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Comparison of Respiratory, Cardiovascular, and Hand Grip Strength of Adolescents Living in the Republic of Karakalpakstan by Ecological Regions

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Abstract This article analyzes the functional health status of adolescents aged 14-15 living in different ecological regions of Karakalpakstan by assessing hemodynamic parameters (blood pressure and heart rate), respiratory function (vital lung capacity), and hand grip strength. The study revealed that adolescents living in the Turtkul district demonstrated advantages in respiratory and hand grip strength indicators, while in the Muynak region an increase in hemodynamic parameters was observed. Adolescents from Nukus city showed intermediate values for these parameters. Such differences can be explained by ecological factors, air quality, lifestyle, physical activity, and nutritional habits.

Keywords Ecological condition, Karakalpakstan, Blood pressure, Heart rate, Vital lung capacity, Hand grip strength

1. Introduction

The health of adolescents and young people is an important indicator of the future of society. In particular, the development of the cardiovascular, respiratory, and muscular systems determines the overall health of a child. Adolescence is a period of active development of the cardiovascular system, during which heart rate (HR) and blood pressure (BP) are variable. Since adolescents are in the process of growth and development, studying their hemodynamic parameters helps to assess the normal functioning of the cardiovascular system and to determine such indicators as BP and HR. Changes in hemodynamic parameters may serve as early signs of cardiovascular diseases, BP abnormalities, or other pathologies [1]. In addition, hemodynamic parameters are considered important indicators in evaluating how well the heart and circulatory system function in adolescents engaged in sports and how they respond to physical load.

Vital lung capacity (VLC) is considered a key criterion in assessing the respiratory health and overall physical capabilities of adolescents [2]. A decrease in respiratory volume negatively affects not only sports performance, but also social activity and concentration during classes. Children with low VLC are more likely to experience fatigue, reduced attention, sleep disturbances, and even psychological discomfort [3].

Hand grip strength (HGS) is also one of the important indicators of the level of physical development. HGS below the norm may be associated with insufficient physical activity, improper nutrition, chronic diseases, or socio-psychological stress [4].

The territory of Karakalpakstan is distinguished by its desert and semi-desert nature, climatic conditions, and limited water and food resources. Studying the physiological indicators of adolescents under these conditions helps to develop specific and effective preventive measures in the field of healthcare. The aim of this study is to assess the overall health status of school-aged adolescents living in different ecological regions of Karakalpakstan by analyzing hemodynamic indicators (circulatory and cardiac function), respiratory function (VLC), and HGS parameters, to determine their association with environmental factors, and to develop effective practical recommendations for the field of public health.

2. Materials and Methods

2.1. Participants and Study Area

For regional zoning, it is noted that changes in the geological characteristics of the area, including air pollution caused by dust and wind erosion indicators, the state of the biocenosis, the diversity and abundance of plant and animal life inhabiting the region, the degree of negative impact

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from aridization and pesticide contamination, as well as the distance from the ecological disaster center, are taken into account [5-7]. Three ecological zones of the Republic of Karakalpakstan are distinguished from each other [5-7]:

1. Participants residing in the northern district of the Republic of Karakalpakstan, specifically in the Muynak district, were included in the "Muynak" group. This area is considered an ecological disaster zone (0-200 km – up to 200 km from the shore of the Aral Sea).
2. Representatives living in Nukus city, the central region of the Republic of Karakalpakstan, were included in the "Nukus" group. This area is classified as being under ecological disaster risk and is located approximately 200 km south of the Muynak district.
3. The "Turtkul" group consisted of volunteers residing in the southern districts of Karakalpakstan, namely Turtkul and Ellikkala. This region is located about 400 km away from Muynak district and is considered one of the ecologically favorable settlements of the Republic [5-8].

