DOI 10.25789/YMJ.2025.92.20

УДК 628.1.033

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EVALUATION OF THE APPLICABILITY OF NONPARAMETRIC REGRESSION MATHEMATICAL MODELS FOR ASSESSING CAUSE-AND-EFFECT RELATIONSHIPS BETWEEN DRINKING WATER QUALITY AND POPULATION MORBIDITY

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Introduction. The health of the population depends on the chemical composition of water used for domestic and drinking purposes. The chemical composition of consumed drinking water can have a negative impact on various human organ systems. There are sanitary and hygienic standards for maximum permissible concentrations (MPC) of chemicals in drinking water, which can be used to determine its safety. To study the degree of influence of the chemical composition of drinking water on public health, it is necessary to identify causal relationships between water quality and specific disease nosologies in the population. There is also a need to find the optimal statistical and mathematical model and to compare different models.

Objective. To assess the applicability of regression models for establishing a relationship between drinking water quality (water samples non-compliant in chemical indicators) and population morbidity.

Materials. Open data from social-hygienic monitoring over an 11-year period (2013–2023) for the Republic of Bashkortostan.

Methods. Correlation analysis (Spearman's) and three regression models robust to small samples and outliers: robust regression, polynomial regression, and Theil-Sen regression.

Results. Statistically significant relationships were identified between poor-quality water in terms of chemical indicators and the following diseases: angina pectoris, diseases of the circulatory system, and diseases of the musculoskeletal system. For many other diseases (congenital anomalies, respiratory diseases, diabetes mellitus, neoplasms, etc.), no significant relationship with water quality was found within this model.

Discussion. The results partially agree with literature data (e.g., the influence of hard water on the cardiovascular system, strontium on the musculoskeletal system). The main limitation is the small sample size (only 11 data points - by year), which reduces the study's power. The model is generalized and does not account for specific chemicals and their concentrations (e.g., hardness, nitrates, iron) that are prevalent in the region. Morbidity is also influenced by other factors (lifestyle, environmental conditions, socio-economic factors) not accounted for in the model.

Conclusion. Potential causal relationships were found between poor-quality drinking water and the incidence of angina pectoris, other diseases of the circulatory system, and possibly diseases of the musculoskeletal system in the Republic of Bashkortostan. Further research with larger datasets, analysis of specific pollutants, and consideration of additional risk factors is needed to confirm these links. Enhanced monitoring of both the chemical composition of water and population morbidity is necessary for implementing targeted measures to improve the situation.

Keywords: drinking water, mathematical model, regression, causal relationship, morbidity, public health monitoring (SGM).

For citation: Rakhimova, A.R., Valeev, T.K., Suleimanov, R.A., Saligaskarov, I.I., Davletnurov, N.Kh., Nuretdinova, K.S., Baktybaeva, Z.B., Stepanov, E.G. Evaluation of the applicability of nonparametric regression mathematical models for assessing cause-and-effect relationships between drinking water quality and population morbidity. Yakut Medical Journal. 2025; 92(4): 87-91. https://doi.org/10.25789/YMJ.2025.92.20

Introduction. Providing the population with high-quality drinking water is a significant challenge. Although access to quality drinking water is increasing, a portion of the population still receives water of unsatisfactory quality from centralized water supply systems. According to Rospotrebnadzor, cases of morbidity associated with the consumption of poor-quality drinking water have been registered in the Russian Federation. The chemical composition of drinking water can affect the gastrointestinal tract, genitourinary and musculoskeletal systems, among others [27].

Within the framework of the global sustainable development goals set for 2030, one of the key tasks is to ensure universal and equitable access to safe and affordable drinking water for all inhabitants of the planet. In Russia, the regulation of drinking water quality is particularly important, as it directly affects the health and quality of life of the population. In this context, state initiatives and measures to control and improve water supply quality become a priority, aimed at creating conditions for sustainable development and the well-being of citizens [14, 18].

The chemical composition of drinking water is one of the factors affecting public health, both in terms of general morbidity and specific disease nosologies. The most common diseases associated with the consumption of poor-quality drinking water are considered to be diseases of the genitourinary, digestive, musculoskeletal, and cardiovascular systems. Exceeding hygienic standards for certain chemicals can negatively affect the health of both adult and child populations [1, 5, 6, 9, 10, 12, 16, 23, 26].

The list of controlled chemical substances in drinking water includes about 70 chemicals, but it is also necessary to consider that water should be physiologically complete for human health. The list of sanitary-chemical indicators of drinking water that significantly affect public health includes chemicals of both natural and artificial origin [3, 17, 25].

