Environmental Engineering and Management Journal

May 2015, Vol.14, No. 5, 1217-1229

http://omicron.ch.tuiasi.ro/EEMJ/

"Gheorghe Asachi" Technical University of Iasi, Romania

ENVIRONMENTAL RISKS OF WASTE THERMAL WATER DISPOSAL: LONG-TERM EFFECTS OF THERMAL WATER SEEPAGE ON DIFFERENT SOIL TYPES

Andrea Farsang[1*], Tivadar M. Tóth[2], Kitti Balog[3]

[1]Department of Physical Geography and Geoinformatics, University of Szeged, H-6701, Szeged, P. O. Box 653, Hungary
[2]Department of Mineralogy, Geochemistry and Petrology, University of Szeged, H-6701, Szeged, P. O. Box 651, Hungary
[3]Institute for Soil Sciences and Agricultural Chemistry, Centre for Agricultural Research, Hungarian Academy of Sciences, H-1525 Budapest, P.O. Box 102, Hungary

Abstract

In Hungary, 0.5 million m^3 of thermal water is exploited every day for diverse purposes. After utilization, this enormous amount of thermal water becomes sewage water with a high concentration of salts, heavy metals, ammonia, nitrate, an unfavorable ion composition and high temperature. A common treatment is to dispose of waste water into a surface recipient through uninsulated channels surrounded by arable land. By infiltration, sewage water can cause potential salinization/sodification/alkalinization and contamination of soil and groundwater. This work investigates the manifestation of these problems in different soil types, Chernozem, Phaeozem and Arenosol, representing case studies regarding the environmental risks of used thermal water.

The results conclude that seeping thermal water has a high Na^+-concentration and salt content, which represents risk of soil sodification/salinization, while leaching facilitates a rise in the salty groundwater table, and a change in the chemical type (Na^+-dominance) surrounding the channel. Together, these factors lead to soil degradation in the investigated Chernozem and Phaeozem profiles. In Arenosol, the aforementioned processes were not observed, but infiltrating thermal water reached groundwater adjacent to the channel and enhanced its total salt content and Na^+-rate. Referring to the Chernozem and Phaeozem soils, statistical analyses were carried out to determine the significant variation in soil properties between profiles located at different distances from the channel. Via principal component analysis combined with discriminant analysis, Mg^{2+}-mobilization and salinization processes were identified near the channel. On the basis of the computed discriminant function, sample groups of two localities (control and thermal water affected) can be unambiguously distinguished.

Key words: human-induced soil-salinization, soil degradation, waste thermal water seepage, discriminant analysis

Received: June, 2013; Revised final: September, 2014; Accepted: October, 2014

1. Introduction

In several countries in Europe a huge amount of thermal water has been applied for decades. Hungary is especially on the cutting edge of having geothermal reservoirs. At present, 0.5 million m^3 of thermal water per day from the 850 active thermal wells is available to two-thirds of the country's area (Kovács et al., 2007). The exploitation and utilization of this natural resource is extremely diverse: balneotherapy, mineral water, agricultural and industrial heating, municipal hot water supply and so on (Árpási, 2003). Due to excellent natural resources, greenhouse farming is widespread in the Great Hungarian Plain.

These horticultural estates are the main agricultural users of thermal water for heating in winter. Sewage water is then piped into cooling pools through unlined ground channels. A similar technique is practiced by the intensively expansive thermal spas. As a result, a large amount of waste water with high temperature, high salt content and

[*] Author to whom all correspondence should be addressed: e-mail: farsang@geo.u-szeged.hu; Phone: +36-62-544-195; Fax: +36-62-544-158

inadequate ion composition (a predominance of Na^+ and Mg^{2+}) (Mirel et al., 2006) is channelized, and is consequently able to infiltrate into the soil (Alam and Bhutta, 2004) of nearby plough land.

Leakage of waste thermal water raises several problems from the rising groundwater table to altering soil salinity and ion composition. The main aim during establishment of these unlined channels was the delivery of water to a natural ultimate recipient, which – nevertheless - changes water quality of the recipient from time to time (Yilmaz and Koc, 2014). Water quality in the channel and the ultimate recipient depend on also other circumstances, like climatic factors (the amount of annual precipitation, the number of intense precipitation events, the length of dry periods etc.) (Popita et al., 2014). However, the type, texture, water retaining ability and buffering capacity of the given soil or the land use were not taken into account. Therefore, it is essential to determine the impact of thermal water seepage on different soil types.

Human-induced salinization and degradation have been paid scant attention until recently. The Great Hungarian Plain currently sustains important levels of productivity, with intensive agricultural cultivation on soils near unlined ground channels. These areas are endangered by the seepage of thermal water having high salt, ammonia and phenol content and, moreover, unfavorable ion composition. Occasionally, this sewage water can reach the groundwater causing sodification and salinization, physical and chemical soil degradation (Beltrán, 1999; Jiang et al., 2009; Shanyengana et al., 2003) which can subsequently influence agricultural yield (de Clercq et al., 2008; Rotaru and Răileanu, 2008). To avoid these unfavorable processes, according to the Government Regulation no. 379/2007 (XII 23) part 4 no. 29 § (2) proceeding energy production, water from the thermal wells flowing in closed pipelines is required to be reinjected into geothermal aquifers, a rather expensive process.

The law of obligatory reinjection is suspended (Government Decree no. 1002/2012 (I. 11.)), thus it is permitted to create surface impoundments to dispose used thermal water. Therefore it is important to determine the extent of the negative impact on the channel- or surface reservoir adjacent soil-groundwater system.

In the light of all the previously-mentioned information, the main aims of the present study can be summarized as follows:

(1) to identify the types of potential/human-induced soil degradation caused by thermal water infiltration (salinity, sodicity and/or alkalinity);
(2) assessing differences and similarities;
(3) to reveal the horizontal and vertical extent of the effects (on and under the surface) induced by channelized thermal water.

2. Material and methods

2.1. Study sites

Cserkeszőlő is situated in the Tiszazug region (Fig. 1), on an alluvial fan (83–95 m ASL). The region has a warm, dry climate, with annual precipitation below 550 mm. The groundwater table is at a depth of 4 m. Two main soil types were investigated at this sample site: a Chernozem (1 t: Luvic Orthicalcic Chernozem (Pachic), 2 t and 3 t (control) sample points: Luvic Orthicalcic Chernozem (Anthric, Pachic)) and a Phaeozem (4 t: Luvic Calcic Phaeozem (Abruptic) and 5 t (control) sample point: Luvic Calcic Phaeozem (Anthric, Abruptic)) (FAO et al., 2006; FAO, 2006) (Fig. 1). A spa has operated in Cserkeszőlő since 1952 with two wells:

- *bottom depth$_1$:* 2311 m, open section: 2293-2311 m, aquifer: Miocene, water temperature$_1$: 82 °C; approximate average production: 205 l/min (Rónai, 1974; Urbancsek, 1977).
- *bottom depth$_2$:* 1159 m, open section: a few meters above the bottom depth, aquifer: limit of the Upper and Lower-Pannonian, water temperature$_2$: 67 °C.

Waste thermal water originating from the spa is released into the environment through an unlined natural channel 9.5 km in length and finally enters the River Körös (Fig. 1). The channel width ranges from 2 to 2.5 m, while depth ranges between 1.5 and 2 m. Thermal water extraction considered to be continuous, as the spa is operating all year. Between May 1 and September 30 each pool of the spa is open, and less of them operating during the winter reducing sewage water flowing into the channel. In nearby lands maize is produced. Tiszakécske (86–89 m ASL) is located in the Pilis-Alpár sand ridge (Fig. 2), thus the predominant soil type is Arenosol (FAO et al., 2006). The annual precipitation and the groundwater table depth range from 540 to 580 mm and 1.3 to 2.4 m, respectively. The area has a hot and moderately dry climate with sweltering summers. The hot water requirements of the investigated horticultural estate are satisfied by a thermal-water well established in 2000:

- *bottom depth$_1$*: 987 m, open section: a few meters above the bottom depth, aquifer: Upper-Pannonian, water temperature$_1$: 56 °C. Since then, cooled thermal water has flowed into an unlined ground channel (6.7 km) and ultimately flows into the Tisza River (Fig. 2, Table 2). The channel varies from 2.5 to 3 m in width, and around 2 m in depth. The water is only used for heating greenhouses during the winter, so the well is closed during the summer season. Thus uninsulated channel has periodic loading. The main crops produced on channel-adjacent areas are rye, hay and sunflower.

