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Perspective

Challenges of Changing Water Sources for Human Wellbeing in the Arctic Zone of Western Siberia

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Abstract: The availability of clean drinking water impacts the quality of life of Arctic populations and is affected by climate change. We provide perceptions based on: (1) a study of the accessibility of the natural surface water to the nomadic and settled Indigenous inhabitants living in rural areas (in settlements and remote camps) in the Arctic zone of Western Siberia during climate change and industrial development; (2) an assessment of the impact of consuming different surface water resources on human health. We include primary data sources from medical examinations and surveys collected in the regions between the rivers of Ob, Nadym, Taz, and Yenisey in 2012, 2014–2019, and 2022 whereas the chemical analysis of the surface waters in the region was based on previous research. A total of 552 local residents from the Arctic zone of Western Siberia participated in the study. We discuss how the availability of high-quality drinking water is limited for them due to climatic and anthropogenic risks, despite the abundant water resources. The consumption of river water is associated with high health risks since it contains heavy metals (Pb, Cd, Mn, Fe), whereas the consumption of lake ice melt water likely affects health because of the low concentrations of beneficial ions.

Keywords: surface water resources; adaptation; climate change; environmental changes; Arctic ecosystems; access to drinking water; risks; water analysis

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1. Introduction

The Arctic experiences a complex set of interacting factors that are not usually considered in the water supply and water quality analyses, such as the combination of very remote settlements with poor infrastructures and often limited amounts of liquid water most of the year [1]. The availability and free access to clean drinking water are targets of the Sustainable Development Goals (SDGs) of the United Nations [2] and a global challenge. Water is a vital resource, the quality and availability of which affect human health and wellbeing [3]. Many Arctic communities are facing an insufficient supply of high-quality drinking water since it is impacted by a number of environmental [4–7] and anthropogenic factors [8–10]. The Arctic regions are specifically vulnerable to global climate change due to "the low level of mass and energy exchanges in cold latitudes, the rapid moving of ecotoxicants in short food chains and the high sensitivity of organisms to adverse effects" [8]. Climate change [11–14] and the transboundary transfer of contaminants from the atmosphere [15] impact Arctic ecosystems and result in changes in the quality and quantity [4,16–18] of drinking water for local communities. The quality of drinking water is defined and assessed by the qualitative analysis of water and its biological and chemical components [19].

In the Arctic, the available water sources for many communities are limited to shallow thermokarst ponds located on permafrost, seasonal streams, and marshes, and sometimes, a lake or a river [1]. In the circumpolar North, many factors impact household drinking water access. This is perceived as an "axis of vulnerability" [20] and is a critical factor for improving water management. In Alaska, local native communities experience problems with clean water supplies [10] and water security, e.g., perfluoroalkyl substances (PFASs) contamination near Gustavus [7]. In 2013, PFASs in food and water also became a special focus of research in the Faroe Islands [21]. In Canada, the Indigenous communities in Nunavut suffer from water insecurity [14,22] and a high risk of microbes in drinking water [23]. In 2017, Canadian governmental reports declared the risk of high water stress in eight communities due to changing precipitation regimes, other climatic threats to their primary water source, and population growth [24], which threatens the sustainable development of these Arctic territories. In Russia, Arctic local communities are facing challenges of an insufficient supply of high-quality drinking water rich in the beneficial trace elements necessary for maintaining human health and adaptation to severe climates [25]. The changes include the anthropogenic pollution of water bodies (i.e., with heavy metals due to the prevalence of extracting industries, e.g., mining and oil and gas extraction) [26–30] and the distribution of harmful trace elements in surface waters [31–34] together with a violation of sanitary and hygienic conditions for the extraction and transportation of water to the population [35]. All these challenges demand the prioritisation of freshwater quality monitoring across the pan-Arctic region [36]. This is a significant step toward achieving sustainable socio-economic-hydrology systems and providing local communities with access to pure drinking water.

The Yamal Nenets Autonomous Okrug—YNAO—one of the regions of the Arctic zone of the Russian Federation located in Western Siberia, is the special focus of our research. It is a remote area with a relatively small population and is, therefore, less represented in the literature than those of the more populated regions. However, its environment is changing quickly. In the YNAO, access to drinking water is limited due to a long snow period. Throughout most of the year, local populations melt ice or snow to obtain pure drinking water. In winter, drilling wells and holes in water bodies (rivers or lakes) is a complicated task owing to the harsh environmental conditions and technical limitations. Additionally, it is not safe during the off-season (late autumn or early spring) because of fragile ice. Therefore, there are two main drinking water sources available to the local residents: sources of potentially ultra-fresh water (snow, ice and water from snow-fed lakes [37]) and rivers.

Snow in the Arctic region has very low concentrations of Mg, K, and Ca; thus, the available water resources are poor in minerals [38,39]. This low mineral concentration in potable water is insufficient for replenishing and maintaining the micronutrient balance in the human body. These micronutrients play a central role in the regulation of blood pressure [40]. Long-term intake of ultra-fresh water does not affect human health if a significant amount of local fish and venison is consumed [41], as this is beneficial due to containing sufficient amounts of the trace elements lacking in pure water [42].

