

ENVIRONMENTAL ASSESSMENT OF THE EFFECTS OF AIR POLLUTION AND GEOMAGNETIC ACTIVITY ON HEMATOLOGICAL PARAMETERS IN CHILDREN WITH CONGENITAL HEART DEFECTS IN BAKU

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Summary. Children with congenital heart defects (CHDs) may be particularly vulnerable to environmental stressors. This study investigated associations of geomagnetic activity and ambient air pollution with hematological parameters in 42 children aged 3 months to 15 years with echocardiographically confirmed CHDs in Baku, Azerbaijan. Participants were examined on 21 different days in 2023. Geomagnetic activity was characterized using the Kp index, while air pollution was assessed using daily indicators, particularly PM2.5 and particulate matter. Associations with leukocyte, erythrocyte, and platelet parameters were evaluated using Pearson's correlation coefficient. The Kp index was negatively correlated with PLT ($r = -0.414$, $p < 0.01$) and PCT ($r = -0.419$, $p < 0.01$). Particulate pollution showed positive correlations with WBC ($r = 0.321$), RDW-SD ($r = 0.360$), and RDW-CV ($r = 0.415$), and negative correlations with BAS% ($r = -0.434$), EOS# ($r = -0.444$), and EOS% ($r = -0.436$) ($p < 0.01$). PM2.5 was negatively correlated with PLT ($r = -0.374$), PCT ($r = -0.406$), BAS# ($r = -0.567$), BAS% ($r = -0.478$), and EOS# ($r = -0.334$) ($p < 0.01$). No significant correlations were found between geomagnetic activity and air-pollution indicators ($p > 0.05$). These findings suggest that geomagnetic activity and particulate air pollution are associated with distinct hematological variations in children with CHDs and warrant further investigation in larger longitudinal studies.

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1. Introduction

Environmental and geophysical stressors are increasingly investigated as potential modifiers of cardiovascular and hematological health. Among these factors, ambient air pollution and geomagnetic activity have attracted particular attention because of their reported associations with cardiovascular events and physiological responses. Previous studies have suggested relationships between geomagnetic disturbances and cardiovascular outcomes, including changes in hemostatic and platelet-related processes [1–4].

Children with congenital heart defects (CHDs) may represent a particularly vulnerable population because cardiovascular abnormalities and chronic hypoxia can influence compensatory and hematological mechanisms [5–8]. Environmental exposures may therefore be of particular relevance in this population. However, the hematological responses of children with CHDs to external physical and environmental factors remain insufficiently characterized.

Ambient air pollutants, particularly fine particulate matter (PM2.5) and other airborne particles, may also be associated with hematological and inflammatory responses. Although the effects of geomagnetic activity and air pollution have been investigated separately, considerably less is known about their relationships with hematological parameters in children with CHDs. Moreover, whether geomagnetic activity and local air-pollution indicators represent related exposures or act as independent environmental stressors remains unclear.

Baku provides a relevant setting for examining these relationships because children living in the city may be exposed to variations in both ambient air quality and geomagnetic conditions. Evaluation of these exposures

together with leukocyte, erythrocyte, and platelet indices may provide additional information on the hematological responses of children with CHDs.

Therefore, this study aimed to investigate the relationships between geomagnetic activity, represented by the Kp index, ambient air-pollution indicators, and hematological parameters in children with CHDs living in Baku, Azerbaijan. In addition, the study evaluated the relationship between geomagnetic activity and the investigated air-pollution indicators to determine whether their variations were statistically associated.

2. Materials and Methods

2.1. Study Population

The study included 42 children with congenital heart defects (CHDs) admitted to the Department of Pediatric Cardiac Surgery of the Scientific Surgery Center named after Academician M.A. Topchubashov, Ministry of Health of the Republic of Azerbaijan, on 21 different days in 2023. The participants ranged in age from 3 months to 15 years, with a mean age of 6.6 years. All participants were permanent residents of Baku, Azerbaijan.

