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The retrospective monitoring of soils under conditions of climate change in the Trans-Ural region (Russia)

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Abstract: Global climate change is a fact that affects all components of the environment. The main aim of this research was to conduct the retrospective monitoring of soils in the Trans-Ural Steppe Zone (Russia) and the analysis in changing of key climatic parameters for the periods 1937–1982 and 1982–2019. We investigated average temperatures and precipitation (monthly and annual) using archived data from a nearby weather station, as well as data from NASA and weather forecast websites. We identified a decrease of soil fertility and an increase in alkalinisation processes over the past 37 years for the studied area. Comparison of these periods showed an increasing the average monthly and annual air temperatures (on 1.4°C) and a decrease in the amount of precipitation in the summer (on 4.4 mm) period. We found that a more arid climate accelerates the rate of soil salinization due to the active evaporation of groundwater. Nevertheless, in some areas there were found the soil desalinization due to the change in the hydrologic regime and lowering of the groundwater level. In general, the climate changing in the studied region is consistent with global warming trend. Increased average annual temperature and reduced precipitation in summer period contribute to aridization of the region. Such conditions will more restrict soil fertility due to development of salinization and desertification processes.

Keywords: climate change, monitoring, soil fertility, Trans-Ural

INTRODUCTION

One of the main issues related to soil science are study, analysis and retention of land degradation [Bagarello *et al.* 2018; Gregory *et al.* 2015]. Nowadays, in addition to anthropogenic pressure, climate change also affects the acceleration of soil degradation, especially salinization in arid and semi-arid territories [Corwin 2021; Haj-Amor, Bouri 2020; Libutti *et al.* 2018; Pankova *et al.* 2015]. Moreover, such conditions contribute to an increased risk of desertification [Solangi *et al.* 2019]. Ma *et al.* [2021] studied the period 1985–2015 and established a trend of increasing temperatures and precipitation in the territory of Central Asia. Based on the predictive model, the authors forecasted the climate processes for the next hundred years and found that the climate of this region will become warmer and wetter. Another study found an increasing trend in temperatures and precipitation for the 1950–2015 period in the Buqtyrma River Basin, Kazakhstan [Rakhimova *et al.* 2020]. The authors also predicted an increasing of temperatures and precipitation in the future.

The IPCC special report noted that in Russia, climate change occurs several times faster than its world average [IPCC 2019]. Saline soils are predominantly located in the southern parts of the country. At the same time, the main agricultural lands are also located in the southern regions of Russia, where the accelerating of warming processes are observed [Kattsov 2017; Shishov, Pankova 2006]. There is also an increase in the number of years with prolonged droughts during the growing season in Trans-Ural region [Komissarov *et al.* 2019]. Furthermore, natural fires are more frequent due to the dryer climate in Bashkortostan and in Russia a whole [Kattsov 2017]. It is revealed, that fires lead to an increase in the content of water-soluble salts and exchangeable sodium in this region [Gabbasova *et al.* 2019]. The above-mentioned factors indicate the development of a more arid climate in this area.

The main criteria of soil fertility declining, i.e. its degradation is the organic carbon (C_{org}) loss, this process is also accompanied by decreasing of humus horizon thickness and soil alkalinisation. The salinisation level is also an important factor of soil degradation, which reduces soil fertility. The objectives of this research are the following: (i) study of the basic soil properties transformation from 1982 to 2019 in the Trans-Ural steppe zone (Russia); (ii) analysis of temperature and precipitation changes at the study region from 1937 to 2019.

MATERIALS AND METHODS

The study was conducted in the Trans-Ural (Steppe Zone) of the Republic of Bashkortostan (Fig. 1). The research area is about 60 km^2. The relief in the study area is gentle with height differences ranged from 280 to 340 m a.s.l. There are several water reservoirs are located on the studied territory.

sulfate, chloride-sulfate, and mixed type of salinisation. The genesis of saline soils is due to a high content of water-soluble salts in soil-forming rocks, mineralised groundwater, and the arid climate in the Trans-Ural region [Bulchuk 1973].

