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Remote Study of Natural and Man-Caused Transformation of the Soil Cover of Intermountain Basins in Southern Siberia

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Abstract—Based on decoded satellite images and digital models of relief, large-scale maps were compiled to make a basis for estimating the natural and man-caused transformation of typological diversity of the soil cover of the steppe basins in the Altai-Sayan region. The boundaries and information content of soil contours with amendments from the remote data can be used as controllable indicators when creating schemes of soil-ecological monitoring.

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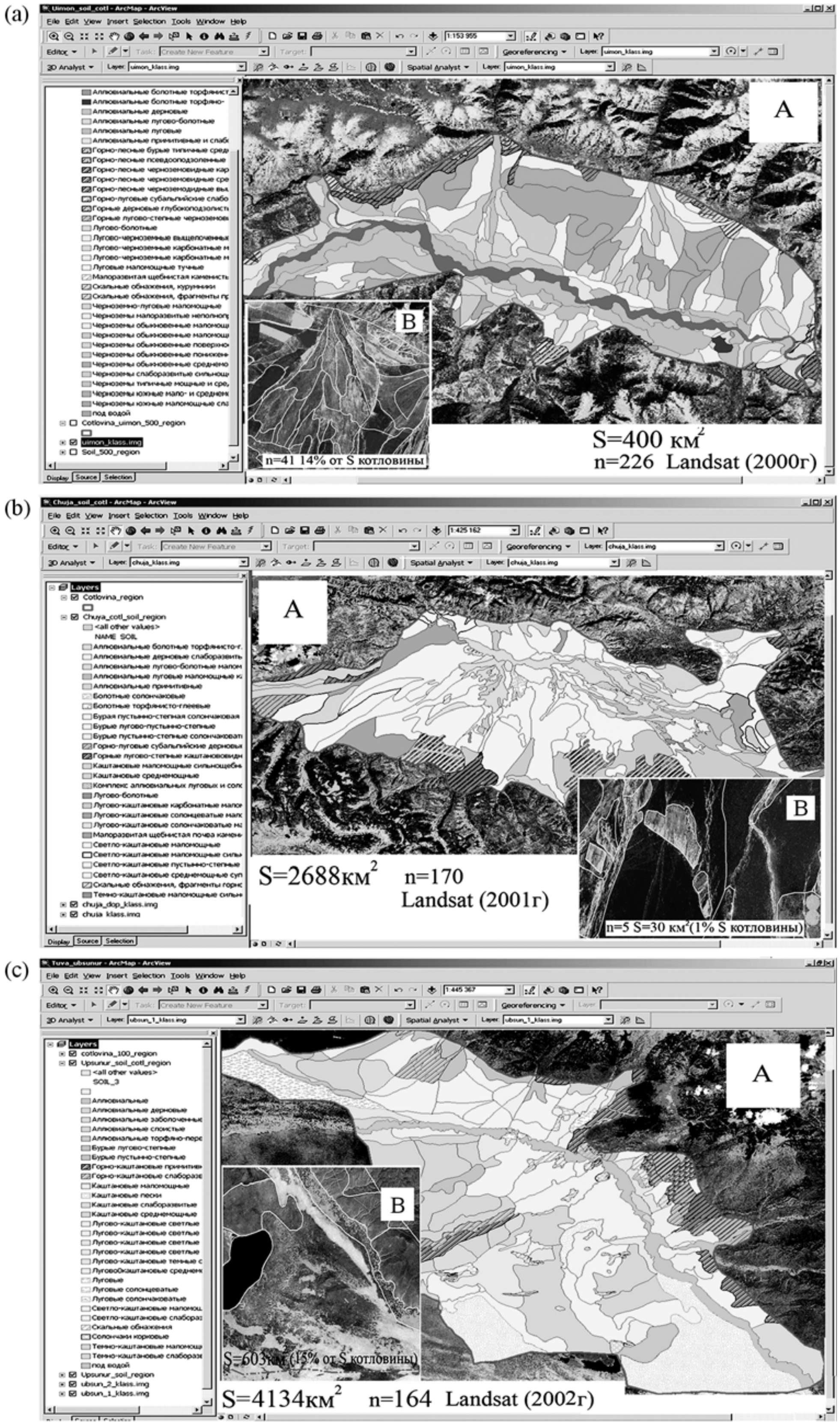
Key words: soil-ecological monitoring, geoinformation systems, digital model of relief, typological diversity, steppe basins