2.2. Sampling method

Samples were collected during October 2008 and June 2009 in Cserkeszőlő and Tiszakécske, respectively. Since the objective of this study is to reveal spatial, not temporal changes of soil, a single sampling was applied with different distances from the channel. As the properties of infiltrating sewage water (e.g. salt content and composition) vary along the channel (Németh et al., 1997), samples were taken at each section of the channel. Due to the diversity of soil types at the study locations, it was possible to take samples (thermal water, sewage water from the channel, groundwater and soil) from various points enabling a comparison of features caused by infiltration on different soil types. An outline of the sampling strategy can be seen in Fig. 1 and 2; coordinates and characterization of the samples are presented in Tables 1 and 2. Soil cores were drilled to groundwater depth using Eijkelkamp spiral auger, with samples collected every 20 cm. Groundwater was sampled after the set of standing groundwater-level.

2.3. Laboratory methods

After sample preparation, a series of laboratory analyses was carried out (Table 3) by the authors in the accredited laboratory of Department of Physical Geography and Geoinformatics, University of Szeged.

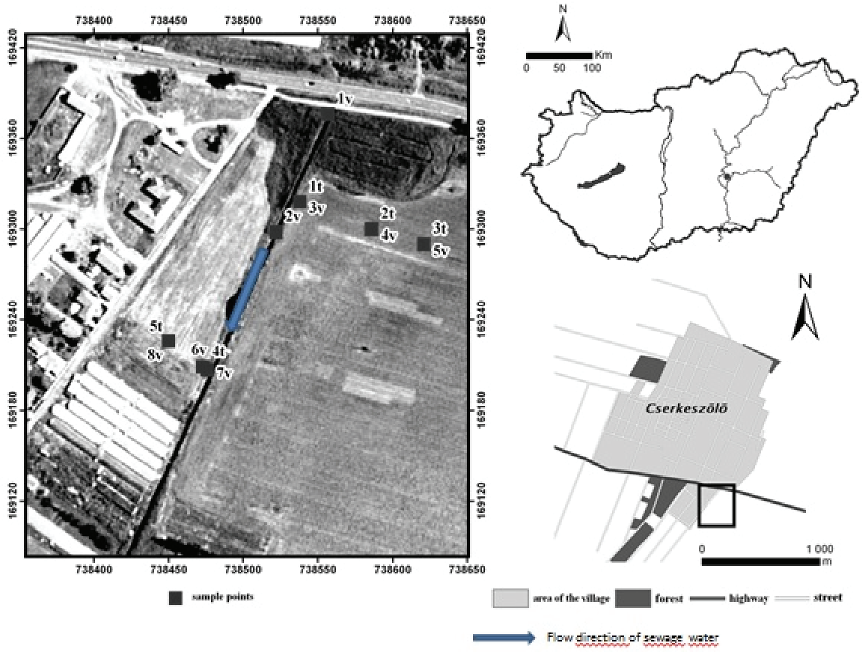

Fig. 1. Location of the sample points in Cserkeszőlő

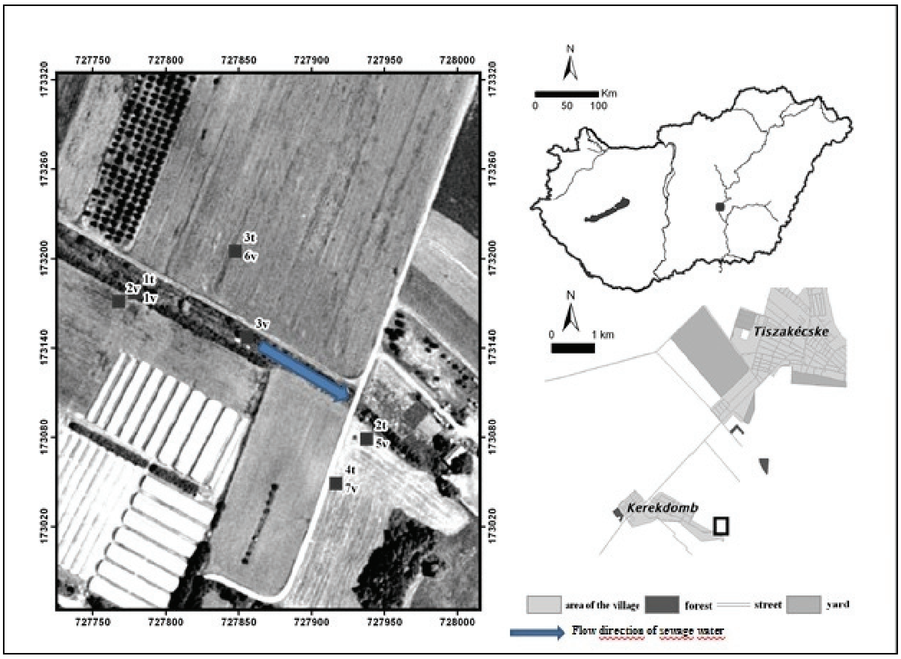

Fig. 2. Location of the sample points in Tiszakécske

Table 1. Description of Cserkeszőlő sample points

Sample number	EOV coordinates		Description
	X	Y	
1 v	738557	169376	Thermal water from the channel inflowing point
2 v	738522	169298	Sewage water from channel, 75 m far from the thermal water inflowing point
1 t, 3 v	738538	169318	Luvic Orthicalcic Chernozem (Pachic) profile and its groundwater, 10 m far from the channel (75 m far from the thermal water inflowing point), standing water level: 0.83 m
2 t, 4 v	738586	169300	Luvic Orthicalcic Chernozem (Anthric, Pachic) profile and its groundwater, 35 m far from the channel, standing water level: 1.00 m
3 t, 5 v	738621	169290	Luvic Orthicalcic Chernozem (Anthric, Pachic) profile (control) and its groundwater (control), 60 m far from the channel, standing water level: 1.10 m
4 t, 6 v	738473	169209	Luvic Calcic Phaeozem (Abruptic) profile and its groundwater, 10 m far from the channel (360 m far from the thermal water inflowing point), standing water level: 1.10 m
7 v	738476	169207	Sewage water from the channel, 360 m far from the thermal water inflowing point
5 t, 8 v	738450	169226	Luvic Calcic Phaeozem (Anthric, Abruptic) profile (control) and its groundwater (control), 30 m far from the channel, standing water level: 1.15 m

*(**EOV** (Uniform National Projection System) is the projection system of survey maps in Hungary since 1975. The same coordinates can be seen on Fig. 1 and 2. Conversion to WGS84: http://www.psoft.hu/szolgaltatasok/eov-wgs84-gps-koordinata-atszamitas.html)*
*Standing Water Level (**SWL**) is the height to which the water rises up in the hole when reached by the drill rig. This is the natural level of the water when no pumping.*

Table 2. Description of Tiszakécske sample points

Sample number	EOV coordinates		Description
	X	Y	
1 t, 1 v	727779	173177	Albic Arenosol profile and its groundwater, 5 m far from the channel, (15 m far from the thermal water inflowing point), standing water level: 1.70 m
2 v	727768	173171	Thermal water from the tap of the well
3 v	727856	173147	Sewage water from the channel, 100 m far from the thermal water inflowing point
2 t, 5 v	727938	173079	Albic Arenosol profile and its groundwater, 10 m far from the ground channel (235 m far from the thermal water inflowing point), standing water level: 2.36 m
3 t, 6 v	727848	173205	Albic Arenosol profile (control) and its groundwater (control), 50 m far from the channel, standing water level: 1.05 m
4 t, 7 v	727917	173049	Haplic Arenosol profile (control) and its groundwater (control), 50 m far from the channel, standing water level: 3.53 m

Table 3. Catalogue of the analyzed laboratory parameters

Water Samples	Soil Samples	Type of Instrument and Measurement Technology
pH	pH (H_2O)	WTW inoLab pH 720
total salt content with EC measurement		OK-104 conductometer
cation composition (Ca^{2+}, Mg^{2+}, Na^+, K^+)		Atomic absorption and emission flame Spectrophotometer Perkin Elmer 3110
anion composition (Cl^-, HCO_3^-, CO_3^{2-}, SO_4^{2-})		Titration, Helios Gamma UV-VIS spectrophotometer
SAR (calculated)		
	Carbonate content ($CaCO_3$ content)	Scheibler-type calcimeter
	Soda content (Na_2CO_3 content)	Titration
	Humus content	Helios Gamma UV-VIS spectrophotometer
	Texture	yarn test of Arany

Total salt content shows that what fraction of the total *weight of soil is* salt*, expressed in weight %. It is counted from electrical conductivity measurement.*

Besides basic soil parameters, properties regarding sodification were also analyzed. E*xtract*s of *1:5 soil*: distilled *water* were prepared in order to investigate cation and anion composition and concentrations, calculating sodium adsorption ratio (SAR) values. For statistical analysis, available nutrient (Ca^{2+}, Mg^{2+}, K^+, Na^+) concentrations were determined using 1:20 ammonium-lactate:soil extract (Hungarian Standard No. 20135:1999 4.1.3., 4.2.1.). Soil texture was measured by Arany's yarn test. Potential salinization and sodification were characterized using typical indices: total salt content and the proportion of Na^+ to other exchangeable cations (e.g. SAR). The sodification effect of the water and the sodicity of the soil were evaluated using SAR values (the risk in the water: > 10; in the soil: > 4) (Darab and Ferencz, 1969; ENVASSO Projekt, 2007). In order to provide a more complex analysis, carbonate, humus and soda content, $pH_{(H2O)}$ and texture were also measured.