Establishing cause-and-effect relationships between the health status of the population and the influence of environmental factors is the basis of social-hygienic monitoring (SGM). This system ensures continuous observation and assessment of environmental factors, as well as forecasting potential adverse consequences. Based on the data obtained, decisions are made aimed at reducing risks to public health [28].

Research Objective. To assess the applicability of regression models for evaluating causal relationships between drinking water quality and population morbidity.

Materials and Methods. Data from open sources were used as materials. Morbidity rates per 1000 population of the Republic of Bashkortostan were taken from statistical collections, and information on drinking water quality was obtained from the annual state reports of the UPRNRB.

Morbidity categories per 1000 population included: neoplasms, diseases of the endocrine system (including diabetes mellitus), diseases of the blood and blood-forming organs and certain disorders involving the immune mechanism (including anemias), diseases of the nervous system, diseases of the circulatory system (including diseases characterized by elevated blood pressure, ischemic heart disease, including angina pectoris and myocardial infarction), diseases of the respiratory and digestive organs (including gastric and duodenal ulcers), diseases of the skin and subcutaneous tissue, as well as diseases of the musculoskeletal system and connective tissue.

The analyzed factors influencing population morbidity were selected as the proportions of drinking water samples from non-centralized and centralized (distribution network) water supply systems that did not comply with sanitary-chemical standards (Figure 1).

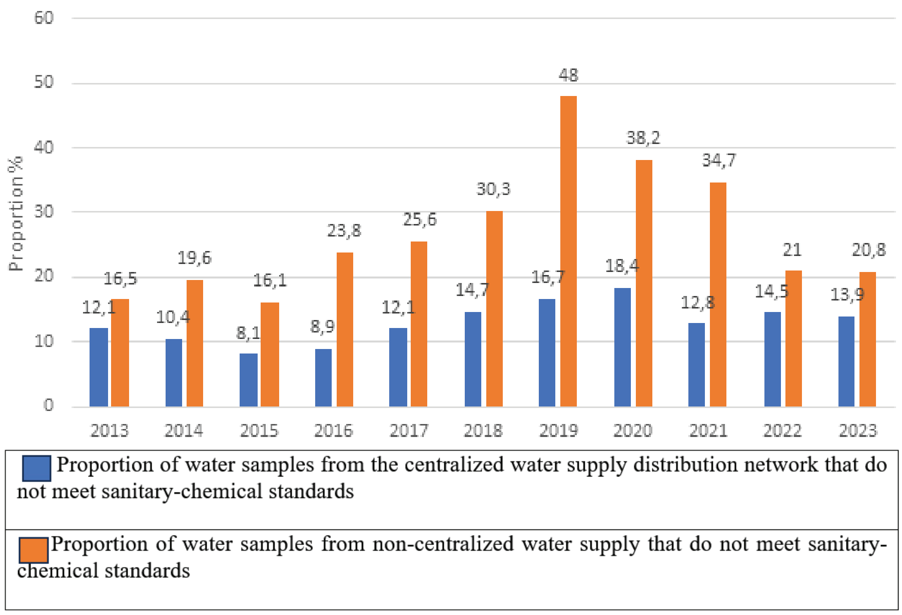
The sample covered an 11-year period from 2013-2023. The average proportion of non-compliant samples for hardness was 26.7%; the average proportion of non-centralized water supply samples non-compliant for sanitary-chemical indicators was 26.8%; the average proportion of non-centralized water supply samples for the rural population non-compliant for sanitary-chemical indicators was 26.8%; the average proportion of samples from centralized water supply systems non-compliant for sanitary-chemical indicators was 12.9%.

Average morbidity rates over the 11-year period according to state statistics (per 1000 population) were: neoplasms – 42.6; Diseases of the endocrine system, nutritional and metabolic disorders – 67.5; Diabetes mellitus – 29.9; Diseases of the blood and blood-forming organs and certain disorders involving the immune mechanism – 24.4; Anemias – 23.2; Diseases of the nervous system – 128; Diseases of the eye and adnexa – 110.25; Diseases of the ear and mastoid process – 45.86; Diseases of the circulatory system – 286.6; Elevated blood pressure – 128.9%; Ischemic heart disease – 62.4%; Acute myocardial infarction – 1.22%; Angina pectoris – 18.31%; Diseases of the respiratory organs; Diseases of the digestive organs – 166.38%; Gastric and duodenal ulcers – 7.05%; Diseases of the genitourinary system; Diseases of the skin and subcutaneous tissue – 69.8%; Diseases of the musculoskeletal system – 146.7%; Congenital anomalies – 6.53%. The statistical collections provided general morbidity rates per 1000 population without specifying ICD codes.

