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Association between Different Levels of Water Hardness and Anthropometric Indices, Blood Pressure, and Demographic Factors in Adults from Zarand and Sarbisheh Cities

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Abstract

Background: Obesity is a major risk factor for cardiovascular diseases, diabetes, and high blood pressure. The impact of water hardness on these anthropometric and cardiovascular parameters remains debated. This study aimed to explore the relationship between water hardness, blood pressure, and obesity in adults from Zarand and Sarbisheh cities.

Methods: A cross-sectional study was conducted in 2024 on 600 adults (18–75 years) from Zarand and Sarbisheh. Water hardness was measured in urban and rural areas. Demographic data, physical activity, drinking water supply and filtration status, and medical history were collected through a questionnaire. Systolic blood pressure (SBP) and diastolic blood pressure (DBP), waist circumference (WC), and body mass index (BMI) were measured. Data analysis was performed using regression and GLMTree models to assess moderating factors.

Results: The mean age was 40.27 ± 14.54 years, and 68.8% were women. The mean water hardness in Zarand and Sarbisheh was 686.09 and 286.86 mg/L (as $CaCO_3$), respectively. Regression analysis revealed significant associations between high water hardness and BMI, as well as medium-to-high water hardness and SBP ($p < 0.05$). WC and DBP were lower among individuals using home water purifiers. The GLMTree model indicated that age, gender, cigarette smoke exposure, hypertension history, and water type moderated the relationship between water hardness and BMI, WC, SBP, and DBP.

Conclusions: High and moderate levels of water hardness may be associated with changes in blood pressure and anthropometric indices, potentially moderated by demographic and lifestyle factors. To confirm and further elucidate these associations, additional research, particularly through cohort studies, is warranted.

Keywords: Water hardness, Blood pressure, Obesity, BMI

1. Introduction

Obesity is a chronic, progressive disease that has become a global public health challenge (1, 2). Over the past few decades, its prevalence has risen sharply across all age groups, regardless of geographic location or socioeconomic status (3, 4). Defined by an increased body mass index (BMI), obesity is a major risk factor for numerous non-communicable diseases, including cardiovascular diseases, diabetes, and high blood pressure (5). The primary causes of obesity are linked to high-energy, high-fat diets, physical inactivity, shifts in transportation methods, urbanization, and exposure to environmental pollutants (5, 6).

Changes in water quality, particularly variations in mineral content, can lead to the introduction of environmental pollutants that may influence health outcomes such as obesity and high blood pressure (7). The hardness of drinking water is determined by the concentration of dissolved minerals, primarily calcium (Ca) and magnesium (Mg), which commonly occur in combination with bicarbonate (HCO_3^-), sulfate (SO_4^{2-}), and chloride (Cl^-) ions (7). In addition to being essential components of food, Ca and Mg are crucial for various physiological processes (7). Hard water, especially very hard water, serves as a significant source of these minerals, both of which play vital roles in metabolism and blood pressure regulation (8). Calcium is necessary for blood clotting, nerve transmission, and muscle contraction, while Mg contributes to energy transfer and release, as well as heart function (9). However, the impact of water hardness on metabolic and cardiovascular diseases remains a topic of ongoing debate (10).

Several studies have explored the impact of water hardness on the incidence or reduction of various conditions, including diabetes, metabolic syndrome, neurological disorders, high blood pressure, bone fractures, and bone growth in children (11-13). Research indicates that water hardness may be linked to a reduced risk of death from heart disease, but its effects on obesity and blood pressure are not yet fully understood. This might be because soft water is more corrosive than hard water, potentially causing cadmium, lead, and other toxic metals to dissolve into drinking water (9). The regulatory mechanism of intestinal absorption, controlled by 1,25-dihydroxyvitamin D, also protects against excessive calcium intake. However, Ca can inhibit the absorption of iron (Fe), zinc (Zn), Mg, and phosphorus (P). Since insulin function depends on Mg, low serum Mg levels are common in individuals with metabolic syndrome and type 2 diabetes. Recent evidence suggests that subclinical Mg deficiency may play a role in the development of diabetes (8).

Water is essential for all living organisms, and the quality of groundwater directly affects human health. With the increasing demand for water resources, especially in developing countries, ensuring a safe and adequate water supply has become critically important. The need for water in regions with unique climatic and geological conditions, such as Iran, underscores the necessity for further research on the relationship between water quality and health issues like obesity and blood pressure (14, 15). While some studies have confirmed a link between water hardness and cardiovascular diseases and mortality, the precise relationship remains unclear. More research is needed, particularly in Iran, given its specific climate and high mortality rates (6). Therefore, this study aimed to explore the relationship between water hardness, blood pressure, and obesity in the adult population (18 to 75 years) of Zarand and Sarbisheh cities.

2. Materials and methods

1.2. Study area

Zarand is a city in Kerman Province, Iran, covering an area of 11,521 square kilometers. It is situated at 56°34' east longitude and 30°49' north latitude, with an average elevation of 1,660 meters above sea level. The city has a semi-desert climate, with average temperatures of 37.8°C in summer and 13°C in winter. The region receives approximately 140 mm of annual rainfall (16).

Sarbisheh is a border city in South Khorasan Province, eastern Iran, covering an area of approximately 8,199 square kilometers and located 65 kilometers from the provincial center. Geographically, it lies between 59°32' and 59°58' east longitude and 32°15' and 32°51' north latitude. Sarbisheh has a temperate and dry climate, which transitions to semi-arid in the highlands. Annual rainfall in the region ranges from 95 to 375 mm, with an average of 206 mm, and the average temperature is 12.2°C. The city's drinking water supply relies entirely on underground sources such as wells, aqueducts, and springs (17).

2.2. Study population

This cross-sectional study was conducted in 2024, targeting adults aged 18 to 75 years living in the cities of Zarand and Sarbisheh. A total of 600 participants were randomly selected, with 296 individuals from Zarand and 304 from Sarbisheh. Informed consent was obtained from all participants before their inclusion in the study. The inclusion criteria were residing in Zarand or Sarbisheh for at least one year and being between 18 and 75 years old (18). The study protocol was approved by the Ethics Committee of Shahid Sadoughi University of Medical Sciences, Yazd (IR.SSU.SPH.REC.1402.197), and written informed consent was obtained from all participants.