2.4. Data analysis

In order to identify seepage-affected and non-affected (control) horizons, principal component (PC) analysis and discriminant function analysis with

Wilks' Lambda method were applied using the statistical program SPSS 12.0 for Windows.

Principal components defined by factor analysis became the variables for the discriminant function analysis, helping to classify the set of observations (samples) into predefined classes. This procedure determines the class of an observation based on a set of variables known as predictors or input variables, by maximizing between-group variance and minimizing within-group variance (Legendre et al., 1998). In the multivariate space of PCs, discriminant analysis is applied in order to test and quantify differences between soil samples close to and far from the channel. Main processes (PC 1–4) governing the composition of soils in the study area, the samples of which are classified based on their distance from the channel. This approach is suitable for calculating the optimal function of variables (the discriminant function) for distinguishing two known sample groups. In the calculations, a stepwise method using Wilks' Lambda minimization is applied.

Out of correlation methods, Spearman's rank correlation was chosen due to its robustness, rather than the more traditionally used Pearson's correlation. This coefficient measures, as one variable increases, the extent to which the other tends to increase, without requiring that increase to be represented by a linear relationship (Shaw, 2003).

3. Results and discussion

3.1. Thermal water and groundwater

pH values of thermal and groundwater in Cserkeszőlő represent weakly alkaline reactions. The original total salt content of thermal water was 3659 mg/L. Mixing with the cold water of the wells having different ion compositions, this value decreased to 874 mg/L in the sewage water (Table 4); however, SAR increased (from Well I.: 56.35 to 1 v: 80.75). As these indices of sewage water exceed limit values, potential soil salinization/sodification can occur due to infiltration.

Both index values of waste thermal water continually decline with distance in the channel: total salt content changes from 874 (1 v), 867 (2 v) to 863 mg/L (7 v). Based on the ion composition, these waters can be classified into the Mg-Na-HCO_3 chemical type dominated by the two most harmful cations from the viewpoint of soil degradation.

Groundwater samples from the upper section of the channel in Cserkeszőlő (Chernozem) have a high total salt content (1248–1913 mg/L). In these water samples, Ca^{2+} is the dominant ion besides Na^+, consequently these waters are classified into the Ca-Na-HCO_3 type and have low SAR values (5.91–9.02). On the lower section (Phaeozem), the total salt content of the groundwater is risky (3032–2431 mg/L). The SAR is limit-exceeding only near the channel (6 v: 33.47), not in the control (8 v: 8.16). In sample point 6 v, the chemical type of the water changes and reaches that of the thermal water.

The reaction of the thermal water and groundwater in Tiszakécske is alkaline and weakly alkaline, respectively (Table 5). SAR and total salt content of the used thermal water are 16.15 and 477 mg/L, respectively. Total salt content is not too high, although the composition of ions is unfavorable due to the predominance of Na^+. In groundwater, the proportion of Na^+ increases close to the channel (e.g. from Ca-Mg-HCO_3 type it changes to Na-HCO_3-Cl type) by thermal water seepage. With distance along the upper section of the channel, total salt content (from 754 to 507 mg/L) and SAR (from 6.95 to 3.72) gradually decrease, but, in the lower section, salt content rises (from 509 to 557 mg/L), while SAR diminishes (from 12.48 to 2.04).

With respect to SAR values, only thermal water and groundwater on the lower section reach sodification threshold values. Salt accumulation in soil can be generated exclusively by groundwater, however it is negligible. On this sample site, alkalinization may be the significant soil alteration caused by waste thermal water seepage.

Table 4. Main chemical parameters of thermal- and groundwater in Cserkeszőlő

	Original thermal water well I.	***Mixed thermal water***	***Water in the channel***	***Ground-water***	***Ground-water***	***Ground-water (control)***	***Ground-water***	***Water in the channel***	***Ground-water (control)***
		1 v	***2 v***	***3 v***	***4 v***	***5 v***	***6 v***	***7 v***	***8 v***
pH	n.d.	7.94	7.98	7.83	7.95	8.08	8.27	8.15	8.12
Total salt cont. (mg/L)	3659	874	867	1248	1913	1768	3032	863	2431
Total salt cont. (%)	n.d.	0.10	0.09	0.13	0.21	0.19	0.33	0.10	0.27
CO_3^{2-} (mg/L)	n.d.	0.00	5.21	0.00	69.04	44.29	50.08	26.71	67.74
HCO_3^- (mg/L)	1380	662	648	838	742	804	1240	1287	705
Cl^- (mg/L)	181	120	128	170	466	406	554	49	594
SO_4^{2-} (mg/L)	< 25.00	3.91	5.74	53.13	78.96	69.35	246.10	8.81	154.00
Ca^{2+} (mg/L)	6.6	1.3	1.4	358.7	376.3	364.3	8.9	1.1	335.5
Mg^{2+} (mg/L)	0.70	1.55	1.63	97.55	156.40	5.61	11.14	1.46	73.50
K^+ (mg/L)	12.2	6.0	6.8	5.6	4.3	3.0	2.2	11.9	2.7
Na^+ (mg/L)	570	574	519	489	633	633	634	428	634
SAR	56.35	80.75	70.56	5.91	6.91	9.02	33.47	62.80	8.16

Table 5. Main chemical parameters of thermal- and groundwater in Tiszakécske

	Ground-water	*Thermal water*	*Water in the channel*	*Ground-water*	*Groundwater (control)*	*Groundwater (control)*
	1 v	*2 v*	*3 v*	*5 v*	*6 v*	*7 v*
pH	8.19	8.78	8.14	8.47	7.67	7.86
Total salt content (mg/L)	754	477	600	509	507	557
Total salt content (%)	0.08	0.05	0.06	0.05	0.05	0.06
CO_3^{2-} (mg/L)	5.82	11.64	1.46	8.73	0.00	2.91
HCO_3^- (mg/L)	109.47	79.88	115.38	94.67	71.00	56.21
Cl^- (mg/L)	107.86	101.97	113.74	100.01	105.90	60.79
SO_4^{2-} (mg/L)	39.10	0.81	2.88	5.22	34.56	37.23
Ca^{2+} (mg/L)	120.80	22.21	20.76	32.19	132.70	148.10
Mg^{2+} (mg/L)	23.73	1.51	2.12	5.81	26.11	78.33
K^+ (mg/L)	22.99	5.90	8.22	5.63	1.31	33.13
Na^+ (mg/L)	319.5	291.6	342.10	293.1	179.1	123.3
SAR	6.95	16.15	19.12	12.48	3.72	2.04

3.2. Soil

3.2.1. Chernozem

The pH values of the investigated soil range from 8.5 to 9.3, representing alkaline soil profiles with strongly alkaline lower horizons (Fig. 3 C). In parallel with the pH-profile, a gradual increase with depth can be observed also in carbonate content (min: 3.2 %; max: 32.8 %). In the topsoil, humus supply is moderate or good, but below 60 cm, only weak to very weak humus content can be noticed. The texture ranges from sandy-loam to clayey-loam. Total salt content of the soil can be characterized with the minimum value of 0.04 % and the maximum value of 0.11 % (Fig. 3 A). Consequently, soils can be classified into the categories of low salt content (< 0.05 %) and slightly solonchak (0.05–0.15 %). This extent of salt accumulation has not led to yield depletion. The real problem is type and distribution of the salts along the profiles and not the amount. Dominant soda out of the salts accumulates mainly in the A or B horizons (Fig. 3 B), exactly in the root zone.