CHD diagnoses were confirmed by echocardiography and included different structural cardiac abnormalities, such as atrial septal defect, ventricular septal defect, patent ductus arteriosus, and tetralogy of Fallot.

The inclusion criteria were permanent residence in the study area for at least six consecutive months and clinical and instrumental confirmation of CHD. Children with acute infectious diseases in the active phase, hematological or autoimmune diseases, or use of medications capable of directly affecting hematological parameters were excluded. Participation was based on formal ethical consent from the children and their parents or legal guardians.

2.2. Hematological Assessment

Venous blood samples were collected in the morning under fasting conditions from the antecubital vein into K3-EDTA tubes. Hematological measurements were performed using a fully automated hematology analyzer.

The investigated parameters included leukocyte indices (WBC, NEUT#, NEUT%, LYM%, BAS#, BAS%, EOS#, IG#, and IG%), erythrocyte indices (RBC, HGB, HCT, MCV, MCH, MCHC, RDW-CV, and RDW-SD), and platelet indices (PLT, PCT, MPV, PDW, and P-LCR).

2.3. Environmental and Geomagnetic Data

Daily environmental and medical data were recorded for the same 21 observation days in 2023. Geomagnetic activity was characterized using the Kp index, a global measure of disturbances in the Earth's magnetic field expressed on a scale from 0 to 9. Kp data were obtained from international monitoring sources.

Ambient air-pollution data were obtained from ground-level air-quality monitoring stations. The available environmental indicators included daily mean concentrations of carbon monoxide (CO) and PM_{2.5}, together with particulate pollution data used in the subsequent analyses.

2.4. Statistical Analysis

Associations between geomagnetic activity, air-pollution indicators, and hematological parameters were evaluated using Pearson's correlation coefficient (r). Statistical calculations were performed using Microsoft Excel. A value of $p < 0.05$ was considered statistically significant.

3. Results

3.1. Relationship Between Geomagnetic Activity and Air Pollution

No statistically significant correlations were observed between the Kp index and the investigated air-pollution indicators, including CO, SO₂, NO₂, PM₁₀, PM_{2.5}, and particulate matter ($p > 0.05$). Thus, variations in geomagnetic activity during the observation period were not statistically associated with variations in the measured ambient air-pollution indicators.

3.2. Geomagnetic Activity and Hematological Parameters

Significant negative correlations were observed between the Kp index and PLT ($r = -0.414$, $p < 0.01$) and between the Kp index and PCT ($r = -0.419$, $p < 0.01$) (Figure 1). In contrast, correlations between the Kp index and RBC ($r = 0.203$, $p > 0.05$) and RDW-SD ($r = 0.266$, $p > 0.05$) were weak and not statistically significant. No correlation between the Kp index and MPV was reported.

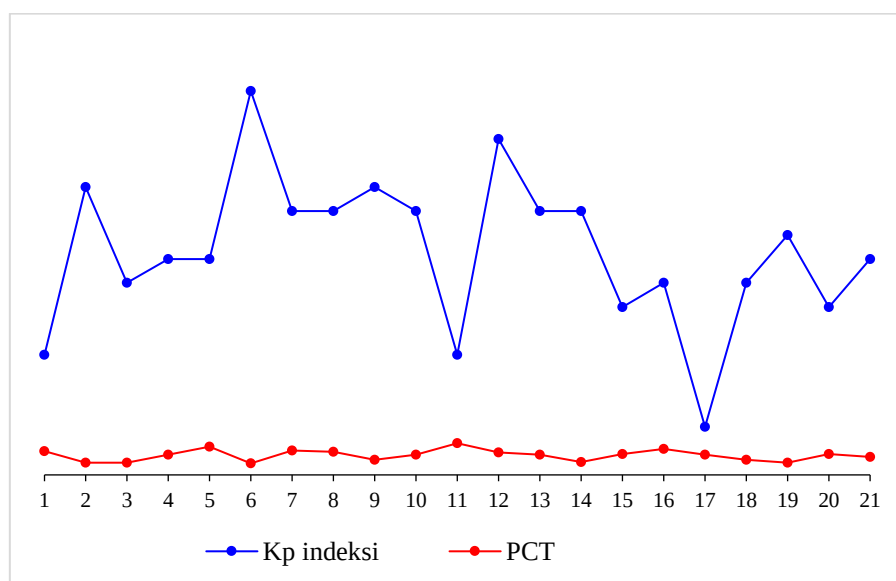


Fig. 1. Relationship between the Kp index and PCT in children with congenital heart defects in Baku