The location of the soil points (pits), which were laid in the 1982 year was determined based on archival soil maps. The maps were georeferenced and digitised in the QGIS. The coordinates of soil points were imported into a tablet computer with a GPS navigator function and then used to find archived soil pits locations *in situ* of the investigated area. The archived soil pits were identified using a global positioning system (GPS) with an accuracy of ±3 m in the field. Then the five soil pits around each archived point were excavated. The soil for analyses was sampled from genetic horizons (A, AB, B). The scheme of the soil points location is presented on the map (Fig. 1).

All collected soil samples were air-dried, homogenised, and sieved by 1 mm mesh. The chemical analyses were carried out using standard (in soil science) laboratory methods [Arinushkina 1970; Sokolov (ed.) 1975]: the C_{org} content was determined by using the Tyurin method according to Orlov and Grindel; pH_{H2O} of soil solution – by potentiometry.

The concentrations and composition of water-soluble salts (dry residue) were determined in standard extract at soil/water ratio 1:5 [Mamontov 2002]. For it, the 100 g of prepared soil was mixed with 500 cm^3 of carbon dioxide-free water, then 3 min blending, and filtered. This solution was evaporated (dried) in ceramic cups, weighed and the soil-water extracts were calculated. The soil salinisation range is presented in Table 1.

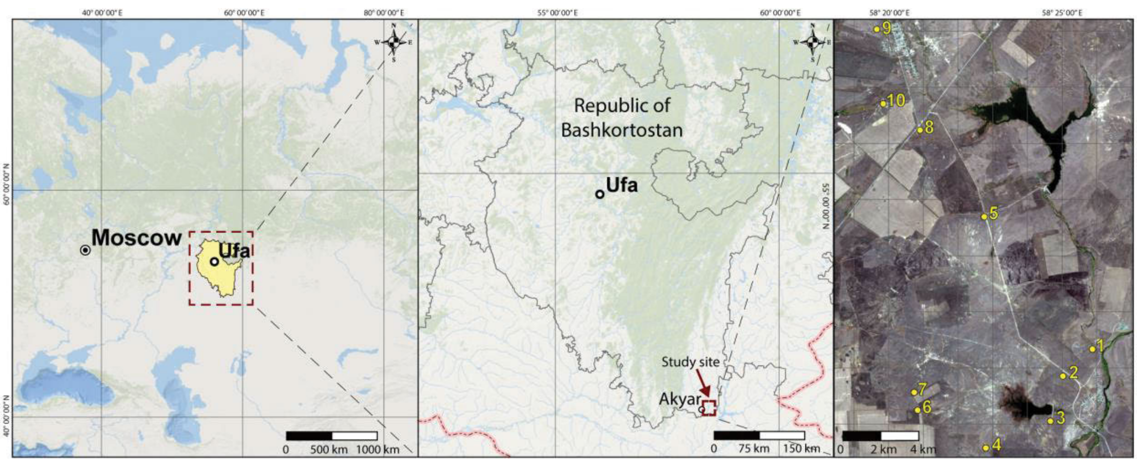

Fig. 1. Location of the study site and position of soil points (pits); source: own elaboration based on: Esri, Garmin, GEBCO, NOAA NGDC, Copernicus Open Access Hub, and other contributors

The study area has an extreme continental climate. The Atlantic air masses penetrating this zone, at the same time, they are transformed into drier and more continental due to the distance from the seas and oceans. Such conditions cause a high air temperature during summer period. The Asian anticyclone is affect during the cold season. This anticyclone is forms an extreme continental climate with cold winters and hot summers [Bogomolov 1954].

The soil cover is presented mainly by chernozems and solonetz soils with low C_{org} content in the Trans-Ural region. The soil-forming rocks (parent material) are mainly diluvial yellow-brown carbonate clays and heavy loams. The saline soils belong to

Table 1. The soil salinisation range

Level of soil salinisation	Content of dry residue (%)
Non-saline	<0.25
Slightly saline	0.25–0.50
Moderately saline	0.50–1.00
Highly saline	1.00–2.00
Extremely saline	>2.00

Source: Mamontov [2002].

