

Article

Quality of Drinking Water in the Balkhash District of Kazakhstan's Almaty Region

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Abstract: The thinly populated Balkhash District of Kazakhstan's Almaty Region lies in the lower reaches of the Ili-Balkhash basin, which is shared by China and Kazakhstan. The district is arid and heavily dependent on inflows of surface water, which are threatened by the effects of upstream population growth, economic development, and climate change. The quality of drinking water from centralized water systems and tube wells in nine villages of the district was analyzed, and the organoleptic properties of water from these sources was also assessed by an expert and via surveys of local residents. Although most samples met governmental standards for the absence of chemical impurities, high concentrations of mineralization, chlorides, boron, iron, and/or uranium were present in some well water samples. Levels of these pollutants were as much as 4-fold higher than governmental maxima and as much as 16-fold higher than concentrations reported previously in surface water. All centralized water samples met standards for absence of microbial contamination, but total microbial counts in some well water samples exceeded standards. Organoleptic standards were met by all the water from five villages, but centralized water from one village and well water from four villages failed to meet standards based on expert judgment. Residents were, for the most part, more satisfied with centralized rather than well water, but there was no obvious relationship between the failure of water to meet standards and the locations or populations of the settlements. This is the first comprehensive assessment of groundwater used for drinking in the lower Ili-Balkhash basin, and although it relies on a limited number of samples, it nevertheless provides evidence of potentially serious groundwater contamination in the Balkhash District. It is thus imperative that additional and more detailed studies be undertaken.

Keywords: water quality; rural Kazakhstan; Ili-Balkhash basin; organoleptic analysis of groundwater; risk identification and assessment

1. Introduction

Although a sustainable and affordable supply of high-quality drinking water is one of the most important priorities in the modern world, many populated areas do not have adequate access to water and modern water purification technologies [1]. The Republic of Kazakhstan and other countries that

emerged from the former Soviet Union are among those facing such challenges [2–4]. About 80% of Kazakhstan’s territory is located in a climatic and geographical zone of deserts, semi-deserts, and dry steppes [5]. The hydrographic network in these arid areas is meager and subject to significantly fluctuating inflows. A shortage of fresh water has thus become one of the most pressing environmental problems impeding sustainable development of the country. Acute water scarcity is consequently recognized as Kazakhstan’s fourth most important global challenge of the 21st century [6].

The problem of water supply in Kazakhstan is exacerbated by the disadvantageous geographical position of the country, which is located in the downstream areas of several important transboundary river basins [7,8]. Among them is the Ili-Balkhash basin, the main catchment area of which is located in the Xinjiang Uyghur Autonomous Region of China [8–10]. In contrast, the downstream reaches of the Ili River and its final destination, Lake Balkhash, are situated in the deserts of southeastern Kazakhstan (Figure 1). In recent decades, water consumption has been growing in the Chinese part of the Ili-Balkhash basin against a background of rapid population growth and economic development [8,11,12]. Kazakhstan, on the other hand, is experiencing a difficult period of socio-economic transformation that aggravates problems of the use, distribution, and pollution of water resources, including those in the Ili-Balkhash basin.