Arctic rivers in the permafrost areas of Western Siberia are fed by water that undergoes freeze–thaw cycles and snow that accumulates on the surface of water bodies (e.g., lakes). The chemical composition of surface water varies depending on its origin (a reservoir, such as a lake, or a watercourse, such as a river or a stream). The chemical composition of the watercourses in the YNAO is determined by the interactions of water with underlying rocks and soils, which leads to lower pH values through lower concentrations of basic cations. Water, localised in depressions of the relief, in contrast to flowing river water, has higher concentrations of dissolved organic matter (DOC) due to the input of organic compounds from runoff. The chemical composition of lakes is also significantly affected by the thawing of organogenic soil horizons [43]. However, the surface waters contain large amounts of Fe, Mn, Cd, Pb, and Cu absorbed by organic components [38,44–46], and in many river sediment samples, high levels of petroleum products, such as Pb, Cr, Zn, Ni, Fe, Mn and Cu (compared to the approved values [47–49]), have also been detected [46]. The trace elements accumulate in the seasonally thawed active layer from thawing snow and melting ice in spring, and they are concentrated in autumn as they are expulsed from the freezing active layer. These elements enter the river and lake waters, which are available for drinking. They can then affect the kidneys and the vascular endothelium and increase the risk of arterial hypertension [50].

Our objectives were: (1) to present the patterns of water use by local people in a remote area of northern Siberia; (2) to highlight the environmental impacts on water sources and water quality and the potential challenges of these impacts for the wellbeing of local people in a rapidly changing northern environment; (3) to identify areas of research and the actions needed to safeguard the quality of water and protect the health and wellbeing of local people.

In this paper, we present the results of a multidisciplinary approach using ecological, sociological and medical research methods. We include the results of a retrospective study of the impact of drinking water sources on the risks to human health and wellbeing in the remote territories of the YNAO in 2012, 2014–2019, and 2022, and we present our perspectives on the need to address the achievement of the sustainable drinking water challenge.

2. The Arctic Zone of Western Siberia: Settings

The YNAO is an economically important region located in the northwest of Western Siberia (Figure 1). It has a population of 544,008 [51], which live in an area of 769,250 square kilometres [52] with a population density of 0.71 people per square kilometre. The location of this Arctic region (more than half of its territory is above the Arctic Circle) significantly influences the traditional livelihoods and human health of its population. It is a unique territory because almost half of the minority Indigenous population of the Russian Arctic (about 45,000 people) reside there. A total of 14,600 Indigenous Peoples are nomadic, living in tundra areas [53].

The geological structure of our research area, the Yamal and Gydan peninsulas and inland parts, according to Figure 1, reflects the regressive displacement of the coastline of the Arctic Ocean. The surfaces of the peninsulas are gently sloping, low, swampy plains up to 100 m asl, combined with areas of gently undulating relief, where the height asl reaches 200 m. The natural southern border is formed by the Siberian ridges, and the western one—by the spurs of the Polar Urals—has a height of up to 1330 m asl. The northern parts of the Yamal and Gydan territories are located in a continuous permafrost zone with a thickness of about 300–400 m. In the southern part of the Yamal Peninsula, the permafrost zone is discontinuous. Various forms of permafrost relief are presented: thermokarst depressions, pingos, etc. Quaternary sedimentary rocks are represented by layered sandy-clayey strata of marine and lacustrine-alluvial genesis [54]. Soil formation in the region is generally determined by severe climatic conditions, the flatness of the territory, and permafrost, whereas processes that operate locally include litter formation, gleying, cryoturbation, and cryogenic structuring [55].

The climate is arctic and subarctic [56]. The winter is long (more than 8 months) and severe, and the duration of stable frosts varies from 220 days in the north to 180 days in the south (at the Arctic Circle). Strong winds and snowstorms are characteristic. The average temperature in January varies from −22 °C in the southern part to −27 °C in the north. The average temperature in July varies from +4 to +16 °C, and the precipitation varies from 200 mm/yr in the north to 500 mm/yr in the south, mainly in the second half of summer. In the northern part, the height of the snow cover is 20–25 cm, and its duration is 240 days or more, whereas, on the flat southern landscapes, the snow cover reaches up to 80 cm with a duration of up to 200 days.

