THE POSSIBILITIES OF REMOTE DIAGNOSTICS OF SOILS SALINISATION IN ARID REGIONS

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Abstract

The possibilities of using of aero- and space photographs for the remote diagnostics of the salinisation processes in arid regions are considered in the work. The area of investigations was territory of Dzhizakskaya steppe of Uzbekistan (the former Soviet Union). The main soil types are: serosems, meadow-serosemic, meadow, swampy-meadow soils (with different salinity level) and different species of the solonchaks. Analysis of remotely measured data showed that soils spectral brightness linearly correlates with the salts contents. Standard error of salts estimation is 2.34 %. The regression has a negative character: the more salinity level, the smaller values of soils spectral brightness.

Spectral classification of the colour composite allows to separate 5 classes of salinity:

1) non-saline area (less than 1 mg-eq Na/100 g in the upper 1m layer),
2) areas with slight salinity (1-2 mg-eq Na/100 g),
3) complexes of slight and medium salinity,
4) areas with medium salinity (2-6 mg-eq Na/100 g),
5) areas with high (6-12 mg-eq Na/100 g) and very high(more than 12 mg-eq Na/100 g) salinity.

Most informative for the determination of salinity level is green band, where non saline and slightly saline soils are differed from soils with medium salinity with the accuracy not more than 70%

1. Introduction

Remote monitoring of the soil's condition is especially widely used in arid and semiarid regions, with poor vegetation cover. For these territories the most urgent task is control of the processes of soils salinisation, humus losses and aridisation using remote sensing methods as the most operative tool of the investigation.

Investigations carrying out in the laboratory conditions showed that soil with different salinity have different ranges of the levels of spectral reflectability [3,4]. The most informative part of the spectrum was near infrared band - - values of the spectral reflectance coefficient (SRC) at 750 mcm - ρ_{750}. Spectral reflectance coefficients of arid and semiarid soils significantly correlate with parameters of chemical composition: contents of water-soluble salts, carbonates, gypsum, humus and ferric hydroxides [3,4,8,9]. All these relationships also had been found for the spectral reflectance coefficients measured in the lab - i.e. for the soils with the same moisture (air-dried) and surface conditions (soil samples were crushed and sieved through the sieve with the holes size 0.25 mm, then reflectance surface was smoothed before measurements by special concave glass).

In natural conditions the level of soils' spectral reflectance is the result of multifactor impact of coloured components (and their proportion just at the reflectance surface), soil surface structure and slope, moisture differences, as well as the survey conditions. All these circumstances should be taken to the account for the correct interpretation of the data obtained by the remote sensing (RS) methods.

The aim of the given investigation was an assessment of the possibilities to use remotely measured values of the spectral reflectance for the studying of the soil cover in semiarid regions.

2. Objects and materials

2.1. General characteristic of the area

Area of investigations was the territory of Dzhizakskaya steppe of the Uzbekistan (the former Soviet Union), which is located at the proluvial plain of the Turkestan's Edge and has a continental subtropical climate. The amount of annual rainfall is from 150 to 300 mm, most of the precipitation falls in spring and winter. The mean annual temperature is 14^0 C, summer maximum - $+43^0$ C, winter minimum - -40^0 C in January. Soil's parent material is represented by the proluvial deposits removed by the small water streams from the Turkestan's Edge. At the watersheds - loessy loams, at the foots of the Turkestan's Edge - paleosoian limestones, sandstones and slates are predominated. The distribution of the soil types depends on the lithology, relief and ground water level. The main soil types are: automorphic - serosems, hydromorphic - meadow-serosemic, meadow, swampy-meadow soils (with different salinity level) and different species of the solonchaks (soils are named according to [1, 10] .

2.2. Characteristic of the objects of investigation

The area of the virgin lands at the territory of Dzhizakskaya steppe, square approximately 100 ga was used as a typical (key) site. This territory occupy the southern part of the watershed (part of the loessy hills of the Lomakinskaya plain) and the valley of the temporary waterstream. The height under the sea level: from 398 to 410 m; groundwater level: from 0.3 to 12 m (in spring). Soils have been represented by serosems, serosemic-meadow, meadow-serosemic, meadow, swampy-meadow peaty soils (with different salinity and gypsum contents) and solonchaks (meadow, swampy-meadow and crust species). Soil samples were collected from the surface (0-3 cm)

in autumn simultaneously with the aerophothograpy survey. Humus contents, total amount and the composition of easily soluble salts, gypsum, carbonates, non-silicate ferric compounds were estimated . The data, which we've received for this key-site, were tested for the whole territory of Dzhizakskaya steppe.

