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Assessment of trace element and mineral levels in students from Turkmenistan in comparison to Iran and Russia

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Abstract

The objective of the present study was to assess essential trace element and mineral levels in serum, hair, and urine of healthy first-year students from Turkmenistan (n = 73) in comparison to students from Iran (n = 78) or Russia (n = 95). **Materials and methods.** Examination of foreign students was performed within two days after arrival to Russia during medical examination prior admission to RUDN University. Serum, hair, and urine trace element and mineral levels were assessed with inductively coupled plasma-mass spectrometry (ICP-MS). **Results.** The data demonstrate that the levels of trace elements and minerals in students from Turkmenistan share high similarity to elemental profiles of students from Iran. In comparison to students from Russia, subjects originating from Iran and Turkmenistan are characterized by lower serum cobalt (Co), chromium (Cr), copper (Cu), manganese (Mn), molybdenum (Mo), selenium (Se), vanadium (V), zinc (Zn) levels, higher urinary Cr, Cu, Fe, Mn, V, and Zn, lower urinary Co and hair Mo, Se, and Zn content. Concomitantly, students from Turkmenistan were characterized by lower urinary Cr and Cu, serum Cu and V levels, higher circulating Zn concentration, as well as the lower hair Cr, Cu, iodine (I) and magnesium (Mg) content in comparison to Iranian subjects. The discriminant analysis demonstrated that hair, serum, and urinary trace element and mineral levels contributed to complete discrimination between the groups of students from different countries. **Conclusions.** The high similarity of trace element and mineral status of students from Turkmenistan and Iran is expected to be mediated by similar geochemical conditions in the bordering countries.

Key words: copper; deficiency; micronutrients; trace elements; zinc.

Introduction

Essential trace elements and minerals play a significant role in human health due to their involvement in functioning of various organs and systems. Therefore, deficiency in trace elements and minerals is associated with development of various diseases. Specifically, Zn deficiency is associated with cardiovascular and endocrine diseases, immune deficiency, neurodegeneration, and neuropsychiatric diseases [1]. Due to the role of I as a constituent of thyroid hormones, its deficiency is associated with hypothyroidism and goiter [2]. In addition to endemic Keshan and Kashin-Beck diseases, Se deficiency was shown to be associated with cancer and cardiovascular pathology [3]. Moreover, Se deficiency was shown to affect thyroid function [4]. Both deficiency and overload of other metals including Fe and Cu [5-8], Co [9, 10], trivalent Cr and V [11], Ca and Mg [12, 13], Mn and Mo [14, 15] are associated with a variety of metabolic, cardiovascular, skeletal, and neurological disorders.

The prevalence of trace element and mineral deficiencies is characterized by significant regional differences. Specifically, Zn deficiency [16] and Fe-deficiency anemia [17] were shown to affect up to 17.3% and 24.3% of the world's population with the highest rates reaching 30% and more than 40% in South Asia and Sub-Saharan Africa, respectively. Se deficiency affects up to 1 billion people worldwide with a high rate of suboptimal Se intake in China, the Middle East, and Europe [3]. Moreover, it is expected that recent climate changes may result in a further decrease

in soil Se levels thus aggravating Se deficiency [18]. Regional differences in trace element and mineral status in populations are mediated by multiple environmental factors including environmental pollution rates, dietary and lifestyle patterns [19], as well as geochemistry [20]. Specifically, geochemical provinces endemic for I [21] or Se [22] deficiency have been estimated. Therefore, assessment of trace element status of different populations as recommended by the World Health Organization [23] has been widely used to reveal the subjects at high risk of overexposure or deficiency [24-26].

Turkmenistan is a country in Central Asia bordered by Kazakhstan, Uzbekistan, Afghanistan, Iran, as well as the Caspian Sea. Despite certain reports on the high prevalence of nutritional deficiency in Turkmenistan [27], the available data on essential trace element and mineral levels in Turkmenistan inhabitants are scarce. It has been reported that the Turkmenistan government made significant efforts for improvement of I [28] and Fe [29] intake of the population. However, recent data on Fe, I, as well as other essential trace elements and minerals in Turkmenistan are lacking. The existing indications of high risk of trace element undernutrition in the whole region of Central Asia [30] as well as bordering Iran [31] allow to hypothesize suboptimal body burden of essential trace elements and minerals in the population of Turkmenistan.

Therefore, the objective of the present study was to assess essential trace element and mineral levels in serum, hair, and urine of healthy first-year students of the RUDN University who arrived from Turkmenistan in comparison to students originating from Iran or Russia.

Materials and methods

The protocol of the study was approved by the Local Ethics Committee of the RUDN University (Moscow, Russia). All procedures performed were in agreement with the principles set in the Declaration of Helsinki and its later amendments (2013). All examinees were invited to participate and took part in the present study on a voluntary basis following the principle of informed consent. The present study was performed in the Medical Center of the RUDN University during the admission campaign of 2022-2023 (Peoples' Friendship University of Russia).

Study design

A total of 246 first-year male and female (1:1) students aged 18-30 years old (y.o.) originating from Ashgabat, Turkmenistan ($n = 73, 20.4 \pm 2.0$ y.o.), Tehran, Iran ($n = 78, 22.3 \pm 3.9$), and Moscow, Russia ($n = 95, 21.4 \pm 2.8$ y.o.) were enrolled in the present study. Examination of foreign students was performed within two days after arrival to Russia during medical examination prior admission to RUDN University. Hence, the examined foreign students were not affected by significant alterations in trace element and mineral status that could be caused by changes in dietary patterns due to long-term residence in Russia. Moreover, all examined students underwent medical examination and were healthy thus avoiding the potential impact of chronic diseases on trace element and mineral metabolism. Finally, the examined students did not experience prior occupational exposure to metals or other toxic substances, and thus may represent a sample of occupationally unexposed young adults from Turkmenistan, Iran, and Russia. In addition, smoking, specific dietary patterns (vegetarian), the use of hair dyes and trace element and/or mineral-enriched shampoos and other haircare products, and the presence of metallic implants including dental amalgams, were considered as exclusion criteria.

Sampling and preanalytical treatment

Hair sampling was performed by a nurse using ethanol-precleaned stainless-steel scissors after washing the hair with shampoos routinely used by examinees. A total of 0.05-0.1 g of the proximal parts (1-2 cm) of occipital scalp hair strands was collected and stored in paper envelopes until analysis.

Venous blood samples were collected in a fasting state from the cubital vein in the sitting position using 9-ml Vacuette® tubes (Greiner Bio-One International AG, Austria) with subsequent centrifugation at 1600 g for 10 min for separation of blood serum.

The second portion of urine was collected by the examinees in the morning after fasting overnight using Vacuette® Urine Collection Cups and subsequently used for analysis. The obtained serum and urine samples were transferred and stored in Eppendorf tubes at the temperature of -80°C until analysis.

Prior to analysis, hair, serum, and urine samples were subjected to preanalytical treatment. Briefly, hair samples were washed with acetone, rinsed three times with distilled deionized water ($18.2 \text{ M}\Omega \cdot \text{cm}$), and dried on air at room temperature to a stable weight. The washed hair samples were introduced into Teflon tubes for microwave-assisted acidic digestion in concentrated (65%) nitric acid (Sigma-Aldrich Co., USA) in TopWave (Analytik Jena, Germany) system for 20 min ($170 - 180^{\circ}\text{C}$). After cooling the system to a room temperature, the obtained digests were adjusted to a final volume of 15 ml with distilled deionized water.

Serum and urine samples were defrosted at room temperature and subsequently diluted (1:15 v/v) with a diluent containing 1% 1-Butanol (Merck KGaA, Germany), 0.1% Triton X-100 (Sigma-Aldrich, Co., USA), and 0.07% HNO_3 (Sigma-Aldrich, Co., USA) in distilled deionized water.

Analytical procedures and quality control

Analysis of serum, hair, and urine levels of essential trace elements (Co, Cr, Cu, Fe, I, Mn, Mo, Se, V, Zn) and minerals (Ca, Mg) was performed using inductively-coupled plasma mass-spectrometry with Agilent 7700x (Agilent Technologies, Tokyo, Japan) (Table 1). The limits of detection (LOD) and quantification (LOQ), as well as the background equivalent concentrations (BEC) for the analyzed elements are provided in Table S1. System calibration was performed using commercial calibrators RECIPE ClinCal Plasma Calibrator REF 9985 LOT 1177 and RECIPE ClinCal Urine Calibrator REF 9988 LOT 1489 (RECIPE Chemicals + Instruments GmbH, Germany). Internal online standardization was performed using 10 mg/L Indium prepared from Agilent 8500-6946 - Indium Internal Standard Stock Solution.