3.2. Questionnaire

Participants were asked to complete a demographic questionnaire covering age, gender, education level (academic or non-academic), income (low: ≤$192, moderate: $192–384, high: ≥$384), smoking status, daily physical activity, history of chronic diseases (including cardiovascular disease, hypertension, diabetes, and kidney problems), medication use, intake of Ca and zinc supplements, type of drinking water (tap water, home water purifier, or well water), and daily water consumption (low: 1–2 glasses, moderate: 3–8 glasses, high: >8 glasses) (18, 19).

4.2. Physical examinations

In this study, physical examinations were conducted, including measurements of height (cm), weight (kg), waist circumference (WC, cm), systolic blood pressure (SBP, mmHg), and diastolic blood pressure (DBP, mmHg). Height was measured with a tape measure while the participant stood with their head, buttocks, and heels in contact with the wall. Weight was recorded using a digital scale, with participants wearing light clothing and no shoes. WC was measured at the widest point between the chest and pelvis using a tape measure. Body mass index (BMI) was calculated by dividing weight (kg) by height (m) squared. SBP and DBP were measured with a digital sphygmomanometer while participants were seated, with measurements taken on their right arm (18, 20).

5.2. Water hardness

Drinking water quality data were obtained in collaboration with the Health Centers and the Water and Wastewater Companies of Zarand and Sarbisheh. In Zarand, drinking water samples were collected from 23 sampling points (22 villages and one city), and in Sarbisheh, from 28 sampling points (25 villages and three cities). Samples were collected from the main distribution networks according to the procedures recommended in Standard Methods for the Examination of Water and Wastewater (21). Each water sample (500 mL) was taken in pre-cleaned polyethylene bottles, which were rinsed three times with the sample water before collection. Samples were kept in dark containers at 4 °C and transported to the laboratory within 24 hours to prevent any chemical alteration.

All analyses were carried out using standard laboratory methods. Total hardness (as $CaCO_3$) and bicarbonate (HCO_3^-) were measured by titrimetric methods using EDTA and acid-base titration, respectively. Chloride (Cl^-) concentration was determined by argentometric titration (Mohr method), sulfate (SO_4^{2-}) by the turbidimetric method using a spectrophotometer, and nitrate (NO_3^-) by UV spectrophotometry at 220 nm. Total dissolved solids (TDS) were determined gravimetrically after evaporation at 180°C, and electrical conductivity (EC) was measured in situ using a calibrated conductivity meter with ±1 µS/cm accuracy. All instruments were calibrated daily using certified standard solutions. Duplicate analyses were performed on 10% of the samples to assess precision and reproducibility. Analytical accuracy was verified using standard reference materials (Merck, Germany), and the results were within ±5% of the certified values, ensuring the reliability of the measurements. Water hardness was categorized into three groups: low (≤200 mg/L), medium (200–500 mg/L), and high (≥500 mg/L) (18).

6.2. Statistical analysis

Statistical analyses were performed using R software (version 4.3.3). The data were examined both descriptively and inferentially. For analytical procedures, Chi-square tests, analysis of variance (ANOVA), correlation analysis, univariate regression, and multivariate regression models were applied, with a significance level set at 5%. Additionally, the partykit package (version 1.2-20) and the glmtree function were employed to construct regression tree models.

3. Results

Table 1 presents the demographic characteristics of the study population. The results showed that the mean age of the study population was 40.27 ± 14.54 years, 68.8% of the participants were female, 30% of the population had an academic education, 54.2% of participants had a job, 50.8% had a low income, and 95.2% were not smokers. 38.7% of the participants reported engaging in physical activity less than 3 days a week. The mean WC was 83.32±19.31 cm, BMI was 24.92±4.88, SBP was 110.86±13.89 mmHg, and DBP was 71.51±10.17 mmHg.

Table 1. Participant characteristics by water Hardness levels.

Variables	Hardness (Level)				p-value*
	Total	Low	Moderate	High	
	N (%)				
Gender					
Female	413 (68.8)	15 (3.6)	233 (56.4)	165 (40.0)	<0.001*
Male	187 (31.2)	19 (10.2)	118 (63.1)	50 (26.7)	
Education					
Academic	180 (30.0)	3 (1.7)	93 (51.7)	84 (46.7)	
Non-academic	420 (70.0)	31 (7.4)	258 (61.4)	131 (31.2)	<0.001*
Job					
Yes	325 (54.2)	14 (4.3)	187 (57.5)	124 (38.2)	0.175
No	275 (45.8)	20 (7.3)	164 (59.6)	91 (33.1)	
Income[a]					
Low	305 (50.8)	20 (6.6)	201 (65.9)	84 (27.5)	
Moderate	248 (41.3)	14 (5.6)	123 (49.6)	111 (44.8)	<0.001*
High	47 (7.8)	0	27 (57.4)	20 (42.6)	
Smoking					

Yes	29 (4.8)	4 (13.8)	17 (58.6)	8 (27.6)	0.127
No	571 (95.2)	30 (5.3)	334 (58.5)	207 (36.3)	
Body activity (day)					
None	105 (17.5)	3 (2.9)	58 (55.2)	44 (41.9)	
<3	232 (38.7)	7 (3.0)	126 (54.3)	99 (42.7)	
3-7	161 (26.8)	21 (13.0)	104 (64.6)	36 (22.4)	<0.001*
Every day	102 (17.0)	3 (2.9)	63 (61.8)	36 (35.3)	
		Mean±SD			
Age (year)	40.27±14.54	46.38±17.82	38.72±14.65	41.84±13.41	0.002*
WC (cm)	83.32±19.31	85.67±15.17	80.98±19.59	86.78±18.93	0.002*
BMI	24.92±4.88	23.64±4.98	24.50±4.73	25.80±5.01	0.003*
SBP (mmHg)	110.86±13.89	111.47±12.70	110.68±12.79	111.06±15.74	0.919
DBP (mmHg)	71.51±10.17	66.76±6.72	71.25±9.34	72.67±11.61	0.005*

[a]Low: ≤192$, Moderate: 192-384$, and High: ≥384$

* Chi-square test or ANOVA, p-value<0.05

Figure 1 presents the mean concentrations of selected chemical parameters in drinking water samples from Zarand and Sarbisheh, compared with the permissible limits set by the Iran National Standards Organization (INSO, 6th Revision, 2025; Standard No. 1053) and the World Health Organization (WHO, 2022) guidelines. The results indicate that the mean concentrations of total hardness, fluoride, and sulfate (SO_4^{2-}) in Zarand are higher than those in Sarbisheh ($p > 0.05$), whereas the mean concentration of nitrate (NO_3^-) is significantly lower in Zarand compared to Sarbisheh ($p < 0.001$). Figure 1 also shows that the mean water hardness in Zarand is 686.09 mg/L (as $CaCO_3$), significantly higher than the permissible limits set by both INSO (300 mg/L) and WHO (200 mg/L). In contrast, the mean water hardness in Sarbisheh is 286.86 mg/L (as $CaCO_3$), which exceeds the WHO guideline of 200 mg/L.