For analysing the climatic parameters and their changes in the study area, the data from the closest meteorological station "Akyar" (51.867543 N, 58.220405 E), as well the additional data were obtained from sources: NASA and website www.pogodaiklimat.ru were used.

RESULTS AND DISCUSSION

The investigated soils were considered as virgin soils and presented by Chernozem Haplic Endosalic [IUSS Working Group WRB 2015] (soil points No. 1, 4), Chernozem Calcic Pachic (No. 2, 3), Solonetz Gypsic (No. 5, 6, 7, 10) and Chernozem Calcic Endosalic (No. 8, 9). Only the soil point No. 2 was previously in agricultural use, and for the last 10 years, it was abandoned.

According to the results of the 2019 survey, the content of organic carbon (C_{org}) is characterised as "low" and decreases with depth. The values range from 1.6 to 2.4% in A_1 horizon, and from 0.8 to 2.4% in AB horizon (Tab. 2). The comparison of C_{org} content values in soils dating to 1982 with 2019 shows, that the deterioration process was occurring for most areas (at least in 7 of 10 test sites). In some places, a decrease of C_{org} content by half was found (for example, point No. 2). We suggest that is due to the cessation of organic fertiliser application and the development of alkaline hydrolysis processes of organic matter. The development of these processes is indicated by an increase in pH of soil. We observed the reduction in thickness of humus-accumulative horizons (A + AB) during the last 37 years in most studied soil pits. Similar results were obtained under retrospective monitoring of the soils in the Ufa district (350 km north from the studied site). It was showed that for a long period of farm use (1982–2016), the fertility indicators have changed for the worse in most cases: there was a tendency of reduce in the thickness of humus-accumulative horizons and decrease in humus content and nutrients [Asylbaev *et al.* 2020].

Table 2. Changes in the parameters of soils in 1982 and 2019

Parameter	Content of organic carbon (%)		Humus horizon thickness (cm)		pH		Content of dry residue (%)	
	1982	2019	1982	2019	1982	2019	1982	2019
No. 1. Chernozem Haplic Endosalic: 285 m a.s.l. *n* = 5, t_{tbl} = 2.31 ($p \le 0.05$), t_{tbl} = 3.36 ($p \le 0.01$)								
A_1 0–30	3.7	2.5	48	47	6.6	7.6	0.04	0.2
t_{emp}	10.5		0.2		11.5		3	
AB 30–47	2.9	1.9	nd.	nd.	6.8	8.1	nd.	0.3
t_{emp}	7.2		nd.	nd.	16.5		nd.	nd.
B 47–65	1.7	1.2	nd.	nd.	6.8	8.2	nd.	0.6
t_{emp}	4.4		nd.	nd.	11.5		nd.	nd.
No. 2. Chernozem Calcic Pachic: 307 m a.s.l. *n* = 5, t_{tbl} = 2.31 ($p \le 0.05$), t_{tbl} = 3.36 ($p \le 0.01$)								
A_1 0–32	4.9	2.4	55	55	6.6	7.6	nd.	0.1
t_{emp}	38.5		0.7		9.7		nd.	nd.
AB 32–55	4.4	2.4	nd.	nd.	6.8	8.1	nd.	0.1
t_{emp}	23.9		nd.	nd.	7.8		nd.	nd.
No. 3. Chernozem Calcic Pachic: 301 m a.s.l. *n* = 5, t_{tbl} = 2.31 ($p \le 0.05$), t_{tbl} = 3.36 ($p \le 0.01$)								
A_1 0–27	2.1	2.4	47	45	7.2	7.9	nd.	0.1
t_{emp}	2.8		0.9		4.9		nd.	nd.
AB 27–45	2.0	2.2	nd.	nd.	7.2	8.1	nd.	0.1
t_{emp}	1.6		nd.	nd.	5.6		nd.	nd.
No. 4. Chernozem Haplic Endosalic: 320 m a.s.l. *n* = 5, t_{tbl} = 2.31 ($p \le 0.05$), t_{tbl} = 3.36 ($p \le 0.01$)								
A_1 0–15	2.9	1.9	38	37	6.6	6.9	nd.	0.3
t_{emp}	15.8		0.7		3.3		nd.	nd.
AB 15–37	1.5	1.0	nd.	nd.	6.2	7.7	nd.	1.0
t_{emp}	113		nd.	nd.	19		nd.	nd.
No. 5. Solonetz Gypsic: 324 m a.s.l. *n* = 5, t_{tbl} = 2.31 ($p \le 0.05$), t_{tbl} = 3.36 ($p \le 0.01$)								
A_1 0–16	2.1	1.6	28	27	7.4	8.4	nd.	0.6
t_{emp}	5.9		0.6		10.2		nd.	nd.
AB 16–27	nd.	0.8	nd.	nd.	nd.	6.9	nd.	2.1

