Dynamics of soil salinization in the Nero Lake depression (Upper Volga) in connection with the latest climate change

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Abstract. Over the last 30–40 years, climate changes have resulted in environmental changes within the Upper Volga basin. In this study, an attempt to analyze the soil record of recent climate changes was made. An example of soil evolution induced by climate change was studied on hydromorphic saline soils in the nature reserve of the Varnicy Saline Spring. In a humid climate, soil salinization occurring in discharge areas can quickly change in response to the changed hydrothermal regime because of close relationships between climatic conditions and groundwater systems. In a poorly drained depression, we could observe an increasing soil salinity and developing hydrogenic accumulation of salts, whereas the groundwater salinity was stable.

1. Introduction
The Nero Lake within the Upper Volga basin on the Russian Plain is characterized by an increased salinity and a specific ionic composition compared to the other water reservoirs in this region. The high total dissolved solids (TDS) and heterogeneous water composition in the lake are results of influxes from several saline tributaries and groundwaters draining the lake basin area, where saline soils are distributed [1, 2].

In a humid climate of the central part of the Russian Plain, salinization is not a typical soil process. In the Yaroslavl Volga region, the water and temperature regimes of soils within watershed areas accelerate leaching of soluble compounds and provide for the predominance of Retisols. Poor drainage within depressions leads to soil waterlogging.

Salinization of meadow landscapes and soils on low lake terraces is associated with saline springs and saline groundwater seepages from Permian formations due to hydrogeological conditions [3]. Both saline springs and saline seeps may have an effect on the adjacent rivers and lake water chemistry. Groundwater seepages are usually confined to discharge areas [4]. Soil formation attributed to discharge areas depends not only on the amount of precipitation directly falling to the surface and seeping into groundwater, but also on the surface and subsurface inflows from the recharge area (Borisoglebskaya Upland). The study on such soils is of interest in both fundamental and evolutionary aspects as it can help to identify the latest global and regional climate trends.

Systematic studies on lacustrine saline soils have been conducted within the Upper Volga basin for more than 100 years. The development of soil salinization has been described as a "spreading solonchak" [5]. Phenomena associated with climate change detected in the past include a steady increase in both mean annual temperature and precipitation. Because of a close correspondence
between fluctuations in local climatic and groundwater parameters [4], they are expected to affect soil salinization processes.

In this paper, we shall focus on the current trend of soil salinization on low terraces of the Nero Lake basin. An example of soil salinization within such landscapes was studied in the nature reserve of the Varnicy Saline Spring.

2. Materials and methods

2.1. Study site

The Varnicy key monitoring site was located within the Nero Lake basin at a distance of about 200 km to the north-east of Moscow (Russia). The lake itself is one of the largest water reservoirs within the Yaroslavl Region in the upper reaches of the Volga River. This is a semi-closed lake within a generally flat area of the Rostov Lowland underlain by low-permeable varved clays, therefore, subsurface drainage of discharge areas appears to be restricted and waterlogging is typical on low terraces [6].

The study site (57°12'36.0"N, 39°22'25.2"E) was found on the lake’s second terrace with the saline spring in the center (figure 1). The site had altitudes of 97–98 m a.s.l. and a total area of approximately 50 ha.

![Figure 1](image)

Figure 1. The study site within Upper Volga basin, with the saline spring and soil sampling locations: V – Varnicy key monitoring site; V-1 – soil monitoring pit. Yandex-imagery captured in 2016.

The local drainage basis is the Ishnya River, which borders the study site from the north and north-west. This river is one of the most saline tributaries of the Nero Lake. Shallow groundwater and a gentle slope towards the river lead to constant overmoistening. Soils within the site have high water tables throughout the year, horizons with gleysic features, accumulations of soluble salts, carbonates and gypsum. These soils differ from the other soils in the region. Halophytes and salt-tolerant species (*Juncus gerardii*, *Triglochin maritimum*) found on the site are typical to moist saline meadows and salt marshes.

The choice of the site for monitoring was primarily due to the high salinity level of the spring. This saline spring has been known for a long time, as it was used as a source of salt. However, salt production at the site had stopped several centuries ago. Afterwards soils have developed under natural conditions without any other serious anthropogenic influences. Therefore, the soil salinity...
transformation during the considered time interval (30–40 years) can be reliably associated with change in the hydrothermal regime.