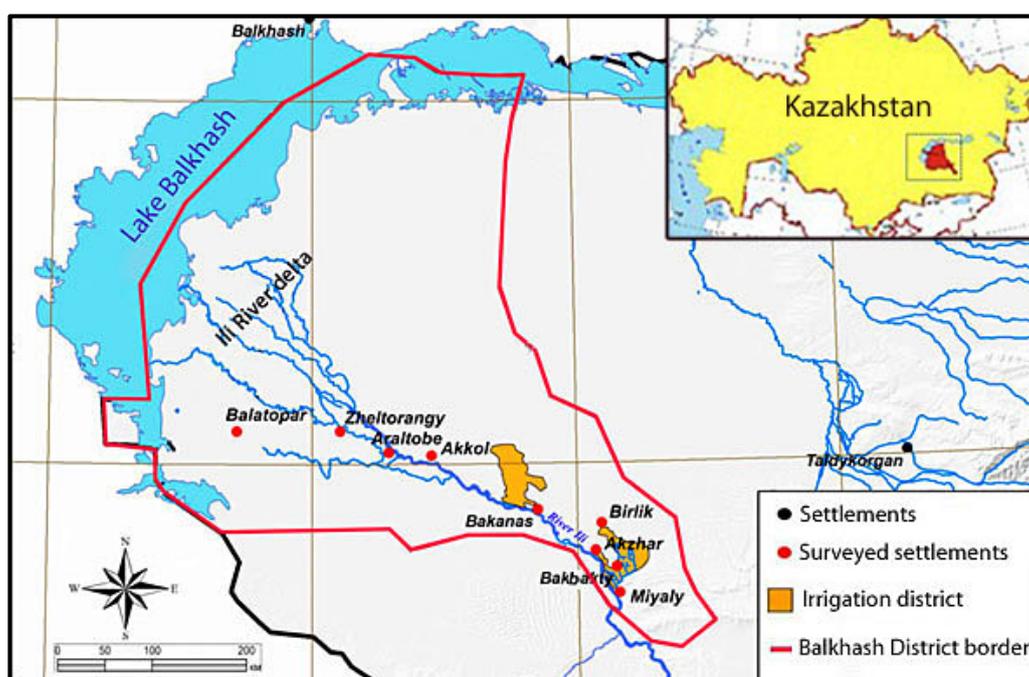


Figure 1. Kazakhstan’s Balkhash District. The large map identifies the borders and chief geographical features of the district, as well as Lake Balkhash and the settlements studied here. The district is boxed and shown in red in the inset, which gives its location in the southeastern part of the country.

The need to provide Kazakhstan with water resources places significant demands on both water quantity and quality, but much of the republic’s water supply and management system has existed since Soviet times and is now physically obsolete and in need of thorough modernization. These issues have created tension and a sense of urgency, which is reflected in a series of presidential decrees and governmental decisions [2,13–17]. These documents commit the government to allocate significant financial resources to improve the water supply system and water management infrastructure in cities and rural areas, but these improvements have not always been implemented, and further investment is required.

The current status and the main risks and problems of water supply and quality in rural settlements of Kazakhstan’s Balkhash District are assessed here as an example of the Republic’s water resource challenges. The Balkhash District is located between 44–47° N and 73–77° E in Kazakhstan’s Almaty

Region. It lies in the lower part of the Ili-Balkhash basin and within the South Balkhash depression, which extends from the Malay Sary ridge to the shore of Lake Balkhash, a large endorheic lake with a surface area of more than 16,000 km² [18]. The Balkhash District includes the Ili River delta, which is the largest in Central Asia and a site of unique biodiversity, with two protected areas of international importance, namely the Altyn-Emel National Park and the Ili-Balkhash Reserve [19].

The Balkhash District receives little rainfall (100–150 mm/year) and experiences a high level of potential evapotranspiration that exceeds 1000 mm/year [5]. The climate is distinctly continental, with characteristically large day/night and summer/winter temperature differentials [9,20]. Winters are cold with little snow, and summers are dry and hot. The scattered natural vegetation is dominated by perennial semi-shrubs and ephemeral plants that often disappear in hot weather [19,21,22]. Soils in most of the district are mainly sandy loams with significant natural salinity and little biological activity [8,23].

Given the harshness of the environment and lack of water, it is not surprising that the 37,400 km² Balkhash District contains just 30,700 inhabitants who live mainly in 34 settlements near lakes and streams. The region's economic activity emphasizes pasture-based animal husbandry, recreational and commercial fishing, and extraction of minerals, and it is based on maximum exploitation of water and other natural resources [24–27]. Due to the extremely arid climate and high energy costs, irrigation for agriculture is only possible in two small gravity-fed areas near the Ili River (Figure 1).

In short, the Balkhash District can be classified as a poorly developed rural region with a severe environment and inadequate economic and social infrastructure. The district's water infrastructure is recognized to be inadequate and largely outdated [8,17,28,29]. Summer water shortages often occur, but in contrast to the attention given to surface water and related environmental concerns [17,18,22,27,30–33], little is known about the quality of drinking water available to residents. The sources and quality of drinking water in nine representative villages of the Balkhash District are consequently examined here for the first time with the goal of assessing potential risks to public health. Numerous methods are available to reduce such risk [34–37], but they are useful only if sound, fundamental information about the nature of contamination is available [38,39].

2. Materials and Methods

2.1. Water Sampling

Thirty-six water samples were collected from nine settlements along the Ili River and its delta at locations indicated in Figure 1. One set of samples was drawn from each settlement's central water supply, which is sourced from artesian wells that range in depth from 30 to 220 m (Table 1). Water from these samples had been treated prior to distribution and use and is designated centralized water. A second set of samples was drawn by either hand or electric pumping from three separate unpressurized tube wells in each of the nine settlements. These wells ranged in depth from 6 to 20 m, and water from them is not treated prior to use. These samples are designated well water.

