Drinking-water Quality Risk Assessment Based on Parameters with Organoleptic (Taste and Odor) Effects Observed in Water from Surface Water Intake and Infiltration Water Intake Facilities

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Abstract. Risks of organoleptic (taste and odor) effects in drinking water from three water intake facilities are assessed, and research results are presented. The highest risk values for water hardness were identified in samples from infiltration water intake; the value for color-related risks was constant and equal to 0.001. For surface water intake samples, the values of water hardness and associated organoleptic risk are the lowest, compared to other water intakes, and do not exceed 0.008. Risk values of organoleptic effects associated with color at the surface water intake facilities are within the range of 0.001–0.003. The risk values for the taste, and odor effects due to turbidity are constant for all water intakes and equal to 0.002. There is no risk of developing organoleptic-olfactory products associated with the chemical oxygen demand parameter in all samples. The research shows that the overall values of the organoleptic risks are the highest in instances form infiltration water intakes compared with the surface water intake. In addition, the water hardness parameter contributes the most to overall organoleptic risks for all water intakes. The authors conclude that the risks associated with organoleptic (taste and odor) effects do not exceed an acceptable level, both for each indicator considered separately and for their combined effect.

Keywords: Multiphase medium · Water quality · Risk assessment · Organoleptic effects · General parameters · Water hardness · Turbidity · Color · Chemical oxygen demand · Surface water intake · Infiltration water intake

1. Introduction

Natural water is a multiphase medium containing various impurities, the quantity, and quality, depending on the water source’s location and the attention paid to its protection. Thus, surface water sources are usually more susceptible to various factors, such as surface runoff from the catchment area, erosion of bottom sediments, water pollutant transfer (flowing rivers and streams), and atmospheric precipitation containing a large amount of hazardous pollutants [22]. The composition of pollutants includes formations in various chemical compounds and forms. As a result of migration in an aqueous medium, chemical element can be in the form of suspended matter, colloids, or in a truly dissolved state [22]. Underground water intakes are less affected by anthropogenic and technogenic factors [21]. Their composition is mainly formed due to the dissolution of salts constituting the rock. However, in this case,
too, the water-polluting insoluble and sparingly soluble hydrophobic components migrate to the aquifers. Thus, anthropogenic factors and their impact on water resources contribute to the fact that indicators, which are the main technological parameters that determine the choice of technology and reagents for the effective operation of water treatment plants (watercolor, turbidity, chemical oxygen demand), are the result of the influence of various pollutants [13, 20]. In the current environmental conditions, environmental monitoring of water bodies is necessary to provide the population with soft drinking water, especially in urban agglomerations with developed oil refining, petrochemical, machine-building, and construction industries, as the basis for developing solutions for managing water quality and improving the efficiency of the water treatment process.

It was previously assumed that the standards set for organoleptic parameters excluded any toxic effects and did not pose any danger to human health. However, when the organoleptic properties of water are not consistent with hygienic standards, it is no less significant than the presence of toxins in water [12], since it can pose a real health danger to the population [11]. Changes in the smell, taste, and color of water, the formation of a film or foam on the surface, can indicate the effects of chemicals that adversely affect health. As a result, water change's organoleptic properties change, and it becomes unsuitable for drinking [5, 8, 11, 17]. Half of the total number of chemicals present in the water, toxic only at elevated concentrations, nonetheless may affect the organoleptic properties of water even when the concentrations stay within the acceptable range [12].

It was previously established that most substances are toxic when their concentration is ten times higher than the maximum permitted concentration [11]. With increasing concentrations of the potentially toxic substance, the organoleptic properties of water, by the Weber-Fechner law, begin to change even before the threshold concentration of the harmful effect is reached (Federal Center for Health and Epidemiology Rospotrebnadzor [FCH&E Rospotrebnadzor] [6, 10]). Thus, even an insignificant deviation from the acceptable concentration range increases the intensity of organoleptic effects, and water becomes unsuitable for drinking [11]. Also, there are problems with the synergism of toxic products in the joint presence of pollutants.

It should be noted that the largest share of the total number of consumer complaints regarding drinking water quality [18] are the complaints made about the unpleasant taste and odor [4, 5, 7, 18]. This is since the organoleptic properties of drinking water that meet hygienic standards can be perceived by consumers as unacceptable [1, 2, 3, 5, 19]. Therefore, drinking water quality standards consider pollution's possible effect on odor, taste, turbidity, foaming, etc. [1, 5, 8, 11, 15, 23].