2.2. Climate
The climate of the Yaroslavl Region is moderately continental with warm short summers and moderately cold long winters. Mean annual temperature is 4.6 °C. The coldest (January) and the warmest (July) months have mean temperatures of −8.5 °C and +19.5 °C, respectively [7]. In recent decades, the mean annual temperature in the Upper Volga basin has steadily risen mainly due to increase in winter and spring temperatures. Since 1976, temperatures have already increased by 2–3 °C in January and by 1–2 °C in July. Duration of winter has shortened from 5 to 4 months, the period with positive temperatures has increased by one month and consequently the growing season has become longer. During the warming period, the mean annual air temperature has been increasing at a rate of 0.55 °C per decade, mainly due to the winter temperature increasing by 0.73 °C per decade [8].

Global warming is likely to have a major impact on the hydrological cycle [9]. Climate changes are expected to accelerate water cycles, as precipitation will generally increase [10].

The study area has a humid climate with the mean annual precipitation of about 500–600 mm, 70% of which corresponds to the growing season, and the precipitation-evaporation ratio of 1.3–1.5 [7]. A large-scale change in the pattern of precipitation within the Upper Volga basin has been evident for the last 30–40 years. The total annual precipitation has increased and the precipitation of the growing season has decreased, while the total amount of evapotranspiration from continental water surfaces has not changed much [2, 7, 11]. Rising temperatures and precipitation have generally affected the thermal regime, water balance, water cycle, water level and environmental conditions within the basin of the Rybinsk Reservoir on the Volga River [8, 12].

Currently, there is undeniable evidence of modern global warming [13]. Various natural indicators including soil regimes and biotic components are sensitive to climate change. Obviously, vertical salt distribution patterns and morphological features associated with the redox regime in hydromorphic soils can quickly change in response to regional climate changes.

2.3. Sampling and methods
The salinization trend analysis was based on temporal, hydrological and soil data, collected in 1988, 1990, 2016 and 2017. Soil salinity assessment at the study site was initially done in 1988 and then repeated in 1990. The background monitoring had provided data on previous level of soil salinity, which was compared to that in modern soils. Water and soil sampling were performed in different seasons during 2016–2017, which allowed to take into account seasonal fluctuations in salt regimes.

Soil salinity assessments were based on analyses of 1:5 soil:water extracts, which were prepared from soil samples passed through a 1-mm sieve [14, 15]. Standard procedures were used for laboratory analyses of water and soil [16]. Soluble Na+, K+, Ca2+ and Mg2+ in water and soil extracts were determined by inductively coupled plasma-atomic emission spectroscopy (ICP-AES). Chloride was analyzed using titration with 0.02 N AgNO3 (Mohr’s method). Gravimetric method was used to analyze SO42− in water-soil extracts after precipitation via 10% BaCl2. Carbonate and bicarbonate ions were determined by titrating samples to an endpoint of pH 8.4 and then to pH 4.7 [17]. Salt content was determined as a sum of major ions (%). Alkalinity and dissolved CO2 in water samples were measured in the field by titrations. TDS was calculated as a sum of concentrations of cations and anions. Carbonate and gypsum contents were determined by gravimetric method in sieved samples (<0.25 mm). Gypsum was analyzed in 0.2 M HCl extract after precipitation via 10% BaCl2 [18]. Carbon dioxide was measured gravimetrically by CO2 loss after dissolution upon reaction with HCl [17, 19]. The electrical conductivity (EC) was measured in the saturated soil-paste extracts [17].

Methods of descriptive statistics were subsequently applied to take into account seasonal variations in water and soil salinity and ionic composition.

3. Results and discussion
3.1. Spring geochemistry

Since the salt accumulation process develops at a landscape scale, it must be interpreted using a hydropedological approach. This approach involves studies on relationships between groundwater balance and soil regime [20].