All samples were collected in sterile 1.5-L containers and transported and stored at 4–8 °C. Water quality assessment was on the basis of three criteria: (i) determination of toxicological contamination with metallic elements and other chemicals (performed on all centralized water samples and one well water sample from each settlement), (ii) determination of sanitary-epidemiological contamination due to the presence of *Escherichia coli* and other pathogenic and opportunistic bacteria (performed on all 36 samples), and (iii) organoleptic determination (performed on all centralized water samples and two well water samples from each settlement).

2.2. Chemical Analysis

Dry residues were measured gravimetrically after the complete evaporation of 100-mL subsamples. Then, pH values and nitrate concentrations were determined with a digital pH meter equipped with a universal electrode and a calibrated ion-selective electrode, respectively. Carbonate hardness was carried out by HCl titration of 50-mL samples with a digital automatic titrator (Aquilon, Moscow,

Russia) equipped with a universal measuring electrode. The presence of sulfates was determined turbidimetrically with barium chloride [40], and chloride ion concentrations were measured by titration with silver nitrate using a platinum measuring electrode and silver chloride reference electrode. Concentrations of a panel of 65 elements (see Appendix A) were determined by inductively coupled plasma spectrometry [41] using an Agilent 7500 instrument (Agilent Technologies, Santa Clara, CA, USA). The detailed protocols for sample preparation and analysis have been published [42].

Table 1. Characteristics of centralized water systems in Balkhash District settlements.

Settlement	Number (Depth) of Artesian Wells	Connections to Water System (Percentage of Households)	Length of Water Supply Network (km)
Akkol	2 (30 m)	12.5	7
Akzhar	2 (160 m)	91	8
Araltobe	2 (64 m)	95	9
Bakanas	1 (80 m), 2 (100 m)	77.1	22.5
Bakbakty	1 (218 m), 1 (220 m)	75	15.1
Balatopar	2 (70 m)	15	15.8
Birlik	2 (30 m)	39.5	7
Miyaly	2 (60 m)	82.5	5.6
Zheltorangy	1 (56 m), 1 (65 m)	50	7.5

2.3. Microbial Analysis

Microbial analysis, which was conducted on duplicate samples of both centralized and well water, was carried out no more than 8 h after initial sampling. Indicators of contamination, including that from fecal sources, included total microbial count (TMC), number of coliform bacteria, number of thermotolerant coliform bacteria capable of growth at 37 °C, and coliphage titer. Standard dilution and plating protocols were employed for these analyses [43,44]. The automated biochemical identification of strains was carried out with the Mikrob-2 microbiological monitoring system (MultiskanAscent, ThermoFisher Scientific, Waltham, MA, USA).

2.4. Organoleptic Characteristics

The organoleptic characteristics of all 36 water samples from the Balkhash District were rated by a specialist certified to detect off odors and taste. In the Republic of Kazakhstan these characteristics are rated from 0 to 5 on a standardized, six-point scale, where 0 indicates no noticeable odor (at 20 °C and 60 °C) or taste (at 20 °C), and 5 indicates strong odor or taste that makes the water undrinkable (Table 2). Government standards set the maximum allowable rating for drinking water at 2 [45]. As part of the survey of local citizens (see Section 2.5), residents of the settlements rated the quality of their drinking water on a simplified scale suitable for non-experts.

Table 2. Assessment scale for determination of water odor or taste in Kazakhstan [45].

Rating	Intensity of Odor or Taste	Description
0	None	Not noticeable
1	Very weak	Detected by specialist, but not consumer
2	Weak	Barely detected by consumer
3	Noticeable	Easily detected, unpleasant to drink
4	Distinct	Strong, consumer hesitant to drink
5	Very strong	Undrinkable

2.5. Surveys

Seven hundred thirty-seven adults aged 18 and older in the nine villages were surveyed to assess their views on local provision of water and water quality (Table 3). The combined population of these

settlements, 19,807, represents 64.5% of the total population of the Balkhash District. The surveys, which were semi-structured and anonymous, were conducted randomly while maintaining an approximately equal sex ratio of respondents. Respondents with access to centralized water or to only well water classified the quality of their drinking water as excellent, satisfactory, or unsatisfactory and were asked to identify any associated sensory characteristics. Sample sizes were selected to achieve 95% or greater confidence in statistical significance [46].

