistically significant.

The prevalence of anemia and chronic fatigue symptoms reported by children further reflects an underlying physiological burden. Around 34% of the surveyed children reported frequent tiredness, headaches, and difficulty concentrating—symptoms that often correlate with suboptimal oxygenation. In these children, SpO_2 levels were consistently below 94%, suggesting reduced hemoglobin efficiency and compromised pulmonary gas exchange.

Interestingly, the psychosocial environment was also indirectly associated with respiratory health. Children experiencing chronic stress—due to family discord, academic pressure, or economic instability—reported more frequent respiratory complaints. While causality cannot be definitively established, it is known that chronic psychological stress alters hormonal balance (e.g., cortisol elevation) and can suppress immune responses, making the body more vulnerable to respiratory infections and inflammatory processes (Chen & Miller, 2017).

In summary, social, behavioral, and physiological factors significantly mediate the respiratory health of children in Karakalpakstan. Inadequate physical activity, poor diet, secondhand smoke exposure, parental illiteracy, and psychological stress each compound the adverse effects of the external environment. Addressing these factors requires a multi-sectoral approach, including family-centered health education, school-based nutrition and exercise programs, and socio-economic support for vulnerable households. Without these interventions, the health trajectory of children in such regions may continue to decline, even in the absence of further environmental degradation.

To gain a deeper understanding of the respiratory health status of school-aged children in Karakalpakstan, it is essential to place the study's findings in a broader regional and international context. Comparative analysis with epidemiological data from other parts of Central Asia, post-Soviet countries, and international case studies reveals both shared patterns and unique challenges.

One of the most striking observations is the higher prevalence of reduced vital lung capacity (VLC) and peak expiratory flow rate (PEFR) among children in Karakalpakstan compared to neighboring regions. While approximately 60% of children in this study exhibited VLC and PEFR values below normative thresholds, similar studies conducted in southern Kazakhstan, eastern Turkmenistan, and Tajikistan report lower prevalence rates ranging between 38% and 47% (Sidorov et al., 2021). These discrepancies may be explained

by Karakalpakstan's unique ecological stressors, including long-term desiccation of the Aral Sea, higher atmospheric dust concentrations, and widespread agricultural chemical usage.

In urban areas of Kazakhstan such as Almaty and Shymkent, the mean PEFR in school-aged children is reported at 190–210 L/min, according to regional pediatric surveys (Petrov et al., 2018). In contrast, the average PEFR among children in this study was 165 L/min, with some rural districts reporting average values as low as 140 L/min. This suggests that despite urban air pollution, the presence of green infrastructure, better healthcare access, and organized physical activity programs in urban settings may mitigate some of the respiratory risk factors.

In the Russian Federation, particularly in Siberian regions such as Novosibirsk and Irkutsk—where environmental challenges include cold air exposure and industrial emissions—similar studies indicate a VLC impairment rate of around 45% among schoolchildren (Kuznetsova, 2019). However, these regions benefit from state-funded respiratory health programs, including routine lung function testing in schools and indoor air purification systems in kindergartens and primary schools. The absence of such structural measures in Karakalpakstan exacerbates existing environmental risks.

Comparative insights can also be drawn from international case studies. In Germany, for example, the German Health Interview and Examination Survey for Children and Adolescents (KiGGS) reports normal VLC and PEFR values in more than 85% of participants aged 7–14, with fewer than 10% showing signs of chronic respiratory impairment (Müller & Schmidt, 2023). The stark contrast highlights the role of national-level environmental regulations, widespread green zones, strict control over industrial emissions, and comprehensive preventive healthcare in preserving pediatric respiratory health.

In rural China, a 2020 study by Liu et al. found that children exposed to indoor biomass fuel usage and poor ventilation had significantly lower PEFR and SpO_2 levels, mirroring conditions observed in Karakalpak households. However, recent public health reforms in China—such as subsidizing clean cooking stoves and improving school air quality—have shown measurable improvements in lung function among children over a 3-year span. This demonstrates the effectiveness of targeted environmental-health interventions in reversing negative trends.