Based on our hydrochemistry monitoring data (table 1), the spring waters were characterized by high concentrations of Na⁺ and Cl⁻, and low concentrations of HCO₃⁻. The spring waters were mostly neutral with a pH range of 6.3–7.4. TDS of the Varnicy Spring waters varied from 12230 to 13589 mg·L⁻¹ with a mean value of 12887 mg·L⁻¹. The highest TDS was detected during the low-flow season (June) and the lowest TDS — during the peak flow season (September). The TDS variation was weakly dependent on the observation season. The coefficient of TDS variation did not exceed 5%. Seasonal fluctuations of individual ion concentrations were also insignificant, within 2–15% (table 1). Only CO₃²⁻, detected once during the monitoring period, and HCO₃⁻ showed substantial variations in concentrations, depending on wet and dry hydrological phases. Moreover, on the basis of comparison of our results with literature data [21], we can conclude that the ionic composition of the spring is relatively stable not only in the annual cycle, but in the course of 100 years.

Table 1. Geochemical composition of the Varnicy Spring waters over the time of monitoring (09/2016 – 09/2017).

| Date of sampling | pH | CO₃²⁻ | HCO₃⁻ | Cl⁻ | SO₄²⁻ | Ca²⁺ | Mg²⁺ | Na⁺ | K⁺ | TDS mg·L⁻¹ |
|------------------|----|-------|-------|-----|-------|------|------|-----|----|-------------|
| 22/09/2016       | 7.0 | 9.6   | 107.0 | 5672| 2163  | 1000 | 360  | 2852| 65.9| 12230       |
| 30/01/2017       | 7.0 | 0.0   | 146.4 | 5601| 2108  | 1000 | 360  | 3013| 54.8| 12283       |
| 16/04/2017       | 6.7 | 0.0   | 104.9 | 6027| 2266  | 967  | 360  | 3075| 56.9| 12856       |
| 11/05/2017       | 6.4 | 0.0   | 48.8  | 6027| 2222  | 927  | 373  | 3039| 57.9| 12693       |
| 31/05/2017       | 7.2 | 0.0   | 48.8  | 6381| 2267  | 923  | 360  | 3367| 55.1| 13403       |
| 12/06/2017       | 7.3 | 0.0   | 122.0 | 6381| 2294  | 840  | 350  | 3555| 46.5| 13589       |
| 26/09/2017       | 7.0 | 0.0   | 122.0 | 6168| 2224  | 888  | 331  | 3369| 49.1| 13151       |
| Statistical parameter | | | | | | | | | |
| Maximum          | 7.3 | 9.6   | 146.4 | 6381| 2294  | 1000 | 373  | 3555| 65.9| 13589       |
| Minimum          | 6.4 | 0.0   | 48.8  | 5601| 2108  | 840  | 331  | 2852| 46.5| 12230       |
| Mean             | 6.9 | 1.4   | 100.0 | 6037| 2221  | 935  | 356  | 3181| 55.2| 12887       |
| Standard deviation | 0.3 | 3.6   | 37.5  | 310 | 65    | 59   | 13   | 251 | 6.3 | 527         |
| Coefficient of variation, % | 4.3 | 264.6 | 37.5  | 5.1 | 2.9   | 6.3  | 3.6  | 7.9 | 11.4| 4.1         |

3.2. Groundwater geochemistry

At the Varnicy site, groundwater was neutral and weakly alkaline with a pH range of 6.5–7.9 (table 2). It was similar to the spring water in composition, but had a lower mean TDS concentration. The groundwater composition was dominated by Na⁺ and Cl⁻, with lesser amounts of Ca²⁺ and SO₄²⁻. In dry seasons the groundwater salinity reached 14577 mg·L⁻¹ (table 2), which was an extremely high value under humid climate conditions. This fact confirmed a significant contribution of subsurface brines to the groundwater supply. Seasonal fluctuations in the groundwater ionic composition, especially with respect to chloride, sodium and hydrocarbonate ions, were also indicative of its meteoric origin and dependence on the supply of precipitation. The highest value of the groundwater TDS was recorded during the season of a low runoff and the lowest water table. Groundwater table fluctuations between winter minimum and spring maximum had an amplitude of 0.05 m, between spring maximum and summer minimum — 0.45 m (table 2). The groundwater table fluctuations correlated with river flow rates within the Nero Lake basin.