Table 3. Demographic and survey characteristics of the Balkhash District settlements.

Settlement	Inhabitants	Households	Respondents Surveyed
Akkol	1160	200	60
Akzhar	560	127	60
Araltobe	587	134	61
Bakanas	6000	875	104
Bakbakty	4475	930	100
Balatopar	2043	422	90
Birlik	2224	382	92
Miyaly	1236	200	80
Zheltorangy	1522	160	90
Total	19,807	3,430	737

3. Results

3.1. Chemical Analysis

Centralized water and well water from the nine villages was analyzed for the presence of dry mineralization, nitrates, sulfates, and chlorides, as well as contamination by a panel of 65 chemical elements that includes toxic heavy metals. The government of Kazakhstan [45] established threshold safety levels of drinking water for all of these pollutants except for 30 of the less common elements (see Appendix A). All tested centralized water met governmental quality standards for heavy metals and other elements (Appendix A), as well as dry mineralization (threshold > 1000 mg/L), nitrates (threshold > 45 mg/L), sulfates (threshold > 500 mg/L), and chlorides (threshold > 350 mg/L). Although levels of contaminants in well water were almost always higher than those in centralized water from the same village, levels of contaminants in most well water samples were also below threshold levels. Both water sources thus met governmental standards in six of the nine villages, but this was not the case in Birlik, Akkol, and Balatopar (Figure 2). Uranium concentrations in well water from Birlik were almost double the governmental threshold and at or near the threshold in Araltobe and Akkol, respectively. Mineralization levels in well water from Akkol exceeded the standard by 6-fold. Pollution was more extensive in Balatopar, where levels of mineralization, boron, and iron were more than 5-fold, more than 3-fold, and almost 2-fold higher, respectively, than governmental standards (Figure 2). Concentrations of uranium in Balatopar's well water were nevertheless very low in comparison to other villages.

3.2. Microbial Analysis

Governmental standards for microbial contamination of drinking water in Kazakhstan require that TMC not exceed 50 colony forming units/mL and that common coliform bacteria, thermotolerant coliform bacteria, and coliphage are absent [45]. All tested centralized water samples from the settlements met these standards, but this was not the case for some well water samples. TMC was 10^2 colony forming units/mL of water from wells in the villages of Bakbakty, Akzhar, and Araltobe and an order of magnitude higher in well water from Bakanas, Balatopar, and Zheltorangy. The average ratio of aerobes to anaerobes in these samples was 72%:28%, with *Bacillus*, *Micrococcus*, *Pseudomonas*, and *Sarcina* spp. identified as the principal bacterial genera present. There was no evidence of fecal contamination.

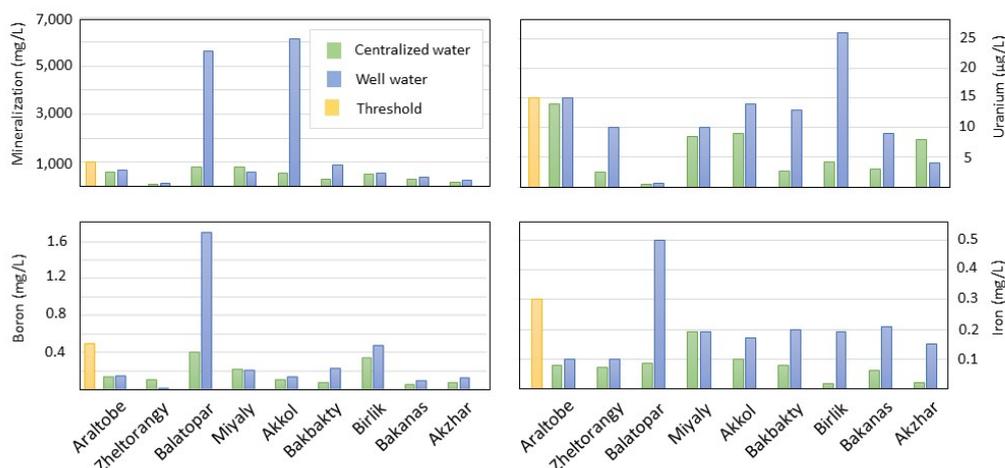


Figure 2. Chemical analysis of centralized water (green bars) and well water (blue bars) from the nine villages for the presence of dry mineralization, uranium, boron, and iron. The yellow bars indicate water quality thresholds as determined by the government of Kazakhstan [45].

