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Soil salinity assessment in the south of the steppe zone of Russia based on multi-temporal high-resolution satellite image

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Introduction

Remote assessment of soil salinity is a rather complicated task; therefore, work in this area is necessary and important. Knowledge of the relationship between spectral characteristics and soil salinity makes it possible to use satellite images for mapping and identification of salinity. This study is devoted to the development of models that can be used to assess soil salinity in the natural solonetzic complex (Republic of Kalmykia, Russia) using multi-temporal high-resolution space images and principal component analysis (PCA) and multiple linear regression (MLR).

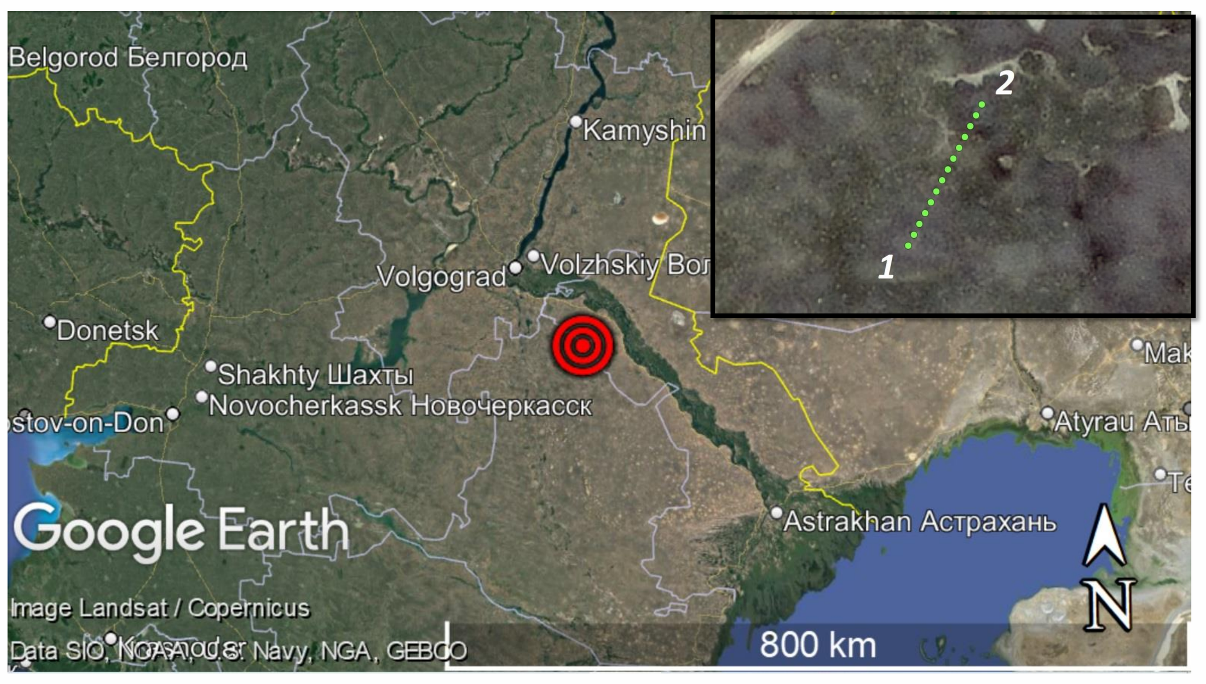

Figure 1: The location of the study area on the Google Earth website and transect on the image from the SuperView-1 spacecraft. Coordinates of the beginning of the transect (point 1) are 47.96472° N, 45.55139° E; coordinates of the end of the transect (point 2) are 47.96524° N, 45.55180° E.

Methodology

The studies were carried out on a key site located in the virgin territory within the Caspian Lowland (Fig. 1). Field work was carried out in 2010 and 2021. A 64-m-long transect was laid from the center of one round depression to the center of another (Fig. 1, 2). Wells 1–2 m deep were drilled and samples were taken. Electrical conductivity (EC1:5) in samples was measured. The weighted averages were calculated for the 0–30, 0–50, and 0–100 cm layers.

Images from the QuickBird (2007) and SuperView-1 (2021) spacecraft with a spatial resolution of 2 m were used. The analysis of high-resolution multi-temporal images was carried out in the SAGA GIS program using the Resampling module and the PCA module (Bahrenberg, Giese and Nipper, 1992).

Mathematical analysis of the relationship between the principal components and soil salinity was carried out by MLR in the STATISTICA program.

