

Fluctuation of the Groundwater Level, and Its Consequences in the Soil-Parent Material-Groundwater System of a Sodic Grassland

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Groundwater is a major factor of soil salinization in alluvial plains with shallow groundwater, such as the Great Hungarian Plain. In Hungary the role of groundwater has been emphasized by many authors (ARANY, 1956; SZABOLCS, 1971; VÁRALLYAY, 1989). There is continuous interest in the study of salt affected soils (BLASKÓ, 1999; SZENDREI, 1999; SZABÓ et al., 1998) and the temporal dynamism of salt accumulation (VÁRALLYAY, 1966; KARUCZKA, 1999).

Our studies on the effects of the fluctuation of groundwater in the soil-parent material-groundwater system started in 1994. We assumed that the changes in salt concentration caused by the rising or dropping groundwater level have not only regional, but also local effects on the differences in salt concentration in near-surface formations. Based on our earlier samplings we supposed that groundwater level fluctuation causes changes in the groundwater's concentration, but not in its chemical type. For the verification of the assumptions we delineated a study site in a salt affected pasture "Nyírölapos" inside the Hortobágy National Park in the Northeastern part of the Great Hungarian Plain in 1994. Within the intensive and detailed investigation of the area we study the salt accumulation processes and the relationship between the occurrence of salt affected soils and groundwater characteristics (Figure 1). This paper describes the groundwater monitoring phase of these salinization studies.

Study site. - The surface of the studied 0.5 km² area is practically flat with a small undulation, not reaching 1 m. The site is located on the inner curve of a river bend, on its lowest parts there are temporary waterlogging spots, but after spring snowmelt combined with plenty of rainfall, most of the site is under waterlogging. This site was described by SZABOLCS (1971), OERTLI & RAJKAI (1988), RAJKAI et al. (1988), TÓTH et al. (1991), TÓTH & KERTÉSZ (1993), TÓTH & RAJKAI (1994) and TÓTH & KUTI (2002).

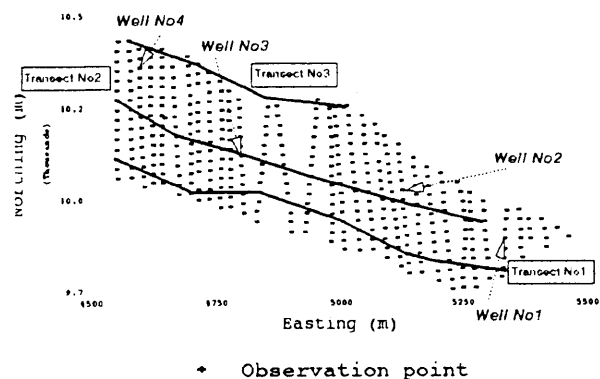


Figure 1

The layout of the geological transects and groundwater observation wells

The surface-near surface formations of the study site are young fluvial-alluvial formations from the Holocene and Pleistocene. On the surface generally 2 m thick Holocene silty clay occurs, eventually grading to clayey silt in some places. Under this layer there is another contiguous 1–1.5 m thick clay-silty clay layer, which is presumably the formation of the border between Pleistocene and Holocene. Under these layers there are coarser Pleistocene fluvial formations with varying thickness and degree of development. The texture of these formations ranges from clayey silt to sand, depending on whether riverbed, riverbank or alluvial formations were reached. Under these coarser formations silty clay is found again (TÓTH & KUTI, 1998).

The CaCO_3 content of the sediments is not great, mainly below 5% with the maximum of 20%, which is typical for this region of the Great Hungarian Plain.

The depth of the groundwater level is between 2.5–5 m, mainly at 3 m.

The total soluble salt concentration of the groundwater varies greatly, ranging from 828 mg/l (minimum) to the 15 029 mg/l (maximum). Sodium ion is dominant, in most of the samples its ratio is greater than 60–70%. In comparison to the cations, the occurrence of anions is more variable. In the W and E margin of the study site bicarbonate is dominant, in the center chloride, and in the SW part sulphate is dominant.

Methods

At the beginning of the study along the W–NW–E–SE axis approximately at its geometric midline, four groundwater observation wells were established at 200 m distances (Figure 1). Their main characteristics are shown in Table 1.