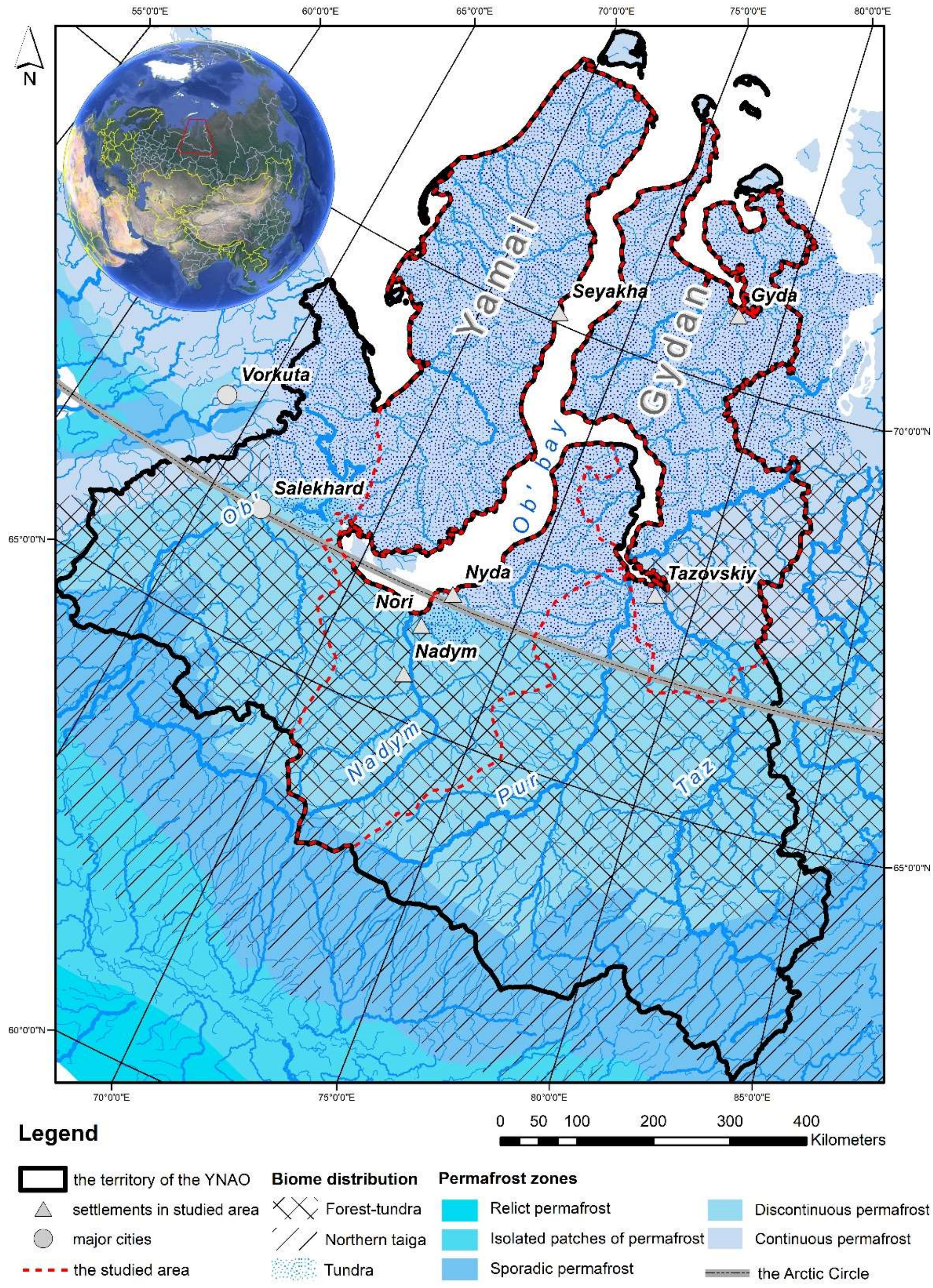


Figure 1. Map of the Yamal Nenets Autonomous Okrug (source: from multiple sources).

The duration of the growing season varies from 44 days in the north to 120 days in the south [57]. The corresponding natural bioclimatic zone is arctic moss-lichen and shrub tundras, developing in the south into the forest tundra. Sedge (*Carex*) and cottongrass (*Eriophorum angustifolium*) bogs occur in the north of the tundra and are replaced to the south by tussock bogs on peat-bog soils [58].

The region's water resources are rich and diverse. Surface water resources are represented by the rivers Ob, Pur, Taz, Nadym, the Gulf of Ob, the coast of the Kara Sea, bays, numerous swamps, and lakes. The Gulf of Ob is a bay of the Kara Sea, which is one of the largest sea bays in the Russian Arctic. Its area is over 44,000 km^2. There are about

300,000 lakes and 48,000 rivers on the territory of the Autonomous Okrug. More than 200 of these rivers are more than 100 km long [59]. Most of them belong to the "flat" ("old river") type, with a slow current, wide floodplains, an abundance of channels, oxbow lakes, and channel lakes.

The rivers are fed mainly by snow but also partly by rain and peat drainage. The rivers flowing from the eastern slope of the Polar Urals and representing mountain streams are fed by atmospheric precipitation, mainly snow. They flood because of the melting of snow, with its peak in June. The rivers in the YNAO remain frozen for up to seven or eight months a year, and most small rivers and lakes freeze to the bottom [60]. The spring freshet (opening of the rivers) occurs in the first half of May in the south and early June in the north. The high water period is extended due to the considerable swampiness of the territory [59].

Most lakes have depths of less than 3.0 m and were formed as a result of thermokarst on constitutional (segregated) ground ice, which is characteristic of the landscape of the YNAO [61,62].

Water withdrawals come from both surface water and groundwater, where the permafrost is discontinuous. According to the data of the Nizhne-Ob Basin Water Authority, the volume of water withdrawn from the natural water bodies of the district in 2017 amounted to 211.6 million m^3, of which 26.01 million m^3 was from surface water bodies [63]. In 2019, the volume of water withdrawn (for drinking water consumption) from the water bodies in YNAO decreased to 195.18 million m^3. A reduced 19.03 million m^3 was taken from surface water bodies [64].

3. Domestic Practices of Water Use by People of the YNAO

Ice is a reliable water source for the Indigenous Peoples during the long winter snow-season. For 8–10 months a year, the nomadic Indigenous population uses melted snow and ice for cooking and drinking (Figure 2). Snow is less popular than ice. Furthermore, the Nenets (the Indigenous Peoples living in these Arctic territories) believe that melted ice water gives life energy.

Figure 2. Preparing ice for drinking water (and food preservation) in the YNAO in winter.

In addition to using snow and melted ice for drinking water, the local residents of the YNAO use ice and compacted snow for food preservation in summer [65]. This traditional "cryo-technology" collects deposits of ice and dense snow and covers them with a tarpaulin, moss, and other natural thermal insulating materials.