A physiometric survey was conducted among 1,855 adolescents aged 14-15 years living in different ecological regions of Karakalpakstan, including 983 boys and 872 girls. Indicators such as VLC, arterial blood pressure, and HGS were measured and compared between groups. In total, 302 boys and 299 girls from the "Muynak" group, 345 boys and 264 girls from the "Nukus" group, and 336 boys and 309 girls from the "Turtkul" group participated in the study. The research was carried out during the spring and summer seasons of 2024 among schoolchildren aged 14-15 years studying at schools No. 8, 12, and 52 in Nukus city (the capital of the Republic of Karakalpakstan); schools No. 3, 5, and 22 in Turtkul district; and schools No. 1, 2, 3, 4, as well as Lyceum No. 1 and a specialized school in Muynak district.

Subjects with somatic, neurological, orthopedic and psychiatric pathologies did not occur among the volunteers who participated in the measurements. Measurements were made during the spring-summer period, during the morning shift in the comfort temperature, in an insulated room with sufficient lighting.

2.2. Measurement of Physiological Parameters

Vital lung capacity (VLC): was measured using a spirometer – Electronic Vital Capacity Tester, FCS-10000, Grows Instrument (China, 2018). The spirometry analysis for determining VLC was carried out according to the following procedure:

1. The subject stood upright or sat in a correct posture.
2. Took a deep breath (maximum inspiration).
3. Exhaled as deeply as possible (maximum expiration).
4. The volume of exhaled air was recorded by the spirometer.
5. Each participant performed the test at least three times, and the most reliable result was documented.

In addition, in the volunteers, blood pressure – systolic arterial blood pressure (SBP), diastolic arterial blood pressure (DBP), and heart rate (HR) – was measured on the upper arm using the Korotkov method with an electronic sphygmomanometer OMRON 711 (HEM-8712-CM2) (China, 2017).