The certified reference materials of human hair (GBW09101, Shanghai Institute of Nuclear Research, China), human plasma (ClinChek® Plasma Control, Levels I, II, Lot 1286, RECIPE Chemicals + Instruments GmbH, Germany), and urine (ClinChek® Urine Control, Levels I, II, Lot 1227, RECIPE Chemicals + Instruments GmbH, Germany) were used for laboratory quality control. All estimates were within the certified range specified by the manufacturer, and the recovery rates for analysis of the certified reference materials of hair, serum, and urine varied in the range of 87-111%, 90-109%, and 88-113%, respectively.

The obtained data were also compared to the internationally estimated reference values of hair, plasma, and urinary trace element content in the same cohort of examinees published by Gouille et al. (2005) [32]. The reference values for missing elements were obtained from other studies [33-35].

Statistical analysis

The obtained data were processed with Statistica 10.0 software (StatSoft, Tulsa, OK, USA). Data distribution was assessed using Shapiro-Wilk test. In view of skewed distribution, median and the respective interquartile range boundaries were used as descriptive statistics. In order to evaluate the contribution of the country of origin, sex, and age into variability of trace element and mineral levels analysis of covariance (ANCOVA) was performed after log-transformation of the raw data. Group comparisons were performed using ANCOVA with Bonferroni post-hoc test. Discriminant analysis was performed in order to assess significant discrimination between the study groups based on urine (Model 1), serum (Model 2), hair (Model 3), and all samples (Model 4) trace element and mineral content with evaluation of significance of the distance between group centroids, as well as assessment of the key elements contributing to group discrimination. All tests were considered significant at $p < 0.05$

Results

Our results demonstrate that serum essential trace element levels in students from Turkmenistan and Iran are nearly similar, being highly different from those in Russian subjects (Table 2). Specifically, serum Co, Cu, Mn, Mo, Se, and Zn concentrations in examinees from Turkmenistan and Iran were significantly lower in comparison to the Russian students by 12% ($p < 0.001$) and 11% ($p < 0.001$), 19% ($p < 0.001$) and 12% ($p = 0.003$), 19% ($p = 0.001$) and 22% ($p < 0.001$), 40% ($p < 0.001$) and 39% ($p < 0.001$), 3% ($p = 0.005$) and 9% ($p < 0.001$), and 11% ($p < 0.001$) and 17% ($p < 0.001$), respectively. Moreover, serum V level was more than 4.75-fold and 4.5-fold higher than in students from Turkmenistan and Iran, respectively ($p < 0.001$). Serum Cr levels in subjects from Turkmenistan were significantly lower than those from Russia by 17% ($p = 0.046$). Concomitantly, students from Iran were characterized by 16% ($p = 0.043$) lower serum concentrations of Zn in comparison from Turkmenian examinees.

The results of analysis of covariance demonstrated that the country of origin had a significant impact on the observed group differences in serum Co, Cu, Mn, Mo, Se, V, and Zn, and to a lesser extent Fe (Table 3). In parallel with the country of origin, sex and age of the examinees also had a significant influence on serum trace element and mineral concentrations. Specifically, the age of the examinees had a significant impact on serum Cu and Fe levels. In turn, serum levels of all studied elements with the exception of I, Mn, and V were affected by sex of the examined students. In general, the data on urinary trace element levels also corroborate the similarity between examinees from Turkmenistan and Iran, although in contrast to serum levels of most of the studied elements in urine exceeded the respective values in Russian students (Table 4). Specifically, urinary Mn levels in students from Turkmenistan and Iran exceeded the respective values in examinees from Russia by 54% ($p < 0.001$) and 55% ($p < 0.001$), respectively. At the same time, urinary Cu and Fe concentrations in Turkmenian and Iranian examinees were more than 2-fold higher than in domestic students (all $p < 0.001$). Urinary V excretion in foreign students exceeded that in Russian examinees by a factor of more than six ($p < 0.001$). At the same time, urinary Cr levels in students from Iran were 48% ($p < 0.001$) and 22% ($p = 0.048$) higher than in examinees from Russia and Turkmenistan, respectively. The level of Zn in urine of students from Iran was nearly significantly higher than that in Russian examinees by 59% ($p = 0.068$), whereas the difference between subjects from Russia and Turkmenistan was not significant due to high variability of the studied parameter.

Analysis of covariance (Table 5) generally confirmed the results of group comparisons, demonstrating the key role of the region of habitation, but not age or sex of examinees, in the observed differences in urinary levels of Cr, Cu, Fe, Mn, Mo, Se, and V. In turn, urinary Co and Zn concentrations were mainly affected by variability in sex of the examinees. Age had a border-significant effect on urinary Co concentration.

Hair trace element levels in students were found to be more heterogeneous (Table 6). Analogous to serum and urine, hair Zn levels in students from Turkmenistan and Iran were 13% ($p = 0.016$) and 16% ($p = 0.002$) lower than the respective values in Russian students. At the same time, hair Cr, Cu, and I content was minimal in students originating from Turkmenistan, being lower than the respective values in Russian and Iranian examinees by 37% ($p = 0.017$) and 48% ($p < 0.001$), 37% ($p < 0.001$) and 34% ($p = 0.057$), 57% ($p = 0.025$) and 53% ($p = 0.004$), respectively. In turn, hair V content was the lowest in Russian examinees, being 19% lower than that in students from Iran ($p = 0.012$).

In agreement with the results of group comparisons, ANCOVA demonstrated a significant impact of the country of origin on hair Cr, Cu, I, Mg, Mn, Se, V, and Zn content (Table 7). At the same time, variability in hair Co, Cu, Fe, Mn, Se, and V content was also significantly affected by sex of the examinees. In addition, hair Cu levels were associated with variability of age in the studied cohort.

Mineral levels were also characterized by significant group differences. Serum Ca concentration in examinees from Iran, but not Turkmenistan, was significantly lower than in Russian students by 3% ($p = 0.045$). No significant group difference in serum Mg concentration was revealed between the countries (Table 2). At the same time, ANCOVA revealed a significant impact of age and sex on serum Ca and Mg levels (Table 3). Urinary Ca concentration in Iranian students was nearly significantly higher than in Russian examinees by 69% ($p = 0.088$) (Table 4). No significant group difference in urinary Mg levels was observed. ANCOVA did not reveal any significant impact of sex, age, or country of origin on urinary mineral levels (Table 5). Significant group differences were revealed in hair mineral levels (Table 6). Hair Ca levels in students originating from Turkmenistan were lower than the respective values in Russian and Iranian examinees by 56% ($p < 0.001$) and 70% ($p < 0.001$), respectively. The highest hair Mg level was observed in Iranian subjects, exceeding that in students from Russia and Turkmenistan by 36% ($p = 0.025$) and 63% ($p = 0.002$), respectively. In agreement with the results of group comparisons, ANCOVA demonstrated a significant impact of the country of origin as well as sex on hair Ca and Mg content (Table 7).