During the snowless season (summer), the Indigenous Peoples living traditional life styles still use river and lake water for drinking and household needs. In small remote settlements and tundra areas, there are no central water supply systems. Therefore, local people stay close to the natural water sources (Figure 3). However, in the population as a whole, there is a current prevalence of consuming drinking water from the central water supply system. This is a result of the traditional lifestyles of the Indigenous population changing and the development of the infrastructure of the big settlements. Nowadays, these populations are more motivated to migrate from the tundra to modern settlements, which guarantees a higher quality of life for their residents [66]. Subsequently, the choice of water from the water supply system is explained by its high availability and filtering. However, residents' preferences for water from these local water supply systems are associated with health risks, as explained below.

(**a**) (**b**) (**c**) (**d**)

Figure 3. River and lake water sources in the YNAO (Gydansky Peninsula, expedition in August 2022). (**a**) Chum at the Gyda River. (**b**) Small thermokarsk lake near the chum. (**c**) Sandy banks and vegetation of the Gyda River. (**d**) The expanse of the Gyda River.

In the permafrost, there are no groundwater horizons because permafrost is a hydro-resistant environment. Consequently, there are no wells and springs. Moreover, most settlements do not have effective treatment facilities (mainly filtering). The local residents of the Arctic zone of Western Siberia mostly use staged filters operating on the principle of ion exchange. However, filtration is ineffective since these filters are inefficient for water that is highly enriched with Fe. The presence of organic substances in water, including organic iron, leads to the rapid overgrowth of the ion-exchange resin with an organic film that serves as a nutrient medium for bacteria [67]. Therefore, filters clog quickly with Fe. This explains the choice of the local residents, who tend to implement boiling as a dominant method of drinking water preparation before consumption.

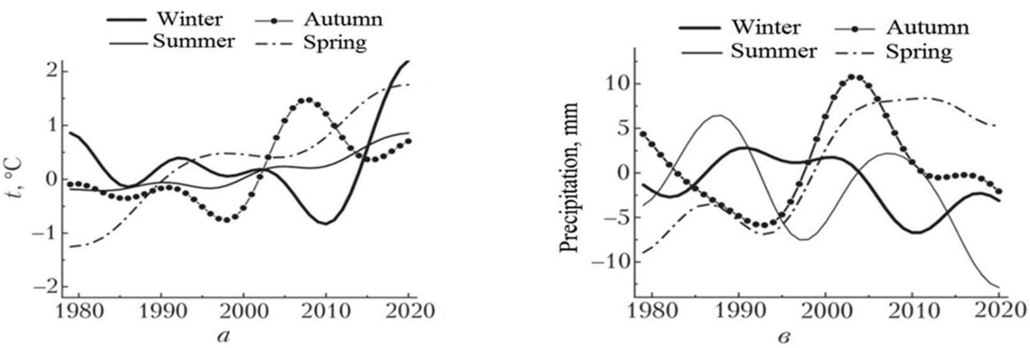
The problem of effective water disinfection remains one of the most significant issues for the YNAO, primarily due to the physical deterioration of the equipment of the treatment facilities, the obsolete wastewater treatment technologies used, and the insufficient capacity of the treatment facilities. In 2017, the proportion of water samples that did not meet hygienic standards in terms of sanitary and chemical indicators amounted to 30.9%, which is 10.4% more than in 2016 (20.5%). Similarly, the proportion of samples satisfying the microbiological standards was 7.7%, which is 2.8% less compared to the previous year (10.5%) [59]. Earlier, in 2012, the monitoring programme of water supply sources and drinking water from the distribution network in the YNAO revealed that the water contents of Fe and Mn exceeded the permissible thresholds in the cities of Nadym and Novy Urengoy. The highest contamination was in the Nadymsky and Purovsky regions. The high concentration of Mn and Fe compounds in water bodies can be explained by the natural conditions (these trace elements enter the surface waters from the peatlands [19]) of the regions [68].

4. Environmental Impacts on Water Sources in the Arctic Zone of Western Siberia

4.1. Climate Change

Climate change dynamics are affecting the availability of pure drinking water. In recent decades, the Arctic and subarctic regions have experienced significant warming trends [69–72], which can have devastating environmental impacts. The increase in the average annual temperature in the Arctic has, on average, an effect three times greater than that in the temperate latitudes. By the end of the twenty-first century, the global mean temperature is expected to rise by 1 to 5 °C [73] and therefore, the Arctic's temperature will rise even more.

Since the beginning of the twenty-first century, warming has been recorded practically throughout the entire territory of Western Siberia [74]. The local communities are probably impacted more by weather events and short-term changes than the long-term mean climate conditions. In 2021, summer temperatures above the climatic norm were observed almost throughout the Russian Arctic zone (except for Chukotka) [75]. The anomalously hot summer was offset by the cold winter of 2020/2021, with the average anomaly for Russia being −0.46 °C. The lowest temperatures were recorded in Western Siberia (the anomaly that averaged over the region was −2.38 °C) (Figure 4). In 2021, significant excesses of annual precipitation were observed in the lower reaches of the rivers Ob and Yenisei, although there was a decrease in precipitation in the area of Ob Bay (Figure 1). The duration of snow cover in the winter of 2020/2021 was significantly lower than the climatic norm, especially in the north of Siberia, where the maximum absolute value of negative anomalies was noted. There was also a shortage of snow in Western Siberia, as well as negative anomalies in the water supply from the snow. In addition, at most measurement locations in Western Siberia, an increasing active layer of thaw thickness was observed in 2021 [76]. (Although shallow snow usually preserves permafrost, the high summer temperatures apparently dominated and resulted in permafrost thaw.) Such short-term changes affect the availability of water to local peoples.