Investigated soils are characterised by sufficiently high level of humification. Humus contents increase with the increasing of soil's hydromorphity: serosemic soils that are located at the top of the watershed (where groundwater doesn't influence processes of soil formation) have lowest organic matter contents, while meadow swampy peaty soils - located at the bottom of the valley have highest values of the humus contents. Gypsum and carbonates may have both automorphic (in serosems) and hydromorphic (in solonchaks) origin, so they are present in all soil types, but their contents in average are higher in the hydromorhic soils. Salts in the investigated soils have hydromorphic origin, so automorphic serosems serosemic-meadow and meadow-serosemic soils in general don't contain water-soluble salts at least in the upper horizons. Solonchaks - especially crust-species - contain in average 7-10% of water-soluble salts. Sulphate- and chloride-anions , natrium- and calcium-cations are prevailed in the salt's composition.

2. 3. Materials and equipment

Multispectral satellite photographs (CT-200, USSR) in the green (0.500-0.600 mcm), red (600-0.700 mcm) and infrared (0.700-0.800 mcm) wavebands, scale 1:500 000 and panchromatic B&W aerophotographs, scale 1:2000,1:5000 have been used for the study. Survey was made in July and September.

The Integrated Land and Water Informational System (ILWIS) developed in the International Institute for Aerospace Survey and Earth Sciences (ITC, Enschede, Netherlands) has been used as a main software for the study.

3. Results and discussion

Panchromatic black-and-white aerophotographs of the key-site were used for the study of relationships between soils salinity and spectral reflectance. The photographs of the key-site of investigated area were scanned and converted into ILWIS (so below all of the photographs will be named maps). Maps had been georeferenced, geometrically transformed and merged to the single map [7]. Soil map (with the same scale) with the set of control points where soil samples had been taken in the field were digitized. Then both maps was overlaid so each point marked at the soil map got the appropriate value of phototone density (spectral brightness) expressed in digital numbers.

As it has been mentioned before, soils spectral reflectance values, measured in the laboratory conditions, correlate with the amount of coloured compounds in the soils. To investigate the possibilities of using of the remotely sensed values of the spectral brightness for the estimation of the extent of salinity, we measured the SB-values of the different soil types in the number of the control points at the photomaps and compared them with salts contents in the corresponding soil's samples. Regression analysis revealed linear correlation between contents of water soluble salts and soils spectral brightness ($r=0.86$ for $n=28$). Salts contents can be calculated from the spectral brightness values as following:

$$\text{salts},\% = 17.32 - 0.07\ SB,$$

where SB - spectral brightness, expressed in the values of the phototone density (conventional units). Standard error of salts estimation is 2.34%.

When multiple regression analysis was applied, the values of the correlation coefficient increased with the increasing of the number of the factors taking to the account. For the set of 4 factors - humus content, carbonates, gypsum and water-soluble salts contents - correlation can be expressed as:

$$SB = 223 - 0.5(C\ org.,\%) - 7.21(salts,\%) + 0.99(CaCO_3,\%) - 1.91(CaSO_4 x 2H_2 0,\%)$$

Correlation coefficient is 0.72 ($n=24$).

Thus the values of the spectral brightness of the soils in natural conditions are determined at 52% (determination coefficient $r^2=0.72^2=0.52$) by the contents and the composition of the 4 main coloured components (i.e. 52 % of the variation of the spectral brightness (SB) values is due to the correlation between SB and four variables mentioned before, the other 48% -are determined by the other random factors, that we didn't take to the account) . This results agree with the data received before (for the measurements made in the lab). According to that data [4] 4 main coloured components: humus, carbonates, gypsum and water-soluble salts - determine the values of the spectral reflectance (ρ_{750}) also approximately at 50%. But in comparing with the lab-data the role of each of the components in natural conditions has changed. If in case of the air-dried soil samples the influence of humus content was greatest (35% of the total variation of the ρ_{750}-values) and the role of salts (6.5% from the total variation), gypsum (5.2%) and carbonates (5.6%) was much more slight [4] then in situ for the soils in the field conditions situation is quite another. According to calculation [2] the influence of the water-soluble salts contents on the spectral brightness is the greatest - 35% from the total 52%, gypsum contents also plays an important role - 15% from 52, and the influence of the humus and carbonates is very small - less than 1.5%. Totally 4 these components determines the level of the soils spectral brightness at 52% (35 + 15 + 0.8 + 1.2 = 52). The rest 48% of the variation of the spectral reflectance probably are caused by the differences in soil mineralogy and -in field conditions - also by water-contents in the soils.