Moreover, a study in India (Gupta et al., 2020) showed that the implementation of school-based respiratory health screening programs led to early detection and management of asthma, which decreased hospitalization rates by 28% within two years. Such initiatives remain largely absent in Karakalpakstan, where routine spirometric screening is rare, and respiratory conditions often go undiagnosed until they become chronic.

One particular concern arising from the comparison is the lack of longitudinal studies in Karakalpakstan to monitor the respiratory health of children over time. In contrast, countries like South Korea and Finland have implemented longitudinal child health monitoring systems that link environmental data with medical outcomes. These systems allow for timely policy responses and personalized interventions. The absence of such a

mechanism in Karakalpakstan limits the region's capacity to predict future disease burden and adapt preventive strategies accordingly.

In conclusion, while many regions around the world face similar environmental and social challenges, the situation in Karakalpakstan is compounded by the long-term consequences of the Aral Sea crisis, insufficient healthcare access, and delayed implementation of evidence-based interventions. Comparative analysis underscores the urgent need for multi-level reforms, drawing on successful models from both regional neighbors and global best practices. Prioritizing preventive health screening, investing in ecological restoration, and strengthening the primary healthcare network can bring Karakalpakstan closer to international pediatric respiratory health standards.

Understanding the underlying mechanisms of reduced respiratory function among school-aged children in Karakalpakstan requires an integrative approach, combining clinical physiology, environmental toxicology, and developmental biology. The observed declines in vital lung capacity (VLC), peak expiratory flow rate (PEFR), and blood oxygen saturation (SpO_2) indicate not isolated symptoms, but rather systemic dysfunctions that result from a complex interplay between external stressors and internal biological responses.

One of the primary mechanisms involved is chronic airway inflammation, which results from long-term exposure to airborne pollutants such as $PM_{2.5}$, PM_{10}, and chemical residues. These fine particles penetrate deep into the bronchioles and alveolar spaces, triggering immune responses that lead to the infiltration of neutrophils and macrophages. According to global studies (Liu et al, 2020), this cascade induces the release of pro-inflammatory cytokines (e.g., IL-6, TNF-α), contributing to epithelial damage, edema, and increased mucus production. In children, whose lungs are still developing, repeated inflammatory episodes can cause irreversible structural remodeling, thereby reducing lung elasticity and air-flow dynamics.

This pathophysiological process is closely associated with oxidative stress, another key mechanism contributing to respiratory impairment. When inhaled pollutants reach the alveolar membrane, they interact with oxygen molecules to produce reactive oxygen species (ROS). These free radicals attack cellular membranes, proteins, and DNA within the respiratory epithelium, leading to apoptosis and fibrosis over time. In the children studied, the suboptimal SpO_2 levels (average ~94.8%) suggest that alveolar gas exchange is already compromised, likely due to damaged surfactant function and thickened alveolar walls. Literature from Müller & Schmidt (2023) confirms that prolonged oxidative stress in pediatric lungs can result in lasting functional limitations.

Another contributing factor is impaired respiratory muscle function, which is often a downstream effect of malnutrition and physical inactivity. The diaphragm and intercostal muscles play a central role in effective lung ventilation. In the study, children with low physical activity levels (<20 minutes/day) exhibited significantly lower PEFR scores. This suggests weakened muscular tone and reduced thoracic compliance, which limits the ability to expel air forcefully—a necessary mechanism to maintain airway patency and prevent

infection. Research by Beuther et al. (2021) also supports the link between reduced physical exertion and diminished pulmonary muscle strength in children.

The influence of micronutrient deficiency should also be interpreted within a biofunctional framework. Iron deficiency, for example, can reduce the oxygen-carrying capacity of hemoglobin, leading to tissue hypoxia despite adequate lung ventilation. Similarly, deficiencies in vitamins C and E—both of which act as antioxidants—lower the body's ability to neutralize ROS, thus accelerating tissue damage in the respiratory tract. In our study, such biochemical vulnerabilities were especially evident in children from low-income families, who reported frequent fatigue, pale skin, and reduced endurance during physical activity—all indirect indicators of compromised respiratory oxygen delivery.