(**a**) (**b**)

Figure 4. Inter-annual variability of smoothed values of average annual seasonal anomalies of (**a**) air temperature and (**b**) precipitation in Western Siberia. Modified from [76]. Winter = December, January, February; Spring = March, April, May; Summer = June, July, August; Autumn = September, October, November.

Climate change has a strong influence on the Arctic's ecosystems due to ongoing warming, which shifts the permafrost boundary northwards and increases the thickness of the "active" seasonally unfrozen layer due to permafrost thaw [77]. Consequently, it is assumed that global warming will lead to an increase in the total area of thermokarst lakes [78–80], including in the central and southern parts of the region [62,81,82], although this is uncertain. Thermokarst lakes cover vast areas of many Arctic regions and often exceed 40% of the area in some of the thermokarst-affected lowland regions [82]. In the YNAO, the prevalence of thermokarst lakes also occurs, which exhibit the highest rate of increase in area compared to the other Arctic ecoregions [81].

Despite this possible climate-induced increase in water, the availability of lake and river water in the Arctic zone of Western Siberia is insufficient for people. Small thermokarst lakes are shallow, covered with ice for over eight months a year, and often frozen to the bottom [83]. According to the local residents [65], the thickness of ice reaches 2 m, and the surface snow cover reaches 1 m [60]. Complete lake ice melt is achieved in June. In summer (during the period of active snowmelt), the water rises by 1.0 m. and is used more often as a drinking water resource. Therefore, although climate change is expected to increase the amount of lake water, its "poor" (see below) quality and seasonal inaccessibility indicate that thermokarst lakes will not increase in importance as a drinking water source. In contrast, a greater area of the thermokarst lakes will allow a greater area of snow on lake ice to be used for drinking water. The balance between future access to lake water, lake ice, and lake snow needs to be predicted from local knowledge and future research, as this balance affects the Indigenous Peoples' water security and wellbeing [84].

4.2. Geochemistry of Potential Drinking Water from Natural Sources

4.2.1. Thermokarst Lakes

Global warming leads to thawing permafrost, which increases the biogeochemical risks due to the release of biological, chemical, and radioactive materials [85] and microbial growth and activity (e.g., by pathogenic bacteria) [61]. The ancient microorganisms released from permafrost are potentially harmful to human health since modern biota has lost resistance to them [85]. The consequences of climate change may also cause an increase in the transfer of particulate organic matter from the thawing permafrost layer and eroding river and lake banks, which may lead to an increase in the concentrations of various chemical elements in lake and river waters [19,86].

We assessed the physicochemical parameters of water in five thermokarst lakes in the south of the Tazovsky Peninsula of the YNAO. This water is used for drinking by Indigenous residents. The methods for determining the elemental composition of the lake and snowmelt waters are described in our previous studies [19,39] and in the online

Supplementary Material File S1. The maximum volume of liquid water is located between the surface and 0.5 m deep (Table 1), and the remainder of the column is frozen to the bottom. (The bathymetric and volumetric graphics of a typical thermokarst lake of the Tazovsky Peninsula are shown in the online Supplementary Material File S1) The distribution of the heavy metals by concentration groups in the water of these thermokarst lakes, which are mostly very shallow (Table 1, Figure 5, online Supplementary Materials Files S1 and S2), is shown in Table 2. Fe and Mn, which are the main natural heavy metals for the surface waters of the region, show the highest values, which are presented in Table 1. However, the low content of anions and cations shows this water would be of low value for human health. The low concentrations are due to extremely low mineralization. Therefore, the water of the lakes is ultra-fresh. This is explained by the overwhelming predominance of atmospheric precipitation in the incoming part of the water balance of these reservoirs [43].

Table 1. Morphometric features and physicochemical characteristics of the water of small thermokarst lakes of the Tazovsky Peninsula (expedition data, 2018; online Supplementary Material File S1).

Lake	Water Volume, mln m^2	Maximum Depth, m	Average Depth, m
Lake 1	0.270	1.5 (very shallow)	0.61 (very shallow)
Lake 2	0.572	1.8 (very shallow)	0.82 (very shallow)
Lake 3	0.052	4.0 (shallow)	0.99 (very shallow)
Lake 4	0.042	2.1 (very shallow)	0.62 (very shallow)
Lake 5	0.095	1.8 (very shallow)	0.84 (very shallow)
Physicochemical characteristics of the water of the studied thermokarst lakes			
Indicator		Mean (min–max)	SD
Total mineralization, mg·L^{-1}		6.6 (4.9–8.9)	1.8
pH		5.7 (5.0–6.5)	0.6
Colour, degrees		77 (55–130)	27.0

Figure 5. Typical unnamed thermokarst lake of the Tazov Peninsula with industrial activity in the background.

The thermokarst lake waters of the YNAO are neutral or weakly acidic in pH and predominantly of calcium-hydrocarbonate and magnesium-hydrocarbonate compositions [43]. Our results show that the waters of the thermokarst lakes of the Tazovsky Peninsula are coloured, with low mineralization and are weakly acidic in pH, with a calcium-hydrocarbonate geochemical composition (Table 1). The waters are fresh and soft, which are formed in the process of chemical leaching of igneous rocks or during the exchange processes of calcium and magnesium ions for a sodium ion. Research by Edel'shtein et al. [60]

confirms our data on the low salinity of the waters of thermokarst lakes, the chemical composition of which is determined by atmospheric precipitation.