The Altai-Sayan highlands hold a special place in the world's civilization. Their vast territories host large industrial complexes, but there are also virgin territories with natural ecosystems largely representing the species diversity of Eurasia. A peculiar combination of natural factors yields unique landscapes. Their functioning is greatly complicated by the economical activities which often lead to ecosystems with partially destroyed components. In some cases the destruction of components of ecosystems totally demolish them. The mountain regions are difficult to access, and climate is very harsh there. Hence, it is unlikely to create an effective system of environmental monitoring with a wide net of stations. As GIS-technologies were introduced into the practice of ecological studies, the situation changed drastically: It has become possible to obtain spatially distributed data providing the necessary efficiency and great surface coverage including the regions that are the most difficult to access. To study the natural objects using the time series of satellite images is of special importance for monitoring the soil cover, since, when supplemented with materials of ground observations, they reveal how the factors of soil formation manifest themselves or how the land is used. The available data characterize the spatial-temporal dynamics of the vegetation cover, water resources, and other objects of the natural environment of the mountain areas in the south of Siberia. However, the soil cover of the region has not been studied in the context of the given problem in spite of its ecological and economical significance. The purpose of our work is to develop the methodology of remote monitoring of the soil cover of steppe basins (Uimon, Chuya, and Uvs-Nuur), each one featuring a special way of soil formation related to the complex of natural conditions and at the same time having much in common in the system of their industrial use. A number of fundamental requirements should be observed while monitoring the soil cover, such as significance of the spatial data and controlled parameters. As general parameters typical of all basins we considered the areas and information content of the soil contours, and as particular parameters, specific effects of the natural and man-caused influence on the soil cover in each of the basins.

MATERIAL AND METHODS

To reveal elements of the anthropogenic infrastructure and degree of the territory fragmentation, we used general geographic maps, which also served as a basis for geographic correction of the space images. Thematic soil and geobotanic maps were used as auxiliary for deciphering [1–4]. Medium-scale soil maps of the key areas are based on the decoded Landsat images (see the figure). Classification of the spectral image in the software environment ERDAS IMAGINE followed by vectorization in ArcGIS was used as a method of interpretation of the Landsat images. The basins are clearly distinguished in the Landsat images by the regular composition of structural elements and are marked as isolated geomorphological units. Within each of the basins the typological diversity was estimated quantitatively, taking into account the specific local conditions of the natural and man-caused factors of soil cover differentiation, which are reflected in the Landsat images. The natural factors that govern the soil diversity and are clearly distinguished in deciphering include vast mountain aprons, fans of temporary streams, river valleys, moraine hills, cryogenic meso- and microforms. Tillage and irrigated agriculture are the basic types of economic activities which lead to newly formed soil varieties, sometimes of high classification rank. To divide



Soil maps based on deciphering of the space images (A) and the basic types of the natural and man-caused transformation of typological diversity of soil cover (B) in basins of southern Siberia: Uimon (a), Chuya (b), Uvs-Nuur (c).

objectively the valley part and the adjacent mountain slopes, the digital models of the relief were created with the help of Spatial Analyst in ArcGIS and ERDAS IMAGINE describing relief as a regular matrix of altitudes of the Earth's surface.