Therefore, the development of wheat produced nearby is slightly sensitive to this type of salt (Pearson, 1960). Referring to the ion composition of soil, HCO_3^- (mean 1438.0 mg/kg) and Cl^- (mean 206.7 mg/kg) are the dominant anions while Ca^{2+} (mean 101177.6 mg/kg) and Mg^{2+} (mean 7184.6 mg/kg) are the significant cations. In case of equal concentrations of Na^+ and Mg^{2+}, Na^+ have greater impact on the development of soil degradation (Filep, 1988). Although Na^+ is presented at a lower concentration (mean 583.6 mg/kg) than Mg^{2+}, its influence on soil degradation expected to be considerably higher.

3.2.2. Phaeozem

The pH of the profiles ranges from slightly alkaline (7.7) in the topsoil to strongly alkaline (10.0) in horizons under 60 cm deep (Fig. 4 C). Slight salt accumulation can be observed in the B and C horizons (Fig. 4 A). The profile near the channel is characterized by lower carbonate content than the control due to the leaching process caused by increased water supply. Very high humus content (3.9 %) is observable in the upper 40 cm of the profile decreasing towards the bedrock (0.55 %). Every texture type can be found from sandy-loam to clay, representing the stratification of distinct soil horizons. The dominant anions and cations present the same character in these profiles as those of the Chernozems, although levels of Na^+ are relatively higher (Fig. 3 D vs. Fig. 4 D).

Salt accumulation is also visible in Luvic Calcic Phaeozem (Abruptic) soil with a mainly sandy-loam texture and very high humus content. The maximum level is 0.12 % in the C horizon, directly above the groundwater table (Fig. 4 A). The salt accumulation of both this profile and the control can be classified as weakly solonchak. Soda content increases between 80 and 140 cm (Fig. 4 B), whereas carbonate content does not transcend levels seen in the control profile; thus, the majority of total salt content in this horizon is considered to be a result of the presence of Na-salts. This horizon also marks the meeting (and mixing) point of salts transported, leached by thermal water and groundwater with high salt content. As salts and Na^+ originate from seeping thermal water, groundwater closer to the channel has a greater total salt content than that further away.

The levels of groundwater table show that water is flowing away from the channel towards the surrounding areas. Beside the increase in total salt content, seeping thermal water also raises actual groundwater levels. All this suggests an indirect thermal water effect on soil by groundwater.

The zone of relative accumulation of Na^+ is located in the B and C horizons (60–80 cm, 100–120 cm) (Fig. 4 D), where the proportion of clayey and fine soil particles increases and, as a consequence, so does the specific surface area leading to more Na^+ being able to adsorb. SAR values trascend the limit and thus sodification evolves mainly in the B and C horizons. Lower pH, carbonate and soda content values are detected in this profile where humus content is high. Due to the humic acids, pH values in the topsoil are lower (Fig. 4 C) so weakly mobile carbonate also begins to migrate beside the easily-soluble soda.

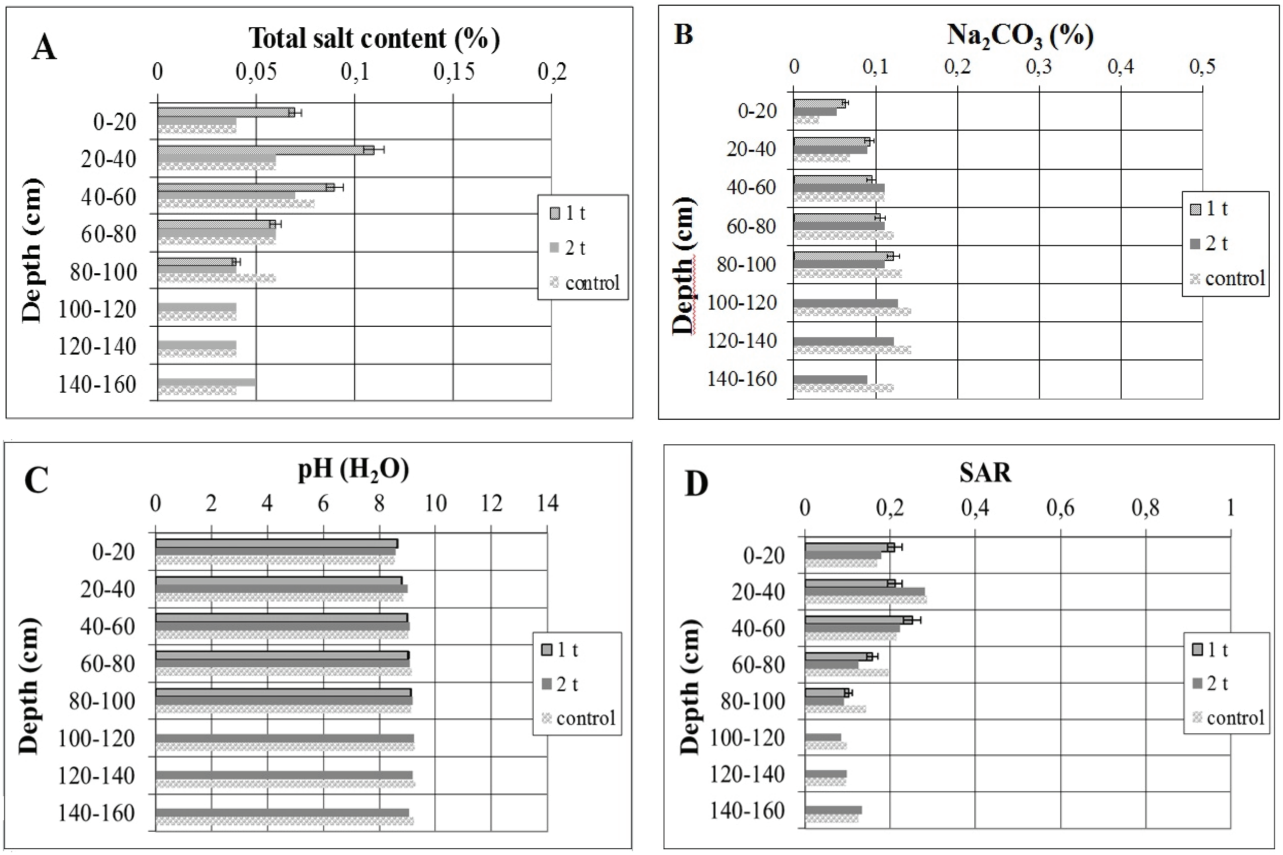

Fig. 3. Main soil indices of the Chernozem. A: Total salt content, B: Soda content, C: $pH_{(H2O)}$, D: SAR of the soil near the channel compared to control