cont. Tab. 2

Parameter	Content of organic carbon (%)		Humus horizon thickness (cm)		pH		Content of dry residue (%)	
	1982	2019	1982	2019	1982	2019	1982	2019
No. 6. Solonetz Gypsic: 335 m a.s.l. n = 5, t_{tbl} = 2.31 ($p \leq 0.05$), t_{tbl} = 3.36 ($p \leq 0.01$)								
A_1 0–9	1.7	2.4	18	20	7.4	7.7	nd.	0.0
t_{emp}	9.4		1.8		2		nd.	nd.
AB 9–20	0.7	2.2	nd.	nd.	7.7	7.9	nd.	0.1
t_{emp}	21.7		nd.	nd.	9.8		nd.	nd.
No. 7. Solonetz Gypsic: 329 m a.s.l. n = 5, t_{tbl} = 2.31 ($p \leq 0.05$), t_{tbl} = 3.36 ($p \leq 0.01$)								
A_1 0–14	3.1	1.7	40	38	7.3	7.36	nd.	0.7
t_{emp}	21.6		1.3		8.7		nd.	nd.
AB 14–38	1.0	1.7	nd.	nd.	7.5	7.9	nd.	0.6
t_{emp}	6.9		nd.	nd.	4		nd.	nd.
B 38–58	nd.	2	nd.	nd.	nd.	7.7	nd.	1.0
No. 8. Chernozem Calcic Endosalic: 323 m a.s.l. n = 5, t_{tbl} = 2.31 ($p \leq 0.05$), t_{tbl} = 3.36 ($p \leq 0.01$)								
A_1 0–33	2.7	2.1	47	46	7.4	7.9	nd.	0.2
t_{emp}	5.9		0.4		3.9		nd.	nd.
B 33–46	2.2	1.7	nd.	nd.	7.2	8.1	nd.	0.1
t_{emp}	10				5.6		nd.	nd.
No. 9. Chernozem Calcic Endosalic: 330 m a.s.l. n = 5, t_{tbl} = 2.31 ($p \leq 0.05$), t_{tbl} = 3.36 ($p \leq 0.01$)								
A_1 0–29	2.6	2.2	49	45	7.1	7.9	nd.	0.3
t_{emp}	5.7		1.8		6.5		nd.	nd.
AB 29–45	2.2	1.6	nd.	nd.	7.1	8.1	nd.	0.1
t_{emp}	10.4		nd.	nd.	7.2		nd.	nd.
No. 10. Solonetz Gypsic: 320 m a.s.l. n = 5, t_{tbl} = 2.31 ($p \leq 0.05$), t_{tbl} = 3.36 ($p \leq 0.01$)								
A_1 0–23	2.0	2.1	37	37	7.3	6.9	0.3	0.0
t_{emp}	1.9		0.7		3.6		3.6	
B 23–37	1.2	1.4	nd.	nd.	7.6	6.1	nd.	0.3
t_{emp}	2.4		nd.	nd.	7.2		nd.	nd.

Explanations: t = Student's t-test, emp = empirical, tbl = from tables, p = probability.
Source: own study.