Canonical discriminant analysis was further applied to evaluate the differences between the groups as well as contribution of the particular trace elements and minerals into these differences. Model 1 (Figure 1A) incorporating the values of urine trace element and mineral levels significantly discriminated Russian students from those originating from Turkmenistan ($MD^2 = 8.58$; $p < 0.001$) and Iran ($MD^2 = 10.81$; $p < 0.001$), while no discrimination between the latter were observed ($MD^2 = 0.55$; $p = 0.080$). Variability of urinary Cr ($p = 0.007$), Cu ($p < 0.001$), Fe ($p = 0.020$), I ($p = 0.016$), V ($p < 0.001$), and Zn ($p = 0.013$) levels contributed significantly to the model. Model 2 (Figure 1B) incorporated the values of serum trace element and mineral levels with the concentrations of Co ($p = 0.022$), Mn ($p = 0.029$), Mo ($p = 0.008$), V ($p < 0.001$), and Zn ($p = 0.016$) being considered significant predictors of group discrimination. In model 3 (Figure 1C) incorporating data on hair elemental content the values of Ca ($p < 0.001$), Co ($p < 0.001$), Cr ($p = 0.039$), Cu ($p = 0.009$), Mg ($p < 0.001$), Mn ($p < 0.001$), V ($p = 0.012$), and Zn ($p = 0.010$) contributed significantly to group discrimination. Although the distance between the centroids of the groups of Russian students and examinees from Turkmenistan ($MD^2 = 4.43$; $p < 0.001$ and $MD^2 = 3.12$; $p < 0.001$) or Iran ($MD^2 = 4.49$; $p < 0.001$ and $MD^2 = 1.54$; $p < 0.001$) was considered significant in models 2 and 3, these models did not discriminate the students from Iran and Turkmenistan yielding short yet significant distances between group centroids ($MD^2 = 0.76$; $p = 0.009$ and $MD^2 = 3.68$; $p < 0.001$). The overall model (Model 4, Figure 1D) incorporating the levels of the studied elements in serum, urine, and hair resulted in the best discrimination between the study groups with the highest distances between the groups of examinees from Russia and Turkmenistan ($MD^2 = 21.91$; $p < 0.001$) or Iran ($MD^2 = 25.09$; $p < 0.001$), as well as between the groups of students from Iran and Turkmenistan ($MD^2 = 6.41$; $p < 0.001$). Discriminant function analysis revealed a significant contribution of urinary Cu ($p < 0.001$) and V ($p < 0.001$), serum Ca ($p = 0.002$), Cr ($p = 0.003$), Cu ($p = 0.033$), Mn ($p < 0.001$), V ($p < 0.001$), and Zn ($p < 0.001$), as well as hair Ca ($p < 0.001$), Co ($p < 0.001$), Mg ($p < 0.001$), and Mn ($p < 0.001$) levels into the model.

Discussion

Our data demonstrate that levels of trace elements and minerals in students from Turkmenistan share high similarity to elemental profiles in students from Iran. Specifically, in comparison to students from Russia, subjects originating from Iran and Turkmenistan were characterized by lower serum Co, Cr, Cu, Mn, Mo, Se, V, Zn levels, higher urinary Cr, Cu, Fe, Mn, V, and Zn concentrations in parallel with increased level of Co in urine, as well as lower hair Mo, Se, and Zn content. At the same time, certain specific patterns were also revealed for students from Turkmenistan including lower urinary Cr and Cu, serum Cu and V levels, higher circulating Zn concentration, as well as lower hair Cr, Cu, I and Mg content in comparison to Iranian subjects. Discriminant analysis also confirmed the significance of differences in essential trace element and mineral profiles in students from Russia, Turkmenistan, and Iran. Generally, higher risk of Zn, Se, and Mn insufficiency is more characteristic for students from Iran, while examinees from

Turkmenistan tend to have significantly lower body burden of Cu. Increased urinary concentrations of the studied elements may be indicative of increased excretion that hypothetically may aggravate the risk of trace element deficiency. At the same time, lower discrimination of the groups based on hair trace element and mineral content may be associated with the role of hair as a long-term biomarker of element status, while blood and urine are indicative of the current levels of trace elements and minerals in the organism [36].

All foreign students were characterized by lower Cu body burden, while higher risk of Cu deficiency was characteristic for subjects from Turkmenistan. Although the worldwide prevalence of Cu deficiency has significantly diminished, it is still observed in sub-Saharan Africa and South Asia [37]. The prevalence of Cu deficiency in South Iran was estimated as 24%, being more prevalent in males than females [38]. Another study in the Greater Khorasan province of Iran revealed lower serum Cu levels of 14.7 $\mu\text{mol/l}$ (0.933 $\mu\text{g/ml}$) [39], corresponding to the present observations. Cu deficiency was also frequently observed in Iranian adolescent girls reaching 21.1% [40]. Systematic data on Cu nutritional intake in Turkmenistan are lacking. Yet, hair Cu levels in schoolchildren from Turkmenistan were reported to be significantly lower compared to those from Russia [41]. A significant reduction in hair Cu was also revealed in a closely located western Kazakhstan, especially in subjects living near the Caspian Sea coast in proximity to oil and gas fields [42], also supporting the hypothesis of high risk of Cu deficiency in the region.

Zn status was shown to be low in students both from Turkmenistan and Iran, being more profound in the latter. Zn deficiency has been originally described by Prof. Ananda Prasad in Iran [43]. Up to 50% of Iranian soils are considered Zn-deficient due to high prevalence of calcareous soils, high bicarbonate intake, and the use of phosphatic fertilizers [44]. In addition to low soil Zn content, wheat flour produced in Iran, as well as various breads, except Baggett and Roghani, are characterized by high phytic acid to Zn molar ratio and thus low Zn bioavailability [45]. Frequent consumption of flat breads with high phytate-to-Zn ratio may contribute to suboptimal Zn status, while consumption of composite dishes maintains moderate Zn absorption [46]. At the same time, Zn bioavailability from breads varies significantly between the provinces and particular cultivars due to variations in phytic acid concentrations [47]. In agreement with the indications of low soil Zn content and reduced Zn bioavailability, approximately 25% of Iranian households were considered Zn-deficient [48]. Correspondingly, Ghasemi et al. (2012) demonstrated that 10.3% of the adult Iranian population are characterized by low dietary Zn intake [49]. The results of the Second National Integrated Micronutrient Survey in Iran indicated that the prevalence of Zn deficiency in Iran varies from 11.4% in adolescents to 19.1% in toddlers, whereas in pregnant women the prevalence of Zn deficiency may achieve 28% [35]. In addition, examination of randomly-selected healthy subjects from Shiraz, Iran demonstrated that 42.5% of all examinees were characterized by serum Zn concentration lower than 100 $\mu\text{g/dl}$ [50]. Finally, the results of the most recent meta-analysis demonstrate that the prevalence of Zn deficiency in the Iranian population may account for 16% [51]. Although Zn serum levels were found to be low in students from Turkmenistan in the present study, it appears the first report of high risk of Zn deficiency in this country. Finally, an earlier study demonstrating poor Zn content in subdesert soils of Turkmenistan [52] is in agreement with our observations.

Hair and serum Se levels in students from Iran and Turkmenistan were lower in comparison to examinees from Russia. The present findings corroborate earlier studies reporting low Se content in Iranian soil and water, especially in northern provinces [53], although the level of the latter in edible crops was sufficient [54]. It has been demonstrated that more than 50% of healthy women from Tabriz (Iran) have a borderline-deficiency in Se levels with values <80 $\mu\text{g/L}$ [55]. However, a study in Tehran revealed significantly higher levels that correspond to adequate Se supply [56]. It is proposed that insufficient Se status due to its limited content in soils and crops may increase susceptibility to Se-deficiency-associated diseases [57]. It has been proposed that a trend for higher Se levels in biosamples in subjects from Turkmenistan as compared to Iranian examinees may be related to high Se levels in water from the Syrdarya and Amudarya rivers [58].

Markers of Co, Cr, V, and Mn status were also found to be lower in students from Iran and Turkmenistan as compared to Russian examinees. A previous study in the Shahrekord district, Iran, demonstrated low soil Co content that resulted in suboptimal Co status in sheep [59]. Although populational data are unavailable, it has been demonstrated that Co deficiency is widespread in goitrous children from Iran and thus may be considered a potential contributing factor to goiter development [60]. Lower levels of Co in the studied samples may be also associated with insufficient intake of Co-containing vitamin B₁₂. Specifically, low serum B₁₂ levels were observed in more than 50% of healthy Iranian adults from the Azar cohort study [61]. The observed difference in Cr and V between students from Russia and Turkmenistan generally correspond to the earlier observed nearly twofold higher hair Cr and V content in Russian children in comparison to those from Turkmenistan [41]. Despite the lack of data on populational levels of Cr in Iran, deficiency of essential trivalent Cr was also frequently observed in association with increased risk of type 2 diabetes mellitus [62]. It has been also demonstrated that Cr content in Iranian rice is nearly twofold lower than that in imported rice [63].

A trend to lower Ca supply was observed in Iranian students, being in agreement with the earlier findings demonstrating high prevalence of inadequate Ca intake reaching up to 91.6% [64]. Insufficient Ca intake is expected to be mediated by low Ca content in diets [65].

The observed lack of significant differences in iodine status between the studied groups of students supports the earlier reported high efficiency of national salt iodization programs in Iran [66] and Turkmenistan [67] that significantly reduced the prevalence of iodine deficiency. It has been demonstrated that optimal ioduria of 188 $\mu\text{g/l}$ was achieved in Turkmenistan due to universal salt iodization strategy [68]. Correspondingly, hair I content in schoolchildren from Turkmenistan did not differ significantly from the respective values in Russia [41].