Table 1
Characteristic data of the groundwater observation wells

Well No.	Elevation above sea level, m	Average depth, cm	Maximal depth, cm	Minimal depth, cm
1	90.00	231	294	137
2	89.32	193	260	92
3	88.80	139	218	56
4	88.68	131	264	53

During drilling the wells we considered the high water level in spring. During monthly monitoring the groundwater level is measured, then the water present in the wells is drawn down completely and the entering fresh water is sampled. The electrical conductivity and pH of the water is measured in the field. The water samples are filtered in the field, conserved and the “complete” chemical analysis is made for Na, K, Ca, Mg, Fe, Mn, NH_4 , Cl, SO_4 , CO_3 , HCO_3 , NO_3 , NO_2 , hardness, alkalinity, and microelement content.

The meteorological data is obtained from the station located in Hortobágy.

Results

The position and movement of groundwater

With declining elevation, the groundwater level depth in the wells is less and less, that is groundwater is the shallowest in the deepest lying areas. A consequence of this is that in the wells of lower areas (wells No. 3 and No. 4) the effect of meteorological factors appear more strongly. Here the seeping precipitation reaches the groundwater, and the salts can be leached from the surface layers down into the groundwater more easily. In the higher lying areas the groundwater level is deeper than the depth of wetting, the salts cannot reach the groundwater and are accumulated in the deeper horizons of the soil. In drier periods the shallow groundwater evaporates more intensively.

The effect of weather can be followed easily with the level of the groundwater observation wells: from October to May the level of groundwater rises, from May to October it drops. In the spring–summer months, due to high temperatures, the rate of evaporation exceeds the amount of precipitation, this deficit of water is manifested in the drop of groundwater level. The water regime in the autumn–winter months is positive, therefore the groundwater level rises.

In addition to the general tendencies, there are smaller local and periodic changes in the groundwater level. These local changes cannot be attributed solely to the changes in precipitation, but also to different geological structures and hydrodynamic parameters in the immediate neighbourhood of the wells.

The groundwater level does not always follow the relief. Basically the slight NW slope of the study site suggests that groundwater flow is going on in the same direction. During wet periods the level of groundwater is higher in the well of lower position than in the wells of intermediate position (Figure 2). From this fact we deduced that the flow of groundwater does not have one direction during the year in the study site. Depending on the amount of precipitation, it can turn back and due to temporary waterlogging it may flow from the deepest areas towards the higher areas, similarly as described by SEELING & RICHARDSON (1994) in North Dakota.

Changes in the chemical composition of the groundwater

In spite of its small territory, within the study site – which is typical for low-land areas – there was great variability in the total salt concentration and chemical composition of the groundwater. This is the consequence mainly of the variability of subsurface geological formations storing the water, of the varying mineral composition and particle sizes. Earlier we showed that the hydraulic conductivity of the different textural classes of sediments differs and correlates with the capillary rise of the formations (TÓTH & KUTI, 1998).

The water of observation well No. 1 is dominantly sodium-bicarbonate-chloride type. Chloride and bicarbonate are present in about the same ratio (45–45 equivalent %) in such a way, that alternatively one or the other exceeds the other by 1–2%. As a consequence of this fluctuation, from time to time the type of groundwater changes to sodium-bicarbonate or sodium chloride-bicarbonate. A strong change in the type of the groundwater was detected only once in November 1996 when the ratio of bicarbonates rose to 83 equivalent %. The same sample provided the maximum of the sodium ratio with 93 equivalent % (Table 2).

The total soluble salt concentration of the groundwater decreased suddenly from 3500 mg/l to 1000 mg/l in September, October and December in the same year (Figure 3). We consider this change to be the consequence of the great amount of precipitation during the months June–September (130 mm). A comparable amount of precipitation was observed in April and June in 1995, but that did not cause a dilution in the groundwater, because the evaporation was much greater as compared to the September evaporation.

In January 1998 the chemical type of the groundwater changed to sodium chloride-bicarbonate, its total soluble salt concentration decreased. This is a slight change and perhaps related to the change of chemical type observed in groundwater well No 2.

In groundwater observation well No. 2 the chemical type of the groundwater is sodium bicarbonate. The ratio of bicarbonate is 70–90 equivalent %. The chemical type of the water changed only once into sodium bicarbonate-

