



INVESTIGATION OF THE EFFECTS OF USED THERMAL WATER IN SURFACE RECEIVERS ON AN EXAMPLE OF A HUNGARIAN SPA

Zoltán Milán MISKI,¹ Ildikó BODNÁR²

¹ University of Debrecen, Faculty of Engineering, Department of Environmental Engineering, Debrecen, Hungary, miskizoltan8@gmail.com

² University of Debrecen, Faculty of Engineering, Department of Environmental Engineering, Debrecen, Hungary, bodnari@eng.unideb.hu

Abstract

In our study, the characteristics and environmental impact of the disposal of used thermal water were investigated in relation to a surface reservoir by a selected local spa using modern field and laboratory test methods at 6 sampling points. The water samples were analysed every 3 months in the field and (within 24 hours of sampling) in the Water Quality Protection Laboratory of the Department of Environmental Engineering, Faculty of Engineering, University of Debrecen, thus, the seasonal changes of the water quality characteristics were effectively monitored. During the laboratory tests, changes in turbidity, biological oxygen demand (BOD₅), chemical oxygen demand (COD), total organic carbon (TOC), total inorganic carbon (TIC) and alkalinity values were studied, and the macro and micro elemental composition of the samples was also analysed by a partner laboratory using modern an elemental analytical method (ICP-OES). Ion chromatographic analyses were also used to determine the typical anion and cation concentration values of the tested water samples.

Keywords: *used thermal water, monitoring, sustainability, environmental protection.*

1. Introduction

Nowadays, the importance and use of thermal water as a renewable energy source is becoming increasingly valued, as its operation has many potentials. Hungary is the one of rare countries in Europe, and even in the world, that has odd geothermal characteristics. Thermal water is used for therapeutic, balneological and drinking water proposes, and is also very popular in our country for heating, electricity generation and agriculture applications [1].

The aim of our research is to provide a general overview of the importance of thermal water utilisation and to examine the environmental impact of the thermal water used by reviewing the current legislation and limit values.

2. Thermal water as a geothermal energy

Geothermal energy refers to the heat from the Earth's interior. More precisely, it is the excess of heat stored in geological formations due to their

higher temperature compared to the average surface temperature [2].

The average annual heat flux from the Earth's interior to the surface is 10^{20} J. The temperature at the centre is about 7000 °C, which is due to the rapid heating of the interior during the condensation of the Earth's materials 4600 million years ago. As a result, the kinetic energy of the condensing materials was converted into thermal energy. Also of significance is the long decay times of radioactive isotopes such as ²³²Th, ²³⁸U and ⁴⁰K that are found in the Earth's interior. The decay of these isotopes releases heat, estimated at 5×10^{20} J per year, but the rate of these decays gradually decreases due to the half-life. The heat generated heats the subsurface rocks and the porewater stored in the rocks by conduction and the resulting water is called thermal water. At a given point on the Earth's surface, the more water stored in pores and the thinner the Earth's crust, the richer the area is in geothermal energy [3].

„In geological terms, thermal water is defined as any water whose temperature exceeds the mean annual temperature of the area concerned. In balneological terms, however, only waters with a temperature of more than 20 °C are called thermal waters.” [4]

3. Material and method

3.1. Description of the surface water courses

The studied spa and beach baths represent an area of 7 hectares, with 9651 m² of pools. These include pools that are open all year round, both indoors and outdoors, as well as seasonal pools. The water temperature ranges from 22-38 °C, while the water volume varies from a 20 m³ children's pool type to a 1750 m³ swimming pool type [5].

The spa uses a significant amount of thermal water for its balneological services, to fill its pools and to supply its showers. The water used for the pools is transported by gravity in a closed concrete canal and pipeline, and then by a transfer pump to the Boating Lake. The water then flows by gravity through reservoir I (7.40 ha) to reservoir II (14.00 ha), which is managed as a fishing lake by the local angling association. From reservoir II, the wastewater is discharged via the open sewer in Üllőlapos canal N°I-8-1-c (primary receiver N°AAB610) to the Német brook (N°AEP843) as primary receiver [5].