RESULTS AND DISCUSSION

Uimon basin. The provincial features and industrial significance of the basin have been thoroughly analyzed in works on its history, structure and soil features [5]. However, the typological diversity has not been reflected on the available maps and schemes of the soil cover of the region because of their small scale. These maps and schemes show the soil plots within the basin in general. The contours of chernozems, meadow-chernozem, chernozem-meadow, and mountain-forest chernozem-like soils unite the soils of auto-, semihydro- and hydromorphic types of soil formation and the adjacent slopes. The Landsat images significantly increase the information value of the thematic content of soil maps. The phototone, structure and texture easily distinguish 10 to 12 varieties of the automorphic soil formation, up to 14 of hydro- and semihydromorphic soil formation, and up to 10 varieties of slope soils (Table 1). Typical features of the basin relief include vast fans of rivers flowing down from the ridge tops (these fans are deeply incised into the basin bottom), wide floodplain of the Katun', its modern terrace and fragments of ancient high terraces. Specific chernozems with poorly developed profile form within the fans in zones of accumulation, while their types and varieties differing in the rubble content and erosion transformation form on the eluvial and transit positions. The results of development of erosion-accumulation processes on the aprons were estimated on the basis of DEM. The degree of erosion transformation of chernozems on the aprons is significantly higher than in the central part of the basin. As follows from the determinations within a separate fan, which makes up to 14% of the basin area, more than 40 soil varieties form (see the figure). The soils of the isolated contours differ in the contents of humus and granulometric fractions, thickness of humus horizon. In general, slightly and moderately washed chernozems occupy 17% of the basin area and contribute more than 5% to the total typological diversity. New structural elements of the soil cover within the basin are due to the agriculture practice, which has a long history and in certain periods was involved with irrigation of both tillages and hayfields. Erosion development in the group of chernozem soils promoted the formation of slightly and moderately washed chernozems and meadow-chernozem soils occupying 30% of the total area and contributing about 10% to the total typological diversity.

Chuya basin. No special studies were conducted to reveal the typological diversity of the soil cover of the basin. The characteristics of genesis, geography and systematics of the most widespread soil types were studied within the system of the other basins [6]. The scheme of distribution of the basic types [3] demonstrates the diversity of automorphic dry-steppe soil formation in the basin within the general contour that occupies 53% of the total area (Table 2). Semihydromorphic nonsaline and saline soils are also isolated within a single contour that occupies 16% of the area. A contour of insignificant area (0.5% of the basin area) includes the whole diversity of hydromorphic soils.

The characteristic features of the basin well distinguished in the Landsat images include the flat, sometimes low hilly moraine or cryogenic relief and wide distribution of desert steppes. Within the basin one can clearly decipher the plots of light chestnut shallow sandy-loam or loam soils in which the solid pebble-rubble horizon is located at a depth of 30 cm, and light chestnut soils high in rubble formed on the moraine deposits filled with pebble and rubble up to the upper horizons. Their plots are presented by the largest contours and occupy 14 and 26.5% of the total basin area. Brown desert-steppe saline soils form under the feather-grass steppes typical of the Chuya basin under the conditions of polygonal bumpy permafrost relief. They form the contours of smaller size and occupy 10% of the total area.

Significant part of typological diversity of the soil cover is formed under the influence of the temporary excessive moistening and salt concentration. In a relatively small area in the Chuya valley and on the shores of small lakes one can follow the whole range of transition from saline chestnut soils to puffed solonchaks. The Landsat image provided data to distinguish 10 varieties of hydro- and semihydromorphic soil formation, which occupy 22% of the total area. The primary anthropogenic factor of the change of typological diversity of soils is the artificial irrigation widely used in agriculture from ancient times to present day. According to the available data, the irrigated meadows of the basin are derivative [3], they appeared in place of the once-existing steppe formations. The zonal chestnut soils are replaced with the meadow, meadow chestnut alkaline and saline soils. The distribution range of these soils is clearly seen in the Landsat image, providing the data for distinguishing the soil differences with an area much larger than semihydromorphic soils of natural ecosystems.

Uvs-Nuur basin. The relief of the basin part located within the Tuva Republic is composed of a flat-undulating plain with relict ranges of hills. The mountain apron plains of the southern slopes of Tannu Ola, ancient terraces and modern valley of the Tes Khem River merge with the Uvs-Nuur lake-adjacent depression. The eolian hilly plains of the Tsuger-Eliss sands occupy a significant area in the southeast. The soil cover of the steppe basins of Tuva is shown on maps of both small and medium scale [1, 6] contrary to the intermountain basins of Altai. This is why the Soil Map of the Steppe

Table 1. Quantitative comparison of the content of soil map of the Uimon basin comped using Landsat images, and schemes of distribution of the main types of soils on the territory of Gorny Altai Autonomous Oblast [3]