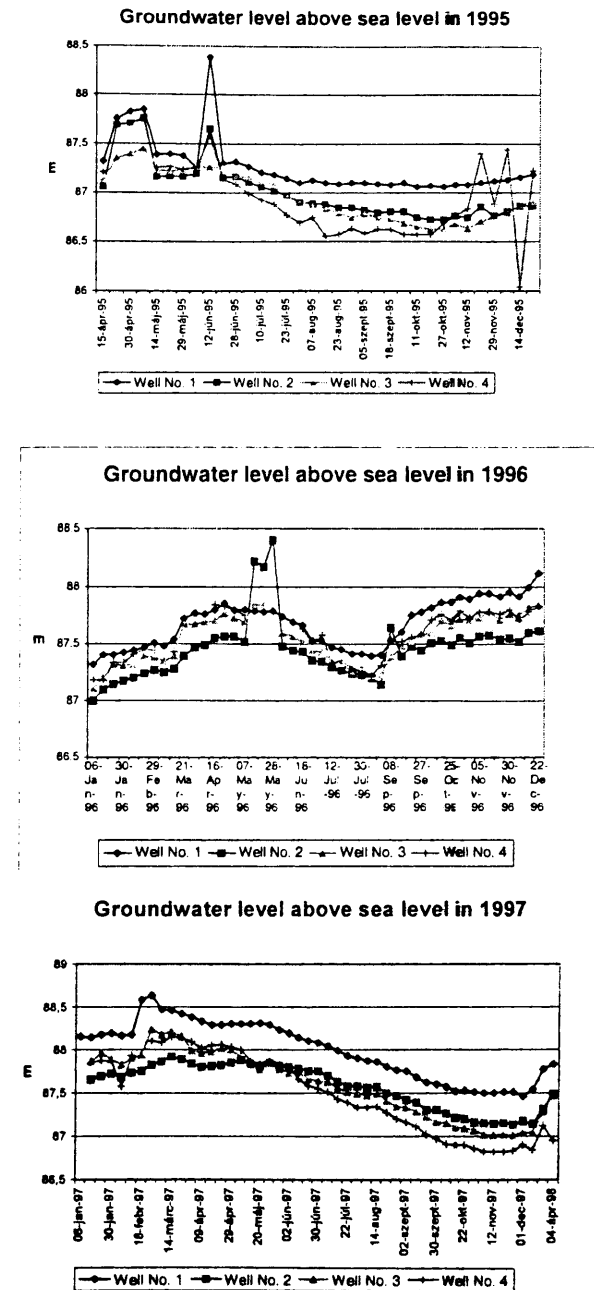


Figure 2
Fluctuation of the groundwater level in the observation wells

Table 2
The chemical type of the groundwater on different days

Yr. month, day	Well No. 1	Well No. 2	Well No. 3	Well No. 4
95. 04. 01.	Na-HCO ₃ -Cl	Na-HCO ₃	Na-Cl	Na-HCO ₃
95. 05. 09.	Na-HCO ₃	Na-HCO ₃	Na-Cl	Na-HCO ₃
95. 06. 12.	Na-HCO ₃	Na-HCO ₃	Na-Cl	Na-HCO ₃
95. 07. 07.	Na-Cl-HCO ₃	Na-HCO ₃	Na-Cl	Na-HCO ₃
95. 08. 14.	Na-HCO ₃ -Cl	Na-HCO ₃	Na-Cl	Na-HCO ₃
95. 09. 14.	Na-HCO ₃ -Cl	Na-HCO ₃	Na-Cl	Na-HCO ₃
95. 10. 25.	Na-Cl-HCO ₃	Na-HCO ₃	Na-Cl	
95. 11. 15.	Na-HCO ₃ -Cl	Na-HCO ₃	Na-Cl	Na-HCO ₃ -Cl
95. 12. 14.	Na-HCO ₃ -Cl	Na-HCO ₃	Na-Cl	Na-HCO ₃ -Cl
96. 01. 19.	Na-Cl-HCO ₃	Na-HCO ₃	Na-Cl	Na-Cl-HCO ₃
96. 03. 07.	Na-HCO ₃ -Cl	Na-HCO ₃	Na-Cl	Na-HCO ₃
96. 03. 29.	Na-HCO ₃ -Cl	Na-HCO ₃	Na-Cl	
96. 04. 29.	Na-HCO ₃ -Cl	Na-HCO ₃	Na-Cl	Na-HCO ₃ -Cl
96. 06. 01.	Na-HCO ₃ -Cl	Na-HCO ₃	Na-Cl	Na-HCO ₃ -Cl
96. 08. 03.	Na-HCO ₃			Na-HCO ₃
96. 09. 03.	Na-HCO ₃ -Cl	Na-HCO ₃	Na-HCO ₃	
96. 10. 04.	Na-HCO ₃		Na-HCO ₃	
96. 11. 16.	Na-HCO ₃	Na-HCO ₃	Na-Cl	Na-Cl-HCO ₃
97. 02. 03.	Na-HCO ₃ -Cl	Na-HCO ₃	Na-Cl	Na-HCO ₃
97. 03. 04.	Na-HCO ₃ -Cl	Na-HCO ₃	Na-Cl	
97. 04. 29.	Na-HCO ₃ -Cl	Na-HCO ₃		Na-HCO ₃
97. 05. 24.	Na-HCO ₃ -Cl	Na-HCO ₃	Na-Cl	Na-HCO ₃
97. 07. 02.	Na-HCO ₃ -Cl		Na-Cl	Na-HCO ₃
97. 08. 21.	Na-HCO ₃ -Cl	Na-HCO ₃	Na-Cl	Na-HCO ₃
97. 10. 12.	Na-HCO ₃ -Cl	Na-HCO ₃	Na-Cl	Na-HCO ₃
97. 11. 14.	Na-HCO ₃ -Cl	Na-HCO ₃	Na-Cl	Na-Cl-HCO ₃
98. 01. 08.	Na-Cl-HCO ₃	Na-HCO ₃ -Cl	Na-Cl	Na-Cl-HCO ₃
98. 03. 05.	Na-HCO ₃ -Cl	Na-HCO ₃	Na-Cl	Na-HCO ₃
98. 04. 01.	Na-HCO ₃ -Cl	Na-HCO ₃	Na-Cl	Na-HCO ₃