Német brook (Fig. 1) is a low-lying, low-gradient, calcareous, moderately fine-bedded intermittent watercourse. The total length of the water body is 12.554 km, the width is 4 meter and the average depth is 1 meter. Its catchment area is 55.86km² and it is fed by the Hortobágy-Berettyó main channel (N°AEP594) [6].

The Német brook also indirectly receives municipal wastewater from two wastewater treatment plants. The treated wastewater of Berekfürdő village is discharged at the 4.4 ckm (channel kilometer) section of the Üllőlapos canal at a volume of

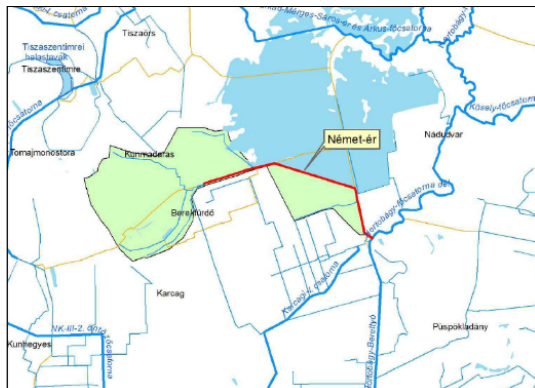


Fig. 1. Német brook's flow. [7]

176000 m³ per year. The treated effluent of Kismadaras town is 82000 m³ per year, discharged at the 6.05 ckm section of the Üllőlapos canal. There is a high thermal water load in the watercourse due to the discharge of bathing water into the canal at four points. Section 1.4 ckm of the Stormwater Drainage Sewer receives 8000m³ of thermal water per year used by the Berekfürdő Spa Hotel, but this volume was lost in 2024 due to renovation works. On section 6.6 ckm of the Üllőlapos canal, the Thermal Hotel Pávai will store 55000 m³ of water per year. The Berekfürdő Spa and beach pools disposes of 124,000 m³ of used thermal water per year at one of its intake points and 431,000 m³ per year at the other [6].

In Hungary, the national Watershed Management Plan (WMP) classifies surface and groundwater bodies into different types. According to WMP2 and WMP3, the Német brook is classified in type 6S (lowland - low gradient - calcareous - medium-fine sediment - small catchment). Due to lack of data, the biological, chemical and ecological status of the Német brook was not classified in the first WMP adopted by the Hungarian Government on 5 May 2010. However, these parameters have been classified in the second and third plan (Table. 1) [8].

Table. 1. Német brook condition based on the VGT2, VGT3

Hydrological object identifier (VOR)	Name of the water	Biological elements status	Physical-chemical elements status	Specific pollutant status	Hydro-morphological elements status	Ecological certification	Ecological target	Year of achievement of the ecological target	Justification for the ecological owmpton	Chemical status	Chemical target
AEP843	Német-ér	poor	poor	good	good	good	Good potential to be achieved	2027+	G2	good	Good status to be maintained

3.2. Sampling points

Since some of the pools are in operation all year round and others only seasonally, we have tried to limit our measurements accordingly, in order to get as much information as possible about the quality and changes in the different water bodies. We carried out our tests every 3 months, with a total of 4 field and laboratory measurements, paying attention to possible seasonal changes (autumn, winter, spring, summer). 6 sampling points were designated, where sampling was carried out with a rod-mounted sampling vessel. Samples were placed in tightly sealable, 2 L, pre-labelled plastic bottles (Fig. 2), and stored at +4 °C in a place protected from sunlight until laboratory testing.

The used water of the Berekfürdő Spa and Beach Baths is primarily discharged into the Boating Lake. The first sampling point (M1) is located at the beginning of the lake, a few metres from one of the intake points, while the second sampling point (M2) is located at the end of the lake (Fig. 3). The third (M3) and fourth (M4) sampling points were located at reservoir I, as this is the gravity flow of the beach waste water downstream of the Boating Lake and the water body also receives the thermal water used by the Thermal Hotel Pávai (Fig. 3). One aeration device was installed in the Boating Lake and one in reservoir I. The third lake in our study was reservoir II, where 2 sampling points were also assigned. The fifth sampling point (M5) was located a few metres from the inlet point of the gravity flow from reservoir I in a closed concrete channel, while the sixth sampling point (M6) was located at the point before the channel N°I-8-1-c of the river that runs parallel to the reservoir (Fig. 3).