3.3. Particulate Pollution and Hematological Parameters

Particulate pollution showed significant positive correlations with WBC ($r = 0.321$, $p < 0.01$), RDW-SD ($r = 0.360$, $p < 0.01$), and RDW-CV ($r = 0.415$, $p < 0.01$). Significant negative correlations were observed with BAS% ($r = -0.434$, $p < 0.01$), EOS# ($r = -0.444$, $p < 0.01$), and EOS% ($r = -0.436$, $p < 0.01$). Positive correlations were also reported for NEUT# ($r = 0.305$, $p < 0.01$) and NEUT% ($r = 0.311$, $p < 0.01$). The relationships between particulate air pollution and WBC, RDW-SD, and RDW-CV in children with congenital heart defects are illustrated in Figure 2.

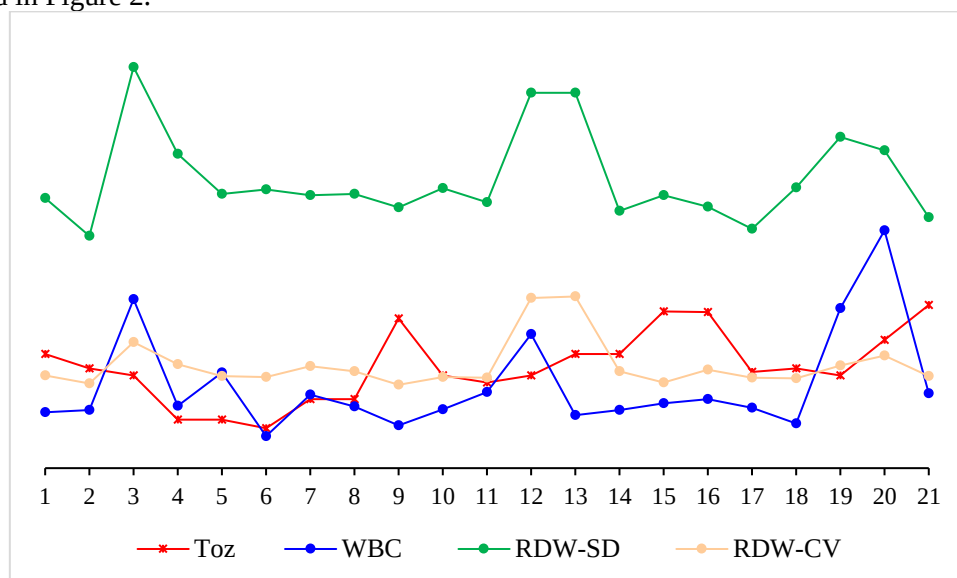


Fig. 2. Relationships of particulate pollution with WBC, RDW-SD, and RDW-CV in children with congenital heart defects in Baku

PM_{2.5} was negatively correlated with several hematological parameters, including PLT ($r = -0.374$, $p < 0.01$), PCT ($r = -0.406$, $p < 0.01$), BAS# ($r = -0.567$, $p < 0.01$), BAS% ($r = -0.478$, $p < 0.01$), and EOS# ($r = -0.334$, $p < 0.01$). Among these associations, the strongest reported correlation was observed between PM_{2.5} and BAS# ($r = -0.567$).

4. Discussion

The present study identified distinct associations between geomagnetic activity, particulate air pollution, and hematological parameters in children with congenital heart defects (CHDs) living in Baku. The principal findings were the negative correlations of the Kp index with PLT and PCT, as well as significant associations of particulate pollution and PM_{2.5} with several platelet, leukocyte, and erythrocyte-related indices. At the

same time, no statistically significant relationship was observed between geomagnetic activity and the investigated air-pollution indicators. Taken together, these findings suggest that geomagnetic variability and ambient particulate pollution may represent different environmental exposures associated with distinct patterns of hematological variation in children with CHDs.