In general it's possible to conclude that the soils of the local part of the Dzhizakskaya steppe, which are located at the different relative heights and has been formed in the different hydromorphic conditions have specific ranges of their spectral brightness. The values of spectral brightness correlate with the salts contents and also depend upon the amount of other coloured components in the soils. In natural conditions the most important role in the formation of the level of the soils spectral brightness play water-soluble salts and gypsum contents. Totally humus, water-soluble salts, gypsum and carbonates determine soils spectral brightness at 52%. Linear equation can be used for the estimation of the salts content in the soils from SB-values with standard error 2.34%. Estimation of the contents of the other components from the SB-values cannot been made because of the insufficient narrowness of the correlation (r^2<0.5).

These results received for the key site, have been checked out for the whole territory of Dhizakskaya steppe .Digitized soil map and map of soils salinity (scale 1:200 000) of the territory, square near 300 000 ga have been overlaid with the geometrically corrected satellite images (CT-200). To check out the possibilities of determination of salinity levels we overlaid the images with the salinity map and calculated the confidence limits of spectral brightness for the sites of the different extent of salinity. The most informative turned out green and near infrared bands

Calculations indicated that non-saline soils (contents of water soluble Na^+ is less than 1-2 mg-eq/ 100 g) can be significantly (with the confidence level 0.7) distinguished from the saline soils with medium (2-6 mg-eq Na/ 100 g), high (6-12 mg/eq Na/ 100g) and very high (>12 mg-eq Na/ 100 g) extent of salinity using both green and near infrared bands. Non-saline soils (mostly - typical serosems) are characterised by the highest values of the spectral brightness, whereas increasing of the salinity level leads to decreasing of the spectral brightness. This is most evident in the infrared band, where soils with very high salinity have the lowest values of the spectral reflectability. Nevertheless, most informative for the determination of the degree of salinisation is green band, that is in accordance with our data received before [5,6]. Using the data of the green band we can determine non-saline soils from the soils of the medium extent of salinity, that is very important for the monitoring purposes.

As far as soils of the different extent of salinity have different reflectance it's possible to carry out spectral classification analysis. Using the method of supervised classification (nearest neighbourhood algorithm) allows to determine 5 salinity classes:

non-saline areas,
areas with slight salinity,
areas with medium salinity,
complexes with slight and medium salinity,
areas with high and very high salinity.

For the final classified map of salinity received as the result of the combination of the classified image and GVI (green vegetation index) - map the accuracy of the classification have been examined. The accuracy of the estimation of the non-saline areas is 69%, areas with medium, high and very high salinity - from 50 to 63%. This results are in accordance with the data received in the calculations of the confidence limits of the SB-values for the soils with different degrees of salinity. This means that differences in the spectral reflectance allows to distinguish soils with the different salinity level using satellite photographs with the accuracy approximately 50-70%.

4. Conclusions

1. Spectral reflectance of the soils depends upon the contents and the composition of the coloured components. Values of the soils spectral brightness in the natural conditions (expressed as a phototone density) significantly correlate with the total amount of humus, carbonates, gypsum, water-soluble salt. These four components determine 52% of the variation of the soils spectral brightness.

The most important role play water-soluble salts and gypsum. Correlation between salts contents (S) and spectral brightness (SB) of the soils is expressed by the negative linear function: S,% = 17.32 - 0.07 SB, value of the correlation coefficient 0.86, standard error 2.34%.

2. Spectral classification of the colour composite allows to separate 5 classes of salinity: 1) non-saline area, 2) areas with slight salinity, 3) complexes of slight and medium salinity, 4)areas with medium salinity, 5) areas with high and very high salinity. Most informative for the determination of the salinity level is green band, where non saline and slightly saline soils are differed from soils with medium salinity with the accuracy not more than 70% (CL=0.7).

3. The accuracy of the spectral classification is in accordance with the range of natural variation of the soils spectral brightness, and can be predicted by means of calculation of the confidence limits of soils spectral brightness.

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