3.3. Description of measurement methods

After the sampling points were selected, pH, temperature, specific conductivity, total dissolved solids (TDS), salinity and dissolved oxygen con-

centration were determined in the field using a Multi-Line P4 electro-analytical portable set. After recording the field test results and proper storage of the water samples to be tested, the samples were further analysed within 24 hours in the Water Quality Protection Laboratory of the Department of Environmental Engineering, Faculty of Engineering, University of Debrecen.

During the laboratory tests, turbidity was determined using a Turb 555-IR type nephelometric turbidimeter device. Biological oxygen demand (BOD_5) was determined using OxiTop IS 12 type manometric volumetric flasks, chemical oxygen demand (COD) was determined using a photometric rapid tester, total organic carbon (TOC) and total inorganic carbon (TIC) were determined using a Shimadzu TOC-V_{CPN} type apparatus. Alkalinity (total and free) was measured by acid-base titration and anion and cation content with DIONEX ICS-3000 dual ion chromatography system.

For the determination of elemental content, the widely used instrumental analytical solution, inductively coupled plasma-optical emission spectrometry (ICP-OES) was used with the assistance of the Environmental Analytical Laboratory, Department of Inorganic and Analytical Chemistry, University of Debrecen.

AquaChem software was also used to investigate further irrigation uses of the used water.

4. Results

4.1. Results of field measurements

The research work was started at the six sampling sites described in the Material and Methods chapter in the second half of November 2023, mid-February and mid-May 2024, and at the end of August 2023. The aim was to monitor the impact of thermal water discharge on the watercourse under study by evaluating the data. Based on the four dates, the measured water quality parameters provide information on all seasons on an an-



Fig. 2. Sampling and storage conditions.



Fig. 3. Sampling points.

nual basis, which greatly helps to detect possible seasonal changes and to intervene if necessary. The **Table 2** provides information on the general water quality characteristics per min-sampling point for the autumn-winter-spring-summer period.

The measured values were evaluated according to the VM Decree 10/2010 (VIII.18.). Column E of Annex 2 to the Regulation contains the limit values for the watercourses under study (lowland, small watercourses).

When examining the temperature values, it was observed that in the late autumn period, when the outside air temperature was 3.5 °C, more than 18 °C could be measured at the first discharge point. This value shows a decreasing trend in all cases during the water's journey through the tested reservoirs until the last sampling point, except during the autumn and winter sampling from sampling point M4 to sampling point M5, where an increase in temperature is observed, due to the fact that the water flows underground for more than 500 meter in a closed concrete channel where it is able to warm up. At the time of sampling in August, the water temperature was more than 30 °C (outside air temperature 36 °C). In this case, there was a temperature drop of 7 °C (33.60-26.60°C) between the first sampling point (M1) and the sixth sampling point (M6), which suggests that the water mass cannot cool down sufficiently, causing a severe thermal stress on the aquatic ecosystem.

The salinity and the measured specific conductivity values are illustrated in **Fig. 4** Compared to the limit values given in column E of the Regulation (<1000 µS/cm), the conductivity values are exceeded by a factor of two and sometimes three. The blue dashed line in the figure also indicates the limit value for the highest limit value set in the Regulation for lowland watercourses with stagnant water (<1200 µS/cm), which is also exceeded by at least two times.

The measured pH values (**Fig. 5**) were close to the upper threshold in the spring and summer measurements, and in the other cases they were within the range of 6.50-9.00.

In the case of the dissolved oxygen values (**Fig. 6**) only the value obtained at the second sampling point (M2) in the autumn sampling, marked in yellow, was below the threshold (5.85 mg/l), and in general the concentration values were within the limits. At the third sampling point (M3), outliers are presumably seen because this sampling point is the closest to the surface aeration facility.