3.3. Organoleptic Analysis

Table 4 shows the results of organoleptic analysis of centralized water and two well water samples from each of the nine villages as determined by a sensory expert who was familiar with governmental standards (see Table 2). The villages can be separated into three categories as follows: (i) all standards were met by centralized and well water (five villages), (ii) all standards were met by centralized water but one or more standard was not met by well water (three villages), and (iii) one standard was not met by both centralized and well water (one village). On a category by category basis, centralized water was usually rated higher and never rated lower than well water from the same village. Distinctions between water from the two sources were greatest in Araltobe and Zheltorangy, where centralized water was odor-free and lacked any off tastes, but well water smelled of sulfur and tasted salty or alkaline. Well water samples from Akkol and Balatopar, respectively, had metallic overtones and tasted of plastic. The organoleptic quality of the well water samples from Araltobe was judged to be especially poor (ratings uniformly 3 or 4).

Table 4. Organoleptic analysis of water from the Balkhash District settlements.

Village	Water Source	Odor at 20 °C	Odor at 60 °C	Taste at 20 °C
Akkol	Centralized	0	0	2 (salty)
	Well	2 (metallic)	3 (metallic)	3 (alkaline)
Akzhar	Centralized	0	0	2 (salty)
	Well	3 (sulfur)	2 (sulfur)	2 (salty)
Araltobe	Centralized	0	0	0
	Well	4 (sulfur)	4 (sulfur)	3 (salty)
Bakanas	Centralized	0	0	0
	Well	0	0	0
Bakbakty	Centralized	0	0	0
	Well	1	1	1
Balatopar	Centralized	0	0	3 (salty)
	Well	2 (plastic)	2 (plastic)	3 (plastic)
Birlik	Centralized	0	0	0
	Well	0	0	1
Miyaly	Centralized	0	0	2 (salty)
	Well	0	0	2 (alkaline)
Zheltorangy	Centralized	0	0	0
	Well	2 (weak sulfur)	2 (weak sulfur)	2 (alkaline)

3.4. Survey Results

A total of 737 individuals from the nine villages responded to surveys about water quality. Ratings from households with centralized water were segregated from those with access to only well water (Figure 3). Water quality was rated excellent by 29–71% of respondents with centralized water and just 14–54% of respondents with well water. Village by village comparisons of ratings of excellent confirm that in six of these eight settlements, the percentage of respondents satisfied with centralized water was higher than the percentage satisfied with well water. The two exceptions to this pattern are Bakbakty, where 29% of respondents in both classes of households rated their water as excellent, and Birlik, where 38% of respondents with centralized water and 54% of households with access only to wells rated their water as excellent.