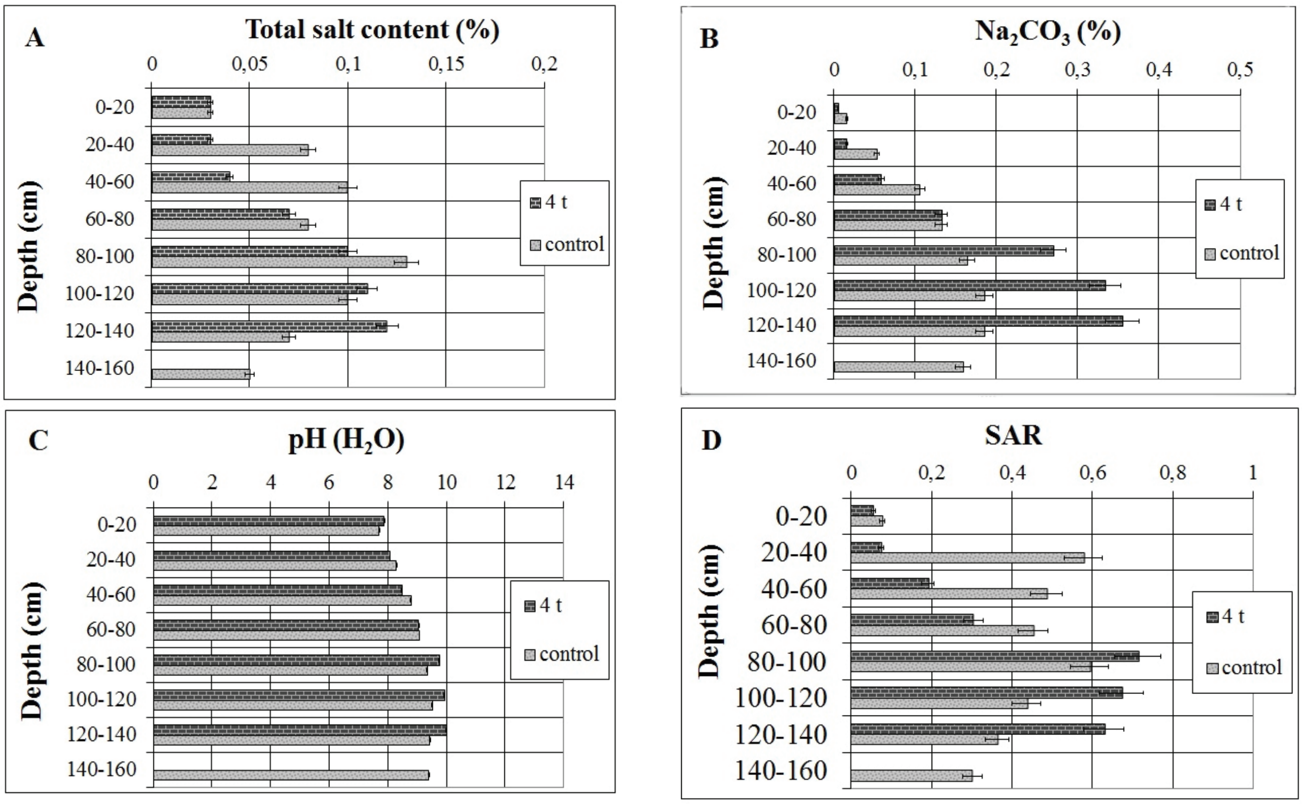

Fig. 4. Main soil indices of the Phaeozem. A: Total salt content, B: Soda content, C: $pH_{(H2O)}$, D: SAR of the soil near the channel compared to control

As a result, leaching of $CaCO_3$ and Na_2CO_3 from the topsoil is apparent, with pH increasing down the profile, becoming highly alkaline in the subsoil.

3.2.3. Arenosol

Areas adjoining the channel can be characterized by Albic Arenosol. pH changing from neutral (7.12) to strongly alkaline (9.63) continuously increasing from the topsoil towards the bedrock (Fig.5 C), showing no significant horizontal relation between alkalinity and distance from the channel. Carbonate levels rise from 0.4 % to 19.1 %. The carbonate content close to the channel is much higher than that of the controls.

The humus content is high at each sampling point. Texture ranges from coarse sand to clayey-loam. The total salt content of the soil samples ranges between 0.00 % and 0.03 % (Fig. 5 A) and the soda content increases to 0.08 %, mainly in the B and C horizons (Fig. 5 B). Of the anions, only HCO_3^- presents in a significant degree (601.8–2557.8 mg/kg), while Ca^{2+}, K^+ and Na^+ are significantly dominating among cations. Thanks to the predominance of Ca^{2+}, ion distributions here cannot be considered unfavorable.

3.2.4. Comparison of the investigated three soil types according to degradation tendency

Out of the investigated three soil types (Chernozem, Phaeozem and Arenosol), salinization appears exclusively in the Chernozem and Phaeozem, although salts have accumulated in different horizons within the respective profiles. In the case of the Chernozem it occurs in the A horizon, while in the Phaeozem salts appear in the C horizon (Fig. 6 a). High salt content thermal water is capable of infiltrating Phaeozem subsoil as well as groundwater. These salts can then be transported by groundwater flow, and precipitation also potentially leaches soluble salts that accumulate in the lower horizons of the profile.

Besides infiltration depth, capillary lift and the depth of the root zone also play an important role in the formation of the salt profiles. Due to the sandy texture of Arenosol, both water retention capacity and capillary lift were negligible and as a consequence, water containing dissolved salts and pollutants can infiltrate lower horizons of the profile.

Accordingly, a high total salt content cannot be seen in these profiles. Na^+ accumulates in the A and B horizons of the Chernozem and Phaeozem, respectively (Fig. 6 b and d).

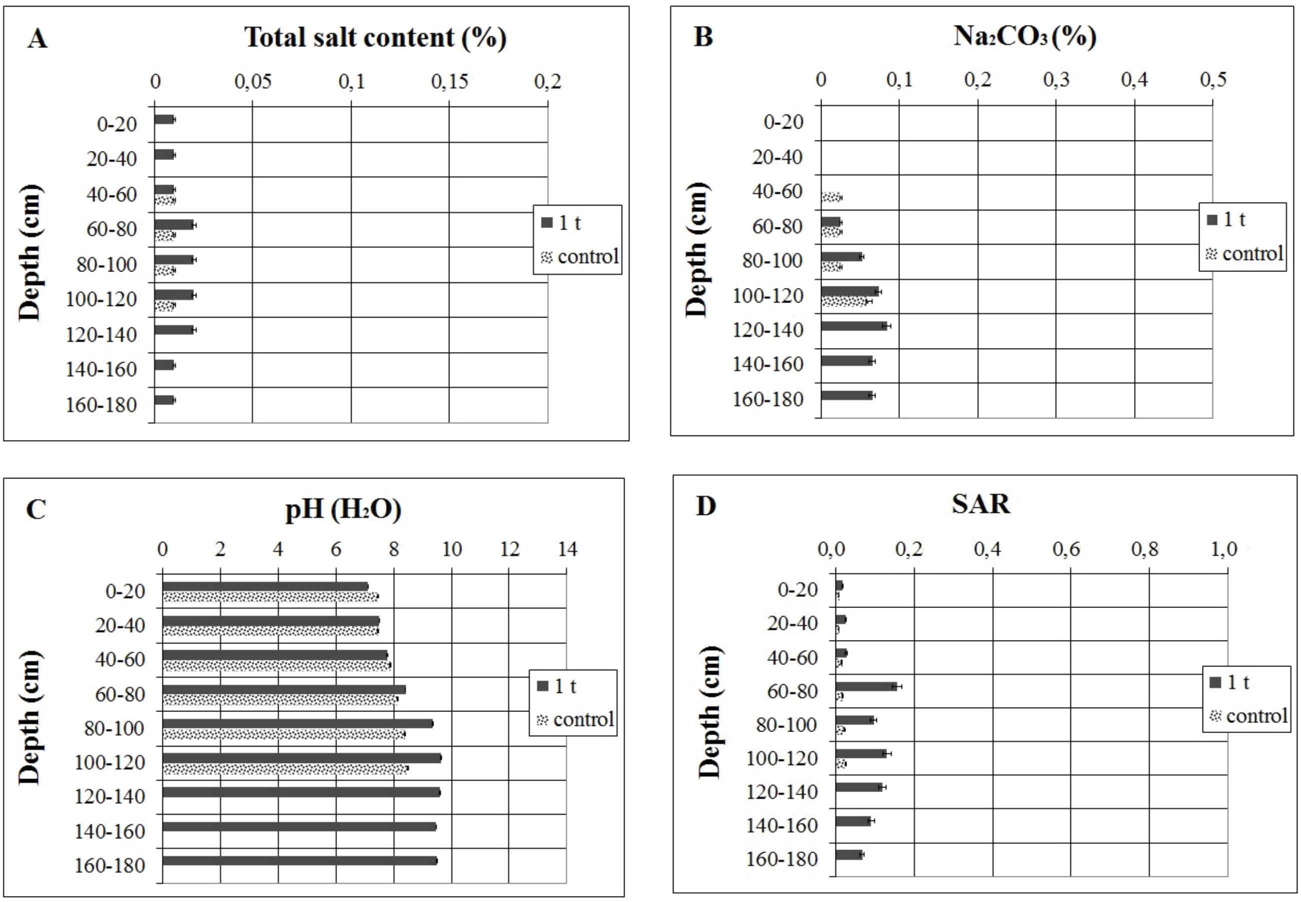

Fig. 5. Main soil indices of the (Albic) Arenosol A: Total salt content, B: Soda content, C: $pH_{(H2O)}$, D: SAR of the soil near the channel compared to control