Table 2. General water quality characteristics during the field measurement

Measurement date:	Samples						
	M1	M2	M3	M4	M5	M6	
1.: 19.11.2023.							
2.: 10.02.2024.							
3.: 16.05.2024.							
4.: 31.05.2024.							
Temperature (T) [°C]	1.	18.60	14.60	10.60	8.00	9.60	7.00
	2.	22.90	20.90	14.50	11.80	12.20	10.80
	3.	29.30	28.30	25.40	22.60	21.50	20.40
	4.	33.60	33.20	30.40	27.50	27.30	26.60
Salinity (Sal) [g/l]	1.	1.50	1.40	1.30	1.30	1.30	1.30
	2.	1.40	1.40	1.40	1.40	1.40	1.30
	3.	1.30	1.30	1.30	1.40	1.40	1.50
	4.	1.20	1.30	1.30	1.40	1.40	1.60
Total dissolved solids (TDS) [g/l]	1.	2.82	2.82	2.69	2.58	2.67	2.66
	2.	2.78	2.72	2.70	2.71	2.79	2.64
	3.	2.52	2.55	2.57	2.74	2.76	2.93
	4.	2.34	2.46	2.48	2.70	2.71	3.05

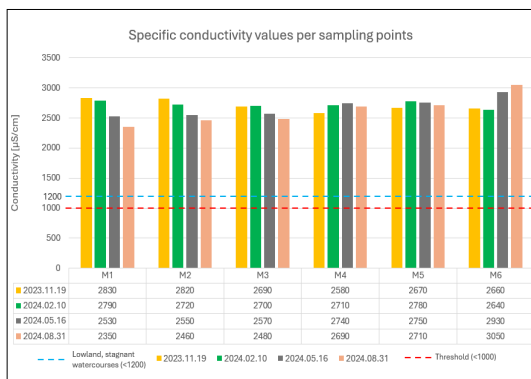


Fig. 4. Specific conductivity values.

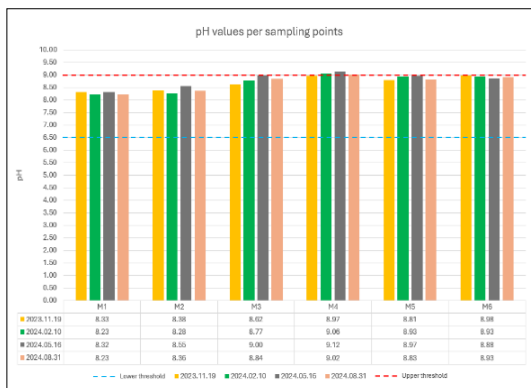


Fig. 5. pH values during the field measurement

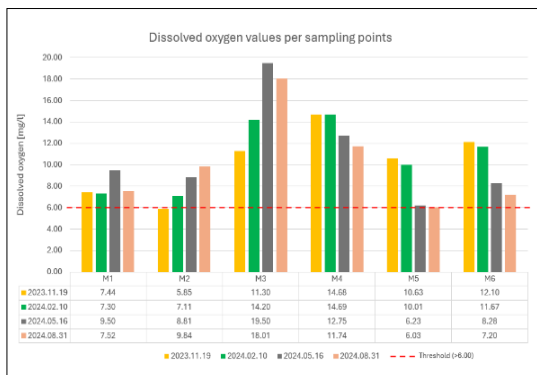


Fig. 6. Dissolved oxygen values in the case of sampling points

4.2. Results of laboratory tests

4.2.1. Assessment of general water quality characteristics

Table 3 illustrates the values obtained for the general water quality parameters analysed in the laboratory. Turbidity values in February and August were generally higher than in the other sampling periods, but the sixth sampling point (M6) had an exceptionally high value in May (172.81 NTU). The discrepancies were due to the higher presence of suspended organic and inorganic matter, as well as a higher proportion of plankton and microorganisms. The turbidity level does not directly determine the actual amount of suspended solids in the water, but it does provide an indication of their presence. The dissolved organic content (TOC) varied between 10.46 and 24.06 mg/l. In most of the tests, BOD values were found to be lower than TOC and COD values, indicating that some of the organic pollutants are not biodegradable.

Table 4 presents the free and total alkalinity values measured by titrimetry at the study sites, which correlate well with the total organic carbon (TOC) values. Based on the relevant standard [9] the amounts of the anions shown in the table were calculated, for which the concentration of bicarbonate was abnormally high, indicating the hydrogen-carbonate nature of the thermal water used. Among the inorganic carbon forms, the carbonate ions showed higher values at points M3-M4, while e.g. hydroxyl ions were not present in detectable quantities in the samples.