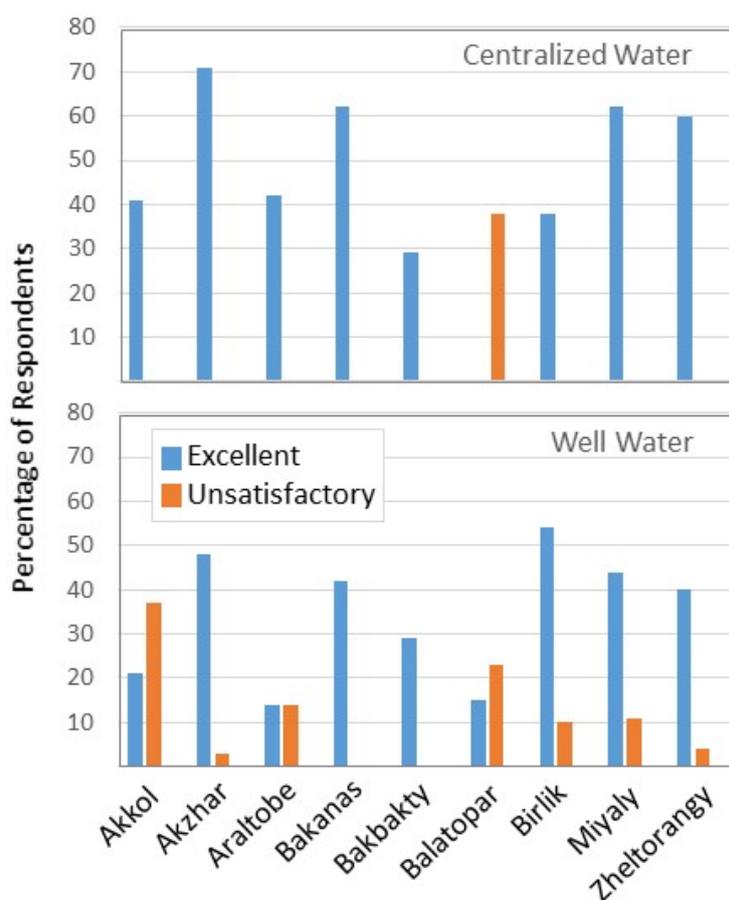


Figure 3. Water quality ratings of excellent (blue bars) and unsatisfactory (brown bars) from residents of the nine surveyed villages. The ratings of respondents with access to centralized water are shown separately from those with access to only well water. The ratings of the intermediate, satisfactory category are not shown.

Distinctions are also evident when ratings of unsatisfactory are considered (Figure 3). Although none of the respondents with centralized water in the eight aforementioned villages rated their water as unsatisfactory, rates of dissatisfaction by those with only well water ranged from 3–37% in six of the eight villages. No such respondents in the remaining villages (Bakanas and Bakbakty) found well water to be unsatisfactory. The sole and striking exception to the above general patterns is Balatopar, where none of the surveyed residents rated the quality of centralized water as excellent. Uniquely, 15% of Balatopar respondents with access to only well water rated its quality as excellent, versus 23% who rated its quality as unsatisfactory (Figure 3).

4. Discussion

4.1. Factors Influencing the Quality and Quantity of Water in the Ili-Balkhash Basin's Balkhash District

The Balkhash District is arid, and because it is heavily dependent on surface water from upstream portions of the basin, it is the recipient of incoming water-borne pollutants. Three important anthropogenic factors influence the quantity and quality of water entering the district. The first factor is Kapchagai Dam, which was constructed by the Soviets in the late 1960s. Impoundment of water behind the dam altered annual flow cycles of the Ili River, decreasing flows into the Balkhash District and leading to significant upstream water loss due to evapotranspiration and seepage from the reservoir [18,47]. Water from the Ili River was diverted to a number of large irrigation tracts, including areas adjacent to five of the villages studied here (Figure 1). Polluted discharge water from these sites is allowed to re-enter the river and flow through the district and into Lake Balkhash [47,48]. Although the extent of irrigation declined precipitously following the collapse of the Soviet Union, subsequent deterioration of remaining irrigation infrastructure has led to significant inefficiencies in water use and continued release of agricultural pollutants into the river and lake.

Increased withdrawals of water from the Ili River and its tributaries in China is the second important factor influencing water in the Balkhash District. Construction of eight large and many smaller Chinese dams over the past two decades [49] has facilitated rapid expansion of irrigation that has more than offset the decreases triggered by the dissolution of the Soviet Union [8,11,12,50]. Average annual Ili River flows from China into Kazakhstan have nevertheless grown by almost 50% between 1988 and 2013 due to a third important factor, climate change [51]. The Ili-Balkhash basin has always been subject to recurring climatic fluctuations, and as reflected by Ili River flows and the level of Lake Balkhash, the current cycle is favorable [52]. The long-term prognosis under conditions of global climate change is nonetheless unfavorable, because the glaciers that charge the Ili River and its tributaries in the upper Ili-Balkhash basin are rapidly receding [22,53,54]. Climate change thus reinforces the stresses caused by increasing water withdrawals upstream of the Balkhash District.

Pollution of water resources in the Ili-Balkhash basin by industrial, agricultural, and domestic wastewater is consequently a persistent problem [7,55]. The water of Kapchagai Reservoir is highly polluted with organic compounds, and levels of these toxicants are rising in Lake Balkhash [56]. Agricultural chemicals contaminate the basin's waterways [57–59], which are also subject to high levels of natural salinity that can be significantly increased in localized areas by irrigation, which draws salts to the surface [60,61]. Metals are nevertheless the major sources of surface water pollution in the basin [21,31,48,62,63]. Some of these pollutants occur naturally or are derived from human activities in Kazakhstan [21,55], but others, including significant loads of copper and zinc, enter the lower basin from China [63,64].