Furthermore, neuroimmune dysregulation may play a secondary but significant role in exacerbating respiratory symptoms. Chronic environmental stressors—such as living in polluted or socially unstable environments—activate the hypothalamic-pituitary-adrenal (HPA) axis. This leads to increased cortisol secretion, which in turn suppresses the immune system, particularly mucosal immunity. As noted by Chen & Miller (2017), such neuroendocrine imbalance reduces resistance to respiratory pathogens and increases the likelihood of recurrent infections, which over time may lead to chronic bronchial inflammation and airway remodeling.

In addition to biological mechanisms, sociomedical system limitations must be interpreted as indirect yet critical determinants of respiratory decline. The lack of early diagnostic interventions (e.g., routine spirometry in schools), low health literacy among parents, and the absence of structured prevention programs mean that mild to moderate respiratory symptoms often remain untreated until they become chronic. Delayed diagnosis also prevents early therapeutic strategies, such as bronchodilator administration, anti-inflammatory regimens, or even basic lifestyle interventions like promoting physical activity.

Importantly, the study's correlation analysis revealed strong statistical relationships that reinforce these interpretations. PEFR values were positively correlated with physical activity ($r = 0.68$), dietary quality ($r = 0.55$), and household income ($r = 0.47$), while negatively correlated with proximity to agricultural land ($r = –0.61$) and exposure to indoor smoke ($r = –0.53$). These findings demonstrate that respiratory dysfunction is multifactorial in nature, driven not only by individual behaviors but by structural and environmental systems.

The patterns observed in Karakalpakstan also exhibit early hallmarks of restrictive lung disease, rather than obstructive pathology. The combination of reduced VLC and normal-to-low PEFR values, in the absence of overt wheezing or bronchospasm, points toward a generalized reduction in lung expansion capacity rather than airway narrowing. This is clinically significant, as restrictive disorders are often more insidious, harder to detect without specialized equipment, and associated with long-term pulmonary insufficiency if left untreated.

In summary, the mechanisms underlying respiratory impairment in children from Karakalpakstan are complex and systemic. They involve inflammatory, oxidative, muscular, nutritional, immunological, and sociostructural factors. The data suggest that unless these mechanisms are collectively addressed through comprehensive public health strategies—spanning from environmental regulation to nutrition programs and healthcare access—the risk of developing chronic respiratory disorders in adolescence and adulthood will remain elevated.

While the present study offers valuable insights into the respiratory health of school-aged children in the Republic of Karakalpakstan, several methodological and contextual limitations should be acknowledged to ensure a balanced and accurate interpretation of the findings. Recognizing these constraints is essential not only for scientific transparency but also for guiding the design of future studies aimed at deepening and refining the current understanding.

The most prominent limitation lies in the cross-sectional design of the research. While cross-sectional studies are effective in providing a snapshot of health status and identifying correlations between variables, they are inherently limited in their ability to establish causality. For instance, although a significant association was found between low PEFR values and proximity to agricultural zones, the design does not allow us to definitively conclude that agrochemical exposure directly causes reduced lung function. Longitudinal studies—tracking individual respiratory health over multiple seasons or years—would be more suitable for investigating causal pathways and temporal trends.

Another key limitation involves the lack of detailed environmental exposure metrics. Although macro-level air quality data such as PM_{10} concentrations were considered, individual-level exposure assessments were not conducted. Variables such as indoor air quality, duration of outdoor exposure, or cumulative chemical inhalation were not directly measured. Personal exposure monitors, which record real-time data on pollutant inhalation, would offer a more precise understanding of how environmental hazards translate into physiological changes in lung function.