Table 3. Analysis of turbidity and organic carbon forms

Measurement date:	Samples						
	M1	M2	M3	M4	M5	M6	
1.: 19.11.2023.							
2.: 10.02.2024.							
3.: 16.05.2024.							
4.: 31.05.2024.							
Turbidity [NTU]	1.	0,84	1,08	6,78	9,93	10,69	89,85
	2.	1,01	0,97	15,46	20,20	20,22	46,60
	3.	6,07	12,60	19,74	14,19	9,81	172,81
	4.	1,93	2,16	20,45	20,47	20,21	111,14
Biological oxygen demand (BOI ₅) [mg/l]	1.	2,00	2,00	10,00	20,00	20,00	10,00
	2.	22,00	9,00	11,00	11,00	17,00	19,00
	3.	5,00	7,00	11,00	8,00	5,00	6,00
	4.	7,00	1,00	15,00	9,00	10,00	6,00
Total organic carbon (TOC) [mg/l]	1.	11,72	11,31	11,15	11,06	11,04	13,19
	2.	12,05	11,30	10,46	11,07	12,57	18,34
	3.	14,45	12,06	13,11	15,07	14,60	23,36
	4.	14,25	11,77	12,98	15,91	16,03	24,06
Chemical oxygen demand KOI [mg/l]	1.	35,00	35,00	47,00	47,00	48,00	45,00
	2.	35,00	31,00	74,00	86,00	87,00	63,00
	3.	58,00	61,00	99,00	73,00	72,00	88,00
	4.	41,00	42,00	67,00	78,00	53,00	66,00

Table 4. Alkalinity values and inorganic carbon forms

Measurement date:	Samples						
	M1	M2	M3	M4	M5	M6	
1.: 19.11.2023.							
2.: 10.02.2024.							
3.: 16.05.2024.							
4.: 31.05.2024.							
Free alkalinity (p') [mmol/l]	1.	0,46	0,46	0,79	0,94	0,81	1,65
	2.	0,70	0,70	1,44	1,37	1,02	1,19
	3.	0,69	0,88	2,67	2,60	1,84	1,72
	4.	0,39	0,90	1,94	2,33	1,01	2,05
Total alkalinity (m') [mmol/l]	1.	20,68	20,66	20,07	20,15	20,20	20,15
	2.	20,50	20,55	20,57	21,47	21,32	20,52
	3.	19,41	19,50	19,77	21,49	21,42	22,91
	4.	18,39	19,18	19,18	21,18	20,95	24,13
Total inorganic carbon (TIC) [mg/l]	1.	277,50	278,20	268,80	260,80	250,60	258,40
	2.	263,90	262,30	251,40	258,20	262,50	243,00
	3.	251,40	247,60	241,60	259,70	221,10	281,90
	4.	212,30	219,10	215,30	227,60	240,30	266,10
Hydroxylion [mmol/l]	1.	0	0	0	0	0	0
	2.	0	0	0	0	0	0
	3.	0	0	0	0	0	0
	4.	0	0	0	0	0	0
Carbonate-ion [mmol/l]	1.	0,91	0,91	1,57	1,88	1,62	3,30
	2.	1,39	1,39	2,84	2,74	2,04	2,39
	3.	1,37	1,77	5,35	5,20	3,68	3,43
	4.	0,78	1,80	3,87	4,66	2,03	4,10
Hydrogen-carbonate-ion [mmol/l]	1.	19,77	19,74	18,50	18,27	18,57	16,85
	2.	19,11	19,16	17,74	18,73	19,28	18,14
	3.	18,03	17,74	14,43	16,29	17,74	19,48
	4.	17,61	17,38	15,31	16,53	18,92	20,03

4.2.2. Evaluation of ion chromatography analyses

Ion chromatography measurements were also carried out during the laboratory tests, where the concentrations of 6 cations (lithium, sodium, ammonium, potassium, magnesium, calcium) and 7 anions (fluoride, chloride, bromide, nitrite, nitrate, phosphate, sulphate) were monitored. Fig. 7 demonstrates the abundances of cations, which indicate sodium, calcium and ammonium ions as the dominant ions, which are also circled in red. The amount of sodium ions exceeds 570.00 mg/l in all cases. The ammonium ion values are higher at the first and second sampling points (M1, M2), with a spike at the fourth sampling point in August (44.76 mg/l). In addition, the magnesium and potassium ion concentrations are also significant. Lithium ion was detected in very small amounts in the water.