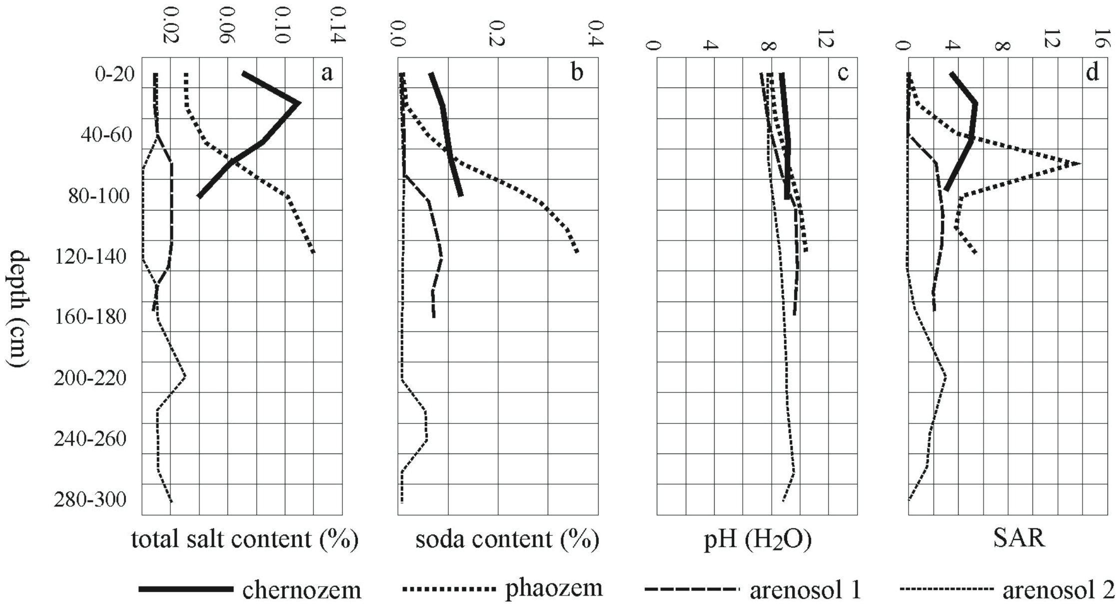

Fig. 6. Comparative depth profiles of the main parameters of different soil types (Arenosol 1: Albic Arenosol, Arenosol 2: Haplic Arenosol, see Table 2)

Table 6. Spearman-type correlation values of the main parameters from Cserkeszőlő (N=28, 1t, 3t, 4t and 5t soil samples, *: significant at the 0.05 level, **: significant at the 0.01 level)

Spearman's rank correlation coefficient	***pH*** ***(H2O)***	***EC (μS/cm)***	***$CaCO_3$ (%)***	***HCO_3^- (mg/kg)***	***Ca^{2+} (mg/kg)***	***Mg^{2+} (mg/kg)***	***K^+ (mg/kg)***	***Na^+ (mg/kg)***	***Soda (%)***	***Humus (%)***	***Texture***
pH $_{(H2O)}$	1	0.49(**)	0.85(**)	0.64(**)	0.85(**)	0.69(**)	-0.72(**)	0.61(**)	0.98(**)	-0.89(**)	0.39(*)
EC (μS/cm)		1	0.20	0.82(**)	0.19	0.09	-0.13	0.89(**)	0.57(**)	-0.29	0.55(**)
$CaCO_3$ (%)			1	0.34	0.87(**)	0.86(**)	-0.79(**)	0.29	0.81(**)	-0.93(**)	0.33
HCO_3^- (mg/kg)				1	0.36	0.84(**)	-0.30	0.89(**)	0.69(**)	-0.42(*)	0.53(**)
Ca^{2+} (mg/kg)					1	0.84(**)	-0.77(**)	0.28	0.82(**)	0.87(**)	0.27
Mg^{2+} (mg/kg)						1	-0.74(**)	0.08	0.62(**)	-0.82(**)	0.28
K^+ (mg/kg)							1	-0.30	-0.70(**)	0.85(**)	-0.09
Na^+ (mg/kg)								1	0.69(**)	-0.41(*)	0.51(**)
Soda (%)									1	-0.86(**)	0.43(*)
Humus (%)										1	-0.29
Texture											1

There is a relationship between Na^+-accumulation and the amount of clayey particles: Na^+ accumulating in those horizons containing more clay. In the Arenosol, humus supply is good, clay content is low and the soil has not been able to adsorb high amounts of Na^+. Sodification appears not to be a significant problem in Arenosol, but, in the Chernozem and Phaeozem, SAR exceeds limit values (Fig. 6 d).

3.3. Statistical evaluation

To determine whether there is any significant variation in soil properties between profiles at different distances from the channel, a series of standard statistical analyses were carried out. The first involved the simultaneous solution of correlation (Table 6.) and principal component analysis (Table 7.). Spearman's rank coefficient shows the extent to which, as one variable increases, the other variable tends to increase, without requiring that increase to be represented by a linear relationship. Significant relationships are marked with asterisks.

For clarity, the relationship between variables is presented as a correlation profile (Fig. 7), in which variables significantly correlating with each other are connected with a tie-line. By using correlation and principal component analysis, groups of variables sharing similar characteristics can be outlined. In an optimal situation, such variable groups may be identified as independent pedological processes.

Hereafter, only the Chernozem and Phaeozem from Cserkeszőlő are discussed, because these are the soils, where the pedological changes can be followed up supremely. On the correlation profile, three complete graphs can be drawn in which each pair of variables has an edge connecting them. These three variable groups can be defined as separate, even if the groups share some common variables (Fig. 7). One group contains pH, humus, carbonate, K^+, Ca^{2+} and Mg^{2+}, another soda, Na^+ and HCO_3^-, while the last is dominated by texture and EC.

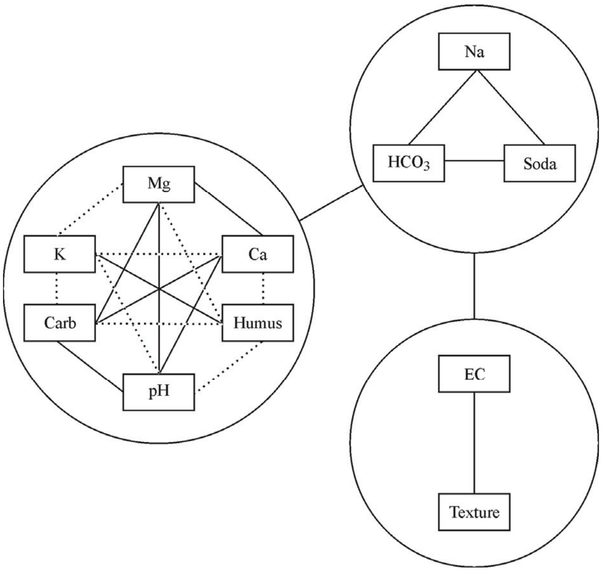

Fig. 7. Correlation profile of Cserkeszőlő sample site. The solid lines refer to positive and dashed to negative correlations, respectively

Principal component analysis (using the Varimax rotation) resulted in four principal components, representing 91.35 % of total variance (Table 7). PC1 contains Ca^{2+}, carbonate, soda, pH, K^+ and humus; PC2 consists of HCO_3^-, Na^+, EC, soda and pH. The only variable dominating PC3 is texture, while PC4 is controlled by Mg^{2+}. The Eigenvalues of the PCs are in order 9.75, 5.99, 1.98, 1.46. Although the variable groups produced by correlation and principal component analysis are slightly different, the results of the two approaches confirm each other.

PC1 can be interpreted as a cumulative index of the main soil features; an increase in the amount of $CaCO_3$ and soda increases pH, while simultaneously decreasing humus and K-content (these latter two have negative sign). PC2 undoubtedly associates with the sodification process. Soil texture does not depend on the above chemical parameters, while mobilization of Mg^{2+} seems to be an independent process.
The computed discriminant function (1) suggests that the two sample groups can be distinguished essentially by PC4 and PC1, that is, Mg^{2+}-mobilization and the alteration of major soil features, where:
PC1 - cumulative index of the main soil features;
PC2 – sodification;
PC3 – texture;
PC4 – Mg^{2+}-mobilization

$$D = 0.65 \cdot PC4 - 0.45 \cdot PC1 - 0.28 \cdot PC3 + 0.18 \cdot PC2 \quad (1)$$

Discriminant analysis classification results imply that 85.7 % of samples are correctly classified. As all but about 10 % of samples are classified in the correct original group (Table 8) using this function, one can state that the channel has a real effect on soil parameters through thermal water seepage. On the appropriate $0.65 \cdot PC4 + 0.18 \cdot PC2$ vs. $- 0.45 \cdot PC1 - 0.28 \cdot PC3$ plot, samples from the two localities clearly separate confirming the above statement (Fig. 8). This plot is also able to characterize any new soil sample from the given pilot area in terms of the extent to which it is affected by the channel.