One of the most notable findings was the negative association between geomagnetic activity and platelet-related parameters. The Kp index was negatively correlated with both PLT ($r = -0.414$, $p < 0.01$) and PCT ($r = -0.419$, $p < 0.01$), whereas no significant association with MPV was reported. Previous investigations have suggested that geomagnetic disturbances may be associated with cardiovascular and hemostatic responses [3–5]. Changes in platelet activity in relation to space-weather conditions have also been discussed in previous studies [3, 7]. The present results extend this line of investigation to a pediatric population with congenital cardiac abnormalities, in which the physiological response to external stressors may differ from that of healthy adults.

The simultaneous negative associations of the Kp index with PLT and PCT deserve particular attention. PLT reflects the circulating platelet count, whereas PCT represents the proportion of blood volume occupied by platelets. Their parallel associations with increasing Kp values may therefore indicate variation in the circulating platelet compartment during periods of increased geomagnetic activity. However, because the present study is observational and correlation-based, these findings should not be interpreted as evidence that geomagnetic activity directly causes platelet depletion or thrombocytopenia. Rather, they demonstrate a statistical relationship that requires confirmation in larger longitudinal studies.

The absence of a significant association between the Kp index and MPV may also be relevant. In the original hypothesis, this pattern was interpreted as potentially reflecting peripheral platelet consumption rather than impaired platelet production. Such an interpretation is biologically plausible in the context of CHDs, because chronic hypoxia and altered cardiovascular hemodynamics may influence platelet activation and microcirculatory processes [7, 8]. Nevertheless, MPV alone cannot distinguish peripheral platelet consumption from altered bone-marrow production. Therefore, the present findings should be regarded as supporting a hypothesis that can be tested using additional markers of platelet activation, coagulation, endothelial function, and bone-marrow response.

The vulnerability of children with CHDs may be particularly relevant when interpreting these observations. Congenital structural abnormalities of the heart can be accompanied by chronic or intermittent hypoxemia, altered blood flow, and compensatory hematological responses. Previous work has described hematological adaptation in pediatric patients with CHDs under chronic hypoxic conditions [8]. Against this background, additional environmental or geophysical stressors could potentially be associated with measurable changes in circulating blood-cell parameters. The present study does not establish the biological pathway responsible for such changes, but the observed platelet-related associations indicate that this question merits further investigation.

In contrast to the platelet-dominant pattern observed for the Kp index, particulate air pollution was associated with a broader spectrum of hematological parameters. Total particulate pollution showed positive correlations with WBC, RDW-SD, RDW-CV, NEUT#, and NEUT%, together with negative correlations with BAS%, EOS#, and EOS%. These findings indicate simultaneous variations in leukocyte and erythrocyte-distribution indices in relation to particulate exposure. The positive association with WBC and neutrophil indices may be consistent with an inflammatory response to airborne particulate exposure, although the cross-sectional correlation analysis used in this study cannot establish an inflammatory mechanism.

The associations involving RDW are also of interest. RDW-CV and RDW-SD characterize variation in erythrocyte size and are commonly used as indicators of erythrocyte heterogeneity. In the present study, particulate pollution was positively associated with both indices. This observation suggests that increased particulate exposure may coincide with greater variability in erythrocyte morphology in children with CHDs. However, RDW is influenced by multiple clinical and nutritional factors. Therefore, the observed relationships cannot specifically be attributed to iron deficiency, vitamin B12 deficiency, folate deficiency, anemia of chronic disease, or any other particular mechanism without corresponding biochemical measurements. The original data did not include these measurements, and these mechanisms should consequently be regarded as possible explanations rather than established outcomes.