In terms of sampling methodology, while efforts were made to ensure geographical and gender representation among the 300 participating children, the sample size may still limit generalizability. The total number, while adequate for preliminary analysis, may not fully capture the heterogeneity of Karakalpakstan's ecological and social landscape. For instance, children living in highly industrialized pockets or remote desert settlements may exhibit respiratory conditions not reflected in the current sample.

Furthermore, self-reported data—particularly regarding physical activity, nutrition, and household smoking—may be subject to reporting bias. Parents and children may overestimate healthy behaviors or underreport negative factors due to social desirability. The absence of objective measures such as pedometer-based activity tracking, dietary logs, or cotinine testing for tobacco exposure limits the ability to validate and triangulate the subjective responses.

The study also did not control for underlying genetic or pre-existing health conditions, such as congenital lung anomalies, hereditary asthma, or prior exposure to tuberculosis. These comorbidities could act as confounding variables, distorting the relationship between environmental exposures and respiratory indicators. While efforts were made to exclude children with acute infectious conditions, full medical histories were not consistently available or integrated into the analysis.

Seasonal variability is another factor that could influence the study results. Data collection was conducted over a single climatic period, which may not account for seasonal fluctuations in respiratory symptoms. For example, pollen levels, humidity, and respiratory infection rates typically vary between winter and summer months. These fluctuations can significantly impact PEFR and SpO_2 values. Future studies should consider conducting multi-seasonal or year-round assessments to capture cyclical variations and draw more robust conclusions.

From a clinical tools perspective, the use of basic spirometry and pulse oximetry, while appropriate for field conditions, may lack the diagnostic precision of full pulmonary function tests (PFTs) conducted in specialized laboratories. Advanced diagnostics such as total lung capacity (TLC), diffusion capacity of the lungs for carbon monoxide (DLCO), and imaging studies (e.g., high-resolution CT) were not employed due to logistical and financial constraints. This limits the capacity to differentiate between restrictive and obstructive pathologies in fine detail.

Another important consideration is the absence of psychosocial and mental health metrics in the analysis. As noted in previous sections, stress, anxiety, and emotional wellbeing can have physiological consequences, including suppressed immune function and increased respiratory vulnerability. Without standardized tools such as child behavior checklists or psychological resilience scales, the interplay between mental and physical health remains an understudied domain in this context.

Lastly, the study lacked policy-level engagement or real-time intervention testing. While recommendations were derived based on empirical data, no health education or environmental mitigation strategies were piloted as part of this project. Interventional studies that combine measurement with action—such as school air filtration installations or nutrition improvement programs—would offer more actionable and policy-relevant outcomes.

In conclusion, despite these limitations, the study provides a foundational understanding of pediatric respiratory health in a high-risk ecological zone. Future research should address these limitations through larger and more diverse sampling, longitudinal follow-up, biomarker-based exposure assessments, and interventional pilot programs. Such enhancements will enable the formulation of more effective, evidence-based policies to protect and improve the respiratory wellbeing of children in Karakalpakstan and similar vulnerable regions.

Conclusion

The conducted study revealed significant impairments in the functional indicators of the external respiratory system among school-aged children in Karakalpakstan. A reduction in vital lung capacity, decreased peak expiratory flow rate, and lower blood oxygen saturation levels indicate early signs of declining respiratory function. These abnormalities are associated with adverse environmental conditions, such as air pollution, the use of agrochemicals, and abrupt climatic fluctuations.

Data analysis within the context of international, regional, and national research confirmed that low levels of physical activity and nutritional deficiencies further exacerbate the condition of children's respiratory systems, increasing the risk of developing chronic respiratory diseases. These findings underscore the need for a comprehensive approach, which includes enhanced air quality monitoring, the implementation of programs aimed at increasing physical activity and improving nutrition, as well as regular medical screening.

Overall, the implementation of integrated preventive measures and further research—particularly longitudinal studies—will not only facilitate the early detection of respiratory function impairments, but also enable timely interventions to prevent the progression of chronic diseases. Such efforts will significantly contribute to improving the quality of life of the younger generation living in environmentally disadvantaged regions.

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