Despite previous indications of high incidence of Fe deficiency and anemia in Central Asia [69], no significant differences in serum and hair Fe levels in students from Iran, Turkmenistan, and Russia were observed. The lack of differences may be indicative of successful reduction of the prevalence of Fe deficiency due to supplementation strategies [33; 70]. Moreover, the prevalence of Fe deficiency anemia in Iran was shown to vary significantly between the provinces [71]. Noteworthy, although being rather high, the prevalence of anemia in Turkmenistan was lower than that in other countries of Central Asia [72].

High similarity of trace element and mineral status of students from Turkmenistan and Iran is expected to be mediated by similar geochemical conditions including high prevalence of arid soils [73]. In turn, soil composition in Russia, even in regions located on the Caspian Sea coast, is significantly different from that in Iran [74]. In addition to differences in soil characteristics and subsequent variations in chemical content of the local foodstuffs, dietary patterns may also contribute to different intake of chemical elements in students from Russia, Iran and Turkmenistan.

At the same time, the present study has certain limitations. First, larger cohort size including subjects of various age and sex would be beneficial to address the differences in populational trace element status. Second, assessment of dietary trace element intake would provide additional information about the contribution of dietary intake into the observed differences. Moreover, evaluation of trace element and mineral content in the local foodstuffs and drinking water would provide beneficial information of geochemical factors contributing to differences in dietary trace element intake.

Conclusions

Taken together, the results of our study provide the first insight into trace element and mineral status of young adults from Turkmenistan. It is demonstrated that trace element and mineral accumulation patterns in students from Turkmenistan and Iran share high similarity hypothetically due to living in the same geochemical province. In comparison to students from Russia, examinees from Iran and Turkmenistan are characterized by lower body burden Co, Cr, Cu, Mn, Mo, Se, V, and Zn levels as assessed by serum and hair, while urinary trace element excretion was found to be higher. At the same time, students from Turkmenistan are characterized by lower levels of Cu in hair, serum, and urine when compared to Iranian examinees, while poorer Zn, Se, and Mn status is observed in students from Iran than in those from Turkmenistan. Given the role of trace element deficiency in development of various diseases, the observed differences in trace element status in young adults from Turkmenistan, Iran and Russia may contribute to distinct patterns of morbidity. However, further studies are required to evaluate the association between geographic patterns of trace element status and health outcomes.

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References

1. A.V. Skalny, M. Aschner, A. A. Tinkov, Zinc, In: *Advances in Food and Nutrition Research*. N. A. M. Eskin (Ed.) 96 (2021) 251–310. <https://doi.org/10.1016/bs.afnr.2021.01.003>
2. M. B. Zimmermann, K. Boelaert, Iodine deficiency and thyroid disorders, *Lancet Diabetes Endocrinol.* 3(4) (2015) 286–295. [https://doi.org/10.1016/S2213-8587\(14\)70225-6](https://doi.org/10.1016/S2213-8587(14)70225-6)
3. A.R. dos Reis, H. El-Ramady, E.F. Santos, P.L. Gratão, L. Schomburg, (2017). Overview of Selenium Deficiency and Toxicity Worldwide: Affected Areas, Selenium-Related Health Issues, and Case Studies, in: E. Pilon-Smits, L. Winkel, Z.Q. Lin (Eds), *Selenium in plants, Plant Ecophysiology*, Springer, Cham. 11 (2017) 209-230. https://doi.org/10.1007/978-3-319-56249-0_13
4. K. H. Winther, M. P. Rayman, S. J. Bonnema, L. Hegedüs, Selenium in thyroid disorders - essential knowledge for clinicians, *Nat. Rev. Endocrinol.* 16(3) (2020) 165–176. <https://doi.org/10.1038/s41574-019-0311-6>
5. S. R. Pasricha, J. Tye-Din, M. U. Muckenthaler, D. W. Swinkels, Iron deficiency, *Lancet.* 397(10270) (2021) 233–248. [https://doi.org/10.1016/S0140-6736\(20\)32594-0](https://doi.org/10.1016/S0140-6736(20)32594-0)
6. M. Altarelli, N. Ben-Hamouda, A. Schneider, M. M. Berger, Copper Deficiency: Causes, Manifestations, and Treatment. *Nutr. Clin. Pract.* 34(4) (2019) 504–513. <https://doi.org/10.1002/ncp.10328>

7. I. Scheiber, R. Dringen, J.F.B. Mercer, Copper: Effects of Deficiency and Overload, in: A. Sigel, H. Sigel, R. Sigel, (Eds), *Interrelations between Essential Metal Ions and Human Diseases. Metal Ions in Life Sciences*, Springer, Dordrecht. 13 (2013) 359–387. https://doi.org/10.1007/978-94-007-7500-8_11
8. N. Abbaspour, R. Hurrell, R. Kelishadi, Review on iron and its importance for human health, *J. Res. Med. Sci.* 19(2) (2014) 64-74.
9. A. V. Skalny, I. P. Zaitseva, Y. G. Gluhcheva, A. A. Skalny, E. E. Achkasov, M. G. Skalnaya, A. A. Tinkov, Cobalt in athletes: hypoxia and doping-new crossroads, *J. Appl. Biomed.* 17(1) (2019) 28-28.
10. K. Yamada, Cobalt: Its Role in Health and Disease, In: Sigel, A., Sigel, H., Sigel, R. (eds) *Interrelations between Essential Metal Ions and Human Diseases. Metal Ions in Life Sciences*, vol 13. Springer, Dordrecht. (2013) https://doi.org/10.1007/978-94-007-7500-8_9
11. J.B. Vincent, Beneficial effects of chromium (III) and vanadium supplements in diabetes, *Nutritional and Therapeutic Interventions for Diabetes and Metabolic Syndrome.* 29 (2018) 365-374. <https://doi.org/10.1016/B978-0-12-812019-4.00029-5>
12. G. Cormick, J. M. Belizán, Calcium Intake and Health, *Nutrients.* 11(7) (2019) 1606. <https://doi.org/10.3390/nu11071606>
13. M. Barbagallo, N. Veronese, L. J. Dominguez, Magnesium in Aging, *Health and Diseases, Nutrients.* 13(2) (2021) 463. <https://doi.org/10.3390/nu13020463>
14. P. Chen, J. Bornhorst, M. Aschner, Manganese metabolism in humans. *Front. Biosci. (Landmark)*, 23, (2018). 1655-1679.
15. G. Schwarz, A.A. Belaidi, Molybdenum in Human Health and Disease. In: A. Sigel, H. Sigel, R. Sigel, (eds) *Interrelations between Essential Metal Ions and Human Diseases. Metal Ions in Life Sciences*, vol 13. Springer, Dordrecht. (2013). https://doi.org/10.1007/978-94-007-7500-8_13
16. K. R. Wessells, K. H. Brown, 2012. Estimating the global prevalence of zinc deficiency: results based on zinc availability in national food supplies and the prevalence of stunting. *PloS one.* 7(11), e50568. <https://doi.org/10.1371/journal.pone.0050568>
17. GBD 2021 Anaemia Collaborators, Prevalence, years lived with disability, and trends in anaemia burden by severity and cause, 1990-2021: findings from the Global Burden of Disease Study 2021, *The Lancet Haematology.* 10(9) (2023) 713–734. [https://doi.org/10.1016/S2352-3026\(23\)00160-6](https://doi.org/10.1016/S2352-3026(23)00160-6)
18. G. D. Jones, B. Droz, P. Greve, P. Gottschalk, D. Poffet, S. P. McGrath, S. I. Seneviratne, P. Smith, L. H. Winkel, Selenium deficiency risk predicted to increase under future climate change, *Proc. Natl. Acad. Sci.* 114(11) (2017) 2848–2853. <https://doi.org/10.1073/pnas.1611576114>
19. Freeland-Graves JH, Sanjeevi N, Lee JJ. Global perspectives on trace element requirements. *J Trace Elem Med Biol.* 2015;31:135-41. doi: 10.1016/j.jtemb.2014.04.006. Epub 2014 May 24. PMID: 24912973.
20. E. Korobova, S. Romanov, A. Silenok, Endemic diseases of geochemical origin and methodological approaches toward their prevention and elimination, *Environ. Geochem. Health.* 42(8) (2020) 2595–2608. <https://doi.org/10.1007/s10653-019-00442-z>
21. R. Fuge, CC. Johnson, Iodine and human health, the role of environmental geochemistry and diet, a review, *J. Appl. Geochem.* 63 (2015) 282-302. <http://dx.doi.org/10.1016/j.apgeochem.2015.09.013>
22. F. Fordyce, Selenium geochemistry and health, *Ambio.* 1 (2007) 94-7. [http://dx.doi.org/10.1579/0044-7447\(2007\)36](http://dx.doi.org/10.1579/0044-7447(2007)36)
23. World Health Organization. Principles and methods for the assessment of risk from essential trace elements. 2002, 228 p. ISBN: 9241572280
24. Hotz C, Lowe NM, Araya M, Brown KH. Assessment of the trace element status of individuals and populations: the example of zinc and copper. *J Nutr.* 2003 May;133(5 Suppl 1):1563S-8S. doi: 10.1093/jn/133.5.1563S. PMID: 12730467.
25. Zheng, J., Li, M., Tang, B., Luo, W., Ma, Y., Ren, M., Yu, Y., Luo, X., & Mai, B. Levels, Spatial Distribution, and Impact Factors of Heavy Metals in the Hair of Metropolitan Residents in China and Human Health Implications. *Environ Sci Technol.* 2021 Aug 3;55(15):10578-10588. doi: 10.1021/acs.est.1c02001. Epub 2021 Jul 23. PMID: 34296597.
26. Li, M., Ma, Y., Du, D., Yan, X., Luo, W., Xu, R., Ren, M., Zheng, J., & Yu, Y. (2023). Spatial distribution, impact factors, and potential health implications of trace elements in human hair from capital residents in China. *Chemosphere*, 328, 138355. <https://doi.org/10.1016/j.chemosphere.2023.138355>
27. Oxford Poverty and Human Development Initiative. Turkmenistan Country Briefing, Oxford Poverty and Human Development Initiative, University of Oxford. (2022) https://ophi.org.uk/wp-content/uploads/CB_TKM_2022.pdf
28. G.A. Geraslmov, L. Ivanovo, A. Nazarov, C. Nazarov, A. Orazov, S. Turayeva, D. Khasanova, *Problemy endokrinologii*, 52(4) (2006) 13–16. <https://doi.org/10.14341/probl200652413-16>