PM2.5 demonstrated a somewhat different pattern. Negative correlations were observed between PM2.5 and PLT ($r = -0.374$), PCT ($r = -0.406$), BAS# ($r = -0.567$), BAS% ($r = -0.478$), and EOS# ($r = -0.334$), with all of these relationships reported at $p < 0.01$. The strongest reported association was between PM2.5 and BAS# ($r = -0.567$). The associations of PM2.5 with PLT and PCT are particularly noteworthy because the same platelet indices were also negatively associated with the Kp index. This convergence identifies platelet-

related parameters as potentially sensitive hematological indicators in the study population, although the mechanisms associated with the two exposures may differ.

Particulate matter, particularly fine particles such as PM_{2.5}, has received substantial attention because of its potential cardiovascular effects. Previous research has established the broader relevance of particulate air pollution to cardiovascular health [1]. Fine particles may interact with the respiratory system and may be associated with systemic biological responses. In children already affected by congenital cardiac abnormalities, such environmental exposure could be particularly important. Nevertheless, the present study measured statistical associations rather than individual-level biological exposure, and therefore direct mechanistic conclusions cannot be drawn.

An additional finding was the absence of statistically significant correlations between the Kp index and the investigated air-pollution indicators ($p > 0.05$). This is important for interpreting the other results. Within the observation period, changes in geomagnetic activity were not statistically synchronized with variations in CO, SO₂, NO₂, PM₁₀, PM_{2.5}, or particulate pollution. Thus, the observed associations of the Kp index and particulate pollution with hematological parameters cannot simply be explained by a significant correlation between these two groups of environmental variables.

However, the absence of correlation between geomagnetic activity and air pollution should not be interpreted as proof that the two exposures act independently on the human body. Demonstrating independent effects would require multivariable statistical modelling in which geomagnetic activity, individual pollutants, meteorological conditions, demographic characteristics, CHD type and severity, and other potential confounders are evaluated simultaneously. The present Pearson correlation analysis does not provide such adjustment. Consequently, the results indicate distinct statistical associations, rather than confirmed independent biological effects.

This distinction is particularly important when considering the original observation that both higher Kp values and higher PM_{2.5} concentrations were negatively correlated with PLT and PCT. Although this pattern raises the possibility that platelet-related parameters may respond to multiple environmental stressors, the current analysis cannot determine whether their associations are additive, synergistic, or independent. A formal interaction analysis would be necessary to establish whether simultaneous elevations in geomagnetic activity and PM_{2.5} are associated with greater hematological changes than either exposure alone.

The study also has potential clinical relevance. Children with CHDs constitute a heterogeneous population, and their hematological status may be influenced by the type and severity of cardiac defect, oxygen saturation, surgical history, medication use, nutritional status, and other clinical factors. Identification of environmental conditions associated with variations in platelet and inflammatory-related indices may therefore contribute to a broader understanding of environmental vulnerability in this population. At the same time, the present results are not sufficient to support specific therapeutic interventions, including antioxidant treatment or changes in clinical management, without prospective clinical evidence.

From an environmental-health perspective, the findings support further investigation of air quality as a potentially relevant factor for vulnerable pediatric groups in Baku. The associations of particulate pollution with WBC, neutrophil indices, RDW indices, basophils, eosinophils, PLT, and PCT suggest that future studies should evaluate not only conventional cardiovascular outcomes but also detailed hematological profiles. Combining environmental monitoring with repeated individual blood measurements could help determine whether short-term changes in particulate exposure precede measurable hematological responses.

The present study also contributes to the comparatively limited literature examining geomagnetic activity in pediatric cardiovascular populations. Most previous research cited in this study has focused on cardiovascular events, mortality, hemostatic responses, or platelet activity in broader or adult populations [2–7]. By focusing specifically on children with CHDs, the present analysis identifies a population in which geomagnetic–hematological relationships have received substantially less attention. This represents one of the main potential contributions of the study, although the findings should be considered exploratory because of the relatively small sample and limited observation period.

4.1. Study limitations

Several limitations should be considered when interpreting the findings. First, the study included 42 children examined across 21 observation days, which limits statistical power and the generalizability of the results. Second, the analysis was based primarily on bivariate Pearson correlations and therefore did not control for potential confounding factors.