| Date of sampling | pH | CO₃²⁻ | HCO₃⁻ | Cl⁻ | SO₄²⁻ | Ca²⁺ | Mg²⁺ | Na⁺ | K⁺ | TDS mg·L⁻¹ |
|------------------|----|-------|-------|-----|-------|------|------|-----|----|-------------|
| 22/09/2016       | 7.0 | 9.6   | 107.0 | 5672| 2163  | 1000 | 360  | 2852| 65.9| 12230       |
| 30/01/2017       | 7.0 | 0.0   | 146.4 | 5601| 2108  | 1000 | 360  | 3013| 54.8| 12283       |
| 16/04/2017       | 6.7 | 0.0   | 104.9 | 6027| 2266  | 967  | 360  | 3075| 56.9| 12856       |
| 11/05/2017       | 6.4 | 0.0   | 48.8  | 6027| 2222  | 927  | 373  | 3039| 57.9| 12693       |
| 31/05/2017       | 7.2 | 0.0   | 48.8  | 6381| 2267  | 923  | 360  | 3367| 55.1| 13403       |
| 12/06/2017       | 7.3 | 0.0   | 122.0 | 6381| 2294  | 840  | 350  | 3555| 46.5| 13589       |
| 26/09/2017       | 7.0 | 0.0   | 122.0 | 6168| 2224  | 888  | 331  | 3369| 49.1| 13151       |
Table 2. Variations in the groundwater geochemical composition and the groundwater table over the time of monitoring (09/2016 – 09/2017).

| Date of sampling | Water table, m | pH | HCO$_3^-$ | Cl$^-$ | SO$_4^{2-}$ | Ca$^{2+}$ | Mg$^{2+}$ | Na$^+$ | K$^+$ | TDS |
|------------------|----------------|----|-----------|-------|-----------|---------|---------|-------|------|-----|
| 22/09/2016       | 0.35           | 7.2| 342.0     | 538.0 | 2396      | 1160.0  | 417     | 2550  | 54.0 | 12307|
| 30/01/2017       | 0.35           | 7.0| 286.0     | 404.1 | 2021      | 1080.0  | 401     | 1980  | 45.0 | 9853 |
| 16/04/2017       | 0.30           | 7.9| 366.0     | 478.6 | 1943      | 1048.0  | 307     | 2174  | 36.2 | 10660 |
| 11/05/2017       | 0.45           | 6.5| 457.5     | 609.7 | 2351      | 1136.0  | 326     | 3150  | 49.9 | 13568|
| 31/05/2017       | 0.70           | 7.2| 244.0     | 673.6 | 2498      | 1000.0  | 374     | 3679  | 47.0 | 14577|

Statistical parameter

|                   |                |     |           |       |           |         |         |       |      |     |
|-------------------|----------------|----|-----------|-------|-----------|---------|---------|-------|------|-----|
| Maximum           | 0.70           | 7.9| 457.5     | 673.6 | 2498      | 1160.0  | 417     | 3679  | 54.0 | 14577|
| Minimum           | 0.30           | 6.5| 244.0     | 404.1 | 1943      | 1000.0  | 307     | 1980  | 36.2 | 9853 |
| Mean              | 0.43           | 7.2| 339.1     | 540.9 | 2242      | 1084.8  | 365     | 2707  | 46.4 | 12193|
| Standard deviation| 0.2            | 0.5| 81.6      | 1060  | 245       | 64.9    | 47      | 703   | 6.6  | 1963 |
| Coefficient of variation, % | 37.3       | 7.0| 24.1      | 19.6  | 10.9      | 6.0     | 12.9    | 26.0  | 14.3 | 16.1 |

3.3. Soils

The salt composition of the studied soils, as of any other soils of hydromorphic salinization, is determined by the groundwater chemical composition, while the salt regime and the intensity of salinization processes depend on the local hydrothermal regime.