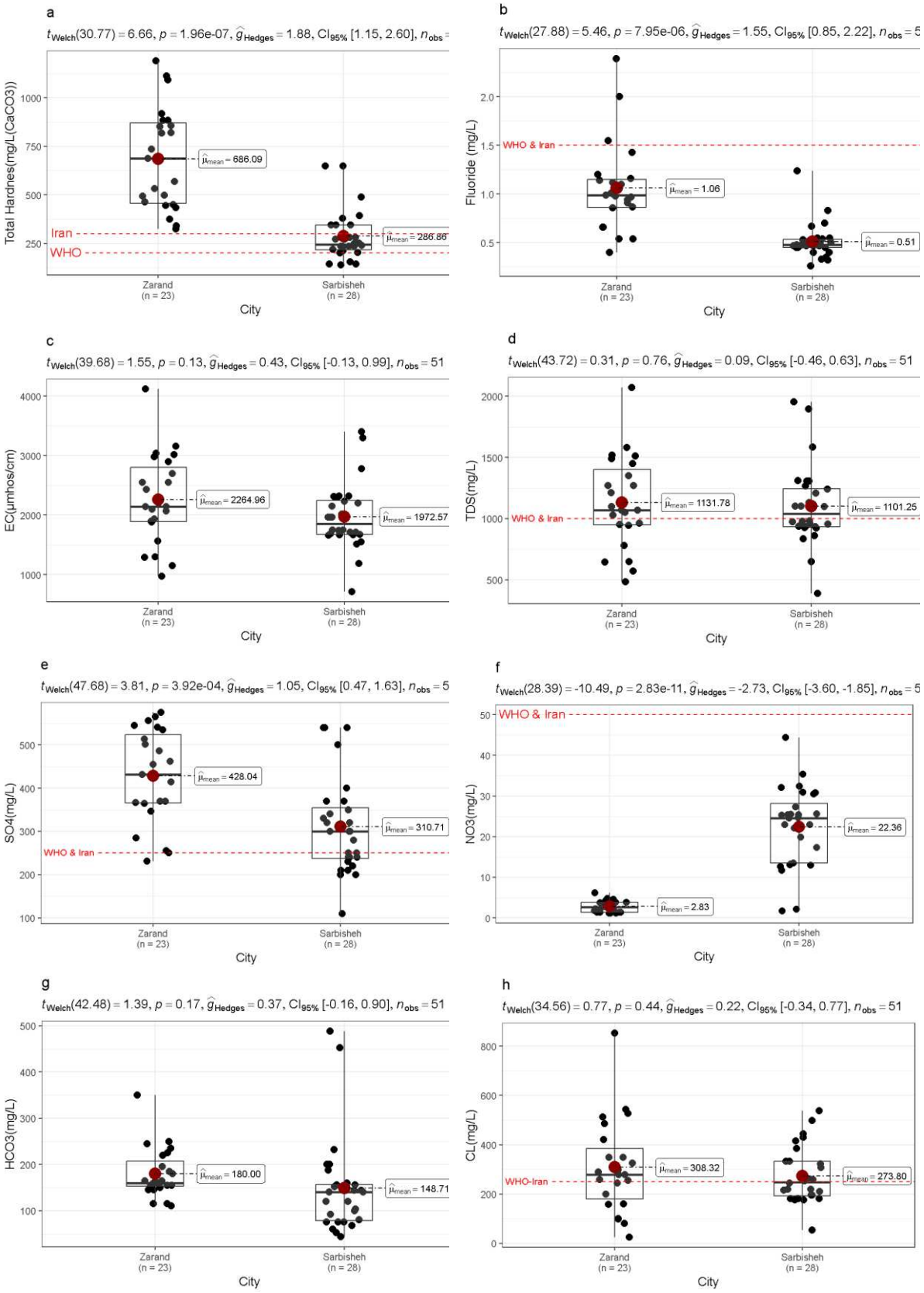


Figure 1. Mean concentration of water chemical parameters: (a) Total Hardness (mg/L ($CaCO_3$)), (b) Fluoride (mg/L), (c) EC (µmhos/cm), (d) TDS (mg/L), (e) SO_4^{2-}(mg/L), (f) NO_3^- (mg/L), (g) HCO_3^- (mg/L), and (h) CL^-(mg/L) in Zarand and Sarbisheh city with Iranian and WHO standards

In Table 2, the prevalence of chronic diseases among the participants is shown based on water hardness levels (low, moderate, and high). The results indicated that 4.3% of participants had a history of cardiovascular diseases. The results indicate that 17.2% of participants had a history of hypertension, 47.6% of participants with a history of hypertension lived in areas with High water Hardness concentration, whereas only 33.4% of participants who did not have a history of hypertension lived in areas with High water hardness concentration (p-value=0.007).

Table 2. Chronic disease status of the participants based on water hardness concentration.

Diseases	Hardness (Level)				p-value*
	Total	Low	Moderate	High	
	N (%)				
Hypertension					
Yes	103(17.2)	8(7.8)	46(44.7)	69(47.6)	0.007*
No	497(82.8)	26(5.2)	305(61.4)	166(33.4)	
Cardiovascular					
Yes	26(4.3)	1(3.8)	11(42.3)	14(53.8)	0.147
No	574(95.7)	33(5.7)	340(59.2)	201(35.0)	
Diabetes					
Yes	40(6.7)	5(12.5)	22(55.0)	13(32.5)	0.153
No	560(93.3)	29(5.2)	329(58.8)	202(36.6)	
Kidney					
Yes	26(4.3)	1(3.8)	17(65.4)	8(30.8)	0.751
No	574(95.7)	33(5.7)	334(58.2)	207(36.1)	

* Chi-square test, p-value is significant at the 0.05 level.