Third, children with different forms of CHD were analyzed together. Atrial septal defect, ventricular septal defect, patent ductus arteriosus, tetralogy of Fallot, and other CHDs may differ substantially in their hemodynamic characteristics and degree of hypoxia. Future studies should therefore stratify participants according to

CHD type, cyanotic status, disease severity, and oxygen saturation.

Fourth, the available analysis does not account for several potentially relevant individual-level variables, including sex, nutritional status, body mass index, iron status, vitamin B12 and folate levels, socioeconomic conditions, and previous surgical interventions. These variables may influence hematological parameters and should be incorporated into future multivariable analyses.

Fifth, ambient monitoring data represent environmental concentrations and may not accurately reflect individual exposure. Personal exposure to PM_{2.5} and other pollutants may vary according to residential location, indoor air quality, daily activity patterns, and time spent outdoors. Future studies would benefit from spatially resolved exposure assessment or individual monitoring.

Finally, the use of multiple correlations across a relatively large number of hematological parameters increases the possibility of chance findings. Future investigations should use larger samples, repeated-measures designs, multivariable regression models, and appropriate correction for multiple comparisons. These approaches would allow a more robust assessment of whether geomagnetic activity and air pollution are independently associated with hematological changes in children with CHDs.

4.2. Implications and future research

Future studies should integrate **geomagnetic, environmental, meteorological, and clinical data** within a unified analytical framework. Repeated hematological measurements in the same children before, during, and after periods of increased geomagnetic activity or elevated air pollution would provide stronger temporal evidence than cross-sectional correlations. Inclusion of platelet-activation markers, inflammatory biomarkers, coagulation parameters, oxygen saturation, and detailed CHD characteristics would also help clarify the biological pathways underlying the observed associations.

Larger multicenter studies involving children from both highly polluted and relatively less polluted areas could further determine whether the associations observed in Baku are reproducible in other environmental settings. Such studies may ultimately help identify environmental conditions associated with increased physiological stress in children with congenital cardiovascular disease.

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ОЦЕНКА ВЛИЯНИЯ ЗАГРЯЗНЕНИЯ АТМОСФЕРНОГО ВОЗДУХА И ГЕОМАГНИТНОЙ АКТИВНОСТИ НА ГЕМАТОЛОГИЧЕСКИЕ ПОКАЗАТЕЛИ У ДЕТЕЙ С ВРОЖДЁННЫМИ ПОРОКАМИ СЕРДЦА В ГОРОДЕ БАКУ

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Резюме. Дети с врождёнными пороками сердца (ВПС) могут быть особенно восприимчивы к стрессовым факторам окружающей среды. В исследовании изучались взаимосвязи геомагнитной активности и загрязнения атмосферного воздуха с гематологическими показателями у 42 детей в возрасте от 3 месяцев до 15 лет с эхокардиографически подтверждёнными врождёнными пороками сердца в городе Баку (Азербайджан). Обследование участников проводилось в течение 21 отдельного дня в 2023 году. Геомагнитная активность характеризовалась индексом Кр, тогда как загрязнение атмосферного воздуха оценивалось по суточным показателям, в частности PM2.5 и содержанию взвешенных частиц. Взаимосвязи с показателями лейкоцитов, эритроцитов и тромбоцитов оценивались с использованием коэффициента корреляции Пирсона. Установлена отрицательная корреляция индекса Кр с показателями PLT ($r = -0,414$; $p < 0,01$) и PCT ($r = -0,419$; $p < 0,01$). Загрязнение воздуха взвешенными частицами продемонстрировало положительные корреляции с WBC ($r = 0,321$), RDW-SD ($r = 0,360$) и RDW-CV ($r = 0,415$), а также отрицательные корреляции с BAS% ($r = -0,434$), EOS# ($r = -0,444$) и EOS% ($r = -0,436$) ($p < 0,01$). Выявлены отрицательные корреляции PM2.5 с PLT ($r = -0,374$), PCT ($r = -0,406$), BAS# ($r = -0,567$), BAS% ($r = -0,478$) и EOS# ($r = -0,334$) ($p < 0,01$). Статистически значимых корреляций между геомагнитной активностью и показателями загрязнения атмосферного воздуха не обнаружено ($p > 0,05$). Полученные результаты свидетельствуют о том, что геомагнитная активность и загрязнение атмосферного воздуха взвешенными частицами связаны с различными изменениями гематологических показателей у детей с врождёнными пороками сердца, что обуславливает необходимость дальнейших исследований с более крупными выборками и продольным дизайном.