The genesis of the Varnicy site soils is similar to that of hydromorphic soils of lake depressions, which can be formed in any climatic zone. Being the lowest topographic depression within the basin, the lake depression acts as a discharge zone of convergent groundwater flow [4]. Therefore, under arid climate such soils accumulate soluble salts, carbonates and gypsum. Soils distributed within such depressions are represented by hydromorphic Solonchaks with a shallow groundwater table. But unlike the arid Solonchaks, in which salt accumulation inhibits other pedogenic processes and becomes the dominant one, the Varnicy site saline soils are similar to saline alluvial soils and salt marshes. These soils undergo significant fluctuations in salinity depending on episodic salt rising or salt leaching processes. Salts are periodically washed out from these soil profiles, primarily, from the surface horizons [22, 23]. In other words, the alternations of the hydrological cycle result in drastic changes in soil water and salt regimes.

The salt regime dynamics of the studied soils is characterized by the ratio of atmospheric precipitation and groundwater discharging. Consequently, it is logical that changes in the vertical distribution of salts within soil profile are primarily due to Cl$^-$ and Na$^+$ fluctuations following the change in the hydrological phases. As follows from the results of the annual monitoring at the Varnicy site (table 3), concentrations of Cl$^-$ and Na$^+$ ions had greater seasonal variability than SO$_4^{2-}$ and Ca$^{2+}$ concentrations, which varied by no more than 20%. These ions had a relatively uniform distribution in the soil profile.

Table 3. Data on soil salinity monitoring (09/2016 – 09/2017).