Table 3 presents the correlation between anthropometric indices and blood pressure and water hardness levels, categorized as low, moderate, and high, analyzed using four models: Crude, adjusted model 1, model 2, and model 3. In model 1, the adjusted parameters include age, gender, educational level, exposure to cigarette smoke, and physical activity. In model 2, the adjusted parameters include the history of hypertension, cardiovascular disease, diabetes, and kidney problems, and in model 3, the adjusted parameters include the drinking water supply and filtration status. The results showed that, in all models, the correlation between high/low water hardness levels is significant with BMI, and in all models, the correlation between (high and moderate)/Low water hardness levels is significant with SBP (p-value<0.05). However, in the model that was run only on Zarand data, no significant correlation was identified (p-value>0.05), and only Sarbisheh data showed a significant correlation between moderate/low water hardness levels and DBP (p-value=0.005). Although at the 10% error level, in Zarand data, the negative correlation between high/low water hardness levels is significant with SBP (p-value=0.075), and in Sarbisheh data, the negative correlation between moderate/low water hardness levels is significant with SBP (p-value=0.081).

Table 3. Correlation between anthropometric indices, blood pressure, and water hardness levels in crude and adjusted models

Models	Water Hardness (Ref=Low)	BMI	WC (cm)	SBP (mmHg)	DBP (mmHg)
		β(SE)	β(SE)	β(SE)	β(SE)
Crude	High	2.16(0.89)*	1.10(3.52)	-0.41(2.56)	5.90(1.85)*

Model 1	Moderate	0.86(0.87)	-4.69(3.43)	-0.79(2.49)	4.48(1.81)*
	High	1.78(0.91)*	4.07(3.51)	0.72(2.54)	5.59(1.92)*
Model 2	Moderate	0.83(0.86)	-1.87(3.34)	1.12(2.42)	4.68(1.83)*
	High	2.34(0.88)*	1.19(3.48)	-0.48(2.28)	6.03(1.77)*
Model 3	Moderate	1.20(0.86)	-3.71(3.39)	0.80(2.22)	5.29(1.72)*
	High	2.08(0.91)*	3.11(3.60)	-0.98(2.63)	4.85(1.90)*
Zarand	Moderate	0.80(0.88)	-3.19(3.47)	-1.23(2.53)	3.71(1.83)*
	High	0.32(0.60)	2.16(2.36)	3.25(1.80)	1.43(1.38)
Sarbisheh	Moderate	-	-	-	-
	High	-0.48(3.45)	-12.3(13.8)	-1.47(9.48)	5.73(6.43)
	Moderate	0.50(0.86)	-6.05(3.46)	0.22(2.37)	4.49(1.61)*

* p-values ≤ 0.05 are considered statistically significant.

In Figure 2, the mean WC in people who used home-water purifiers was 82.03 cm, which was lower than that of people who used tap water, which was 85.19 cm (p-value=0.040). Also, the mean DBP in people who used home-water purifiers was 72.55 mmHg, which was lower than that of people who used tap water, which was 70.00 mmHg (p-value=0.001).