29. G.R. Gleason, T. Sharmanov, Anemia prevention and control in four central Asian republics and Kazakhstan, *J. Nutr.* 132(4) (2002) 867–70. <https://doi.org/10.1093/jn/132.4.867S>
30. UNICEF, Working to close nutrition gaps in the Europe and Central Asia Region. <https://www.unicef.org/eca/reports/focus-working-close-nutrition-gaps-europe-and-central-asia-region> (2019)
31. H. Pouraram, A. Djazayeri, K. Mohammad, M. Parsaeian, Z. Abdollahi, A. Dorosty Motlagh, M. Djalali, K. Khodaverdian, G. Sotoudeh, A. Yarpardar, R. Heshmat, F. Siassi, Second National Integrated Micronutrient Survey in Iran: Study Design and Preliminary Findings, *Arch. Iran. Med.* 21(4) (2018) 137–144.
32. Goullé, J. P., Mahieu, L., Castermant, J., Neveu, N., Bonneau, L., Lainé, G., Bouige, D., & Lacroix, C. (2005). Metal and metalloid multi-elementary ICP-MS validation in whole blood, plasma, urine and hair. Reference values. *Forensic science international*, 153(1), 39–44. <https://doi.org/10.1016/j.forsciint.2005.04.020>
33. Tietz NW (1995) *Clinical guide to laboratory tests*. WB Saunders Co.
34. Yu, S., Wang, D., Cheng, X., Zhang, Q., Wang, M., Guo, H., Yu, B., Zhang, X., Xia, L., Sun, D., Cheng, Q., Li, P., Yin, Y., Ma, C., Hou, L., Zou, Y., Li, H., Li, D., Qiu, L., & Ichihara, K. (2020). Establishing reference intervals for urine and serum iodine levels: A nationwide multicenter study of a euthyroid Chinese population. *Clinica chimica acta; international journal of clinical chemistry*, 502, 34–40. <https://doi.org/10.1016/j.cca.2019.11.038>
35. A.V. Skalny. Reference values of chemical element content in hair obtained by ICP-AES (ANO Center for Biotic Medicine). *Trace Elements in Medicine*, 2003, 4(1): 55-56
36. K. Chojnacka, A. Zielińska, H. Górecka, Z. Dobrzański, H. Górecki, Reference values for hair minerals of Polish students, *Environ. Toxicol. Pharmacol.* 29(3) (2010) 314-319.
37. L.M. Klevay, The contemporaneous epidemic of chronic, copper deficiency, *J. Nutr. Sci.* 11 (2022) e89. <https://doi.org/10.1017/jns.2022.83>
38. M. H. Dabbaghmanesh, N. M. Salehi, J. Siadatan, G. R. Omrani, Copper concentration in a healthy urban adult population of southern Iran, *Biol. Trace Elem. Res.* 144(1-3) (2011) 217–224. <https://doi.org/10.1007/s12011-011-9074-1>
39. M. Ghayour-Mobarhan, A. Shapouri-Moghaddam, M. Azimi-Nezhad, H. Esmaeili, S. M. Parizadeh, M. Safarian, S. M. Kazemi-Bajestani, G. H. Khodaei, S. J. Hosseini, S. M. Parizadeh, G. A. Ferns, The relationship between established coronary risk factors and serum copper and zinc concentrations in a large Persian cohort, *J. Trace Elem. Med. Biol.* 23(3) (2009) 167–175. <https://doi.org/10.1016/j.jtemb.2009.03.006>
40. K. Gonoodi, A. Moslem, S. Darroudi, M. Ahmadnezhad, Z. Mazloun, M. Tayefi, S. A. T. Zadeh, S. Eslami, M. Shafiee, Z. Khashayarmanesh, H. M. Haghghi, G. A. Ferns, M. Ghayour-Mobarhan, Serum and dietary zinc and copper in Iranian girls, *Clin. Biochem.* 54 (2018) 25–31. <https://doi.org/10.1016/j.clinbiochem.2018.02.006>
41. A. R. Grabeklis, K. A. Abazov, A. A. Skalny, Yu. N. Lobanova, Regional approach to providing WFP UN services: comparison of multielement hair data of schoolchildren from Tajikistan, Azerbaijan, Kazakhstan, Turkmenistan, Bangladesh, Macedonia, Croatia, and Russian Federation, *Trace Elem. Med. (Moscow)*, 19(2) (2018) 49-56. DOI 10.19112/2413-6174-2018-19-2-49-56.
42. G. Umarova, G. Batyrova, Z. Tlegenova, V. Kononets, S. Balmagambetova, Y. Umarov, I. Yessengaliyeva, A. Mamyrbayev, Essential Trace Elements in Scalp Hair of Residents across the Caspian Oil and Gas Region of Kazakhstan, *Toxics*. 10(7) (2022) 364. doi: 10.3390/toxics10070364.
43. A. S. Prasad, Impact of the discovery of human zinc deficiency on health. *J. Trace Elem. Med. Biol.* 28(4) (2014) 357–363. <https://doi.org/10.1016/j.jtemb.2014.09.002>
44. B. J. Alloway, *Zinc in Soils and Crop Nutrition*. (second ed.), International Zinc Association, Brussels, Belgium, 2008.
45. B.P. Gargari, S. Mahboob, S.V. Razavieh, Content of phytic acid and its mole ratio to zinc in flour and breads consumed in Tabriz, Iran, *Food Chem.* 100(3) (2007) 1115-1119. doi: 10.1016/j.foodchem.2005.11.018
46. N. Abbaspour, R. Wegmueller, R. Kelishadi, R. Schulin, R. F. Hurrell, Zinc status as compared to zinc intake and iron status: a case study of Iranian populations from Isfahan province, *Int. J. Vitam. Nutr. Res.* 83(6) (2013) 335–345. <https://doi.org/10.1024/0300-9831/a000175>
47. M. Tavajjoh, J. Yasrebi, N. Karimian, V. Olama, Phytic acid concentration and phytic acid: Zinc molar ratio in wheat cultivars and bread flours, Fars province, Iran, *J. Agr. Sci. Tech.* 10(5) (2011) 743-55.
48. N. Houshiar-Rad, M. Esmaeili, M. Abdollahi, N. Mazaheri, M. Mohammadi, N. Kalantari, Zinc intake pattern in Iranian households and risk of zinc deficiency at national level, *J. Nutr. Sci. Food Technol.* 7(5) (2013) 409-419.