Table 7. Rotated principal component matrix of measured parameters in Cserkeszőlő. Significant variables are highlighted

	Principal Component			
	PC1	***PC2***	***PC3***	***PC4***
pH (H_2O)	**0.643**	**0.655**	0.240	0.223
EC (mS/cm)	-0.071	**0.869**	0.394	-0.001
$CaCO_3$ %	**0.833**	0.189	0.253	0.413
HCO_3^- (mg/kg)	0.236	**0.939**	0.007	-0.021
Ca^{2+}(mg/kg)	**0.904**	0.127	0.140	0.146
Mg^{2+} (mg/kg)	0.410	-0.100	-0.109	**0.888**
K^+(mg/kg)	**-0.852**	-0.182	0.141	-0.048
Na^+ (mg/kg)	0.212	**0.936**	0.131	-0.107
Soda (%)	**0.539**	**0.811**	0.034	0.087
Humus %	**-0.850**	-0.293	-0.199	-0.317
Texture	0.163	0.234	**0.943**	-0.070

Table 8. Correctly classified results of discriminant analysis

		Distance from channel	***Predicted Group Membership***		***Total***
			control	***sample point near the channel***	
Original	Count	control	13	3	16
		sample point near the channel	1	11	12
	%	control	81.2	18.8	100.0
		sample point near the channel	8.3	91.7	100.0

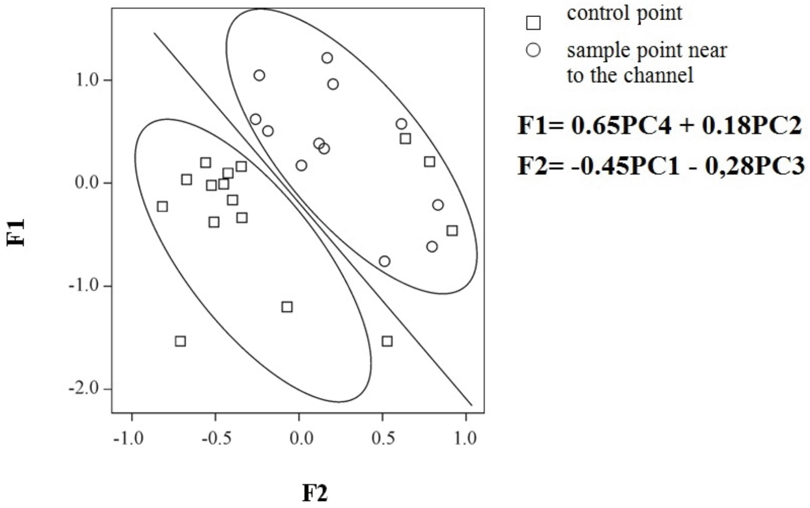

Fig. 8. Separation of sample points based on the calculated discriminant function
(Ordinate axis consists of positive (F1), while abscissa consists of negative members (F2) of the Eq. (1))

Comparing mean values of the most discriminating variables close to and far from the channel, a significant decrease in PC4 and an increase in PC1 are obvious. This suggests that there is no significant rise in PC2 due to long-term seepage. This fact is also confirmed by Fig. 9 which compares the values of different variables close to and far from the channel.

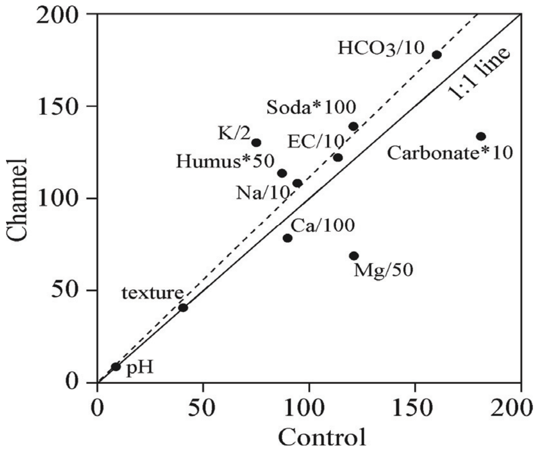

Fig. 9. Comparison of the mean values of variables near to and distant from the channel. The solid (1:1) line illustrates uniformity, while the dashed line represents a slight increase adjacent to the channel

As expected, soil texture is the most conservative variable, lying on the 1:1 line suggestive of no change. The most significant alteration is associated with a decrease in Mg^{2+} and carbonate content and a simultaneous increase in K^+ and humus. As a high SAR value in thermal water may guarantee a continuous Na^+ supply, adsorbed Ca^{2+} and Mg^{2+} ions are therefore able to be constantly exchanged. The consequently mobilized cations are easily washed out of soil profiles close to the channel, resulting in a simultaneous gain in Na^+ and depletion in Ca^{2+} and Mg^{2+}. At the channel, the wet environment increases plant activity and together with reduced agricultural cultivation may cause a significant increase in humus content. The amount of K^+ increases accordingly. As Na^+, EC, soda and HCO_3^- are located on the same line, this shared behavior could suggest a minor role of sodification. Although pH seems to be a conservative variable, it is definitely affected by all the above mobilization processes, the dilution of Ca^{2+} and Mg^{2+} as well as the accumulation of K^+ and Na^+, which may in fact mean the constant pH seen throughout the study area must be virtual.

3.4. Waste thermal water management

Unwanted seepage of salty sewage water facilitates a rise in the groundwater table and a change in chemical type (Na^+-dominance) surrounding the investigated channel, meanwhile periodic draughts induce capillary uplift, transporting salts towards the surface (Duncan et al., 2008). Due to the above mentioned processes and unfavorable chemical composition (e.g. high SAR value) of thermal water, it would not be advisable to use that for irrigation avoiding any purification pretreatment or allow the water to infiltrate into the soil medium from uninsulated channels. Table 9 shows a "Water Quality Matrix" that compares the water quality of the sample sites with the categories of the FAO Irrigation and Drainage Paper (Ayers and Westcot, 1994) in terms of the salt sensitivity of grown crops.

Serious salt effect – influencing water consumption of the plants – has occurred exclusively in the groundwater of Phaeozem. In the case of other samples, only a weak salt effect could be detected. The rate of water infiltration, which requires joint evaluation of Electrical Conductivity of Water and SAR values, is considered to be strong in both study areas for thermal water. With regard to specific ion toxicity forming due to surface irrigation and the effect on sensitive plants, Na^+ is significant in the thermal water and canal water of Cserkeszőlő and the groundwater of Phaeozem.

Table 9. Assessment of water quality for irrigation in the sample sites according to Ayers and Westcot (1994)

Sample indication	*Potential Irrigation Problem*				
	Salinity	*Infiltration (affects infiltration rate of water into the soil)*	*Specific Ion Toxicity*		*Miscellaneous Effects*
			Na^+	*Cl^-*	*HCO_3^-*
Cs 1v (tw)	SM	S	S	N	S
Cs 2v (sw)	SM	S	S	N	S
Cs 3 v (gw)	SM	SM	SM	SM	S
Cs 4v (gw)	SM (S)	N	SM	S	S
Cs 5 v (gw)	SM (S)	N	S	S	S
Cs 6v (gw)	S	N	S	S	S
Cs 7v (sw)	SM	S	S	N	S
Cs 8v (gw)	S	N	SM	S	S
T 1v (gw)	SM	SM	SM	N	SM
T 2v (tw)	SM	S	S	N	N
T 5v (gw)	N	S	S	N	SM
T 6v (gw)	SM	N	SM	N	N
T 7v (gw)	SM	N	N	N	N

Cs: Cserkeszőlő, T: Tiszakécske, tw: thermal water, sw: sewage water in the channel, gw: groundwater, N: None, SM: Slight to moderate, S: severe, SM (S): on the border of Slight to moderate and Severe (EC and TDS resulted alter category)

At Tiszakécske, specific ion toxicity is significant in the thermal water and the groundwater of Arenosol adjacent to the lower section of the channel. In other cases, there is only a weak effect. Based on the aforementioned information, it is not advisable to irrigate from the channelized used thermal water or groundwater, just in case it dilutes water of appropriate quality, or the ions having environmental risk are precipitated from the water, or possibly zeolite water filtration is used.