| Depth, cm | pH | Salt content | HCO$_3^-$ | Cl$^-$ | SO$_4^{2-}$ | Ca$^{2+}$ | Mg$^{2+}$ | Na$^+$ | K$^+$ | CaCO$_3$ | CaSO$_4$·2H$_2$O |
|-----------|----|--------------|-----------|-------|-----------|---------|---------|-------|------|----------|------------------|
|           |    | %            | cmol(-)·kg$^{-1}$ soil | cmol(+)·kg$^{-1}$ soil | %        |
| 22/09/2016|    | 6.6          | 1.68      | 1.38  | 8.8       | 16.2    | 14.6    | 2.9   | 7.5  | 0.34     | 29.4              | 5.2               |
| 0–10      |    | 7.2          | 1.41      | 0.35  | 4.0       | 17.0    | 16.0    | 1.1   | 4.0  | 0.17     | 13.0              | 27.8              |
| 10–20     |    |              |           |       |           |         |         |       |      |          |                   |                  |
| Depth, cm | pH  | Salt content | HCO₃⁻ | Cl⁻ | SO₄²⁻ | Ca²⁺ | Mg²⁺ | Na⁺ | K⁺ | CaCO₃ | CaSO₄·2H₂O |
|----------|-----|--------------|-------|-----|-------|------|------|-----|----|-------|----------|
|          |     | % | cmol(−)·kg⁻¹ soil | cmol(+)·kg⁻¹ soil | % |
| 20–25    | 7.0 | 1.63 | 0.35 | 7.0 | 18.0 | 16.2 | 1.8 | 5.9 | 0.33 | 15.7 | 33.6 |
| 25–35    | 7.5 | 1.53 | 0.31 | 6.0 | 17.5 | 16.5 | 1.7 | 4.4 | 0.32 | 8.9  | 1.7 |
| 35–45    | 7.4 | 1.72 | 0.24 | 7.0 | 19.7 | 16.6 | 3.1 | 5.9 | 0.34 | 16.0 | 42.8 |
| 30/01/2017 | | | | | | | | | | | |
| 0–10     | 7.0 | 2.14 | 1.90 | 16.2 | 16.1 | 14.3 | 3.8 | 15.1 | 0.10 | 32.7 | 5.8 |
| 10–20    | 7.1 | 1.35 | 0.35 | 6.1  | 14.6 | 13.7 | 2.1 | 4.9  | 0.11 | 13.4 | 32.6 |
| 20–25    | 7.0 | 1.22 | 0.17 | 3.5  | 15.1 | 11.3 | 2.6 | 4.6  | 0.04 | 16.1 | 32.1 |
| 25–35    | 7.1 | 1.51 | 0.18 | 6.4  | 16.8 | 12.6 | 2.0 | 8.5  | 0.01 | 35.0 | 47.4 |
| 35–45    | 7.3 | 1.73 | 0.18 | 9.9  | 17.0 | 14.1 | 2.16 | 10.7 | 0.06 | 27.9 | 54.4 |
| 11/05/2017 | | | | | | | | | | | |
| 0–10     | 6.5 | 2.00 | 0.54 | 14.4 | 16.9 | 13.5 | 3.6 | 14.2 | 0.27 | 24.9 | 12.6 |
| 10–20    | 7.2 | 1.91 | 0.61 | 13.4 | 16.2 | 14.6 | 1.8 | 13.4 | 0.14 | 20.8 | 38.6 |
| 20–25    | 6.7 | 1.86 | 0.54 | 12.6 | 16.1 | 14.4 | 1.8 | 12.8 | 0.15 | 19.6 | 48.1 |
| 25–35    | 7.1 | 1.25 | 0.40 | 5.4  | 13.6 | 11.9 | 1.7 | 5.5  | 0.09 | 11.3 | 60.4 |
| 35–45    | 7.7 | 1.28 | 0.42 | 5.3  | 13.9 | 13.9 | 1.7 | 4.0  | 0.17 | 15.7 | 40.6 |
| 12/06/2017 | | | | | | | | | | | |
| 0–10     | 7.2 | 2.93 | 1.41 | 19.9 | 25.0 | 17.6 | 4.4 | 23.0 | 0.28 | 28.8 | 25.0 |
| 10–20    | 6.6 | 2.02 | 0.39 | 7.0  | 23.7 | 18.9 | 2.4 | 8.9  | 0.16 | 8.3  | 48.4 |
| 20–25    | 6.8 | 2.26 | 0.33 | 8.9  | 25.6 | 19.0 | 3.6 | 11.6 | 0.34 | 18.6 | 42.6 |
| 25–35    | 7.1 | 2.02 | 0.47 | 6.0  | 24.2 | 18.8 | 2.3 | 9.0  | 0.27 | 13.2 | 46.7 |
| 35–45    | 7.1 | 2.15 | 0.65 | 7.3  | 24.8 | 18.9 | 2.4 | 11.0 | 0.19 | 19.3 | 52.8 |
| 26/09/2017 | | | | | | | | | | | |
| 0–10     | 6.7 | 1.53 | 0.64 | 6.0  | 16.9 | 16.0 | 2.1 | 5.0  | 0.31 | 9.8  | 12.3 |
| 10–20    | 6.9 | 1.50 | 0.47 | 3.5  | 18.7 | 17.6 | 1.2 | 3.2  | 0.28 | 5.6  | 44.8 |
| 20–25    | 7.0 | 1.55 | 0.40 | 3.6  | 19.3 | 17.3 | 1.2 | 4.3  | 0.30 | 15.0 | 28.4 |
| 25–35    | 7.0 | 1.72 | 0.41 | 3.3  | 22.2 | 17.7 | 1.2 | 6.0  | 0.21 | 7.7  | 33.2 |
| 35–45    | 6.9 | 1.58 | 0.34 | 4.3  | 19.3 | 18.5 | 1.2 | 3.9  | 0.21 | 9.2  | 53.9 |
| 45–60    | 6.8 | 1.79 | 0.33 | 6.5  | 20.5 | 18.6 | 1.7 | 6.8  | 0.18 | 10.7 | 69.1 |
| 60–70    | 6.7 | 2.05 | 0.33 | 8.7  | 22.7 | 18.8 | 2.4 | 9.9  | 0.24 | 12.9 | 60.8 |

**Statistical parameter**

|                |       |     |     |     |       |     |     |     |
|----------------|-------|-----|-----|-----|-------|-----|-----|-----|
| Maximum        | 7.7   | 2.93| 1.90| 19.9| 25.6  | 19.0| 4.4 | 23.0|
| Minimum        | 6.5   | 1.22| 0.17| 3.3 | 13.6  | 11.3| 1.1 | 3.2 |
| Mean           | 7.0   | 1.75| 0.52| 7.8 | 18.8  | 16.0| 2.2 | 8.3 |
| Standard deviation | 0.3 | 0.37| 0.40| 4.2 | 3.6   | 2.4 | 0.9 | 4.6 |
| Coefficient of variation, % | 4.0 | 21.3| 77.5| 53.4| 19.1  | 14.8| 39.3| 55.4|