49. A. Ghasemi, S. Zahediasl, F. Hosseini-Esfahani, F. Azizi, Reference values for serum zinc concentration and prevalence of zinc deficiency in adult Iranian subjects, *Biol. Trace Elem. Res.* 149(3) (2012) 307–314. <https://doi.org/10.1007/s12011-012-9445-2>
50. M.H. Dabbaghmanesh, H. Taheri Boshrooyeh, M.R. Kalantarhormozi, G.H. Ranjbar Omrani, Assessment of zinc concentration in random samples of the adult population in Shiraz, Iran, *Iran. Red Crescent Med. J.* 13(4) (2011) 249-55.
51. M.J. Eslami, M. Khoshhali, R. Kelishadi, A Systematic Review and Meta-Analysis on the Prevalence of Zinc Deficiency in Iranian Population, *J. Pediatr. Rev.* 11(3) (2023) 209-20.
52. H. Aubert, M. Pinta, Trace Elements in Soils, *Zinc. Elsevier.* 7 (1977) 85-93.
53. L. Nazemi, N. Sh, M.R. Eshraghyan, M. Younesian, H. Sereshti, A. Moameni, J. Shahtaheri, S. Nasseri, Selenium concentration in soil of Iran. In: 19th World congress of soil science, soil solutions for a changing world, Brisbane, Australia, 2010.
54. L. Nazemi, S. Nazmara, M. R. Eshraghyan, S. Nasseri, K. Djafarian, M. Yunesian, H. Sereshti, A. Moameni, S. J. Shahtaheri, Selenium status in soil, water and essential crops of Iran, *Iranian J. Environ. Health Sci. Eng.* 9(1) (2012) 11. <https://doi.org/10.1186/1735-2746-9-11>
55. M. Rafraf, R. Mahdavi, M.R. Rashidi, Serum selenium levels in healthy women in Tabriz, Iran, *Food Nutr. Bull.* 29(2) (2008) 83–86. <https://doi.org/10.1177/156482650802900201>
56. R. Safaralizadeh, M. Sirjani, Z. Pourpak, G. Kardar, S. Teimourian, S. Shams, Z. Namdar, A. Kazemnejad, M. Moin, Serum selenium concentration in healthy children living in Tehran, *BioFactors.* 31(2) (2007) 127–131. <https://doi.org/10.1002/biof.5520310203>
57. B. Atarodi, A. Fotovat, Selenium status in Iran: a soil and human health point of view, in: G.S. Banuelos, Z.-Q. Lin, M.F. Moraes, L.R.G. Guilherme, A.R. dos Reis (Eds), *Global Advances in Selenium Research from Theory to Application.* CRC Press, Taylor & Francis Group, London, UK, 2016, pp. 91-92.
58. D.S Barber, B.S. Yuldashev, K. K. Kadyrzhanov, D. Yeleukenov, S. Ben Ouagrahm, V.P. Solodukhin, U.S. Salikbaev, A.A. Kist, I.A. Vasiliev, A.A. Dzhuraev, J.D. Betsill, H.D. Passel, B.M. Tolongutov, V.L. Poznyak, R.I. Radyuk, V.M. Alekhina, I.V. Kazachevskiy, B.B. Knyazev, S.N. Lukashenko, S. Khajekber, L.I. Zhuk, A.N. Dzhuraev, E.D. Vdovina, S. Mamatibraimov Radio-Ecological Situation in River Basins of Central Asia Syrdarya and Amudarya According to the Results of the Project “Navruz”, in: N. Birsen, K.K. Kadyrzhanov (Eds), *Environmental Protection Against Radioactive Pollution, NATO Science Series,* Springer, Dordrecht. 33 (2003) 39-51. https://doi.org/10.1007/978-94-007-0975-1_5
59. G.A. Kojouri, The status of cobalt in soil, plants and sheep in Shahrekord district, Iran, *Iran J. Vet. Res.* 7(1) (2006) 66-9.
60. M. Sanjari, A. Gholamhoseinian, A. Nakhaee, The Association between Cobalt Deficiency and Endemic Goiter in School-Aged Children, *Endocrinol. Metab. (Seoul).* 29(3) (2014) 307-311. doi: 10.3803/EnM.2014.29.3.307.
61. S. Azimi, E. Faramarzi, P. Sarbakhsh, A. Ostadrahimi, M. H. Somi, M. Ghayour, Folate and vitamin B12 status and their relation to hematological indices in healthy adults of Iranians: Azar cohort study, *Nutr. Health.* 25(1) (2019) 29–36. <https://doi.org/10.1177/0260106018815392>
62. L. Tavakkoli, N. Khanjani, Environmental and occupational exposure to cadmium in Iran: a systematic review, *Rev. Environ. Health.* 31(4) (2016) 457-63. DOI: 10.1515/reveh-2016-0042
63. A. Jafari, B. Kamarehie, M. Ghaderpoori, N. Khoshnamvand, M. Birjandi, The concentration data of heavy metals in Iranian grown and imported rice and human health hazard assessment, *Data Br.* 16 (2017) 453–459. <https://doi.org/10.1016/j.dib.2017.11.057>
64. E. Babaali, S. Rahmdel, E. Berizi, M. Akhlaghi, F. Götz, S. M. Mazloomi, Dietary Intakes of Zinc, Copper, Magnesium, Calcium, Phosphorus, and Sodium by the General Adult Population Aged 20-50 Years in Shiraz, Iran: A Total Diet Study Approach, *Nutrients.* 12(11) (2020) 3370. <https://doi.org/10.3390/nu12113370>
65. G. El-Hajj Fuleihan, Vitamin D Deficiency in the Middle East and Its Health Consequences. in: M. Holick, (eds), *Vitamin D. Nutrition and Health.* Humana Press, 2010, pp. 469–494, https://doi.org/10.1007/978-1-60327-303-9_24
66. F. Azizi, R. Sheikholeslam, M. Hedayati, P. Mirmiran, H. Malekafzali, M. Kimiagar, M. Pajouhi, Sustainable control of iodine deficiency in Iran: beneficial results of the implementation of the mandatory law on salt iodization, *J. Endocrinol. Invest.* 25(5) (2002) 409–413. <https://doi.org/10.1007/BF03344029>
67. G. A. Gerasimov, L. Ivanovo, A. Nazarov, C. Nazarov, A. Orazov, S. Turayeva, D. Khasanova, Prevention of iodine deficiency in the nutrition of the population of Turkmenistan through general table salt iodination: results of the nationwide representative study, *Probl. Endokrinol.* 52(4) (2006) 13–16. <https://doi.org/10.14341/probl200652413-16>

68. G.A. Gerasimov, F. Van der Haar, J.H. Lazarus, Overview of iodine deficiency prevention strategies in the South-Eastern Europe and Central Asia Region: 2009–2016, *Clin. Exp. Tryroid.* 13(4) (2018) 16-22. <https://doi.org/10.14341/ket9531>
69. Safiri, S., Kolahi, A. A., Noori, M., Nejadghaderi, S. A., Karamzad, N., Bragazzi, N. L., Sullman, M. J. M., Abdollahi, M., Collins, G. S., Kaufman, J. S., & Grieger, J. A. (2021). Burden of anemia and its underlying causes in 204 countries and territories, 1990-2019: results from the Global Burden of Disease Study 2019. *Journal of hematology & oncology*, 14(1), 185. <https://doi.org/10.1186/s13045-021-01202-2>
70. Riahi, S. M., Mohammadi, M., Fakhri, Y., Pordanjani, S. R., Soleimani, F., & Saadati, H. M. (2019). Prevalence and determinant factors of anemia in children aged 6-12 months after starting an iron supplement in the east of Iran. *Archives de pediatrie : organe officiel de la Societe francaise de pediatrie*, 26(6), 347–351. <https://doi.org/10.1016/j.arcped.2019.08.007>
71. Zamani, M., Poustchi, H., Shayanrad, A., Pourfarzi, F., Farjam, M., Noemani, K., Ghaderi, E., Mohammadkarimi, V., Kahnooji, M., Mansour-Ghanaei, F., Rastegar, A., Mousavizadeh, A., Rafati, S., Johari, M. G., Moosazadeh, M., Salehifardjouneghani, A., Ostadrahimi, A., Mohebbi, I., Khorram, A., Ardakani, F. E., ... Malekzadeh, R. Prevalence and determinants of anemia among Iranian population aged ≥ 35 years: A PERSIAN cohort-based cross-sectional study. *PLoS One.* 2022 Feb 9;17(2):e0263795. doi: 10.1371/journal.pone.0263795. PMID: 35139138; PMCID: PMC8827433.
72. Lutter CK. Iron deficiency in young children in low-income countries and new approaches for its prevention. *J Nutr.* 2008 Dec;138(12):2523-8. doi: 10.3945/jn.108.095406. PMID: 19022983.
73. M.R. Ghassemi, E. Garzanti, Geology and Geomorphology of Turkmenistan, A review, *Geopersia.* 9(1) (2019) 125-140. DOI:10.22059/GEOPE.2018.265613.648416
74. I.N. Semenkov, M.V. Konyushkova, A. Heidari, E.D. Nikolaev, Chemical differentiation of recent fine-textured soils on the Caspian Sea coast: A case study in Golestan (Iran) and Dagestan (Russia), *Quat. Int.* 590 (2021) 48-55. DOI: 10.1016/j.quaint.2020.05.053