The salt content of a soil horizon represents high temporal and spatial variability. Hence, certain environmental effects can be observed in definite parts of the year. The long-term effect of salty waste thermal water can raise problems of salinization/sodification. In the case of chloride-sensitive crops, problems occur related to groundwater at Cserkeszőlő, but the same cannot be seen at Tiszakécske. The strong effect of bicarbonate in each water sample from Cserkeszőlő can also be detected; but none of the water samples were characterized by this effect at Tiszakécske. The waste thermal water really has insufficient salinity to cause harmful hazards to crops, just moderate harm, but in the case of groundwater, especially at Cserkeszőlő (6v, 8v) it has a severe effect which can be hazardous due to capillary lift in a period of drought. Salt-tolerant plant types could be selected matching the water salinity along the channel.

5. Conclusions

Our hypothesis assumed that seepage of waste thermal water in uninsulated earthen channels can lead to salinization/sodification/alkalinization in nearby soils/groundwaters. These processes appear differently (extension, rate) in different soil types (Chernozem, Phaeozem and Arenosol). Negative effect of salts and environmentally risky ions can reduce the yield on surrounding arable lands.

We found that thermal water infiltration in the earthen channels is a real human-induced linear salt and Na^+ source causing potential soil degradation (like salinization/sodification/alkalinization processes) as it was stated by Tedeschi and Dell'Aquila (2005). Statistical evaluation represents processes of slight salinization/sodification, Mg^{2+} mobilization and ion exchange near the channels. Besides, an increment in the K^+ and humus content can also be seen. The aforementioned changes in the state of the soil are mainly local, affecting a 30–35 m zone surrounding the channel in soils having finer texture (e.g. loamy). In case of sandy soils, these processes - if any appear – affect narrower zones sorrunding the channels, their extent is mainly vertical and bearing a threat to groundwater base. Alkalinization seems to be a more extended process.

From the agricultural viewpoint, some of these degradation processes have an impact on plant life (e.g. osmotic effect, specific ion toxicity and salt effects (van Es, 2012) and yield (Cardon et al., 2014). According to Cardon et al. (2014), 10 % relative decrease in maize (produced in Cserkeszőlő sample site) yield can be observed if it is irrigated with water having 2500 μS/cm. All surface and subsurface water in this area have lower salt content, except 6v, where production of less salt-sensitive crops (e. g. barley or wheat) is proposed. On the other sample site, reduction of yield is not expected. Contrary to our hypothesis, level of soil degradation processes is not dangerous, and does not able to reduce yield between the current climatic and pedological circumstances.

References

Alam M.M., Bhutta M.N., (2004), Comparative evaluation of canal seepage investigation techniques, *Agricultural Water Management*, **66**, 65–76.

Árpási M., (2003), Geothermal development in Hungary – country update report 2000–2002, *Geothermics*, **32,** 371–377.

Ayers R.S., Westcot D.W., (1994), Water quality for agriculture, FAO Irrig. and Drain. Paper, 29, FAO, Rome.

Beltrán J.M., (1999), Irrigation with saline water: benefits and environmental impact, *Agricultural Water Management*, **40**,183–194.

Cardon G.E., Davis J.G., Bauder T.A., Waskom R.M., (2014), Managing Saline Soils, Colorado State University, On line at: http://www.ext.colostate.edu/pubs/crops/00503.html.

Darab K., Ferencz K., (1969), Soil mapping and control of irrigated areas (in Hungarian), OMMI Press, Budapest.

de Clercq W.P., Van Meirvenne M., Fey M.V., (2008), Prediction of the soil-depth salinity-trend in a vineyard after sustained irrigation with saline water, *Agricultural Water Management*, **96**, 395 – 404.

Duncan R.A., Bethune M.G., Thayalakumaran T., Christen E.W., McMahon T.A., (2008), Management of salt mobilization in the irrigated landscape – A review of selected irrigation regions, *Journal of Hydrology*, **351**, 238–252.

ENVASSO Projekt, (2007), Environmental Assessment of Soil for Monitoring, **I**: Indicators and Criteria, Soil Salinization, 141–154, On line at: http://eusoils.jrc.ec.europa.eu/projects/envasso/documents/ENV_Vol_I_Final2_web.pdf.

FAO, (2006), World reference base for soil resources 2006. A framework for international classification, correlation and communication, p. 95, On line at: ftp://ftp.fao.org/agl/agll/docs/wsrr103e.pdf.

FAO, IUSS, ISRIC, (2006b), World reference base for soil resources. A framework for international classification, correlation and communication, Food and Agriculture Organization of the United Nations, International Union of Soil Sciences, International Soil Reference and Information Centre, Rome, Italy, On line at: http://www.fao.org/ag/agl/agll/wrb/doc/wrb2006final.pdf.

Filep G., (1988), *Soil Chemistry* (in Hungarian), Akadémia Press, Budapest, Hungary.

GR, (2007), Government Regulation no. 379/2007 regarding the rules concerning facilities and activities for elimination of damages and facilitate protection and utilization of water, part IV, no. 29 § (2) from 23rd of December 2007.

GD, (2012), Government Decree no. 1002/2012 regarding suspension of the obligation to reinject thermal water exploited for energetical use in the area of agricultural production, part I, from 11st of January 2012.

Jiang Y., Wu Y., Groves C., Yuan D., Kambesis P., (2009), Natural and anthropogenic factors affecting the groundwater quality in the Nandong karst underground river system in Yunan, China, *Journal of Contaminant Hydrology*, **109**, 49–61.

Kovács B., Szanyi J., M. Tóth T., Vass I., (2007), Geothermal heat potential of Hungary with special regards to high enthalpy basement, (in Hungarian), *Publications of Miskolc University*, **72**, 81–94.

Legendre P., Loic F., Legendre J., (1998), *Numerical Ecology*, Elsevier, Amsterdam.

Mirel I., Mitrasca M.A., Pantea E.V., Abrudan D.M., (2006), The geothermal water treatment for water and energy resources conservation, *Environmental Engineering and Management Journal*, **5**, 1245–1254.

Németh T., Stefanovits P., Várallyay G., (1997), *Soil Protection, Scientific Background of National Soil Conservation Strategy, Remediation Booklet, 3. Factors Impeding Soil Functions, Soil Degradation Processes, Ministry of Environment and Water*, *2005*, (in Hungarian), On line at: www.kvvm.hu/szakmai/karmentes/kiadvanyok/talaj.../talaj_tajek-3.htm.

Urbancsek J., Ed., (1977), Deep drilling wells cadastre of Hungary VII, (in Hungarian), National Institute for Water Resources, Water Resources Research Institute, Publisher: Vízdok Vituki, Budapest.

Pearson G.A., (1960), Tolerance of crops to exchangeable sodium. U.S.D.A., *Agriculture Information Bulletins*, **216**, On line at{ http://naldc.nal.usda.gov/download/CAT87210325/PDF

Popiţa G.-E., Varga I., Gurzau A., Bence F., Yuzhakova T., Haţegan R.M., Redey A., Popovici A., Măruţoiu C., (2014), Environmental impact and risk assessment int he area of „Pata Rat" landfill site, Cluj-Napoca, Romania, *Environmental Engineering and Management Journal*, **13**, 435-447.

Rotaru A., Răileanu P., (2008), Groundwater contamination from waste storage works, *Environmental Engineering and Management Journal*, **7**, 731–735.

Rónai A., (1974), Geologic Atlas of the Great Hungarian Plain, (in Hungarian), Csongrád. Budapest, MÁFI.

Shanyengana E.S., Seely M.K., Sanderson R.D., (2003), Major-ion chemistry and ground-water salinization in ephemeral floodplains in some arid regions of Namibia, *Journal of Arid Environments*, **57**, 71–83.

Shaw P.J.A., (2003), Multivariate statistics for the Environmental Sciences, Hodder-Arnold, London, 233.

Tedeschi A., Dell'Aquila R., (2005), Effects of irrigation with saline waters, at different concentrations, on soil physical and chemical characteristics, *Agricultural Water Management*, **77**, 308–322.

van Es H.M., (2012), Saltwater Inundation: Implications for Agriculture, On line at: http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs141p2_018281.pdf.

Yilmaz E., Koç C., (2014), Research on water quality of Lake Bafa in Turkey, *Environmental Engineering and Management Journal*, **13**, 153-162.