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Based on the electrical conductivity in saturated paste extract, which had values from 16 to 30 dSm/m, the studied soil should be classified as strongly saline [24]. Such properties as a high salt content (> 1%) and a shallow position of salic horizon were in agreement with the WRB criteria of Solonchaks [25]. Nevertheless, the seasonal salinity coefficient (the ratio of the autumn salinity to the spring one [26]) had values of less than 1.0 in surface horizon suggesting that infiltration prevailed within the aeration zone and promoted leaching of salts during the frost-free period. The salt accumulation took place during the period of a low runoff and a high evaporation. Thus, the soil salinity values were particularly high in winter and summer (table 3). In the annual cycle, salinity values could vary by up to 2 orders of magnitude, which caused variations in vertical salt distribution within soil profile. During low runoff seasons (winter and summer), content of chlorides increased in the upper part of the soil profile, and the total salinity exceeded 2%. However, the high salt content remained throughout the soil profile, which was due to the large amount of soluble salts in the groundwater, like in all soils of hydromorphic salinization. Thus, the shift of the salinity maximum and the change in the type of salt profile followed the change in the hydrological cycle phase. The water-saturated zone was less susceptible to seasonal fluctuations compared to the surface horizons. The coefficient of seasonal salinization in the water-saturated zone, in contrast to the surface horizon, had a value greater than 1.0, indicating processes of progressive salt accumulation.

The studied soils had a very high gypsum content. Sulfate excess in the groundwater solution resulted in sequential deposition of gypsum. Gypsum and carbonate pedofeatures occurred throughout the soil profile.

Carbonate and gypsum contents significantly varied depending on the depth in the soil profile as well as seasonal factors (table 3), which was also manifested in soil morphological features in dry and wet seasons. Such a wide range of fluctuations in contents of carbonates and gypsum could be caused not only by seasonal changes in moisture regime, but also by an irregular pattern of their accumulation within the horizons, i.e., gypsum and carbonates accumulated in the form of lenses and intercalations, but not continuous layers.

Gypsum and carbonates present in the fine earth fraction of soil have a hydrogenic origin. The horizons of the water-saturated zone were relatively homogeneous and less affected by leaching processes, so, in a humid climate, they were more reliable for assessments of evolutionary transformation of the salinity state. Hydrogenic gypsum and carbonate formations combined with a high content of soluble salts were indicative of the ongoing process of modern salt accumulation in this landscape. According to the WRB [25], the studied soil was classified as Gleyic Gypsic Calcic Solonchak (Chloridic/Sulfatic, Hypersalic).

To reveal the soil salinization trend, we compared the results of seasonal monitoring of the soils in 2016–2017 with the salinity data on the soils sampled in July 1988 and September 1990. The latter were regarded as background soils (control), because they were sampled at the start of the latest regional climate change (table 4).

Table 4. Data on soil salinity of background soils.

| Depth, cm | pH | Salt content | HCO\textsubscript{3}\textsuperscript{−} | Cl\textsuperscript{−} | SO\textsubscript{4}\textsuperscript{2−} | Ca\textsuperscript{2+} | Mg\textsuperscript{2+} | Na\textsuperscript{+} | K\textsuperscript{+} | CaCO\textsubscript{3} | CaSO\textsubscript{4}·2H\textsubscript{2}O | % | cmol(−)·kg\textsuperscript{−}·soil | cmol(+)·kg\textsuperscript{−}·soil | % |
|----------|----|-------------|----------------|--------------|----------------|--------------|-------------|-------------|--------------|-------------|----------------|----------------|-----------|----------------|----------------|---|
| 20/07/1988 | | | | | | | | | | | | | | | | | |
| 0–26 | 7.2 | 1.30 | 0.93 | 2.61 | 16.1 | 13.5 | 3.55 | 2.22 | 0.26 | 33.8 | 23.0 |
| 26–32 | 7.3 | 1.26 | 0.90 | 1.68 | 16.3 | 13.4 | 2.99 | 2.08 | 0.29 | 30.9 | 29.1 |
| 32–37 | 7.4 | 1.14 | 0.51 | 0.98 | 15.5 | 13.7 | 1.82 | 1.06 | 0.31 | 26.1 | 34.2 |
| 37–54 | 7.5 | 1.03 | 0.24 | 0.84 | 14.3 | 13.1 | 1.74 | 0.70 | 0.12 | 10.1 | 35.5 |
| 54–70 | 7.5 | 1.03 | 0.28 | 1.14 | 13.9 | 12.9 | 1.38 | 1.20 | 0.07 | 10.2 | 39.5 |
| 23/09/1990 | | | | | | | | | | | | | | | | | |
| 0–12 | 6.2 | 1.47 | 0.89 | 2.22 | 18.5 | 15.5 | 1.11 | 5.20 | 0.17 | 16.6 | 39.5 |
In July 1988, the salt concentration corresponded to the lowest value of the modern salinity variation range (table 3). The salt profile with the maximal salt concentration in the top horizon was observed during the season of intensive evaporation. During the latest warming, the year 1990 was the most humid with an extremely high rainfall [8]. The spring water and groundwater had TDS values of 11034 and 11183 mg·L⁻¹, respectively. The soil salinity in September 1990 was below the average of the current monitoring period 2016–2017. The distribution of salts within the soil profile was indicative of salt leaching during the wet period. Thus, "old" salinity profiles had shapes similar to those of the corresponding seasonal profiles observed during the current monitoring.