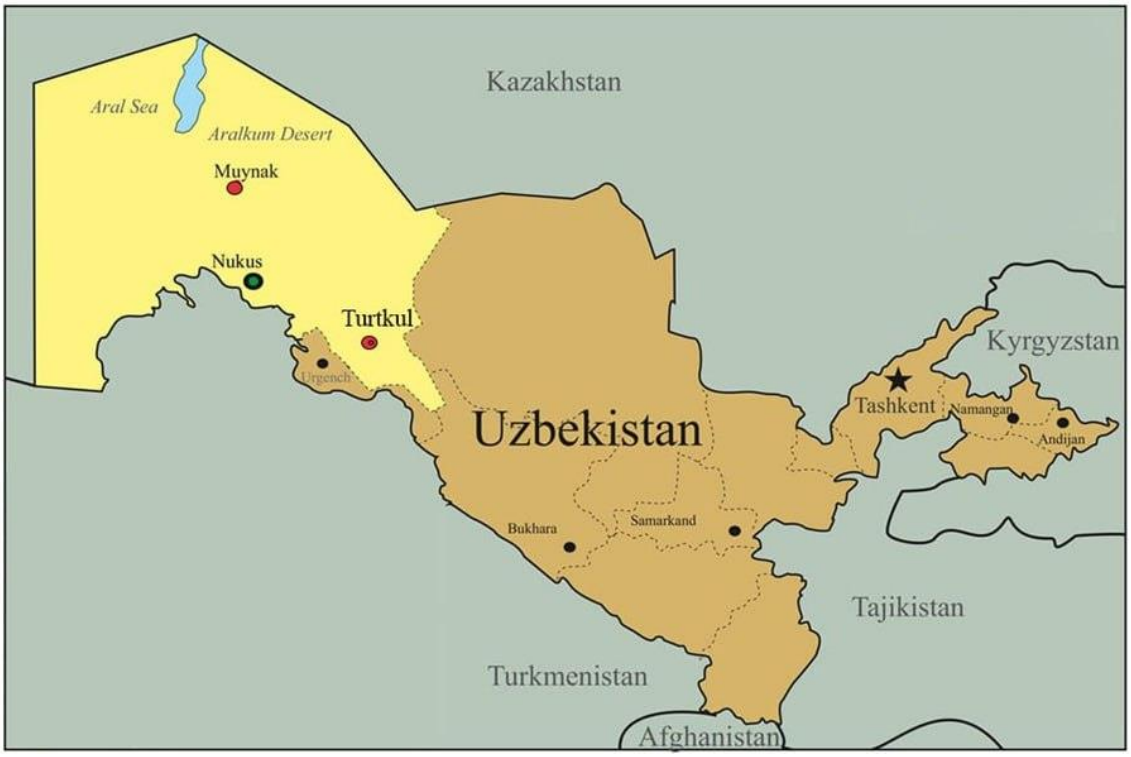

Figure 1. Schematic map of the location of the territorial groups on which research was carried out

The level of HGS was assessed using the dynamometric method. HGS was determined with a hand dynamometer MEGEON-34090 (Russia, 2017), with a measurement accuracy of 0.5 kg, allowing for reliable determination of handgrip force. For the test, the participant stood upright with the arm extended laterally and gripped the dynamometer with maximum effort. The test was repeated 2-3 times, and the highest value was recorded in kilograms.

2.3. Statistical Analysis

The statistical hypotheses about the difference of central tendencies in the three groups were tested for quantitative variables using the Kraskell-Wallis criterion. When statistically significant differences were identified, a posteriori comparisons were performed using the Mann-Whitney criterion with Bonferroni correction to correct for inflation of the 1st kind of error. The results were considered statistically significant at $p<0.05$. All results were performed using Excel program functions installed in Microsoft Office 2010 application package; using Past (version 2.17, Norway, Oslo, 2012) statistical data processing program. All data are presented as mean (μ) values and lower (LL) and upper limit (UL) of the 95% confidence interval (μ; (LL; UL 95% CI)) of the physiometric parameter.

3. Results and Their Discussion

The results of the comparison of respiratory function, hemodynamic parameters, and HGS in adolescents living in different ecological regions of the Republic of Karakalpakstan are presented in Tables 1 and 2.

Among adolescent boys residing in areas with different ecological conditions, statistically significant differences were found in VLC, hemodynamic indicators such as SBP and DBP, and HGS (for both right and left hands) ($p<0.001$) (Table 1). However, the comparative analysis of heart rate showed no statistically significant intergroup differences ($p>0.05$).

Data analysis revealed that adolescents living in Turtkul district had significantly higher values of VLC compared to their peers from Muynak and the city (3629.76 ml; 3312.05 ml; 3355.06 ml, respectively) ($p<0.001$). Regarding HGS (right hand), adolescents from Turtkul showed significantly higher values compared to their peers from Muynak (34.88 kg vs. 32.23 kg, respectively) ($p<0.001$). For left- HGS, significantly higher values were observed in adolescents from Turtkul and Nukus compared to those from Muynak (33.12 kg; 32.70 kg; 29.97 kg, respectively) ($p<0.01$).

SBP values followed the trend Muynak > Nukus > Turtkul (123.95 mmHg; 120.03 mmHg; 116.00 mmHg, respectively) ($p<0.001$). Adolescents from Muynak demonstrated significantly higher DBP (81.49 mmHg) compared to their peers from the city (78.00 mmHg) ($p<0.01$).

Among adolescent girls living in regions with different ecological conditions, statistically significant differences were found in VLC, hemodynamic indicators such as SBP, HGS (for the right hand), and HR ($p<0.01$) (Table 2). Only in terms of HGS (for the left hand) and DBP, the comparative analysis did not reveal statistically significant intergroup differences ($p>0.05$).

Data analysis revealed that adolescents living in the Turtkul district had a statistically significantly higher VLC compared to their peers from Muynak and the city (3175.58 ml; 2961.66 ml; 3037.67 ml, respectively) ($p<0.05$). HGS (right hand) was also found to be significantly higher among adolescents from Turtkul compared to their peers from Muynak (27.95 kg vs. 26.00 kg) ($p<0.05$).