The relief has a significant impact on soil formation, nutrients distribution, and salinization processes [CHAIEB *et al.* 2019; NASRI *et al.* 2015; PANKOVA *et al.* 1996; SCHOFIELD, KIRKBY 2003; SULEYMANOV *et al.* 2021a]. In points No. 3, 6, and 10 a insignificant increase in C_{org} content was found compared to 1982. There is also no salinization in the humus-accumulative horizons at these points. Both prosecces probably is due to the location of these points on elevated terrain elements, as well as because of a grazing reduction, which leads to decreasing in pasture degradation and soil erosion. The elevated terrain in most cases characterised by relatively deep groundwater and a capillary boundary. This indicates the absence or insignificant evaporation and upward movement of salts into the humus-accumulative horizons.

However, the points No. 1, 4, 5 and 7 are characterised by the presence of salts in soil profile, with increasing of them with depth, i.e. salinization/solonetzisation processes are occurring. The level of salt content in the studied soils is characterised from non-saline to highly saline (Tab. 1). The decrease in salinization occurred in point No. 10, which is located in the river floodplain. A decrease in exchangeable sodium and pH was also detected at this point. Probably a salinity reduction in this area related to the lowering of the groundwater level. Such processes were noted and described in the first soil salinity research work in this region [BULCHUK 1973]. Also a slight increase in C_{org} content and thickness of humus horizon at this point was observed.

The analysis of hypothetical salts composition shows that toxic salts are predominant in the series of studied saline soils. The toxic salts are presented by Na_2CO_3, $NaHCO_3$, $Mg(HCO_3)_2$, Na_2SO_4, $MgSO_4$, $MgCl_2$; non-toxic salts presented by $Ca(HCO_3)_2$ and $CaSO_4$. Water-soluble alkaline salts can raise soil pH to values that inhibit plants. Thus, some of the studied areas are characterised by depressed or absence of vegetation.

The salinisation processes are closely related to pH values in soil. The increase in pH was revealed at most soil points, which indicates the ongoing alkalinisation processes. The increasing of soil pH is due to the partial accumulation of harmful alkaline salts and sodium carbonates (points No. 8, 9). The carbonates can be inherited directly from calcareous parent material [Gile *et al.* 2007; Wilford *et al.* 2015]. The appearance of carbonates is due to the movement of carbonates from the underlying horizons to the upper layers. The increase in salinity and alkalinity of groundwater was also identified in the region [Abdrakhmanov, Popov 2010], which also affects on the increase of pH in the soil.

Over the past 37 years (1982–2019), the air temperature increasing has been observed for all months with comparing to the period 1937–1982 (Tab. 3). Therefore, the winters (November–January) are getting warmer and summers (June–August) are hotter. The average annual air temperature according to the data of the "Akyar" meteorological station is increased by 1.4°C over the analysed periods.

Our results are also comparable with other studies for the research area. According to the study [Abdrakhmanov, Popov 2010] the average air long-term temperature for 1994–2008 with comparing to the 1937–2008 period is increased by 1°C in the Trans-Ural steppe. The works of Sobol *et al.* [2015] and Sobol [2016] noted that in this region the air temperature increased by 1.8°C in 2000–2013 with comparing to the 1881–1980 period. At the same time, the most significant changes are observed for winter, i.e., the cold seasons of the year become much warmer.

The increase of average annual air temperatures in the Trans-Ural is combined with global patterns. The feature for the this region and the majority territory of Russia, that the air temperature is growing much faster (0.45°C in 10 years) than it averages in the world [Kattsov (ed.) 2017].

The comparing precipitation amounts for two periods (past time and modern) shows an increase of 28 mm in the average annual values (Tab. 4). However, a detailed analysis of the data shows that the increase in average annual values is due to an increase in precipitation from winter to spring (November–May). There is a decrease in precipitation in all summer and hottest months on 4.4 mm from 1937–1982 to the last 37 years has been identified. The obtained results are consistent with the reported scenario [Kattsov 2017], which predicts an increase in winter and reduction of summer precipitation in the 21st century in southern European Russia.