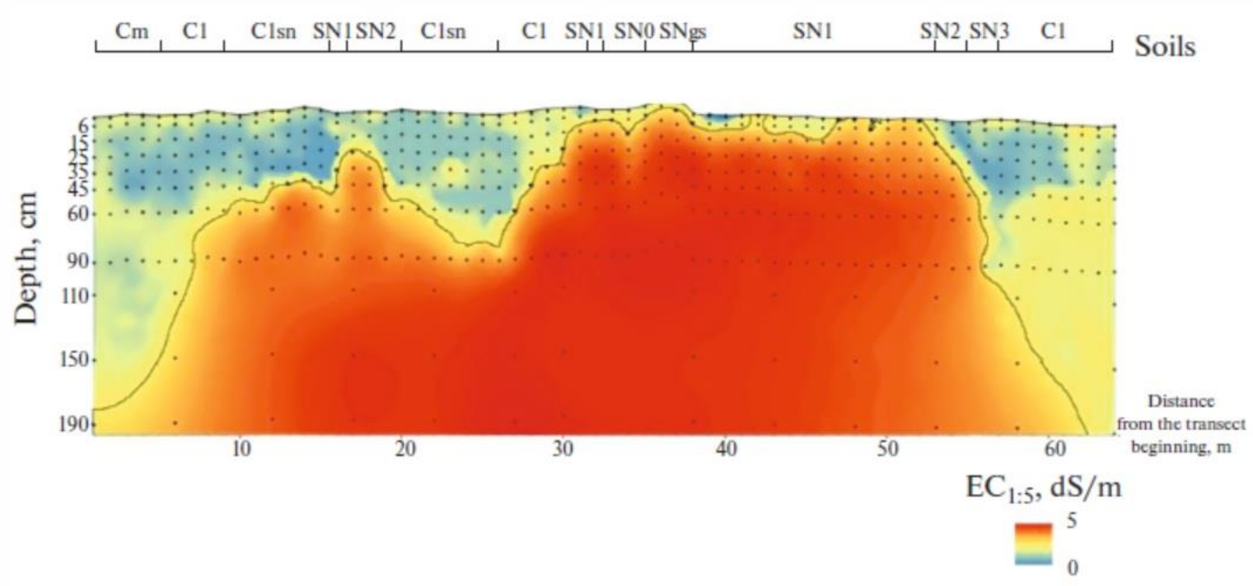

Figure 2: The soil salinity profile along a 64-m transect (EC1:5). The following soils were found on the transect: meadow-chestnut soils (Cm), light chestnut nonsaline (C1), light chestnut solonetzic soils (C1sn), crusted solonetz (SN0), shallow solonetz (SN1), medium solonetz (SN2), deep solonetz (SN3). The dots show the location of the soil samples (mean sampling depth). The line delineates the boundary between the saline and nonsaline layer (EC1:5 = 0.25 dS/m).

Results and Discussion

The PCA is used to reduce the number of parameters while keeping important information as components. The resulting components were used in MLR analysis to build soil salinity prediction models. Insignificant parameters were removed one by one from each model and the models were rebuilt until all the coefficients turned out to be significant (Tab. 1). The models below are the final version and can be used to map soil salinity (all parameters are statistically significant with $p < 0.05$).

Table 2: The final results of MLR for components and salinity in different soil layers.

EC 0-30 см n=64	Mult. R=0.81, R^2=0.65, adjusted R^2=0.63, MSE=0.07, RMSE=0.26 F(3,60)=37.306, p<0.00, Standart estimation error: 0.28					
	BETA	SE BETA	B	SE B	t(60)	p-level
α			5.17	2.16	2.39	0.02
Component 1	-0.28	0.08	-0.01	0.00	-3.46	0.00
Component 2	0.62	0.08	0.02	0.00	8.06	0.00
Component 4	0.46	0.08	0.04	0.01	5.74	0.00
EC 0-50 см n=64	Mult. R=0.88, R^2=0.77, adjusted R^2=0.75, MSE=0.14, RMSE=0.37 F(4,59)=48.947, p<0.00, Standart estimation error: 0.39					
α			1.89	5.06	0.37	0.71
Component 1	-0.38	0.08	-0.01	0.00	-4.52	0.00
Component 2	0.54	0.08	0.03	0.00	6.75	0.00
Component 3	-0.23	0.10	-0.02	0.01	-2.37	0.02
Component 4	0.50	0.07	0.08	0.01	7.56	0.00
EC 0-100 см n=64	Mult. R=0.91, R^2=0.83, adjusted R^2=0.82, MSE=0.18, RMSE=0.42 F(4,59)=71.938, p<0.00, Standart estimation error: 0.44					
α			-8.04	5.72	-1.41	0.16
Component 1	-0.51	0.07	-0.03	0.00	-7.12	0.00
Component 2	0.37	0.07	0.02	0.00	5.49	0.00
Component 3	-0.37	0.08	-0.04	0.01	-4.49	0.00
Component 4	0.61	0.06	0.13	0.01	10.69	0.00

In the MLR analysis, approximating models were selected for different soil layers:

in the 0–30 cm layer:

$$EC = -12.1562 - 0.0071g1 + 0.0185g2 - 0.0053g3 + 0.0340g4 + 0.0171g5 - 0.0564g6 + 0.0368g7,$$

in the 0–50 cm layer:

$$EC = -2.79553 - 0.01338g1 + 0.02568g2 - 0.01841g3 + 0.07428g4 + 0.00131g5 - 0.03214g6 + 0.00937g7,$$

in the 0–100 cm layer:

$$EC = -3.33529 - 0.02327g1 + 0.02080g2 - 0.04066g3 + 0.11265g4 - 0.00594g5 - 0.02470g6 - 0.04929g7,$$

where g is the grid of the corresponding component.

Conclusions

The analysis of remote data was used as a basis to calculate principal components. It was found that the first three components explained almost 97% of the entire space image variance.

The models built on the basis of the analysis between salinity and the main components of the satellite image by the multivariate regression method describe soil salinity well according to remote sensing data (R2 of the model is 0.68, 0.77, and 0.83 for the 0– 30, 0–50, and 0–100 cm layers, respectively).

When tested on the control independent sample, the constructed models showed good convergence between the predicted and real data.

In this study, models have been developed that will be useful for assessing the salinization of soils in the solonetzic complex of the dry steppe using high-resolution satellite images.

References

[1] Bahrenberg, G.; Giese, E.; Nipper, J. Statistische Methoden in der Geographie 2—Multivariate Statistik; Borntraeger Gebrueder: Stuttgart, Germany, 1992; pp. 198–277.

Acknowledgements

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International Network of Salt-Affected Soils

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