Fig. 8 summarises the anion concentrations measured by ion chromatography. For the seven anions, chloride and sulphate ions were found to be dominant. Among the N- and P-forms as nu-

trient forms, the concentration of the nitrate ion shows significant variations, especially in winter when the efficiency of nitrification is lower. Nitrite ion was not detected in the water.

The chemical character of natural waters is mainly determined by the eight ions, the so-called macroions (four cations: Na⁺, K⁺, Ca₂⁺, Mg₂⁺; and four anions: CO₃²⁻, HCO₃⁻, Cl⁻, SO₄²⁻) which represent the majority of the salts dissolved in water. The sodium and potassium ions belong to the alkali metal group and are highly soluble in water. The measured data were also evaluated using the so-called Maucha star chart to obtain a visual comparison of the character of the water. In the star charts, the quantities of eight macroions are expressed as equivalence percentages. The radius of the circle used in the diagrams is proportional to the total ion concentration in the water. Ions with a concentration greater than 30 equivalence percent are called the dominant cation or anion, which determines the type of water [10].

Fig. 9 compares the results measured at the first sampling point to illustrate the seasonal varia-

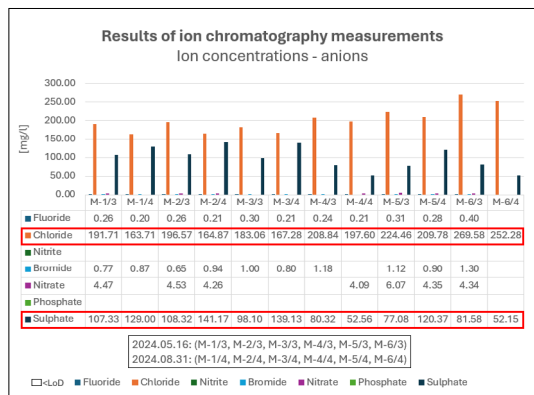
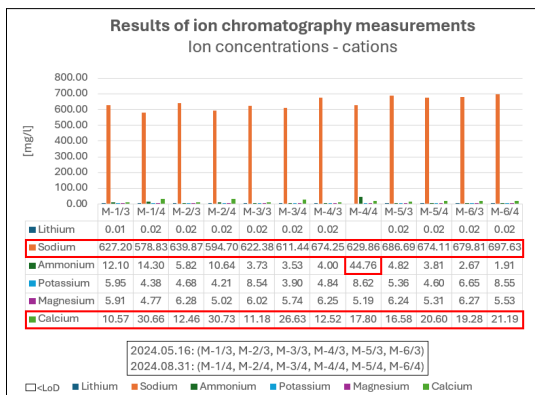
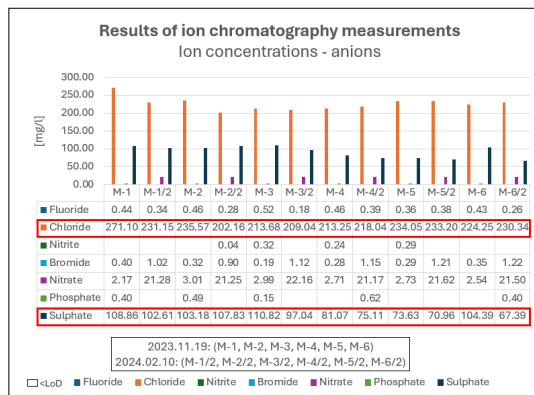
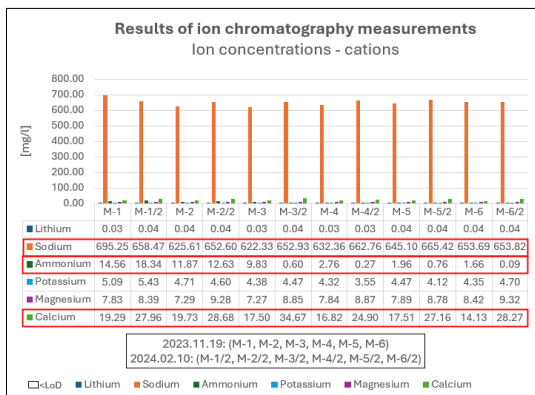


Fig. 7. Cationic concentrations in the case of sampling points.