chloride in January 1998, and this change was accompanied by an increase in the total soluble salt concentration. This change cannot be attributed to the changes in the local precipitation, since there was considerable precipitation during the previous period, therefore dilution of groundwater was expected.

In November 1996 (similarly to Well No. 1) the total soluble salt concentration also decreased by 500 mg/l, but the chemical type of the water did not change. In contrast to Well No. 1, in this case the amount of bicarbonate decreased by 10–15 equivalent %.

The groundwater of Well No. 3 is of sodium chloride type. The amount of chloride is about 70 equivalent %, and – compared to other wells – it is quite stable in the study period. Only two months (September and October 1996)

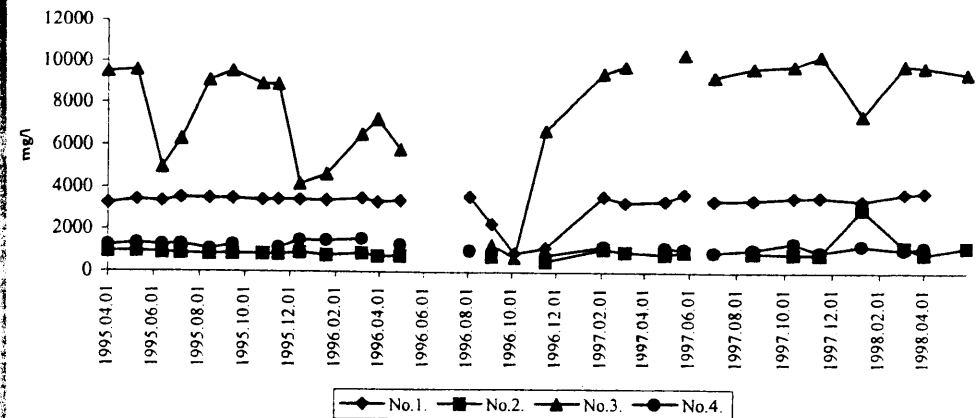


Figure 3
Changes in the total soluble salt concentration of the groundwater

were exceptions to stability, when the ratio of chloride decreased to 15 equivalent % and the groundwater changed to sodium bicarbonate type.

The groundwater of Well No. 4 is dominantly sodium bicarbonate type. In this well there are frequent fluctuations in the ratio of chloride and bicarbonate ions and as a consequence the groundwater changes temporarily into sodium bicarbonate-chloride or sodium chloride-bicarbonate type. The total soluble salt concentration fluctuates as well, and decreased like the water in other wells in November 1996.

The relationship of groundwater movement, chemical type with the meteorological elements and salt accumulation

Compared to our preliminary assumptions, the observations showed changing chemical type of groundwater (Table 2). Several factors can affect this phenomenon. Precipitation plays an important role in the changes in the salt concentration of groundwater. Precipitation falling onto and seeping into the surface dissolves significant amounts of salts from the layers above the groundwater and transport them towards the deeper layers. When seeping precipitation water reaches the groundwater it can change the chemical type of the groundwater. At the same time precipitation collecting as waterlogging and the seepage water saturating the near-surface layers prevent evaporation, that is the further concentration of the groundwater.

The surface sediments with low hydraulic conductivity within the study sites hinder or slow down the movement of precipitation into the groundwater, therefore the leaching affect of precipitation is not manifested at all or only very

limited. This phenomenon is characteristic of salt affected regions, and it is one factor of near-surface salt accumulation.