The composition of the region's precipitation contains hydrogencarbonate-sulphate, hydrogencarbonate-chloride-sulphate, chloride-sulphate magnesium-sodium-calcium, magnesium-calcium, and sodium-magnesium-calcium. The mineralisation of precipitation over the long term is varies significantly: from 10.6 to 81.5 mg·dm^{-3}, depending on location in the South Urals [Abdrakhmanov, Popov 2010]. The intensification of technogenic impacts led to a shift in the extreme pH values both towards acidification (up to 2.0) and towards alkalinisation (up to 9.0).

The reduction of precipitation amount, high air temperatures in summer months, and increase of precipitation in winter create the conditions for two opposite processes, depending on soil location and groundwater level. On the one hand, the decrease in the groundwater level is gradually leading to desalination of solonchaks soils and their transformation into solonetz type. On the other hand, in the areas with close groundwater levels (near rivers, reservoirs and lakes), the high air temperatures and low precipitation lead to active evaporation. Such evaporation leads to an upward movement of water-soluble salts, which are accumulated in the upper layers or subsurface of the soil. Thus, for agricultural issues and other soil measures, the constant monitoring and mapping of saline soils are necessary [Suleymanov *et al.* 2021b].

Table 3. Values of the average monthly and annual air temperature (°C)

Period (years)	Temperature in												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	year
1st (1937–1982)	–16.4	–15.4	–8.7	3.9	13.2	17.9	19.8	17.8	11.7	2.5	–5.8	–12.5	2.3
2nd (1982–2019)	–13.8	–13.2	–6.9	5.0	13.6	19.2	20.5	18.9	12.3	4.4	–4.9	–11.1	3.7
Change (2nd–1st)	↑2.6	↑2.2	↑1.8	↑1.1	↑0.4	↑1.3	↑0.7	↑1.1	↑0.6	↑1.9	↑0.9	↑1.4	↑1.4

Explanation: ↑ = increasing (warming).
Source: own study based on NASA [undated] and Pogoda i klimat [undated].

Table 4. The amount of precipitation (mm)

Period (years)	Precipitation in													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	J-J-A	year
1st (1937–1982)	13.7	17.3	15.8	19.7	28.9	41.6	45.6	35.9	22.2	24.1	18.5	16.3	41.0	299.4
2nd (1983–2019)	22.5	21.4	22.6	28.3	32.2	34.1	44.3	31.3	23.6	23.6	22.3	22.0	36.6	327.4
Change (2nd–1st)	↑8.8	↑4.1	↑8.6	↑1.4	↑8.6	↓7.5	↓1.3	↓4.6	↑1.4	↓0.5	↑3.8	↑5.7	↓4.4	↑28.0

Explanations: ↑ = increasing, ↓ = decreasing, J-J-A = summer months (July, June and August).
Source: own study based on NASA [undated] and Pogoda i klimat [undated].

CONCLUSIONS

The climate is one of the main factors in soil formation. We detected the degradation processes – salinisation and alkalinisation since 1982 in the Trans-Ural steppe zone. It was also determined a decrease in C_{org} content and thickness of the humus horizon during the last 37 years at most study sites. The toxic salts predominate in saline soils, indicating a decreasing trend in soil fertility and biological activity.

Changes in the climatic parameters at the Trans-Ural (Steppe Zone) are consistent with global trends and forecasts for Russia. We have identified a trend of increase in average annual and particularly summer air temperatures, a decrease in summer precipitation with their high mineralisation. The increasing of alkalinity and mineralisation of groundwater indicate the intensifying processes of aridisation in this territory. At the same time, depending on the level of groundwater and hydrological regime, the processes of desalinisation of saline soil occur; or vice versa salinisation due to active evaporation and the rise of water-soluble salts to the soil surface. We assume that if this climatic scenario continues, the degradation processes will proceed at an accelerated pace. Increasing temperatures and decreasing precipitation in the summer will contribute of soil fertility decline, salinisation, and desertification. Such negative processes will become more frequent in the arid and semi-arid regions.

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