Table 1. Comparison of respiratory function, hemodynamic parameters, and HGS in adolescent boys from the studied regional groups (μ; 96% CI) (n=983)

Regions / Parameters	Muynak District (n=302)	Nukus city (n=345)	Turtkul District (n=336)	P value	P-values for pairwise comparisons between groups		
					Muynak-Nukus	Muynak-Turtkul	Nukus-Turtkul
Lung vital capacity, ml	3312,05 (3238,8; 3385,3)	3355,06 (3286,3; 3423,8)	3629,76 (3550,3; 3709,2)	$2,327\times10^{-12}$	0,8654	$4,776\times10^{-11}$	$8,11\times10^{-9}$
Handgrip strength (right hand), kg	32,23 (31,39; 33,07)	33,84 (32,88; 34,80)	34,88 (33,96; 35,86)	0,0002224	0,2679	$8,96\times10^{-5}$	0,07466
Handgrip strength (left hand), kg	29,97 (29,14; 30,79)	32,70 (31,82; 33,57)	33,12 (30,40; 35,83)	$5,613\times10^{-5}$	0,01746	$3,141\times10^{-5}$	0,3785
Systolic blood pressure, mmHg	123,95 (122,39; 125,52)	120,03 (118,36; 121,70)	116,00 (114,56; 117,43)	$1,062\times10^{-13}$	0,0001226	$6,037\times10^{-14}$	0,001224
Diastolic blood pressure, mmHg	81,49 (79,93; 83,04)	78,00 (76,58; 79,42)	79,28 (78,13; 80,43)	0,006973	0,005785	0,8922	0,1233
Heart rate, beats/min	85,46 (84,34; 86,59)	85,55 (84,31; 86,80)	86,85 (85,70; 88,00)	0,06837	1	0,2241	0,09339

Note. * – calculated using the Kruskal-Wallis test; ** – calculated using the Mann-Uitney test.

Table 2. Comparison of respiratory function, hemodynamic indicators, and HGS in adolescent girls living in the studied regional groups (μ; 96% CI) (n=872)

Regions / Parameters	Muynak District (n=299)	Nukus city (n=264)	Turtkul District (n=309)	P value	P-values for pairwise comparisons between groups		
					Muynak-Nukus	Muynak-Turtkul	Nukus-Turtkul
Lung vital capacity, ml	2961,66 (2886,80; 3036,60)	3037,67 (2978,8; 3096,6)	3175,88 (3124,0; 3227,8)	$7,9\times10^{-9}$	0,03415	$8,474\times10^{-9}$	0,0004671
Handgrip strength (right hand), kg	26,00 (25,22; 26,78)	26,10 (24,57; 27,64)	27,95 (25,83; 30,06)	0,02204	1	0,02064	0,2308
Handgrip strength (left hand), kg	23,64 (23,07; 24,21)	24,40 (23,78; 25,00)	24,22 (23,46; 25,00)	0,1883	0,217	0,6612	1
Systolic blood pressure, mmHg	117,14 (115,85; 118,43)	109,80 (108,43; 111,16)	110,22 (108,89; 111,55)	$1,996\times10^{-15}$	$1,278\times10^{-13}$	$2,745\times10^{-10}$	0,7417
Diastolic blood pressure, mmHg	76,66 (75,63; 77,70)	76,98 (75,62; 78,35)	77,24 (76,30; 78,18)	0,3249	1	0,3101	1
Heart rate, beats/min	88,43 (86,88; 89,97)	87,58 (86,33; 88,83)	84,13 (82,99; 85,26)	$1,393\times10^{-5}$	1	0,0002482	0,001120

Note. * – calculated using the Kruskal-Wallis test; ** – calculated using the Mann-Uitney test.