Fig. 8. Anionic concentrations in the case of sampling points.

tions between cases. The star charts clearly show the sodium bicarbonate nature of the waters analysed.

Based on the measured data, further conclusions can be drawn from the so-called Wilcox diagram, which can be used to characterise the usability of water for irrigation. The values are given logarithmically. On the y-axis the so-called sodium hazard (sodium adsorption ratio-SAR), on the x-axis the salinity hazard as specific conductivity ($\mu\text{S}/\text{cm}$) is shown. Based on the SAR and salinity values four zones (low, high, high, very high) are formulated, which can be used to classify the tested water samples. According to the Wilcox diagram edited by the AquaChem software, it can be observed that in all cases the used thermal water samples are classified in the fourth as "very high" zone (Fig. 10), which means that its further use for irrigation is not recommended [11].

4.2.3. Elemental analytical tests

With the help of the Laboratory of Environmental Analysis of the Department of Inorganic and Analytical Chemistry, University of Debrecen, the elemental composition of the water samples was determined by inductively coupled plasma-optical emission spectrometry (ICP-OES). Results from November 2023, February 2024 and May 2024 were evaluated Fig. 11 shows the macroelemental composition of the samples. The graphs show that the sodium content of the samples is significant (572.00-702.52 mg/l) and the calcium content is also significant in February. The dominant elements were therefore sodium and calcium, which is in good correlation with the ion chromatography results.

The measured micro elemental composition is illustrated in Fig. 12 The boron content of groundwater is stratified and is the dominant micro element in these samples. Boron is an essential nutrient for both aquatic organisms and terrestrial plants, but at high concentrations it can be toxic. Possible dissolution from structural materials in contact with water, e.g. chromium, nickel, lead, was not detected.

5. Conclusions

Based on the measurement results in the studied area, the following conclusions can be drawn. The disposal of the used thermal water of the Berekfürdő Spa and Beach Baths in a surface intake could have a negative impact on the water quality of the Német brook as a receiver. Com-

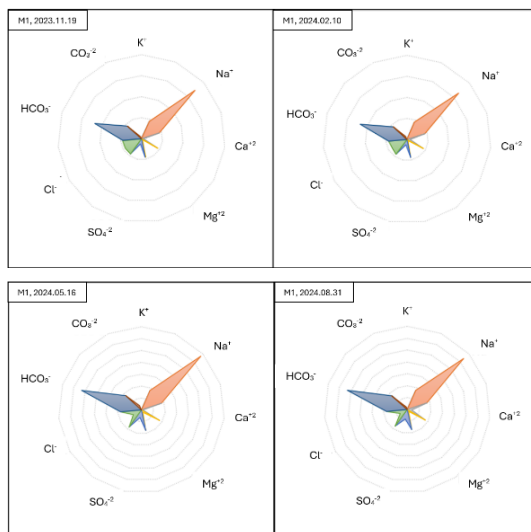


Fig. 9. Star plot of results measured at the first sampling point.

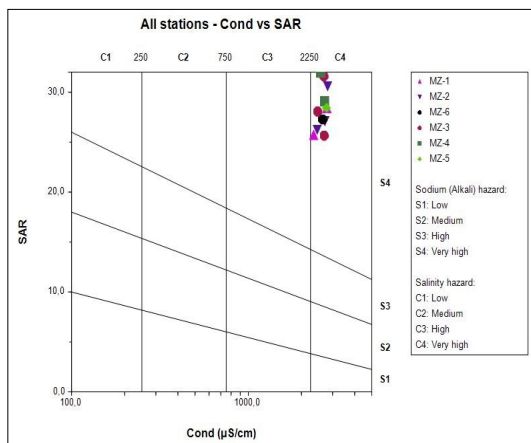


Fig. 10. Wilcox diagram based on measured summer values.