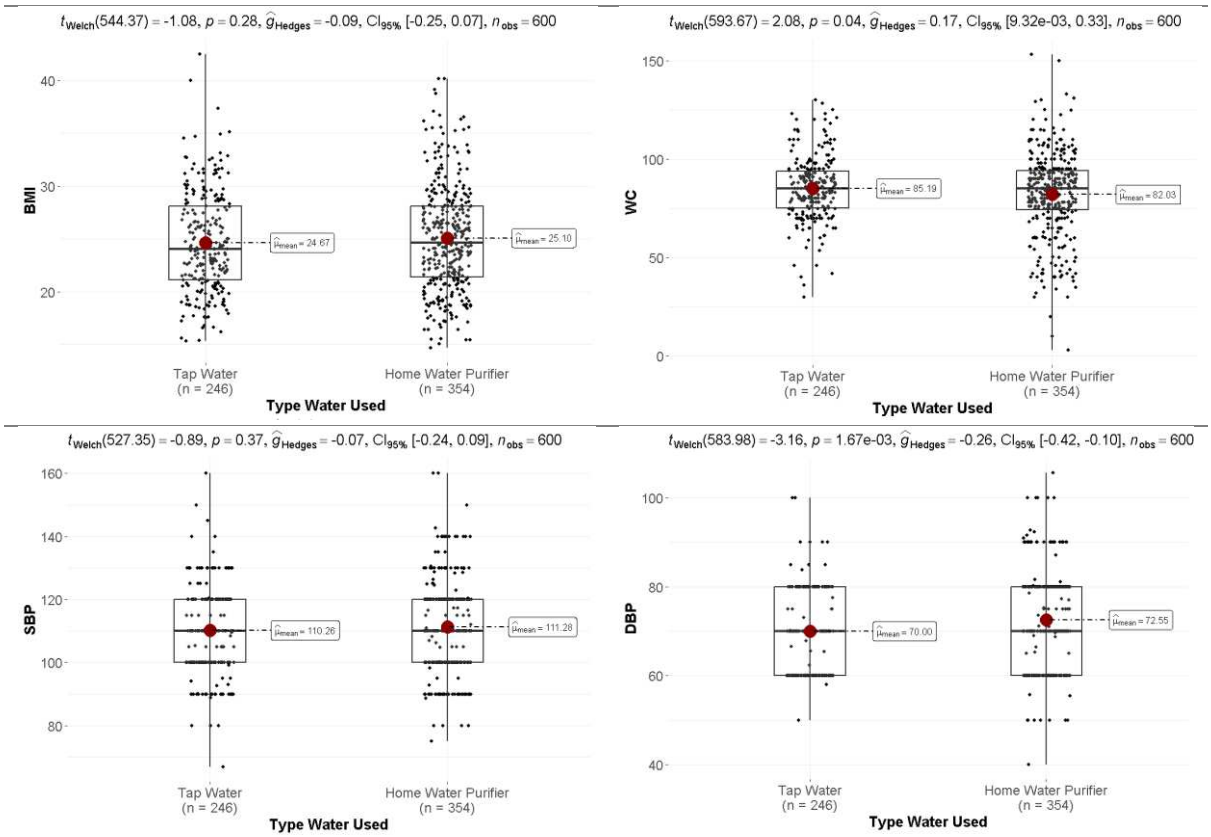
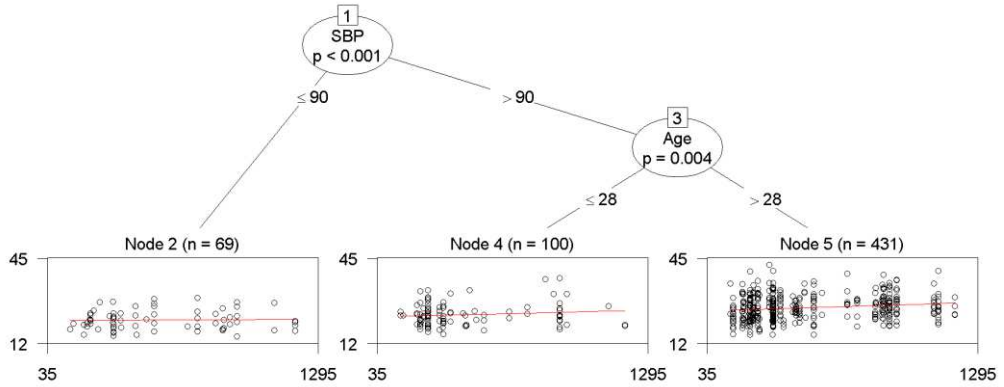
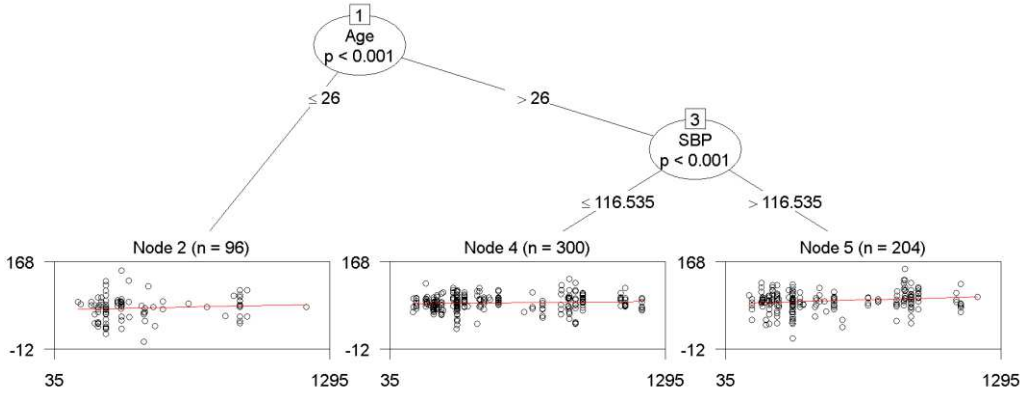
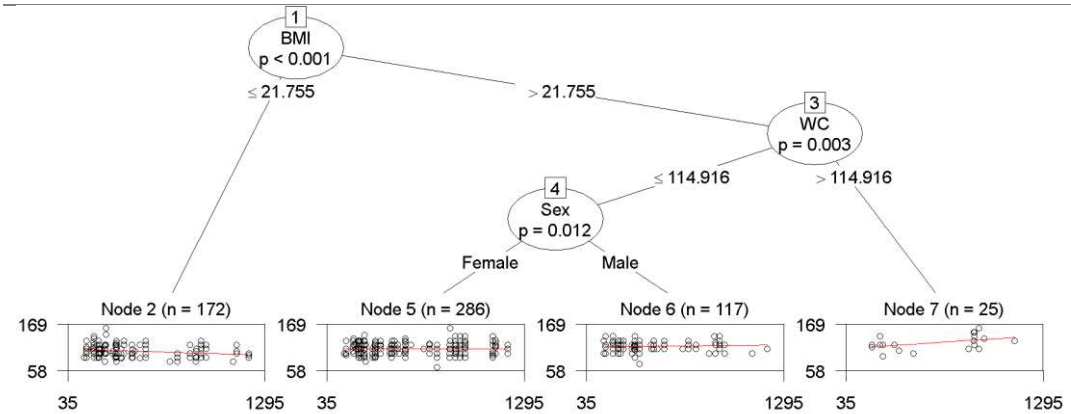


Figure 2. Mean anthropometric parameters and blood pressure by type of water consumed

Figure 3 shows the association of water hardness with BMI, WC, SBP, and DBP using the GLMtree model, after adjusting for the effect of influential variables. For BMI, among people over 28 years of age and with SBP over 90, there was a stronger association between water hardness and BMI ($\beta_{\text{Hardness}} = 0.003$). For WC, there was also a stronger association between water hardness and WC ($\beta_{\text{Hardness}} = 0.016$) among people with SBP above 116 and over 28 years of age (compared to people

with blood pressure above 116 but under 28 years of age ($\beta_{\text{Hardness}} = 0.004$)). For SBP, the association between water hardness and SBP is negative in people with a BMI below 21.75 (β_{Hardness} =-0.011), while it is positive in people above 21.75, especially in people with a WC above 115 ($\beta_{\text{Hardness}} = 0.023$). In people with a BMI below 21 and a WC above 115, the association between water hardness and SBP is stronger in males ($\beta_{\text{Hardness}} = 0.004$) than in females ($\beta_{\text{Hardness}} = 0.001$). Finally, for DBP, Water hardness is positively correlated with DBP in people with EC levels higher than 2320 (β_{Hardness} =0.011) and negatively correlated in people with lower EC levels ($\beta_{\text{Hardness}} = -0.007$).

variables	GLMtree Models
	Node2: $\beta_{\text{Hardness}} = 0.001$, Node4: $\beta_{\text{Hardness}} = 0.002$, Node5: $\beta_{\text{Hardness}} = 0.003$
BMI	
	Node2: $\beta_{\text{Hardness}} = 0.010$, Node4: $\beta_{\text{Hardness}} = 0.004$, Node5: $\beta_{\text{Hardness}} = 0.012$
WC	
	Node2: β_{Hardness} =-0.011, Node5: $\beta_{\text{Hardness}} = 0.001$, Node6: $\beta_{\text{Hardness}} = 0.004$, Node7: $\beta_{\text{Hardness}} = 0.023$
SBP	
DBP	Node2: β_{Hardness} =0.011, Node5: $\beta_{\text{Hardness}} = -0.007$

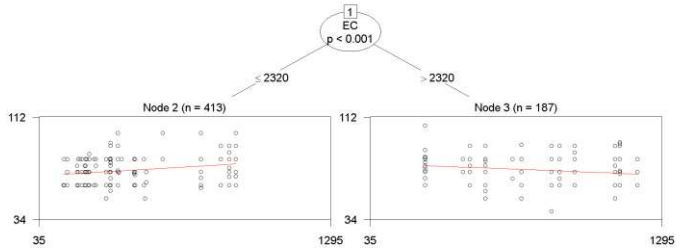


Figure 3. Investigating the relationship between water hardness and BMI, WC, SBP, and DBP variables by adjusting for the effect of influential variables using a tree model.