Assessment of the organoleptic properties of drinking water by laboratory experts is conducted through testing whether the water samples are within the standards established for the parameters “watercolor,” “turbidity,” as well as a chemical composition that affects the organoleptic properties of water (specifically water hardness and chemical oxygen demand) [14]. However, the parameters listed above should be evaluated not as physical properties of water, but as an olfactory organoleptic effect on the human organism.

Thus, the aim of this work is an attempt to manage water quality, which is an assessment of the organoleptic risks present for drinking water supplied from the clean water tank (CWTs) storing water from two types of water intake facilities, based on parameters of water hardness, turbidity, color and chemical oxygen demand (oxidation), as well as the overall risk of organoleptic effects.

2. Materials and Methods
Three of the most productive water intake facilities were selected for the study: one surface water intake facility (SWF) and two infiltration water intake facilities (IWF1 and IWF2). At SWF, the surface waters of the Ufa River were the primary water source. Groundwaters fed by precipitation and infiltrated waters from the river supplied water to the infiltration facilities. Water treatment at IWF1 and IWF2 includes natural filtration of groundwater through the soil and its further disinfection. Simultaneously, the SWF uses a two-stage treatment system with disinfection before and after water treatment. After chlorination, the water is stored in the transparent water tank (CWT), which feeds the city's water distribution network. CWT1 and CWT2 are located on IWF1 and SWF, respectively; IWF2 has three CWTs
Four key parameters were selected to assess the organoleptic risks, with standards listed by their effect on water's organoleptic properties (table 1).

The average annual values of the four studied parameters were used to calculate the risk levels. The long-term average values of the parameters recorded at the CWTs over the period from 1997–2014 were used to estimate the overall organoleptic risk.

Table 1. Organoleptic parameters for drinking water quality assessment in Ufa.

| Parameter              | TLV/ Standard       | Effect Criteria       |
|------------------------|---------------------|-----------------------|
| Hardness               | 7 degree of hardness| General parameter     |
| Turbidity              | 1.5 mg/dm³          | Organoleptic parameter|
| Color                  | 20 degrees          | Organoleptic parameter|
| Chemical oxygen demand | Five mgO/dm³        | General parameter     |

Source: [14].

By their effect on drinking water's organoleptic properties, risk assessment with four selected parameters was carried out following complacent with the law of normal probability distribution [6].

To assess the risk to public health posed by chemicals in drinking water causing olfactory organoleptic effects, three risk assessment models were used: water turbidity, watercolor, and other parameters affecting the organoleptic properties water [6].

The following equation calculated risk by parameter:

$$
Risk = \left(\frac{1}{\sqrt{2\pi}}\right) \times \int_{-\infty}^{\text{Prob}} e^{-\frac{t^2}{2}} dt,
$$

where
- $e$ – the base of the natural logarithm;
- $d$ – differential;
- $t$ – confidence coefficient;
- Prob – the probability of adverse effect (Risk), expressed as a normal probability scale.

For water color-related risk assessment, Prob was calculated by the following equation:

$$
Prob = -3.33 + 0.067 \times C,
$$

where $C$ is watercolor (measured in degrees).

The following equation calculates Prob by turbidity parameter:

$$
Prob = -3 + 0.25 \times M,
$$

where $M$ is the turbidity value.

Prob by other parameters, by their effect on organoleptic properties of water, was calculated by the following equation:

$$
Prob = -2 + 3.32 \times \log(\text{Concentration/standard}),
$$

The overall risk of organoleptic effects was assessed by choosing the maximum value from the entire sample for each parameter [6]. The amount of 10% or 0.1 is set as the acceptable risk of olfactory organoleptic effects [6, 9].

3. Results

Having assessed the olfactory organoleptic effects in drinking water from three water sources, water
quality's key organoleptic parameters were obtained. The risk values were considered negligible at shallow values (Prob*) of selected parameters (figure 1, figure 2).