All of the above factors directly affect surface waters, but they also influence the interconnected groundwater network, especially in the lower basin [65]. Pollution of groundwater that is used for drinking represents a potential threat to public health, yet in contrast to surface water [17,22,31,32,66–68], relatively little is known about the quality of groundwater reserves in areas such as the Balkhash District. It is consequently difficult to assess the potential threat of contamination. An assessment of these risks can lead to practical approaches to preserve public health, but this requires data such as those generated here, so that risks can be identified [35,39].

4.2. Quality of Well and Centralized Water in the Balkhash District

Almost all of the 34 villages in the district, including the nine studied here, have access to centralized water. This is a favorable situation, given that such access averages just 29% in rural Kazakhstan [3] and can be less than 5% in villages of the nearby Pavlodar Region [69]. The service is nevertheless used by an average of just 59% of residents in the villages (range = 12.5–95%). The remaining residents obtain water for drinking and other household needs from shallow wells and sometimes even open sources. This is because residents either lack access to centralized water (distribution systems in the

Balkhash District often do not extend to cover the entire area of each village) or choose not to connect to the available system. Cost, a known impediment to the use of centralized water [69], was cited as one reason for not connecting, but other disincentives have also been identified [2].

Although levels of contaminants in well water from six of the villages did not exceed governmental safety thresholds [45] for a comprehensive panel of chemical elements and other pollutants, levels of one or more contaminant in the remaining three villages were high—sometimes very high (see Section 3.1). Iron levels in well water from Balatopar were almost 3-fold above those measured in the Ili River, which is known to harbor substantial levels of this element in its sediments [62,63], and those of boron in well water from this village were 16-fold above that detected in Lake Balkhash [55]. Uranium, which is present and mined in the lower Ili River basin [70], was present at levels nearly double the governmental threshold in well water from just one village: Birlik.

The presence of heavy metals such as iron and uranium, or of salts released into water by irrigation, is not wholly unexpected in untreated groundwater of the Balkhash District [60–64,70]. There is nevertheless no obvious relationship between excessive levels of these pollutants in well water and either the location (Figure 1) or population of individual settlements (Table 3). The well water of Balatopar, which lies far downstream from the other villages, was heavily contaminated with four pollutants, but the profiles of contamination at villages that are located near one another was often sharply divergent, e.g., Birlik versus Akzhar or Akkol versus Araltobe. The delta region's complex geomorphology and poorly understood hydrology are undoubtedly determinants of the variability observed here [8,9,28], and thus more extensive monitoring and analysis is clearly warranted to reveal patterns that are not now evident.

A comparative analysis of water from wells and centralized water systems of the nine villages confirms that, with rare exception, centralized water adheres to governmental standards to exclude chemical and microbiological contamination and avoid off odors and tastes [45]. Adherence to these standards is not surprising, because centralized water is drawn from deep aquifers, treated prior to distribution, and subject to quarterly quality control by governmental agencies. In contrast, the quality of water pumped from nearby shallow tube wells is not routinely tested and can be influenced by short-term fluctuations in the water table and the presence of salinity and other pollutants from surface water [69,71,72]. Water from shallow wells is also subject to contamination by microorganisms traceable to poor sanitation, but although low levels of microbial contamination were detected in some of our samples, there was no evidence of fecal contamination. This is somewhat surprising, in light of earlier reports that nearly 20% of tested water samples in the Balkhash District fail to meet microbial standards [2].

The presence of the above pollutants in drinking water does not necessarily influence organoleptic qualities, and so it was of interest to compare expert assessment of the taste and smell of water in the settlements with the subjective opinions of residents who consume the water. Well water quality was distinctly substandard in two villages as determined by a sensory expert. The intensity of off tastes and smells was pronounced (expert ratings of 3 or 4) in Araltobe, a village where chemical contamination of well water did not exceed government thresholds, and also in Balatopar (expert ratings of 2 or 3), a village where well water was significantly contaminated with minerals, boron, chloride, and iron. The assessment of resident non-experts was more nuanced. Thus 29–54% of the respondents from Bakanas, Bakbakty, Birlik, and Miyaly rated their well water as excellent and just 0–11% as unsatisfactory. These responses are in good agreement with expert opinion, but the corresponding responses for respondents from Araltobe and Balatopar, 14–15% excellent and 14–23% unsatisfactory, differed greatly from expert opinion. In contrast, residents of eight of the nine villages were generally satisfied with their centralized water, i.e., significant numbers of respondents gave excellent ratings, and no one gave unsatisfactory ratings. The opposite was true in Balatopar, where none of the respondents rated centralized water as excellent and 38% rated it as unsatisfactory—as did the expert.