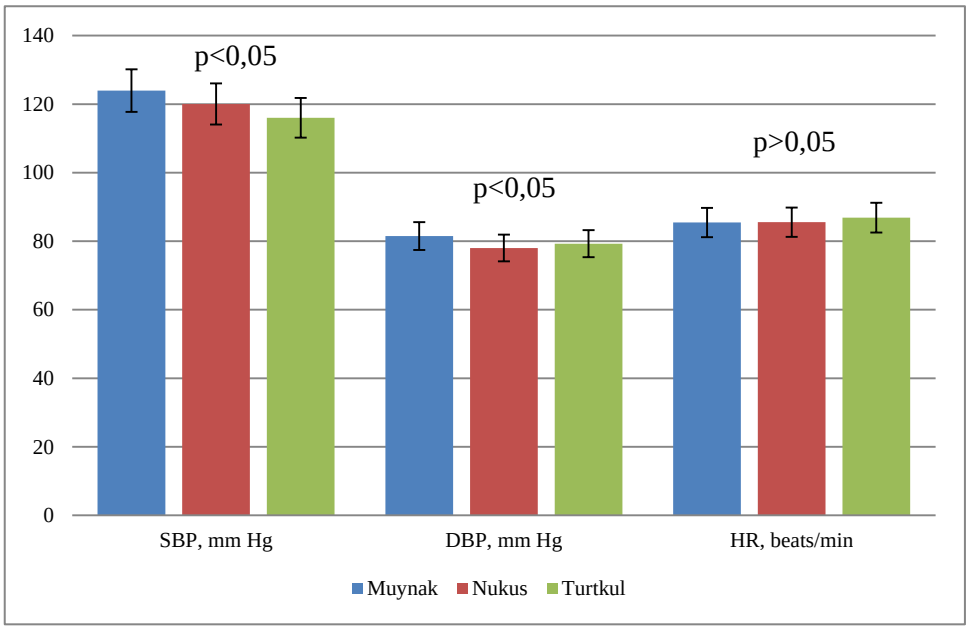

Figure 2. Comparison of hemodynamic parameters in boys living in the studied regions (n=983)

It was found that the SBP values of girls from Muynak were statistically significantly higher than those of girls living in Nukus city and Turtkul district (117.14 mmHg; 109.80 mmHg; 110.22 mmHg, respectively) ($p<0.001$). Among Muynak and urban adolescent girls, DBP values (88.43 mmHg; 87.58 mmHg) were statistically significantly higher compared to their peers in Turtkul district (84.13 mmHg) ($p<0.01$).

When analyzing and summarizing the obtained results by regions, it was noted that the VLC among adolescents living in the Turtkul district was higher compared to their peers from other regions. In particular, the vital capacity indices of boys from Turtkul were 9-10% higher than those of adolescents from Muynak and Nukus city, while in girls this difference amounted to 4-7%. HGS was also relatively higher in the Turtkul district, with boys showing an advantage in both hands, and girls demonstrating a significant superiority in right-HGS.

In contrast, hemodynamic indicators were found to be higher among adolescents living in the Muynak region. In boys, SBP increased in the sequence Muynak > Nukus > Turtkul. Likewise, DBP in Muynak adolescents was higher compared to their peers from urban areas. A similar trend was observed in girls: SBP in Muynak was recorded to be 6-7% higher than in Nukus and Turtkul, while DBP in Muynak and Nukus girls was 4-5% higher compared to those

from Turtkul. These findings suggest that adolescents residing in ecologically unfavorable conditions experience increased functional load on the hemodynamic system.

Overall analyses indicate that adolescents residing in Turtkul district demonstrate advantages in terms of respiratory function and HGS, whereas those in the Muynak region exhibit elevated hemodynamic indicators. Adolescents in Nukus city occupy an intermediate position across these parameters. Such differences may be explained by ecological factors, air quality, lifestyle, physical activity, and nutritional characteristics.

The higher VLC observed in Turtkul may be attributed to relatively favorable ecological conditions, better air quality, more active daily routines, and adequate nutrition. In contrast, the lower VLC recorded in Muynak (exposed to saline dust aerosols, dry winds, and ecological stress) can be associated with airway inflammation, increased bronchial reactivity, and a tendency toward ventilatory restriction.