Figure 1. Discriminant analysis score plot of students from Russia (blue), Turkmenistan (red), and Iran (green) based on the patterns of trace element and mineral levels in urine (A), serum (B), hair (C), or all studied samples (D)

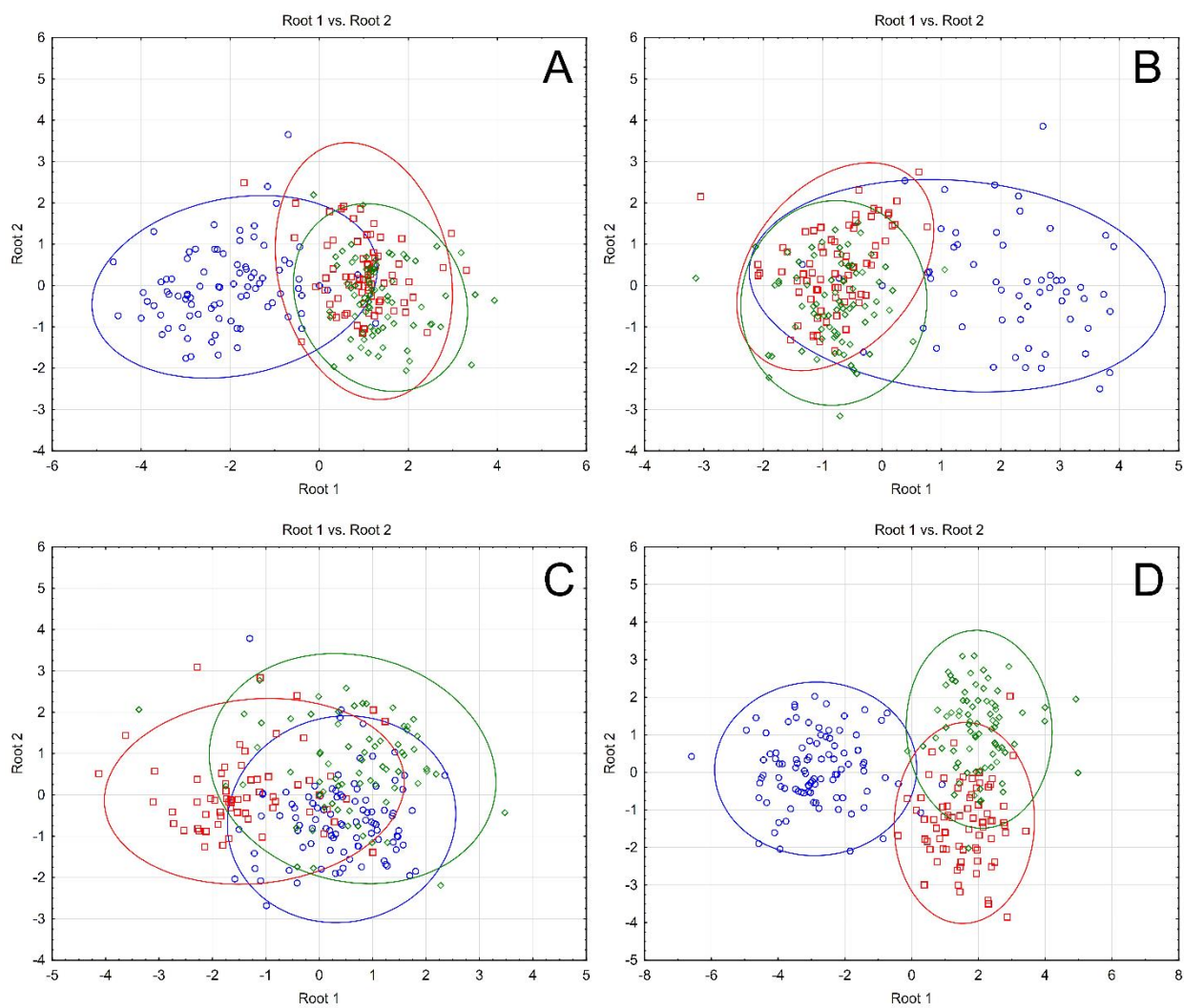


Table 1. The parameters of ICP-MS system used for serum, urine, and hair trace element and mineral analysis

Plasma power	1550 W
Plasma argon flow	15 L/min
Aux argon flow	0.8 L/min
Nebulizer argon flow	1.09 L/min
Sample introduction system	MicroMist G3266-65003 nebulizer and Scott double-pass quartz spray chamber G3280-80008 (Agilent Technologies Inc., Santa Clara, CA 95051 United States)
Sampler and skimmer cone material	Nickel
Injector	Glass Expansion Quartz 1.0 mm I.D. G3280-80001
Sample flow	663 μ L/min
Internal Standard flow	58 μ L/min
Dwell time and acquisition mode	10-100 ms and peak hopping for all analytes
Sweeps per reading	1
Reading per replicate	10
Replicate number	3

Table 2. Circulating serum essential trace element and mineral concentrations in first-year students from Iran and Turkmenistan as compared to Russian students

Element	Russia	Turkmenistan	Iran	Reference values
Ca, μ g/ml	102.473 (95.797 - 109.71)	101.514 (94.936 - 105.197)	99.216 (93.793 - 103.730) ¹	84 - 102 ^[33]
Co, ng/ml	0.528 (0.487 - 0.672)	0.463 (0.381 - 0.544) ¹	0.419 (0.349 - 0.479) ¹	0.30 - 1.02 ^[32]
Cr, ng/ml	1.414 (1.059 - 2.332)	1.166 (0.998 - 1.307) ¹	1.203 (1.054 - 1.342)	-
Cu, μ g/ml	0.993 (0.86 - 1.122)	0.805 (0.72 - 0.962) ¹	0.870 (0.779 - 0.992) ¹	0.794 - 2.023 ^[32]
Fe, μ g/ml	1.502 (1.191 - 1.837)	1.511 (1.084 - 1.862)	1.510 (1.064 - 2.067)	0.4 - 1.5 ^[33]
I, μ g/ml	0.060 (0.053 - 0.065)	0.053 (0.043 - 0.068)	0.057 (0.048 - 0.07)	36 - 79 ^[34]
Mg, μ g/ml	22.154 (21.079 - 23.183)	22.05 (20.578 - 23.149)	21.857 (20.435 - 23.039)	15.8 - 25.5 ^[33]
Mn, ng/ml	2.127 (1.875 - 2.831)	1.712 (1.545 - 1.953) ¹	1.662 (1.456 - 1.909) ¹	0.63 - 2.26 ^[32]
Mo, ng/ml	1.081 (0.919 - 1.245)	0.653 (0.536 - 0.799) ¹	0.660 (0.509 - 0.832) ¹	-
Se, μ g/ml	0.100 (0.093 - 0.118)	0.097 (0.081 - 0.105) ¹	0.091 (0.08 - 0.1) ¹	79 - 141 ^[32]
V, ng/ml	5.939 (4.321 - 7.89)	1.249 (1.091 - 1.374) ¹	1.326 (1.17 - 1.455) ¹	-
Zn, μ g/ml	0.953 (0.871 - 1.052)	0.850 (0.791 - 0.945) ¹	0.799 (0.726 - 0.907) ^{1,2}	551 - 925 ^[32]

Data expressed as median and the respective interquartile range (IQR) boundaries; ^{1,2} – significant group difference in comparison to values in students from Russia and Turkmenistan at $p < 0.05$, respectively

Table 3. The influence of sex, age, and the country of origin on serum trace element and mineral levels in first-year students