Soil	Area of a soil contour, km^2		
	Total	min	max
Chernozems	**291.9**	–	—
regular medium	48.4	0.3	10.2
regular surface-boiling	25.6	0.4	8
regular lowered-boiling	0.9	–	–
regular thin slightly washed	4.3	1.7	2.7
regular thin moderately washed	3.3	1.2	2.1
south thin and medium	5.2	2.0	3.2
south thin slightly washed	44.4	1.9	20.9
immature highly rubbly	2.2	–	–
undeveloped	27.8	1.1	5.6
undeveloped non-full-profile	8.1	0.4	1.6
Meadow-chernozem and chernozem-meadow leached	**85.9**	–	–
meadow-chernozem leached	10.5	0.4	2.3
thin meadow-chernozem carbonate and medium	14.7	0.3	2.6
thin meadow-chernozem carbonate slightly washed	15.4	0.2	2.9
thin chernozem-meadow	31.9	0.2	4.1
medium chernozem-meadow	31.9	0.2	4.1
thin meadow rich	7.7	0.2	2.1
meadow-boggy	0.5	–	–
alluvial meadow	41.2	0.3	8.5
alluvial boggy peaty and peaty-gley	1.5	0.4	1.2
alluvial meadow-boggy	6.2	1.0	1.4
alluvial sod	32.6	0.2	11.6
alluvial primitive and raw	16.2	0.2	4.0
Mountain-forest chernozem-like soils	**23.3**	–	–
mountain-forest chernozem-like thick and medium	2.8	0.3	1.6
thin mountain meadow-steppe chernozem-like	2.2	0.1	0.7
mountain-forest chernozem-like carbonate	6.7	0.3	1.9
mountain sod deeply podzolic	3.2	0.3	1.8
mountain-forest pseudopodzolic	0.5	0.1	0.4
typical medium mountain-forest brown	0.3	0.1	0.2

Note: Here and in Table 2 bold type indicates soil contours and their areas in soil map [3], dash stands for no data.

Basins of Tuva Autonomous Oblast, 1955, and the map compiled on the basis of Landsat images are quite close in the number of soil plots and their contours. At the same time the remote data allow a more complete presentation of the soil diversity of the basin. For example, the joint contours of the prevailing subtypes of chestnut and light chestnut soils can be divided to isolate contours of dark chestnut or meadow chestnut soils, which occupy small areas, less than 7% of the total area, but ecologically are very important (Table 3). The Landsat imagery clearly shows not only brown meadow-steppe soils, which form here, as in the Chuya basin, beneath feather-grass and saltwort vegetation, but also the brown desert-steppe soils, the most xeromorphic ones among the plain soils. The specific factor of differentiation of typological diversity of the soil cover in the

Table 2. Quantitative comparison of the content of soil map of the Chuya basin composed with the use of the Landsat image, and the scheme of distribution of the main types of soils on the territory of Gorny Altai Autonomous Oblast [3]

Soil	Area of a soil contour, km^2		
	total	min	max
Chestnut	**1412.5**	**1.3**	**1207.7**
dark chestnut thin highly rubbly	37.4	–	–
chestnut medium	2.3	–	–
thin chestnut highly rubbly	180	1.7	33.1
light chestnut medium sandy-loam	54	2.1	14.4
thin light chestnut	494.3	6.8	113.2
thin light chestnut highly detritic	217.5	1	54.1
thin light chestnut desert-steppe	244.3	2.9	115
brown desert-steppe alkaline	126.4	0.7	23.7
brown meadow-desert-steppe	130.7	0.7	65.6
thin meadow chestnut carbonate	268.7	1.5	100.1
thin meadow chestnut saline	36.9	–	–
thin meadow chestnut alkaline	28.6	0.3	3.9
Meadow-boggy	**19.3**	**3.4**	**15.9**
alluvial sod raw carbonate	37.1	1	5.2
alluvial meadow shallow carbonate	58.7	0.7	27.1
thin alluvial meadow-boggy	10.6	1.7	21.9
alluvial boggy peaty-gley	37.5	–	–
alluvial primitive	86.2	1	32.1
Saline with meadow chestnut and boggy	**438.9**	–	–
complex of alluvial meadow and saline soils	17.3	3.1	4.8
boggy saline	16.5	1.3	6.5
boggy peaty-gley	24.4	1.2	23.3
Mountain-steppe of the dry steppe slopes	**477.1**	**2.6**	**67.6**
mountain meadow-steppe chestnut-like	74	7.4	15.2
Mountain-meadow alpine and subalpine	**83.7**	**4.2**	**65.2**
mountain-meadow subalpine sod	36.8	8.3	28.5
Mountain-tundra automorphous	**34.5**	**1.9**	**32.6**
Mountain-tundra hydromorphous	**3.3**	–	–
Raw soils of stony slopes highly rubbly	**116.8**	**3**	**82.3**
raw soils of stony slopes highly rubbly	138.2	5.4	62.8
rock denudations, stone river beds	162.1	47.1	58.3