Sensory evaluation of water is complex, and the number of villages and samples included in the current study was limited [73,74]. It is nevertheless concerning that on the basis of a relatively small number of samples, significant levels of groundwater contaminants that pose risks for human health could be identified. Although the presence of these contaminants was sometimes but not always correlated with off tastes and smells as detected by expert sensory evaluation and/or by village residents, Balatopar in particular stands out as a priority hotspot for more detailed analysis. This study makes it clear that such analysis is warranted to pinpoint the sources of such high levels of contamination, to better understand their distribution patterns, and to identify risks. Further analysis will allow risks to be assessed and managed in ways that preserve the health of residents in the Balkhash District.

5. Conclusions

The present study, which is based on investigations in nine villages, demonstrates that the inhabitants of Kazakhstan's Balkhash District are at risk due to consumption of water from shallow tube wells that is contaminated with heavy metals and other pollutants. Importantly, this study also demonstrates that this risk can be managed if properly treated water from deep underground sources is made available and used by local residents. The research reported here thus simultaneously identifies a serious problem, e.g., the contamination of drinking water, and offers a practical solution, e.g., provision of centrally treated water. Some water treatment systems are already in operation in the Balkhash District and other areas of rural Kazakhstan, but they face a number of practical challenges. These include prolonged interruptions in operation due to planned and unforeseen repairs associated with frequent breakdowns of pumps, leakage from the water supply network, power outages, and shortages of operating funds [75–77]. Households also frequently lack the resources needed to access available centralized water supplies, and residents are often unaware of the benefits of treated water [61,78]. All of these factors contribute to continued reliance on poor quality water from shallow tube wells and other dangerous sources.

Full accounting of the extent and seriousness of water-borne risks across the Balkhash District mandates detailed knowledge of current and potential future sources of contaminants to the domestic water supply. Understanding these dynamics will require expertise in geomorphology, hydrology, and epidemiology, and should be viewed as a research priority. The expansion of the survey of village residents to more explicitly assess ability and willingness to pay for centralized water is also warranted. It is also crucial that all levels of government not just acknowledge, but also respond to the risks posed by growing levels of pollution and by the obsolescence and insufficient development of water infrastructure [2,6,32]. Adequate funding and well-coordinated steps to modernize and maintain water intake, purification, and supply systems is needed, as are facilities to treat wastewater. The government also has a responsibility to ensure that all households in the district have access to such infrastructure, and it should implement programs to raise citizen awareness about the importance of consuming water that is pure and safe.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Concentrations of the elements listed below were determined in samples of well and centralized water from the Balkhash District. Concentration thresholds in drinking water have been specified by the government of Kazakhstan [45] for 35 of the 65 listed elements and are given in parentheses. Thresholds were exceeded only in the case of boron, iron, and uranium (see Section 3.1 for details). The tested elements are: aluminum (0.5 mg/L), antimony (0.05 mg/L), arsenic (0.01 mg/L), barium (0.1 mg/L), beryllium (0.0002 mg/L), bismuth (0.1 mg/L), boron (0.5 mg/L), cadmium (0.001 mg/L), calcium (140 mg/L), cerium, cesium, chromium (0.05 mg/L), cobalt (0.1 mg/L), copper (1 mg/L), dysprosium, erbium, europium (0.3 mg/L), gadolinium, gallium, germanium, gold, hafnium, holmium, indium, iridium, iron (0.3 mg/L), lanthanum, lead (0.03 mg/L), lithium (0.03 mg/L), lutetium, magnesium (8.5 mg/L), mercury (0.0005 mg/L), molybdenum (0.07 mg/L), neodymium, nickel (0.1 mg/L), niobium (0.01 mg/L), osmium, palladium, platinum, potassium (20 mg/L), praseodymium, rhenium, rhodium, rubidium (0.1 mg/L), ruthenium, samarium (0.024 mg/L), scandium, selenium (0.01 mg/L), silver (0.05 mg/L), sodium (200 mg/L), strontium (7 mg/L), tantalum, tellurium (0.01 mg/L), terbium, thallium (0.0001 mg/L), thulium, tin, titanium (0.1 mg/L), tungsten (0.05 mg/L), uranium (0.015 mg/L), vanadium (0.1 mg/L), ytterbium, yttrium, zinc (5 mg/L), zirconium.

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