**Figure 1.** Organoleptic risk assessment results by water hardness over the period between 1997 and 2014: a) CWT1 IWF1, b) CWT2 SWF, c) CWT 3 IWF2. Y-axis – risk value; x axis – timeline. **Source:** Compiled by the authors.
Figure 2. Organoleptic risk assessment results by watercolor by CWT2 SWF over the period 1997–2014. Y-axis – risk value; x axis – timeline. Source: Compiled by the authors.

According to [6], the total risk of organoleptic effects is assessed by selecting the maximum value from the entire sample for each parameter, respectively (table 2).

Table 2. Assessment of organoleptic risks for drinking water from water intake facilities.

|      | IWF1 | SWF | IWF2 |
|------|------|-----|------|
|      | Prob* | Risk | Prob* | Risk | Prob* | Risk | Prob* | Risk |
| Hardness | -2.325 | 0.010 | -2.551 | 0.005 | -2.061 | 0.020 | -1.977 | 0.024 | -2.005 | 0.022 |
| Turbidity | -2.869 | 0.002 | -2.874 | 0.002 | -2.867 | 0.002 | -2.867 | 0.002 | -2.867 | 0.002 |
| Color | -2.995 | 0.001 | -2.867 | 0.002 | -2.992 | 0.001 | -2.993 | 0.001 | -2.992 | 0.001 |
| Oxidation | -4.724 | 0 | -3.724 | 0 | -4.477 | 0 | -4.523 | 0 | -4.504 | 0 |
| Overall risk of organoleptic (taste and odor) effects | 0.01 | 0.005 | 0.020 | 0.024 | 0.024 | 0.022 |

Note: acceptable risk value of organoleptic (taste and odor) effects is 0.1

Source: Compiled by the authors.

4. Discussion

It was revealed that the values of organoleptic risk related to water hardness do not exceed an acceptable level of 0.1 for drinking water from all water intake facilities. The maximum values of organoleptic risk associated to water hardness on IWF1 were observed in 1997 and 2003 and were 0.012; for SWF, maximum risk values were 0.008 reported in 2010 and 2012; at IWF2, the cost was slightly higher 0.023 in 1997 and 2000, and 0.031 and 0.035 for each CWT water intake respectively. The maximum value of the risks of olfactory effects related to water hardness is observed in samples from IWF2, ranging from 0.017 to 0.035 over the entire study period (figure 1).

For drinking water from IWF1, SWF, and IWF2, the organoleptic risk values for turbidity do not exceed an acceptable level of 0.1, their values are constant for all 18 years of observation, and equally 0.002.

For drinking water from all water intakes, an acceptable level of organoleptic risk associated with watercolor, i.e., not exceeding 0.1 (or 10%), is reported. Thus, for IWF1 and IWF2, the risk values for olfactory effects from 1997 to 2014 are 0.001. For SWF, they range from 0.001 to 0.003. The highest organoleptic risk values for the color of drinking water are observed in samples from surface water intake facility in 1997–2000, 2003, 2005, and 2006 (figure 2).

Water oxidation in samples from all drinking water intakes has shallow values (Prob*). Therefore, the risk of olfactory organoleptic effects is equal to zero.

The total assessment of the organoleptic risks for drinking water samples studied in this paper demonstrates that water hardness is the most significant parameter. The values of overall organoleptic risk for drinking water from all water intake facilities do not exceed the acceptable range. The maximum chance of olfactory – organoleptic effects is observed in drinking water from IWF2 and is 0.02 for CWT3.1; it is 0.024 for CWT3.2 and 0.022 CWT3.3.
5. Conclusion
The values of organoleptic risks related to water hardness are higher at infiltration water intake facilities than at surface water intake facilities. Water turbidity-related risks are constant regardless of the type of water intake. Color-related threats are ongoing at infiltration water intakes and range from 0.001–0.003 in the surface-sourced water. There is no risk of olfactory organoleptic effects related to oxidation.

Results demonstrate that water hardness affects the overall values of organoleptic risks at all drinking water intake facilities. It is determined that the risk of olfactory effects in water sourced from infiltration water intake facilities is higher than in water from the surface water intake.

It is concluded that consumption of drinking water from the surface and infiltration water intake facilities is safe and risk of organoleptic (taste and odor) effects related to water hardness, turbidity, color, and chemical oxygen demand, as well as risks associated with simultaneous exposure to all of the above, do not exceed the acceptable range.

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