Table 2. Concentrations of heavy metals in snow melt and thermokarst lake waters of the Tazovsky District of the YNAO compared with permissible levels.

Trace Element (Heavy Metal)	Water of Thermokarst Lakes, mg·L^{-1} (Mean)				Melt Snow Filtrate, mg·L^{-1}		Maximum Permissible Concentrations, mg·L^{-1} [91]
	Our Data	Agbalyan et al., 2019 [87] (Tazovsky District)	Manasypov et al., 2015 [88] (Lakes < 500,000 m^2, Summer)	Manasypov et al., 2014 [89] (Lakes > 200,000 m^2)	Our Data	Pozhitkov et al., 2019 [90] (Insoluble and Soluble Forms, Background Areas)	
Fe	0.338	-	0.251	0.13	0.009	0.023	0.3
Mn	0.018	0.02	0.016	0.0016	0.003	0.005	0.1
Cd	1.1×10^{-5}	-	2.4×10^{-5}	3.0×10^{-5}	9.5×10^{-6}	7.3×10^{-5}	0.001
Pb	0.0001	-	0.0003	0.0001	0.0001	0.0001	0.01
Ni	0.0015	-	0.0003	0.0026	0.0003	0.0004	0.02
Cu	0.0012	0.005	0.0005	0.0005	0.003	0.0014	1.0
Zn	0.007	0.02	0.062	0.027	0.057	0.018	1.0

The sources of the predominating heavy metals, Fe and Mn, in the surface waters of thermokarst lakes and snowmelt waters in the southern part of the Tazovsky Peninsula in the summer period are in the catchment area of the lakes (Table 2). In snowmelt waters, the main heavy metal is Zn, and its natural sources require further research. An anthropogenic source for these high Zn concentrations in snowmelt water is the atmospheric emissions from industrial enterprises within and outside the Tazovsky Peninsula [90–94].

Perhaps counterintuitively, thermokarst lakes are not dominant water sources among the local residents of the YNAO. The anaerobic environment on the lake beds and in talik sediments beneath the lakes leads to specific sedimentation and geochemical conditions [95] that cause methane production and make water from some lakes unfit for human use in Siberia. Most shallow lakes are also unsuitable for drinking due to a high population of blue-green algae, which can pollute the water with toxic metabolites [96]. The greenish colour of the water in the lakes and its moderate oversaturation with oxygen indicate a significant development of cold-loving phytoplankton species (in the Arctic, during the growing season, this is facilitated by long daylight hours) [60].

4.2.2. Snow Melt Water

We determined the geochemical composition of the snowmelt water from the snow samples taken in spring on the ice of thermokarst lakes in the south of the Tazovsky Peninsula. The results show that the content of the major elements in melt water is low compared to the content in lake water (Table 2). Extremely low concentrations in snow are noted for Fe, Mg, Al, V, Mn, Ni, As, and Sr. The snowmelt water presented an excess of Zn (57.5 mg·L^{-1} in snow and 7.1 mg·L^{-1} in lake water) and Cu (3.3 mg·L^{-1} in snow and 1.2 mg·L^{-1} in lake water). The content of most microelements in the snowmelt waters was significantly lower (tens of times) compared to the content found in the lake waters. Extremely low concentrations in the snow were shown for Li, Y, Zr, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Yb, Th, and U. Furthermore, Mo, Sb, and Tl were detected in the snow.

4.2.3. River Water

Rivers are a major source of drinking water, but these too are affected by environmental changes: the YNAO river water is influenced by both climatic and technogenic factors, which decrease its quality and make it unsuitable as a drinking water source due to its colour, taste, smell, and high concentrations of heavy metals. In the river waters, concentrations of heavy metals (primarily Fe, Mn, and Zn [39,97,98]) are naturally high. In the Ob river (which is the largest river in the region), the content of mobile forms and biologically active Fe and Mn exceed the limit values (the maximum permissible concentration) of the water quality established in Russia [19]. These excesses are not directly related to anthropogenic impact but to natural factors, including the high swampiness of the catchment areas of the small rivers of the YNAO. High Fe and concentrations of Fe and Mn are a feature of the surface waters of the forest zone of Western Siberia [68,99,100]. In the forest tundra, the input of Fe and Mn into lake water is also due to the decomposition of plant organic matter in the catchment areas that supply humic and fulvic acid complexes of these metals [101,102]. The YNAO territory has a high content of Fe, from 1400 to 6500 mg·L^{-1}, and Mn, from 10 to 2200 mg·L^{-1} [103].

The Fe content in river waters directly affects their colour and turbidity. The water of small rivers is of light brown colour and is specific for swamp waters, which differ from other surface waters in the region by a low mineralization, low content of dissolved oxygen, and high acidity, which promotes the migration of heavy metals from the soil. Swamp waters are saturated with organic matter and are characterised by high oxidizability [99]. The turbidity of natural water in the region, as a rule, is due to the presence of clay and sand. Conversely, the upper reaches of the small rivers in the region, due to the predominance of flat landforms, large swampiness and lakes, are characterised by extremely low erosion and, as a result, low turbidity. This can explain the low concentrations of Zn in the small rivers. The concentration of this trace element in surface waters depends on its content in the soil and bottom sediments, while the determining factor is the geological structure of the territory and the chemical composition of the rocks. In addition, the colour is explained by the presence of coloured organic compounds: the decomposition products of plant residues in the lake–swamp complexes of river sources and transparency (low turbidity) is due to the low erosive activity of the water flow. River waters accumulate heavy metals due to high concentrations of humus. In swampy waters, the content of Fe, Zn, and Cd increases. Then, Fe and Cd are washed out from the soil cover and soil-forming rocks with the watercourse entering the river network, gradually accumulating in bottom sediments [104].