The higher HGS observed in adolescents from Turtkul may be associated with greater physical activity, more favorable anthropometric parameters, and better nutritional quality. In contrast, in Muynak, HGS indicators were relatively lower, which could be explained by chronic ecological stress, micronutrient deficiencies, and respiratory system limitations. Elevated BP in Muynak adolescents may represent an adaptive response to unfavorable ecological conditions and could be related to increased sympathetic activity, endothelial dysfunction, oxidative stress, and psychosocial burdens. In Nukus, higher values of BP may be influenced by urban factors such as vehicle emissions and the fast-paced city lifestyle. Meanwhile, lower hemodynamic parameters observed in Turtkul reflect a relatively "milder" ecological background, suggesting more favorable living conditions compared to the other studied regions [9].

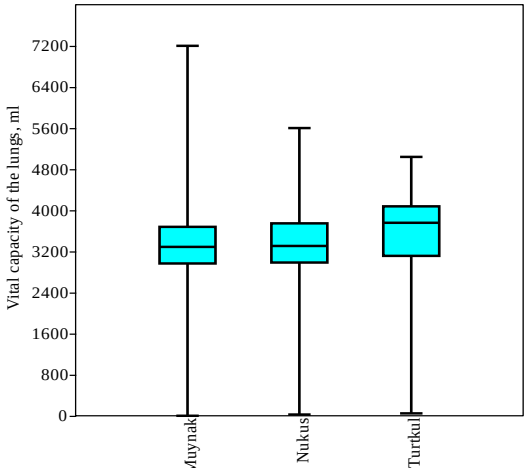

Figure 3. Comparison of VLC among boys living in different ecological regions (n=983)

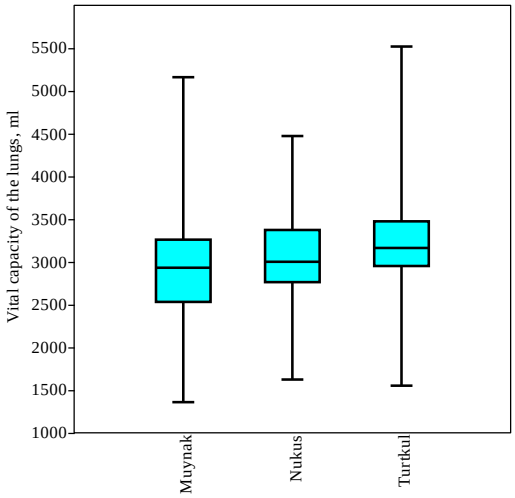

Figure 4. Comparison of VLC among girls living in different ecological regions (n=872)