Spearman's correlation and three regression models were used as statistical methods: robust regression, polynomial regression, and Theil-Sen Regression. The choice of these methods is justified by the fact that non-parametric methods are robust to non-normal distribution, outliers, and small sample sizes.

Spearman's correlation calculation and correlation matrix construction were performed in the JASP statistical program, and regression model construction was done in Python using libraries such as pandas, numpy, scipy.stats, sklearn, etc.

Results. The results of the correlation analysis (Table 1) indicate a significant relationship between the proportion of non-compliant drinking water samples and population morbidity. The most pronounced relationships are with diseases



Proportion of drinking water samples non-compliant with sanitary-chemical standards

Table 1

Spearman's correlation between the proportion of non-compliant drinking water samples by sanitary-chemical indicators and morbidity per 1000 population

Proportion of non-compliant water samples (according to UPRNRB data)	Morbidity category per 1000 population (according to Bashstat data)	Spearman's Correlation Result
Proportion of non-standard samples by hardness, %	Congenital anomalies (malformations), deformations and chromosomal disorders	r=0.59 p-value =0.029
Proportion of water samples from non-centralized water supply non-compliant by sanitary-chemical indicators, %	Diseases of the respiratory organs	r=0.55 p-value =0.044
	Angina pectoris	r=0.53 p-value =0.047
Proportion of water samples from the centralized water supply distribution network non-compliant by sanitary-chemical indicators, %	Diseases of the musculoskeletal system	r=0.71 p-value =0.007
	Diseases of the respiratory organs	r=0.65 p-value =0.016
	Angina pectoris	r=0.76 p-value =0.003
	Diseases characterized by elevated blood pressure	r=0.64 p-value =0.017
	Diseases of the circulatory system	r=0.67 p-value =0.011
	Diseases of the endocrine system, nutritional and metabolic disorders	r=0.60 p-value =0.026
	Diabetes mellitus	r=0.59 p-value =0.028

Table 2

Regression Models for Establishing Causal Relationships between Drinking Water Quality and Population Morbidity

Variables		Regression/Significance			
Dependent Variable	Independent Variable	Robust Regression	Polynomial Regression	Theil-Sen Regression	Significance
Congenital Anomalies	Hard Water Samples	0.0112	[0.0, 0.2872, -0.0038]	0.0208	Not significant (all three models)
Angina Pectoris Incidence	Non-Centralized Supply Samples	0.1914	[0.0, 0.5021, -0.0062]	0.2252	Significant (Robust and Theil-Sen)
Respiratory Diseases	Non-Centralized Supply Samples	1.7916	[0.0, 19.7936, -0.2916]	3.3431	Not significant (all three models)
Angina Pectoris Incidence	Non-Centralized Supply Samples	0.6475	[0.0, 2.2391, -0.0560]	0.6149	Significant (Robust and Theil-Sen)
Circulatory System Diseases	Distribution Network Samples	5.1629	[0.0, 37.3473, -1.1780]	5.2005	Significant (Robust and Theil-Sen)
Elevated Blood Pressure	Distribution Network Samples	2.9351	[0.0, 19.0614, -0.5915]	3.3820	Not significant (all three models)
Musculoskeletal System Diseases	Distribution Network Samples	1.1405	[0, 14.3667, -0.4946]	1.0695	Significant (Robust Regression only)
Respiratory Diseases	Distribution Network Samples	10.4147	[0, 54.9851, -1.6850]	8.9512	Not significant (all three models)
Diabetes Mellitus	Distribution Network Samples	0.5689	[0, 1.9577, -0.0518]	0.8297	Not significant (all three models)
Endocrine, Nutritional and Metabolic Diseases	Distribution Network Samples	0.8676	[0; 8.4592; -0.2790]	0.9350	Not significant (all three models)
Elevated Blood Pressure	Distribution Network Samples	2.9351	[0, 19.0614, -0.5915]	3.3820	Not significant (all three models)
Angina Pectoris Incidence	Distribution Network Samples	0.6475	[0, 2.2391, -0.0560]	0.6150	Significant (Robust Regression only)
Circulatory System Diseases	Distribution Network	5.1629	[0, 37.3473, -1.1780]	5.2005	Significant (Robust Regression only)

of the cardiovascular system, respiratory system, and musculoskeletal system.

For further analysis of the causal relationship, pairs of variables with positive satisfactory Spearman correlation coefficients from Table 1 were selected, and regression analysis was conducted. Three types of regression models were chosen (Table 2): robust, polynomial, and Theil-Sen Regression. These methods are robust to outliers, small sample sizes, and non-normal distribution.