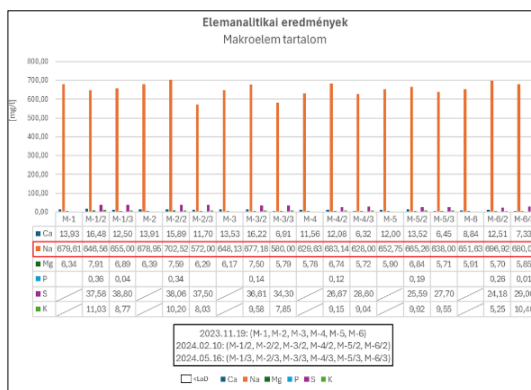


Fig. 11. Macroelemental composition measured by ICP-OES.

paring the measured results with the limit values of the Decree 10/2010 (VIII.18.) of the Ministry of Agriculture and Forestry, it can be concluded that the high dissolved content and heat load not only affects the aquatic ecosystem but also the terrestrial ecosystem. Excessively high temperatures can upset biological equilibrium, cause siltation, accelerate organic matter formation and reduce dissolved oxygen concentrations in water [3].

Water reuse for irrigation proposes is also difficult because the high salinity of the water can lead to salinisation of the soil. Sodium and carbonate salt accumulation can cause the most adverse physical and chemical effects. Salinisation can result in poorly aerated and waterlogged soils with only drought-tolerant plants [3].

Membrane separation treatment as a modern solution can be used to remove high salinity from used thermal water and wastewater, of which e.g. reverse osmosis is an effective method to reduce salinity. Osmosis is a spontaneous solvent flow process that moves from a lower concentration solution to a higher concentration solution through a semipermeable membrane. The membrane allows the solvent to pass through, but does not allow the solute to pass through. Osmosis is based on the difference in osmotic pressure created by the difference in concentration of the solutions. The greater the difference in concentration of the solutes, the greater the osmotic pressure. In so-called reverse osmosis, the solvent (e.g. pure water) flows under external pressure through a semipermeable membrane from the more con-

centrated solution to the contaminated dilute solution. This purification technology is more efficient than any other method, as the membrane properties of the filter remove contaminants thousands of times smaller than bacteria [3].

In Hungary, this method is only used in a few places. One such system is operated by the Nagykun Waterworks in Karcag, near to Berekfürdő. The wastewater to be treated is placed in a closed basin into which membrane cassettes are submerged. The cassette is a structure where hundreds of thin membrane tubes are connected to the head unit (Fig. 13). The water flows from the outside into a thin capillary tube, from where the purified water exits through the head [3].

The upgrading of neighbouring municipal wastewater treatment plants can be an important factor in protecting surface water. The Berekfürdő wastewater treatment plant was established in 1985. "The treatment technology is a flow-through oxidation trench technology with surface aeration, a method which is not state-of-the-art (1970s). The efficiency of the technology is significantly below that of deep aeration plants, which are currently considered state-of-the-art characteristic, i.e. it cannot meet today's needs. Plants similar to the Berekfürdő plant technology have typically been systematically closed down and replaced by more modern technologies over the last decade" [12] In recent years, limit values have been exceeded for TSS (total suspended solids), BOD₅ and COD, and in all cases fines have been imposed [12].

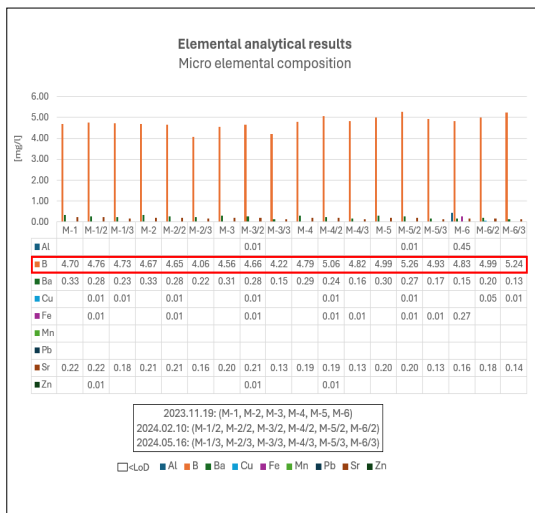


Fig. 12. Microelemental composition measured by ICP-OES



Fig. 13. Membrane technology membrane module element in Karcag [3]

In other words, regular monitoring of the disposal of used thermal water is of paramount importance for the protection of surface water, providing meaningful information on possible changes in the quality of the water being disposed of, the state of the associated ecosystems and the need for intervention.

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