4.3. Industrial and Waste Water Contamination of Water Sources

The chemical composition of river and lake waters is also significantly affected by the industrial development of the region. The surface water quality in the YNAO is impacted by the degree of wastewater treatment, not only by the oil and gas enterprises of the YNAO but also by the extracting facilities located on the territory of the Khanty-Mansi Autonomous Okrug and the Tyumen Region. The distribution of wastewater discharges in the urban and rural areas of the YNAO is extremely unbalanced. A significant amount of discharge is from the cities, whereas the lowest is from rural areas. As a result, the water bodies of the region have increased concentrations of oil products, phenols, heavy metal ions, organic and biogenic substances, conditionally pathogenic microflora, as well as increased organic pollution. Anthropogenic activities can explain the local increase in chloride and sodium ions concentrations in surface waters [43]. Every year, over 38 million m^3 of wastewater is discharged into surface water bodies, of which 70–90% is insufficiently treated [59]. The waters of the rivers of the Arctic zone of Western Siberia have a low ability to self-purify. In this regard, the contents of oil products, heavy metals, and synthetic surfactants are growing in the waters of the rivers in the YNAO. Among the main technogenic factors causing changes in the natural chemistry of river water is the drilling waste generated during the construction of wells for various purposes [104].

5. Impacts of Changing Water Quality on the Health and Wellbeing of Local People

The concentrations of different trace elements in drinking water have ambivalent impacts on the human health of local communities. For example, Zn is necessary for physiological processes. However, it is toxic at high concentrations since it interacts with a number of enzymes, inhibiting their activity. A significant increase in Zn concentration, through the daily consumption of water processed by ion-exchange filtration, impacts the risk of deviations in kidney functioning. Zn retards growth and disrupts the mineralization of water-salt metabolism [105]. High contents of heavy metals in drinking water can be one of the factors affecting increased risks of different diseases (e.g., arterial hypertension).

We studied the practices of water use and the impact on local people of different types of water sources and water treatment on the risk of arterial hypertension (see online Supplementary Material File S2, Table 3).

Table 3. Water sources and water preparation used by the rural residents of the Arctic zone of Western Siberia (n = 552).

Water Sources, %				
water supply system	ice	river	lake	snow
52.6	20.2	16.0	8.7	2.4
Water preparation, %				
direct consumption	filtering	boiling	settling	freezing
13.2	12.9	58.8	12.3	2.8

The dominant water resources for the interviewed rural residents of the YNAO were the water supply system (52.6%), ice (20.2%), and rivers (16.0%) (Table 3). The local population of the settlements and tundra areas prefers to drink boiled water. The direct consumption, filtering, and settling water preparation methods are less popular. The residents of the local settlements have access to the central water supply system or collective ice holes in the river due to the long winter seasons. They often use river water because this requires less effort and fuel.

Based on the fieldwork data on the types of water sources and the incidence of heart diseases, a model of the prevalence of arterial hypertension was developed, depending on the consumption of drinking water from various water sources (Table 4).

Table 4. Estimated parameters of the impact of the type of water sources on the risk of arterial hypertension.

Type of Water Source	b_0 (Constanta)	Ice	Water Supply System	River	Lake	Snow
Estimate	0.114	−1.025	0.175	1.190	0.405	1.346

The Model shows that the highest risk of arterial hypertension is associated with the consumption of water from the river since it is not treated. Drinking melt water (snow, ice) results in a reduced risk of arterial hypertension. Water from the water supply system is also considered to have a positive impact on preventing this risk since it is filtered.

For example, if a patient drinks mostly river water, the probability (p) of the onset of arterial hypertension is calculated by the formulas (1) and (2) in the online Supplementary Material File S2, where x_i is 0 or 1 (if a patient mostly drinks water from this water source, we use 1; otherwise, we use 0):

$$z = (-1.025) \times 0 + 0.175 \times 0 + 1.190 \times 1 + 0.405 \times 0 + 1.346 \times 0 + 0.114$$
$$z = 1.304$$
$$p = \frac{1}{\left(1+e^{(-1.304)}\right)} = 0.787\ (78.7\%).$$

A model of the risk of arterial hypertension from drinking water from various sources is presented in the online Supplementary Material File S2. The values of p = 78.7% show that the studied patient consuming mostly river water has a high risk of arterial hypertension.

Settling and boiling drinking water significantly reduces the risk of arterial hypertension, potentially due to decreasing the concentration of peaty particles that absorb heavy metals (Fe, Pb, Cd, Mn, and Zn) [39,68,99]. Pb [106–108] and Cd [109,110] damage the tubules of the kidneys and vascular endothelium and are an activation factor of the renin-angiotensin system, which results in increased blood pressure and leads to a high risk of arterial hypertension [111–114]. Fe and Mn are Zn [115], and Mg [116–118] are antagonists that reduce arterial hypertension. The shortage of Ca [119] and K [120–122] in the water also impacts the reduction of cardiovascular diseases. Consuming local fish and venison can compensate for the shortage of Ca, Mg, K, Cu, etc., [41,42], which is limited in the drinking water in the YNAO and contributes to decreasing health risks.