Ключевые слова: врожденные пороки сердца, геомагнитная активность, индекс Кр, загрязнение воздуха, PM2.5, гематологические показатели, дети

BAKIDA ANADANGƏLMƏ ÜRƏK QÜSURLU UŞAQLARIN HEMATOLOJİ GÖSTƏRİCİLƏRİNƏ HAVA ÇİRLƏNMƏSİNİN VƏ GEOMAQNİT AKTİVLİYİN TƏSİRİNİN EKOLOJİ QIYMƏTLƏNDİRİLMƏSİ

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Xülasə. Anadangəlmə ürək qüsurları (AÜQ) olan uşaqlar ətraf mühitin stress amillərinə qarşı xüsusilə həssas ola bilərlər. Tədqiqatda Azərbaycanın Bakı şəhərində exokardiografiya vasitəsilə anadangəlmə ürək qüsurları diaqnozu təsdiqlənmiş, 3 aylıqdan 15 yaşadək 42 uşaqda geomaqnit aktivliyi və atmosfer havasının çirklənməsi ilə hematoloji göstəricilər arasındakı əlaqələr araşdırılmışdır. İştirakçılar 2023-cü il ərzində 21 müxtəlif gündə müayinə olunmuşdur. Geomaqnit aktivliyi Kp indeksi əsasında, atmosfer havasının çirklənməsi isə gündəlik göstəricilər, xüsusilə PM2.5 və havadakı asılı hissəciklər əsasında qiymətləndirilmişdir. Leykosit, eritrosit və trombosit göstəriciləri ilə əlaqələr Pirsonun korrelyasiya əmsalı vasitəsilə təhlil edilmişdir. Kp indeksi ilə PLT ($r = -0,414$; $p < 0,01$) və PCT ($r = -0,419$; $p < 0,01$) arasında mənfi korrelyasiya müəyyən edilmişdir. Havadakı asılı hissəciklərlə çirklənmə WBC ($r = 0,321$), RDW-SD ($r = 0,360$) və RDW-CV ($r = 0,415$) göstəriciləri ilə müsbət, BAS% ($r = -0,434$), EOS# ($r = -0,444$) və EOS% ($r = -0,436$) göstəriciləri ilə isə mənfi korrelyasiya nümayiş etdirmişdir ($p < 0,01$). PM2.5 ilə PLT ($r = -0,374$), PCT ($r = -0,406$), BAS# ($r = -0,567$), BAS% ($r = -0,478$) və EOS# ($r = -0,334$) göstəriciləri arasında mənfi korrelyasiya aşkar edilmişdir ($p < 0,01$). Geomaqnit aktivliyi ilə atmosfer havasının çirklənmə göstəriciləri arasında statistik əhəmiyyətli korrelyasiya müəyyən edilməmişdir ($p > 0,05$). Əldə edilən nəticələr geomaqnit aktivliyi və atmosfer havasının asılı hissəciklərlə çirklənməsinin anadangəlmə ürək qüsurları olan uşaqlarda fərqli hematoloji dəyişikliklərlə əlaqəli olduğunu göstərir və daha geniş iştirakçı qruplarını əhatə edən uzunmüddətli tədqiqatların aparılmasını zəruri edir.

Açar sözlər: anadangəlmə ürək qüsurları, geomaqnit aktivlik, Kp indeksi, hava çirklənməsi, PM2.5, hematoloji göstəricilər, uşaqlar