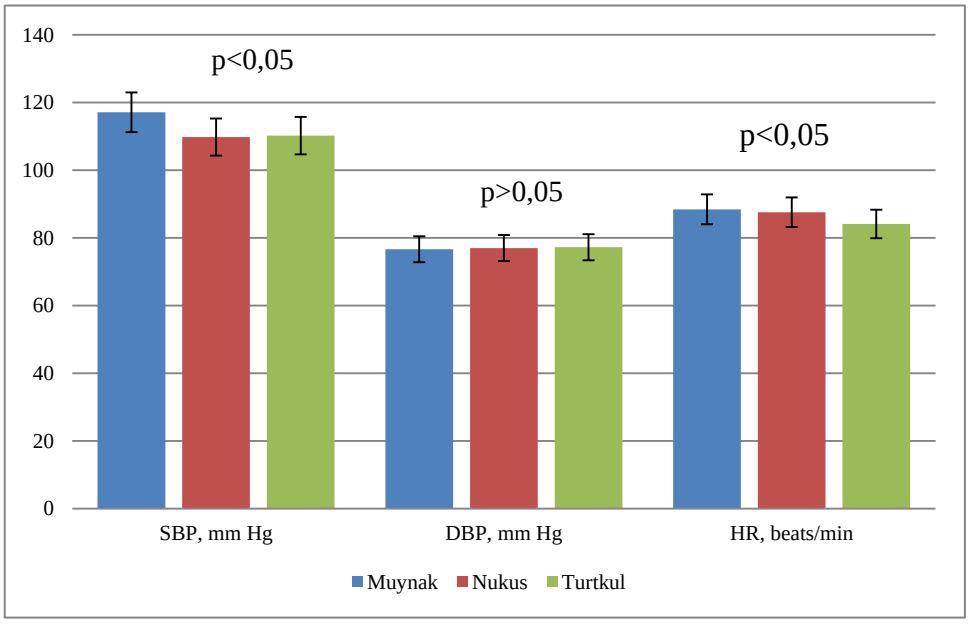

Figure 5. Comparison of hemodynamic parameters in girls living in the studied regions (n=872)

This study demonstrated that adolescents living in different ecological zones of Karakalpakstan exhibit stable and biologically explainable differences in functional parameters. Overall, the findings confirm a directional relationship between the ecological gradient (Muynak – most unfavorable, Nukus – intermediate, Turtkul – relatively favorable) and key physiological indicators, including VLC, hemodynamic parameters, and HGS. The results clearly indicate that respiratory, cardiovascular, and muscular function in adolescents vary significantly across the studied regions. These outcomes are partly consistent with the results of previous research conducted in other ecological contexts, further supporting the evidence that environmental conditions exert a substantial influence on adolescent health and development.

Specifically, a number of studies conducted in the Aral Sea ecological disaster zones have also reported decreased VLC in children and adolescents, accompanied by increased arterial blood pressure. For example, observations among schoolchildren living in the Aral Sea crisis areas and adjacent districts have shown that respiratory parameters are lower compared to those of peers residing in relatively clean ecological regions [10]. This finding is fully consistent with our results, since in our study as well, adolescents living in Muynak demonstrated reduced vital capacity values, whereas SBP and DBP levels were significantly elevated ($p<0.05$). Several epidemiological studies carried out in the Aral Sea region and neighboring areas have also described reductions in pulmonary ventilatory volumes (such as VLC, FVC, and FEV1), along with an increased prevalence of respiratory symptoms [10,11]. At the same time, some studies have suggested that respiratory dysfunctions cannot be fully explained by interregional variations in dust deposition alone, although a negative association between elevated summer dust levels and ventilatory parameters has been identified [12,13]. In other words, while many investigations confirm reductions in overall lung volume parameters in the Aral region, the magnitude of the effect and its causal mechanisms vary across studies.

In a number of international studies, the adverse effects of occupational exposure to organic dust on human health, particularly on the functional parameters of the respiratory system, have been extensively investigated. In particular, observations conducted among workers employed in the textile industry (especially cotton processing factories), paper production, woodworking, agriculture, and flour and grain processing sectors have demonstrated that chronic exposure to organic dust leads to a significant decline in pulmonary functional capacity [14,15]. According to the scientific literature, industrial workers exposed to organic dust show consistent reductions in key spirometric indices [13,16]. These changes are attributed to impaired ventilatory capacity, restricted bronchial conductance, and diminished respiratory reserve function [13-15]. Furthermore, other authors [17,18] have argued that the primary reasons for such pathological alterations include insufficient workplace ventilation systems, as well as inadequate use of protective masks and respirators during occupational activities. This results in workers being directly exposed to high concentrations of dust aerosols. Epidemiological studies carried out in highly polluted regions of Germany revealed that the prevalence of bronchial asthma, chronic cough, and dyspnea among children was nearly twice as high compared to those living in ecologically cleaner areas [19]. Similarly, large-scale studies conducted in China reported that children residing in industrially polluted provinces had 12–18% lower lung volumes compared to their counterparts living in less polluted regions [20].