6. Recommendations to Improve Knowledge on Changing Water Sources and to Support Health

Our study highlighted the potential challenges of fluctuating water sources for the wellbeing of the local people in a rapidly changing northern environment. Furthermore, in order to enhance our knowledge of the changes occurring in the Arctic ecosystems, sustain a safe environment, and support the wellbeing of the Indigenous communities from a drinking water perspective, we recommend the following:

- To reinstate and sustain hydrological monitoring (which has been reduced since the beginning of the 21st century) and improve monitoring to include water quality monitoring for the purposes of better understanding and better adapting to the hydrological and biogeochemical changes due to the climate and environmental changes. This is especially important for small and medium-sized rivers and lakes of Western Siberia, where permafrost is present. This increased monitoring would be important for both the local people and regional authorities, who need information on the availability and amount of water acceptable for consumption.
- To develop research in order to predict future hydrological changes in the water quality and quantity (in different water sources) due to the environmental and anthropogenic impacts to forewarn authorities and increase preparedness.
- To initiate independent professional interdisciplinary research groups to check the quality of the water used by households in the YNAO remote areas and the associated risks, including follow-up assessments of potential developing impacts on local people's health and wellbeing.
- To improve sanitation and water purification to control epidemics and the health issues associated with heavy metal concentrations in water consumed by the Indigenous Peoples.
- To enhance the monitoring of health, including studying the element status of the Arctic local population (chemical analysis of elements' concentrations in the human organism with a special focus on the heavy metals content).
- To improve the control of snow cover pollution due to the exploitation of oil and gas fields in the areas close to the reindeer herding nomadic routes and camps, as well as along the winter roads in the YNAO.
- To improve the water preparation methods for households (e.g., mobile or compact installations for water purification, filters enriched with Mg for purification and enrichment of water to be adopted for the Arctic remote areas).
- To initiate educational and outreach activities and recommendations on the importance of securing sustainable, pure water sources, e.g., the correct use of filters for drinking water preparation for the local population in the remote settlements of the YNAO.

7. Conclusions

The availability of high-quality drinking water is a fundamental pre-condition of the quality of life and sustainable development of the local communities in the Arctic. We present novel perspectives on the traditional livelihoods related to accessing water sources by people living in the YNAO, as well as challenges for obtaining centrally supplied and processed water. We demonstrated that the availability of high-quality drinking water is limited for the local residents due to climatic and anthropogenic risks, despite the abundant water resources (freshwater, snow, ice, lakes, and rivers).

We also demonstrated the potential impact of drinking water on the prevalence of arterial hypertension in the local settled and nomadic populations in the settlements and tundra areas (including the Indigenous Peoples). Our results indicate that the consumption of river water is associated with a high risk of arterial hypertension since it contains high levels of heavy metals (Pb, Cd, Mn, Fe). The consumption of melted snow and ice by the Arctic inhabitants is, therefore, an important component of adaptation to the harsh climatic conditions of the Arctic and reduces the risk of arterial hypertension; however, this health benefit needs to be offset by eating meat and fish in order to obtain the microelements that are scarce in snow water. Although there is an increasing tendency for nomadic people to move into cities, even the water sources provided there require further purification and improvements due to the growing numbers of residents.

The statistical correlations between water sources and health are uncertain and merits further priority research. This research should explore the causal connections between the heavy metal concentrations in water sources and the health risks. The resulting greater understanding could then be used to implement practices to improve health. Gathering such information would allow the implementation of better practices and technologies aimed at improving Siberian population health.

The quality of the water sources, with the exception of snow, is impacted by natural environmental factors and industrial pollution. Reduced access to lake ice and snow in shorter cold seasons is likely to reduce access to drinking water, while an expected increase in surface water due to climate change is not likely to increase the drinking water availability due to poor quality. Therefore, there is a high need to improve the water treatment technologies and to develop recommendations for the preparation (primarily settling and melting) of the drinking water received from natural sources (rivers, lakes) to increase the quality of drinking water and to maintain the health of the local people. However, there are uncertainties related to the availability and quality of future drinking water sources, which are associated with the uncertainties of climate change predictions and industrial developments. These uncertainties need to be reduced with increased research and monitoring of the changes in the human environment and the wellbeing of local people.

In conclusion, the consumption of melted water and ice by the Arctic inhabitants appears to have reduced the risk of cardiovascular diseases and represents an adaptation to the current and past harsh climatic conditions of the Arctic, which we can learn from. However, the modern pollution of water sources, ineffective water treatment, and current climate change call for a reassessment of the provision of safe drinking water.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w15081577/s1, File S1: Research Methods to Characterize the Chemistry of Thermokarst Lake Water [47–49,123–129]; File S2: Material and Methods of Medical Research [130–136].

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Institutional Review Board Statement: This study was approved by the Ethics Committee of the Arctic Scientific Research Centre of YNAO, Salekhard, the Russian Federation, on 16 January 2012 (approval protocol No. 01/1-13). The research has been conducted in accordance with the ethical concerns of working with the Indigenous Peoples in the Russian Federation (Constitution of the Russian Federation, Article 69. 14 March 2020). Communication was initiated with the Associations of the Indigenous Peoples and with representatives from national Indigenous communities in the YNAO early in research planning. This resulted in an expression of interest from their representatives in having the research conducted in their communities.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The study did not report any data.

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