4. Discussion

In this study, the associations between varying levels of water hardness and anthropometric indices, blood pressure, and demographic factors in the adult population were examined. The results showed that the mean total hardness in Zarand city exceeds both the INSO (6th revision, 2025) limit (300 mg/L) and the WHO 2022 guideline (200 mg/L). In Sarbisheh, the mean total hardness is lower than the Iranian standard but still higher than the WHO guideline. Additionally, the mean levels of TDS, SO_4^{2-}, and Cl^- in both cities were found to be higher than the permissible limits set by INSO and WHO. The climatic conditions of the study areas are arid to semi-arid, with a heavy reliance on groundwater resources, particularly in these regions, contributing to changes in water quality. The chemical composition of groundwater is influenced by various factors, including the infiltration of agricultural wastewater and fertilizers, pollutant seepage, land use changes, and natural processes such as rainfall, aquifer geology, water flow pathways, and groundwater retention time (22). The high total hardness in Zarand city may be attributed to natural processes such as oxidation-reduction, mineral decomposition, and water-rock interactions. For instance, certain minerals like carbonates dissolve rapidly in water, altering its chemical composition, whereas silicates dissolve more slowly, exerting a lesser impact on water composition (22-24). The geological structure of Zarand also contributes to these processes. The upper crustal rocks consist of Cambrian-age fossil sediments, including dolomite, limestone, sandstone, and shale (25), which can serve as primary sources of increased water hardness. Additionally, the depletion of groundwater resources and insufficient rainfall in recent years may have led to a higher concentration of salts in the water, further increasing its hardness (26). Conversely, the low nitrate levels in both cities are likely due to reduced agricultural and urban pollutant input into groundwater or natural nitrate reduction processes occurring in the underground environment.

The results of the present study indicated that the majority of individuals with a history of high blood pressure lived in areas with high water hardness. A direct relationship was also observed between high and moderate water hardness and SBP compared to areas with low water hardness. Furthermore, the findings revealed that factors such as age, gender, and type of water consumed could moderate the effects of water hardness on blood pressure. These results align with some previous studies while contrasting with others in certain aspects.

Several studies have explored the relationship between water hardness and cardiovascular health, with varying results. For instance, Yousefi et al. (2018) found that excessive consumption of hard water was associated with a reduced prevalence of hypertension (18). Similarly, a prospective study by Morris et al. (2008), conducted across 24 British cities with varying levels of drinking water hardness, reported a weak inverse relationship between water hardness and the incidence of cardiovascular disease after adjusting for age. Additionally, they observed a significant positive association between individual Mg intake and the incidence of coronary heart disease (27). Conversely, a study by Nerbrand et al. reported

a positive correlation between water Ca content and SBP, while no association was found between water Mg content and cardiovascular risk factors (28). In contrast, other studies have found no significant association between water hardness and blood pressure or cardiovascular disease (29-31). Interestingly, some research has even suggested that reduced water hardness may be linked to an increased risk of cardiovascular disease (32). These conflicting findings may be attributed to differences in geographical conditions, water chemistry, lifestyle, and the genetic factors of the studied populations (33).

The relationship between water hardness, obesity, and blood pressure remains unclear, with several hypotheses proposed, though none have been fully validated. One theory suggests that high levels of Mg in hard water may have protective effects against heart disease. Mg plays a crucial role in regulating energy metabolism, vascular tone, and ion transport by activating the Na^+/K^+ ATPase enzyme. Mg deficiency may lead to increased blood vessel constriction, whereas adequate Mg levels can promote vasodilation by stimulating the secretion of endothelial prostacyclin (32). Ca and Mg serve as opposing enzyme activators in the body; Ca plays a crucial role in nerve transmission, muscle contraction, and blood coagulation, while Mg is essential for cardiac function and is involved in over 300 enzymatic reactions. Hard water is a natural source of both Ca and Mg. One potential explanation for the association between very hard water and atherosclerosis is the role of hypercalcemia as a risk factor. Elevated Ca levels may contribute to arterial calcification and narrowing of the lumen, particularly in the presence of hypercholesterolemia (34).

The results of the present study indicate that at higher levels of water hardness, there was a direct relationship with BMI; however, no association was found between water hardness and WC at any of the tested levels. Furthermore, the findings suggest that factors such as age, smoking exposure, and a history of high blood pressure may moderate the impact of water hardness on anthropometric indices. Only a limited number of studies have explored the link between water hardness and obesity. Consistent with the findings of the present study, a large cohort study reported that moderate water hardness (121–180 mg/L) was associated with a lower risk of atrial fibrillation, heart failure, coronary heart disease, and stroke, while very soft (≤ 60 mg/L) and very hard (> 180 mg/L) water were linked to higher risk (35). However, this finding contrasts with a study by Shimoda et al. (2020), which reported a significant inverse relationship between water hardness and obesity (36). A study by Moghimani et al. in Mashhad, Iran, where the mean total water hardness was 261.40 mg/L, found no association between total water hardness and cardiovascular risk factors in adults aged 25–65, which is not consistent with the findings of the present study (37).

Water hardness, caused by the presence of minerals like Mg and Ca, can impact obesity. Mg plays a key role in regulating glucose metabolism, activating vitamin D, and modulating the function of essential enzymes. Mg deficiency, which is more common in obese individuals, can lead to increased fat storage and an imbalance between Ca and Mg, raising the risk of insulin resistance, high blood pressure, and metabolic syndrome. Therefore, consuming hard water as a natural source of Mg may help mitigate these risks (38). Additionally, the high hardness of water has prompted some homeowners to use water purification systems, particularly ion exchange devices.

In addition, high water hardness has led some homeowners to use water purification devices, particularly ion exchange systems. The results of the present study showed that the mean WC and DBP in individuals who used home water purifiers were lower than those who relied on tap water. In household water softening systems (using ion exchange), divalent ions such as Ca^{2+} and Mg^{2+} are replaced by sodium ions. These systems are usually installed to prevent scale buildup in pipes and appliances, but they are not typically used for drinking water. In contrast, common household purification units like reverse osmosis systems remove almost all minerals, including Ca^{2+} and Mg^{2+}, without adding sodium (7, 39, 40).