Over the 30-year-long period, the salinity value in the upper part of soil profile has increased by approximately 10% during the wet period and almost doubled during the dry period. The rate of salinization varied from year to year. However, the general trend was towards an increase in salt content, however, progressive salt accumulation was hindered by infiltration processes.

On the one hand, the salt regime of a hydromorphic salt-affected soil could be a proxy for changing hydrothermal conditions, which, in turn, resulted from change in the evaporation to precipitation ratio. On the other hand, as we could see, the salt regime was very dynamic and the amplitude of seasonal variations in salinity was comparable with changes over the years (30–40 years). For example, during certain seasons the salinity of soils studied in 1988 and 1990 was within the range of values established by current monitoring. A lack of statistical soil data made it difficult to quantify the salinization trend due to the site micro pattern and horizontal heterogeneities with respect to salt concentration [27].

To provide for a better comprehension of the salinization trend, we analyzed soil morphological characteristics. The soil morphology is often used to improve the characterization of soil water regimes, usually compiled using determinisitic modeling. In some cases, soil morphological data can give more information about water flows than physical or hydrological methods, which is particularly relevant in studies on redox features [20].

In July 1988 small gypsum druzes with ferruginous mottles were documented in the field soil profile description. The organic surface horizon consisted of reed sedge peat with white salt crust. Groundwater table was at a depth of 57 cm. The soil was classified as Gleyic Solonchak. In the soil on micro elevation at the site, the groundwater was observed at a depth of 89 cm. There were abundant ferruginous mottles and loose concretions in the soil profile. Gypsum crystals were observed at a depth of 77–83 cm, and small gypsum plates in the deeper horizons. In September 1990, the groundwater table was at a depth of 37 cm. The surface horizon consisted of semi-decomposed organic matter with peat lenses.

At the present stage of monitoring some general morphological features of the soil profile are similar to the both background soils with features of gleyzation and periodical oxidation processes. In wet seasons greenish and gray colors dominated in mineral horizons. In dry seasons colors became paler, and even turned into white and yellow. The "new" salt accumulations were in the form of "saline efflorescences" on the soil surface appeared in dry seasons. In the soil profile, carbonate-gypsum lenses and interlayers of gazha type [28] and salt crystals were observed. In addition to gypsum transformation, the organic horizon may be interesting in terms of evolutionary assessment. The present surface horizon contained humified organic matter with only few fragments of peat, indicating an enhancement of organic matter mineralization.

4. Conclusions
Based on the above considerations, we may draw preliminary conclusions about the soil water regime and evolutionary aspects of soil formation under changing climate conditions:

1. The salinity level of subsurface and groundwater at the site was stable.
2. An estimation of salinization trend was complicated due to significant seasonal fluctuations in salt content. Generally, after 1990 we could observe salt accumulation process developing on site.
3. Changes in soil morphological features were indicative of increasing rates of hydrogenic accumulation of gypsum and mineralization of organic matter, along with decreasing amounts of poorly decomposed organic matter.

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