Hemodynamic parameters were also observed to be sensitive to environmental factors. In our study, adolescents residing in the Muynak district demonstrated higher SBP and DBP compared to their peers from other regions. Similar findings were reported in studies conducted in Tashkent city and the Fergana Valley [21,22], where adolescents living in environments with high levels of industrial emissions and transport-related pollutants exhibited elevated cardiovascular indicators, particularly arterial blood pressure. In addition, comparable research carried out in ecologically unfavorable regions of Russia also documented reductions in lung volumes and signs of cardiovascular strain among adolescents [23,24]. These findings are consistent with our results, suggesting that the impact of environmental conditions on the health of children follows a similar pattern across different regions.

Recent meta-analyses and numerous observational studies have demonstrated that air pollution – particularly PM2.5 and ultrafine particulate matter (UFP) – is associated with elevated SBP and DBP in children and adolescents. Both short- and long-term exposures have shown positive associations [25-27]. Several studies have noted that SBP tends to be more strongly associated with short- and long-term exposures compared to DBP [26,27]. Analyses indicate that even small increases in PM exposure can influence SBP and DBP levels [25-27]. Mechanistically, PM and toxic substances may enter the bloodstream, enhance inflammatory mediators, induce vasoconstriction, and consequently elevate blood pressure [25,27]. Therefore, the cardiovascular load observed in Muynak, associated with ecological stressors such as dust-salt storms, wind, and other environmental factors, aligns well with mechanisms described in the literature. In addition, region-specific contributors in the Aral Sea area such as long-term contamination of water, soil, and food, the biological accumulation of toxic chemicals (particularly certain POPs and heavy metals) [5,7,8,10,11,28], and psychosocial stress [29] may also play a role in affecting hemodynamic parameters. These aspects highlight the need for future studies integrating comprehensive ecological and biomonitoring data.

Air pollution and other environmental factors have been reported in numerous studies to influence HR and heart rate variability (HRV) disturbances [29]. In particular, short-term PM exposures in children and adolescents have been associated with alterations in HR and HRV [30,31]. Sex-related differences

have also been discussed in the literature. Specifically, differences observed in girls may theoretically be related to pubertal status, psychosocial stress load, and the influence of sex hormones. The literature suggests that the primary mechanisms underlying these changes include alterations in autonomic tone and reductions in HRV [32].

The results on HGS are also consistent with the literature. In particular, data indicate that children living in more favorable ecological environments demonstrate higher physical development indicators, including HGS [33]. In our study as well, adolescents residing in the Turtkul district were found to have higher HGS compared to those from other regions, confirming these literature findings. HGS is a reliable indicator of overall muscle strength and functionality in children and adolescents. Its level is strongly associated with anthropometry, sex, pubertal status, and nutrition. Moreover, low HGS may also be linked to metabolic and cardiometabolic risk factors [34-36]. Lower HGS values compared to normative standards are considered a general indicator of malnutrition, and its use is recommended for nutritional intervention [37]. The importance of nutrition during childhood and adolescence is crucial and depends on the key factors that determine differences and disorders in the child's body. This, in turn, necessitates studying the actual nutrition of adolescents in the investigated regions in future research.

4. Conclusions

Overall, our research findings are consistent with observations conducted in other regions, including the Aral Sea area, industrial zones, and environmentally unfavorable territories. The distinguishing feature, however, is that within Karakalpakstan, the ecological gradient is much more pronounced, with particularly sharp differences observed in adolescents from the Muynak district in terms of respiratory and hemodynamic parameters as well as HGS. These results demonstrate that the impact of ecological factors on the health of the growing generation has specific regional characteristics, which may also be associated with adolescents' lifestyle, physical activity, and nutritional factors.

Conflicts of Interest

The authors declare no conflict of interest.

Author Contributions

K.U. Rozumbetov: Writing – original draft, Supervision and Project Administration, Conceptualization, Visualization, Methodology, Investigation, Resources. **G.K. Shamuratova**: Resources, Data curation. **A.T. Esimbetov**: Writing – review & editing, Validation, Formal analysis, Data curation.

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