The strengths of this study are as follows: It provides more reliable evidence by analyzing water consumption in urban and rural areas with varying levels of hardness (low, medium, and high) and comparing it to the INSO (2025) and WHO (2022) guidelines. The use of a large sample of the adult

population and a structured questionnaire ensured sufficient statistical power to detect effects and enhanced the accuracy of the results. Unlike previous studies, this research accounted for several confounding factors, including demographic characteristics, history of chronic disease, type of water consumed, and physical activity levels. The application of advanced statistical methods and adjustment models allowed for a more thorough examination of the relationships between variables, while the geographical diversity of the study areas improved the generalizability of the findings.

One limitation of this study is that it only measured total water hardness without separately examining other ions such as Na^+, K^+, Cl^-, and SO_4^{2-}, which may have influenced the results. Additionally, collecting questionnaire data through self-report may introduce recall bias. Another limitation is the lack of a detailed analysis of the type of water consumed; specifically, water samples were not collected from the inlet and outlet of water purification devices, and the specific type of device used by each individual was not accurately recorded, which could impact the accuracy of the findings. Furthermore, geographical and cultural differences, along with the limitation of the sample population to specific regions, make it difficult to generalize the results. As the study was cross-sectional, it was unable to examine causal relationships, and confirmation of the findings would require longitudinal studies.

5. Conclusion

The findings of this study suggest a possible association between exposure to water with hardness levels exceeding the INSO (2025) and WHO (2022) standards and increased BMI and SBP in adults. However, these associations should be interpreted with caution, as they may be influenced by confounding factors such as age, gender, smoking status, and the drinking water supply and filtration status. Given the cross-sectional design of the study, causal inferences cannot be made. Therefore, further cohort and experimental research is necessary to better understand and verify the potential effects of water hardness on anthropometric indicators and blood pressure. Moreover, in light of population growth, increasing water demand, and declining groundwater resources, sustainable water resource management and more comprehensive research in this area are strongly encouraged.

Ethics approval and consent to participate

This study was reviewed and approved by the Ethics Committee of Shahid Sadoughi University of Medical Sciences, Yazd (Ethical approval code: IR.SSU.SPH.REC.1402.197). All participants provided written informed consent prior to participation. Participants were informed about the objectives of the study, confidentiality of their data, and their right to withdraw from the study at any stage without consequences. No identifying personal information was collected or published. The study was conducted in accordance with the ethical principles of the Declaration of Helsinki (2013 revision).

Consent for publication

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 2013 revision of the Declaration of Helsinki. This study was approved by the Ethics Committee of Shahid Sadoughi University of Medical Sciences, Yazd.

Availability of data and materials

The supporting data are available from the corresponding author upon reasonable request.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author contributions

All authors contributed to the study's conception and design. Material preparation, data collection, and analysis were performed by A.D, H.A, A.M, M.E, and H.F. The first draft of the manuscript was written by H.N and all authors commented on the previous versions of the manuscript. All authors read and approved the final manuscript. Conceptualization was performed by A.D, H.A, A.M, M.E, H.F, and S.M; Methodology by A.D, H.A, A.M, M.E, H.F, and S.M; Formal analysis and investigation by M.E, H.F, H.N, A.D, and S.M; Writing original draft preparation by H.A, A.M, and M.E; Writing review and editing by A.D, H.A, A.M, M.E, H.F, and S.M.

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References

1. Chen K, Shen Z, Gu W, Lyu Z, Qi X, Mu Y, et al. Prevalence of obesity and associated complications in China: a cross-sectional, real-world study in 15.8 million adults. Diabetes, Obesity and Metabolism. 2023;25(11):3390-9.
2. Chong B, Jayabaskaran J, Jauhari SM, Chan SP, Goh R, Kueh MTW, et al. Global burden of cardiovascular diseases: projections from 2025 to 2050. European Journal of Preventive Cardiology. 2024:zwae281.
3. Chooi YC, Ding C, Magkos F. The epidemiology of obesity. Metabolism. 2019;92:6-10.
4. Behnoush AH, Younesian S, Mousavi SM, Khanmohammadi S, Golestani A, Rashidi M-M, et al. Temporal trends in cardiovascular disease risk factors attributed burden in Iran, 1990–2021. Scientific Reports. 2025;15(1):14279.
5. Pourfarzi F, Sadjadi A, Poustchi H, Amani F. Prevalence of overweight and obesity in Iranian population: A population-based study in northwestern of Iran. Journal of Public Health Research. 2022;11(1):jphr. 2021.475.
6. Hossienifar F, Entezari M, Hosseini S. Water hardness zoning of Isfahan Province, Iran, and its relationship with cardiovascular mortality, 2013-2015. Arya Atherosclerosis. 2019;15(6):275.
7. Akram S, Rehman F. Hardness in drinking-water, its sources, its effects on humans and its household treatment. J Chem Appl. 2018;4(1):1-4.
8. Sengupta P. Potential health impacts of hard water. International journal of preventive medicine. 2013;4(8):866.