Element	Sex	Age	Region
Ca	0.004 *	0.032 *	0.466
Co	< 0.001 *	0.218	< 0.001 *
Cr	0.010 *	0.756	0.128
Cu	< 0.001 *	0.025 *	0.003 *
Fe	< 0.001 *	0.001 *	0.057
I	0.152	0.751	0.130
Mg	0.001 *	0.012 *	0.742
Mn	0.565	0.061	< 0.001 *
Mo	0.019 *	0.079	< 0.001 *
Se	0.046 *	0.104	< 0.001 *
V	0.985	0.462	< 0.001 *
Zn	< 0.001 *	0.305	< 0.001 *

Data expressed as *p* values for the factorial effect;
* - factorial effect is significant at $p < 0.05$

Table 4. Urinary trace element and mineral levels in first-year students from Iran and Turkmenistan as compared to Russian students

Element	Russia	Turkmenistan	Iran	Reference values
Ca, $\mu\text{g/ml}$	102.473 (95.797 - 109.710)	101.514 (94.936 - 105.197)	99.216 (93.793 - 103.730)	
Co, ng/ml	1.087 (0.615 - 1.66)	0.696 (0.49 - 1.527)	0.791 (0.593 - 1.043)	0.16 - 1.14 [32]
Cr, ng/ml	1.266 (0.789 - 1.816)	1.54 (1.056 - 1.981)	1.866 (1.589 - 2.089) ^{1,2}	
Cu, $\mu\text{g/ml}$	0.014 (0.009 - 0.021)	0.038 (0.027 - 0.052) ¹	0.044 (0.034 - 0.058) ^{1,2}	0.004 - 0.012 [32]
Fe, $\mu\text{g/ml}$	0.027 (0.017 - 0.045)	0.068 (0.042 - 0.099) ¹	0.073 (0.047 - 0.094) ¹	
I, $\mu\text{g/ml}$	0.126 (0.066 - 0.184)	0.122 (0.067 - 0.171)	0.134 (0.097 - 0.181)	0.019 - 0.385 [34]
Mg, $\mu\text{g/ml}$	22.154 (21.079 - 23.183)	22.050 (20.578 - 23.149)	21.857 (20.435 - 23.039)	
Mn, ng/ml	1.057 (0.793 - 1.453)	1.637 (1.395 - 1.989) ¹	1.639 (1.427 - 1.975) ¹	0.11 - 1.32 [32]
Mo, $\mu\text{g/ml}$	0.051 (0.021 - 0.078)	0.043 (0.03 - 0.068)	0.051 (0.033 - 0.074)	0.007 - 0.05 [32]
Se, $\mu\text{g/ml}$	0.035 (0.02 - 0.049)	0.037 (0.029 - 0.05)	0.043 (0.033 - 0.051) ¹	0.010 - 0.046 [32]
V, ng/ml	0.094 (0.058 - 0.205)	0.599 (0.428 - 0.817) ¹	0.607 (0.442 - 0.769) ¹	1.4 - 10.2 [32]
Zn, $\mu\text{g/ml}$	0.371 (0.225 - 0.832)	0.637 (0.286 - 1.069)	0.589 (0.426 - 0.923) ¹	0.044 - 0.499 [32]

Data expressed as median and the respective interquartile range (IQR) boundaries; ^{1,2} – significant group difference in comparison to values in students from Russia and Turkmenistan at $p < 0.05$, respectively

Table 5. Assessment of the influence of sex, age, and the country of origin on urinary concentrations of trace elements and minerals in RUDN University students

Element	Sex	Age	Region
Ca	0.665	0.295	0.137
Co	< 0.001 *	0.051	0.149
Cr	0.209	0.946	< 0.001 *
Cu	0.177	0.708	< 0.001 *
Fe	0.525	0.497	< 0.001 *
I	0.309	0.450	0.243
Mg	0.723	0.577	0.584
Mn	0.689	0.635	< 0.001 *
Mo	0.132	0.461	0.046 *
Se	0.268	0.182	< 0.001 *
V	0.843	0.218	< 0.001 *
Zn	< 0.001 *	0.193	0.102

Data expressed as *p* values for the factorial effect; * - factorial effect is significant at *p* < 0.05

Table 6. Hair trace element and mineral levels ($\mu\text{g/g}$) in first-year students from Iran and Turkmenistan as compared to Russian students

Element	Russia	Turkmenistan	Iran	Reference values
Ca, $\mu\text{g/g}$	1006.684 (482.513 - 2753.95)	442.49 (329.68 - 945.033) ¹	1486.94 (618.072 - 3052.52) ²	494 - 1619 ^[35]
Co, $\mu\text{g/g}$	0.011 (0.006 - 0.03)	0.013 (0.009 - 0.036)	0.020 (0.007 - 0.037)	0.004 - 0.14 ^[32]
Cr, $\mu\text{g/g}$	0.134 (0.074 - 0.26)	0.084 (0.065 - 0.153) ¹	0.159 (0.118 - 0.251) ²	0.11 - 0.52 ^[32]
Cu, $\mu\text{g/g}$	13.551 (9.851 - 16.247)	8.543 (7.416 - 10.484) ¹	12.882 (10.351 - 18.070)	9.0 - 61.3 ^[32]
Fe, $\mu\text{g/g}$	14.994 (9.23 - 24.274)	14.910 (11.201 - 18.019)	14.331 (9.902 - 18.967)	11.1 - 40.5 ^[35]
I, $\mu\text{g/g}$	0.261 (0.14 - 0.465)	0.113 (0.078 - 0.401) ¹	0.242 (0.176 - 0.5) ²	0.150 - 0.927 ^[35]
Mg, $\mu\text{g/g}$	84.567 (43.597 - 157.199)	70.304 (46.569 - 127.705)	115.019 (61.009 - 222.521) ^{1,2}	39 - 137 ^[35]
Mn, $\mu\text{g/g}$	0.476 (0.223 - 0.887)	0.366 (0.265 - 0.595)	0.342 (0.203 - 0.693) ¹	0.016 - 0.57 ^[32]
Mo, $\mu\text{g/g}$	0.022 (0.017 - 0.027)	0.031 (0.021 - 0.039)	0.026 (0.019 - 0.032)	-
Se, $\mu\text{g/g}$	0.429 (0.365 - 0.511)	0.371 (0.307 - 0.464)	0.34 (0.229 - 0.494)	0.37 - 1.37 ^[32]
V, $\mu\text{g/g}$	0.021 (0.01 - 0.037)	0.025 (0.017 - 0.031)	0.026 (0.015 - 0.062) ¹	0.001 - 0.051 ^[32]
Zn, $\mu\text{g/g}$	201.792 (169.659 - 251.677)	174.880 (140.933 - 229.660) ¹	168.735 (145.531 - 202.050) ¹	129 - 209 ^[32]

Data expressed as median and the respective interquartile range (IQR) boundaries; ^{1,2} – significant group difference in comparison to values in students from Russia and Turkmenistan at *p* < 0.05, respectively

Table 7. The impact of sex, age, and country of origin on hair trace element and mineral content in first-year students

Element	Sex	Age	Region
Ca	< 0.001 *	0.776	< 0.001 *
Co	< 0.001 *	0.922	0.087
Cr	0.173	0.158	< 0.001 *
Cu	< 0.001 *	0.013 *	0.031 *
Fe	< 0.001 *	0.817	0.340
I	0.280	0.568	0.005 *
Mg	< 0.001 *	0.947	0.005 *
Mn	< 0.001 *	0.627	0.045 *
Mo	0.226	0.788	0.124
Se	0.002 *	0.204	0.025 *
V	0.028 *	0.474	0.025 *
Zn	0.151	0.851	0.003 *
Data expressed as <i>p</i> values for the factorial effect; * - factorial effect is significant at <i>p</i> < 0.05			

Supplementary Table 1. The limits of detection (LOD) and quantification (LOQ), as well as the background equivalent concentrations (BEC) for the analyzed elements

Element	BEC, ppb	LOD, ppb	LOQ, ppb
Ca	23.21	11.78	35.69697
Co	0.004566	0.003906	0.011836
Cr	0.04553	0.003262	0.009885
Cu	0.1252	0.02448	0.074182
Fe	23.2	3.866	11.71515
I	0.2113	0.06497	0.196879
Mg	1.113	0.2886	0.874545
Mn	0.05587	0.0021	0.006364
Mo	0.004446	0.01275	0.038636
Se	0.1285	0.06142	0.186121
V	0.01011	0.000722	0.002188
Zn	0.538	0.09749	0.295424