On the other hand evaporation has an expressed effect on concentration. As a consequence, if the groundwater becomes saturated with a mineral, that mineral precipitates and thus modifies the composition of the groundwater (SKATIE et al., 1987).

Changes in the chemical type of the groundwater can be caused by the lateral movement of groundwater as well. As the groundwater of nearby areas have differing chemical types, a mixing of the groundwaters may occur with lateral flow. According to RÓNAI (1985) in the Hortobágy the lateral flow of the groundwater is small, it is more probable to find stagnant groundwater bodies here. However, our studies showed that in the case of our 4 observation wells there can be lateral flow of groundwater, and occasionally this flow can turn back (Figure 2).

During the study period four characteristic dilution periods were observed. The first was in June–July 1995, the second in January 1996, the third in September–October 1996 and the fourth in January 1998. The largest dilution was the third case, which appeared in each observation well. On the figure of the distribution of precipitation it is clear that in the mentioned periods, or before those, the ratio of precipitation/evaporation increased strongly, and as a consequence the groundwater became diluted without a change in the chemical type.

The effect of the third dilution is probably perceivable in all four wells because of the large amount of precipitation, which fell during the summer and autumn of 1996. In Wells No. 2 and No. 4 the decrease in the total soluble salt concentration is about 100 mg/l, but in Well No. 1 it is 3000 mg/l, and in Well No. 3 about 9000 mg/l. Such dilution cannot be caused simply by the increase in precipitation. This was proven by the fact that there was no rise in the groundwater level of the wells.

From Figure 2 it is clear that during 1996, groundwater flow from the deeper areas towards the higher ones is characteristic. But at the beginning of September the elevation of the groundwater levels above sea level changed in such a way that the level in Wells No. 2 and No. 4 rose above the groundwater level in Wells No. 1 and No. 3. The groundwater flowed from the direction of Well No. 2 towards Wells No. 1 and No. 3, by this way diluted the groundwater there and caused a change in the chemical type. As the total soluble salt concentration of Wells No. 2 and No. 4 was 1000 and 1200 mg/l respectively, therefore, during the mixing the more concentrated waters were diluted, especially if we add the effect of increased precipitation. The groundwater of Well No. 3 changed from sodium chloride and Well No. 1 from sodium bicarbonate-chloride into sodium bicarbonate chemical type. This change in chemical type might be attributed to the groundwater of Well No. 2, as it has a similar chemical type.

The total soluble salt concentration of Well No. 2 increased in January 1998 by more than 2000 mg/l. Although in the preceding period the amount of precipitation was not large, the ratio of precipitation/evaporation was large. The curve of groundwater level shows a rise in each observation well. If we consider all these phenomena, we should observe dilution in the wells, but it occurred only in Wells No. 1 and No. 3. The chemical type of Wells No. 2 and 4 changed at the same time into sodium bicarbonate-chloride. The concentration of chloride ions increased in Well No. 1 too, but only slightly. According to our opinion, the sudden increase in groundwater salt concentration of Well No. 2 occurred because during the rise of the groundwater, it reached a layer with high salt concentration, and by dissolving salts the water became concentrated.

It can be assumed that onflow happened in December 1995, also diluting the groundwater of Well No. 3 and increasing the total soluble salt concentration of Well No. 4. During this process the chemical type of the groundwater shifted towards chloride type.

Summary

Our data verified the relationship between meteorological factors and the fluctuation of the groundwater level. The rate of evaporation dominantly affected the rise and depth of the groundwater level. It is characteristic for the study site that there is an inverse relationship between the elevation of the groundwater observation wells and the depth of groundwater, and the difference between the levels of groundwater in the separate wells reflected the differences in the elevation between the wells. Our observations refuted our previous assumptions, as in the wells not only the concentration of salts changed but also the chemical type of the water. This can be attributed with great probability to the lateral flow of the groundwater, which is caused by the vertical fluctuation, but can be caused by other geological factors as well.

We reached the conclusion that the vertical and sometimes lateral movement of the groundwater affects the development of soils in a given area. It means that the reason behind the mosaic-like appearance of the soil cover of a given area can be searched in the local differences of the chemical composition of the groundwater, which is a major factor of the spatial variability of the salt accumulation of soils.

The observations and analytical results point to that the soils of the study site have developed under the effect of fluctuating groundwater and the elevation is a dominant factor of the spatial variability of the soil salt accumulation. The level of groundwater, the flow of groundwater and its composition show relationship with the surface elevation, and their effect is modified by the geological stratification, which results in a variable appearance of soil salt accumulation and native vegetation.

Key words: groundwater flow, salinization, groundwater composition, soil formation

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