Based on the statistical data processing [19, 20], conclusions can be drawn and it can be suggested that:

- A significant relationship is observed (according to robust regression and Theil-Sen Regression) in the case of drinking water samples from non-centralized water supply and angina pectoris. This indicates a possible influence of water quality from non-centralized sources on the incidence of angina pectoris.
- A significant relationship was found (according to robust regression and Theil-Sen Regression) in the case of samples from the distribution network and angina pectoris. This may indicate the influence of water quality from the distribution network on the risk of developing angina pectoris.
- A significant relationship was identified (according to robust regression and Theil-Sen Regression) in the case of samples from the distribution network and diseases of the circulatory system. This suggests that water quality in the distribution network may influence the incidence of circulatory system diseases.
- A significant relationship was found (only according to robust regression) between samples from the distribution network and diseases of the musculoskeletal system. This may indicate a weak link between water quality and musculoskeletal diseases, but additional data are needed for confirmation.

For congenital anomalies, diseases of the respiratory organs, elevated blood pressure, diabetes mellitus, diseases of the endocrine system, and other diseases, no significant relationship with water samples was found. This may mean that water quality is not a primary risk factor for these diseases in this study.

Discussion. The mathematical model is generalized; the chemical composition of drinking water is diverse, and it is necessary to account for the maximum permissible concentrations (MPCs) of chemicals and the degree of their influence on human organ systems. The model also presents a general indicator of oncological morbidity without localization. For example, according to literature sources, long-term consumption of drinking water with high nitrate content is known to cause malignant neoplasms in the genitourinary system [21]. Our calculations did not find a link between drinking water and malignant neoplasms from the generalized data, but a causal relationship was found between drinking water and diseases of the cardiovascular and musculoskeletal systems.

The research results are supported by literature data. Foreign literature sources contain information on the influence of hard water (calcium and magnesium) on the incidence of cardiovascular diseases [29, 30, 31, 33]. It is known that the water in the Republic of Bashkortostan is quite hard, but our model did not detect a statistically significant link from the generalized data. To establish a connection, it is necessary to study several districts with exceeding hardness indicators and the dynamics of cardiovascular diseases. Literature data also confirm the relationship between the consumption of poor-quality drinking water and diseases of the musculoskeletal system. It is known that strontium in drinking water negatively affects the development of the musculoskeletal system, particularly in children [4, 24, 32]. In addition to musculoskeletal morbidity, literary sources present studies on the influence of the mineral composition of drinking water on the dental morbidity of the child population [22].

The problem of assessing the hygienic safety of water is exacerbated by the insufficient reliability of the maximum permissible concentrations (MPCs) of some chemicals. For example, the MPCs for lead, perchlorates, molybdenum, arsenic, and acrylonitrile do not always provide sufficient protection. In particular, the MPC for arsenic is not sufficiently reliable for women's reproductive health. Furthermore, the MPCs for molybdenum, antimony, perchlorates, nitrates, fluoride, cyanides, dimethylamine, and phthalates do not provide adequate protection for children. These shortcomings highlight the need to revise and refine existing standards to ensure a more reliable assessment of the hygienic safety of water [8, 15].

According to Rospotrebnadzor data for 2023 (Figure 1), 98.435% of the population is supplied with drinking water from centralized systems; an increase in drinking water samples non-compliant for sanitary-chemical indicators is noted. Drinking water does not meet standards for indicators such as "Turbidity," "Total Hardness," "Total Mineralization," "Iron," "Manganese," "Nitrates," "Sulfates," "Lithium," "Strontium" [20].

Conclusion. The study is a mathematical model; the smaller the sample size, the lower the study's power. The sample size significantly affects the accuracy of calculations. In our case, the sample consisted of an 11-year period.

Statistically significant causal relationships are observed between drinking water samples from non-centralized and centralized water supplies, non-compliant for sanitary-chemical indicators, and some diseases of the cardiovascular system, as well as the musculoskeletal system. This may indicate a potential influence of water contaminants on the cardiovascular and musculoskeletal systems. For other diseases, no significant link was found, which may indicate the absence of water quality influence on these diseases within the scope of this study.

To confirm the causal relationship, additional research is needed, including analysis of specific chemicals in drinking water and their impact on public health, as well as accounting for other factors (e.g., socio-economic conditions, lifestyle, etc.).

To reduce diseases associated with the consumption of poor-quality drinking water, monitoring of morbidity and the chemical composition of drinking water is necessary.

To manage the risks associated with exposure to poor-quality drinking water on public health, it is necessary to enhance the chemical monitoring system, improve the regulatory framework and water treatment technologies, and implement zoning for areas with high environmental risks within industrial and economic zones.

The authors declare no conflict of interest.

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