9. Gianfredi V, Bragazzi NL, Nucci D, Villarini M, Moretti M. Cardiovascular diseases and hard drinking waters: implications from a systematic review with meta-analysis of case-control studies. Journal of Water and Health. 2017;15(1):31-40.
10. Catling LA, Abubakar I, Lake IR, Swift L, Hunter PR. A systematic review of analytical observational studies investigating the association between cardiovascular disease and drinking water hardness. Journal of water and health. 2008;6(4):433-42.
11. Rapant S, Letkovičová A, Jurkovičová D, Kosmovský V, Kožíšek F, Jurkovič Ľ. Differences in health status of Slovak municipalities supplied with drinking water of different hardness values. Environmental Geochemistry and Health. 2021;43:2665-77.
12. Yang H, Wang Q, Zhang S, Zhang J, Zhang Y, Feng J. Association of domestic water hardness with all-cause and cause-specific cancers: evidence from 447,996 UK Biobank participants. Environmental Health Perspectives. 2024;132(6):067008.
13. Zhang J, Luo H, Wu H, Qian Y, Tang Z, Wang J, et al. The association between domestic water hardness and kidney stone disease: a prospective cohort study from the UK Biobank. International Journal of Surgery. 2025;111(2):1957-67.
14. Abdelhafez AA, Abbas MH, Kenawy MH, Noureldeen A, Darwish H, Ewis AM, et al. Evaluation of underground water quality for drinking and irrigation purposes in New Valley Governorate, Egypt. Environmental Technology & Innovation. 2021;22:101486.
15. Mohebbi MR, Saeedi R, Montazeri A, Vaghefi KA, Labbafi S, Oktaie S, et al. Assessment of water quality in groundwater resources of Iran using a modified drinking water quality index (DWQI). Ecological indicators. 2013;30:28-34.
16. Malakootian M, Maleki S, Rajabi S, Hasanzadeh F, Nasiri A, Mohammdi A, et al. Source identification, spatial distribution and ozone formation potential of benzene, toluene, ethylbenzene, and xylene (BTEX) emissions in Zarand, an industrial city of southeastern Iran. Journal of Air Pollution and Health. 2022.
17. Eslami A, Ghaffari M, Barikbin B, Fanaei F. Assessment of safety in drinking water supply system of Birjand city using World Health Organization's water safety plan. Environmental health engineering and management journal. 2018;5(1):39-47.
18. Yousefi M, Najafi Saleh H, Yaseri M, Jalilzadeh M, Mohammadi AA. Association of consumption of excess hard water, body mass index and waist circumference with risk of hypertension in individuals living in hard and soft water areas. Environmental geochemistry and health. 2019;41:1213-21.
19. Hashemi M, Rajabi S, Eghbalian M, Suliburska J, Nasab H. Demographic and anthropometric characteristics and their effect on the concentration of heavy metals (arsenic, lead, chromium, zinc) in children and adolescents. Heliyon. 2023;9(2).
20. Nasab H, Rajabi S, Eghbalian M, Malakootian M, Hashemi M, Mahmoudi-Moghaddam H. Association of As, Pb, Cr, and Zn urinary heavy metals levels with predictive indicators of cardiovascular disease and obesity in children and adolescents. Chemosphere. 2022;294:133664.
21. Lipps WC, Braun-Howland EB, Baxter TE. Standard methods for the examination of water and wastewater2023.
22. Rezaei A, Sayadi MH, Zadeh RJ, Mousazadeh H. Assessing the hydrogeochemical processes through classical integration of groundwater parameters in the Birjand plain in eastern Iran. Groundwater for Sustainable Development. 2021;15:100684.
23. Badeenezhad A, Tabatabaee HR, Nikbakht H-A, Radfard M, Abbasnia A, Baghapour MA, et al. Estimation of the groundwater quality index and investigation of the affecting factors their changes in Shiraz drinking groundwater, Iran. Groundwater for Sustainable Development. 2020;11:100435.
24. Takin FZ, Khosravi Y, Zamani A. Investigating the Relationship between Land Use Changes and Physicochemical Characteristics of Groundwater. Journal of Human Environment and Health Promotion. 2021;7(4):205-12.
25. Moosavirad S, Janardhana M, Khairy H. Impact of anthropogenic activities on the chemistry and quality of groundwater: a case study from a terrain near Zarand City, Kerman Province, SE Iran. Environmental Earth Sciences. 2013;69:2451-67.
26. Malakootian M, Dowlatshahi S. Variations of chemical quality for drinking water sources in Zarand plain. Journal of Environmental Health Science & Engineering. 2007;4(4):257-62.

27. Morris RW, Walker M, Lennon LT, Shaper AG, Whincup PH. Hard drinking water does not protect against cardiovascular disease: new evidence from the British Regional Heart Study. European Journal of Preventive Cardiology. 2008;15(2):185-9.
28. Nerbrand C, Agréus L, Lenner RA, Nyberg P, Svärdsudd K. The influence of calcium and magnesium in drinking water and diet on cardiovascular risk factors in individuals living in hard and soft water areas with differences in cardiovascular mortality. BMC public Health. 2003;3:1-9.
29. Meyers D, Williams G. Mortality from all causes, and from ischaemic heart disease, in the Australian capital cities. Medical Journal of Australia. 1977;2(15):504-5.
30. Sonneborn M, Mandelkow J, Schön D, Hoffmeister H, Zoeteman B. Health effects of inorganic drinking water constituents, including hardness, iodide, and fluoride. Critical Reviews in Environmental Science and Technology. 1983;13(1):1-22.
31. MacKinnon A, Taylor S. Relationship between 'sudden'coronary deaths and drinking water hardness in five Yorkshire cities and towns. International journal of epidemiology. 1980;9(3):247-50.
32. Oğuz S. The Relationship Between Aterosclerotic Cardiovascular Diseases and Drinking Water Hardness Level in Çanakkale Province. Namık Kemal Tıp Dergisi. 2021;9(1).
33. Nasab H, Mirzaee M, Ebrahimpour K, Hashemi M. Association of urinary triclosan and methyl-triclosan levels with predictive indicators of cardiovascular disease and obesity in children and adolescents in 2020 (case study: Kerman, Iran). Environmental Health Engineering and Management Journal. 2021;8(3):187-95.
34. Vogiatzi G, Lazaros G, Oikonomou E, Kostakis M, Kypritidou Z, Christoforatou E, et al. Impact of drinking water hardness on carotid atherosclerosis and arterial stiffness: Insights from the "Corinthia" study. Hellenic Journal of Cardiology. 2023;74:32-8.
35. Tian F, Yu G, Yang M, Sun Y, Gui Z, Zhao X, et al. Domestic water hardness, genetic risk, and distinct phenotypes of cardiovascular disease. Environmental Health. 2025;24(1):1-11.
36. Shimoda Y, Okada J, Yamada E, Okada K, Okada S, Yamada M. Association between percentage of obese people and water hardness in water purification plants. Obesity Medicine. 2020;19:100244.
37. Moghimani M, Rahati S, Sobhani SR, Hashemi M, Afshari A. Evaluation of the Relationship Between Water Hardness and Incidence of Cardiovascular Diseases in Mashhad, Iran During 2018–2020: A Cross-Sectional Study. Health Science Reports. 2025;8(3):e70376.
38. Piuri G, Zocchi M, Della Porta M, Ficara V, Manoni M, Zuccotti GV, et al. Magnesium in obesity, metabolic syndrome, and type 2 diabetes. Nutrients. 2021;13(2):320.
39. Wright IA, Morrison K, Ryan M, Cusbert S, Reynolds J, editors. Elevated sodium concentrations in Australian drinking water supplies. IOP Conference Series: Earth and Environmental Science; 2019: IOP Publishing.
40. Codină GG, Voinea A, Dabija A. Strategies for reducing sodium intake in bakery products, a review. Applied Sciences. 2021;11(7):3093.