Uvs-Nuur basin is the eolic relief which shows its typical morphology—meandering, narrow-stripped, ridge, striated or cellular—in the Landsat image.

The separate contours in the Soil Map (1955) outline the turf-covered and chestnut sands occupying more than 20% of the total area. However, the landscape-forming partially secured and shifted sands contributing to the soil diversity are not reflected on this map. Landsat images show considerable areas with typical features of active shifting of sands. The zone of influence of the northeastward and southwestward shifting of sand covers small (3–8% of the total area) contours of shallow the meadow chestnut and raw light chestnut soils which differ significantly in their granulometric composition from the soils of the zonal range. It is most likely that they are the newly formed varieties resulting from sand redeposition.

Table 3. Quantitative comparison of the content of soil map of Uvs-Nuur basin composed with the use of the Landsat image, and Soil map of the steppe basins of Tuva Autonomous Oblast, 1955

Soil	Area of individual soil contour, km^2		
	total	min	max
thin dark chestnut	159.9	19.4	74.6
dark chestnut immature	149.8	14.9	69.7
chestnut medium	**324**	**1.7**	**80.4**
chestnut medium	654.8	13.2	197.6
chestnut shallow and medium	**67.4**	**21.1**	**46.3**
thin chestnut	**1690.9**	**1.3**	**742.1**
thin chestnut	414.5	12.3	76.5
thin chestnut and mountain chestnut	**192.1**	**1.7**	**149.6**
primitive and thin chestnut	**99**	**6.1**	**52.6**
chestnut immature	172.9	4.5	91.6
thin light chestnut	**408.2**	**2.2**	**92.2**
thin light chestnut	356.2	**5**	89.2
light chestnut immature	**88.9**	**0.5**	**65.9**
light chestnut immature	409	2	76.2
light chestnut and alluvial	**89.7**	**27.1**	**62.5**
thin light chestnut	**75.2**	**–**	–
light chestnut and meadow chestnut	**196.6**	–	–
meadow chestnut alkali-saline	**23.47**	**0.8**	**4.4**
meadow chestnut medium with proluvium	29.7	7.4	55.3
thin meadow chestnut light	197	3	26.7
meadow chestnut light saline	200.5	1.8	27.1
meadow chestnut dark alkaline	55.9	4.1	24.2
brown desert-steppe	168.7	–	–
brown meadow-desert-steppe saline	206.4	–	–
meadow	7.1	–	–
meadow saline	162.4	0.7	118.7
crusted saline	31.4	0.4	7.8
alluvial and alluvial sod	**323.4**	**17.4**	**271.2**
alluvial	238.6	5.2	153.5
alluvial sod	23.1	0.6	10.1
alluvial water-logged	50.5	23.4	27.1
alluvial layered	16.7	3.1	13.6
alluvial peaty-humous	13.2	6	7.2
mountain raw chernozems	**5.2**	**0.7**	**4.6**
mountain chestnut immature	201.5	2.4	55.3
thin mountain dark chestnut	**1.4**	**0.2**	**0.7**
thin mountain chestnut	**36.1**	**0.3**	**8**
mountain chestnut primitive	**205.9**	**0.6**	**128.3**
mountain chestnut primitive	182.7	0.2	48.7
chestnut sand	**644**	**0.5**	**417.3**
chestnut sand	603.3	29.6	420.5
turf-covered sand	**210.7**	**33.9**	**134.9**

Note: Bold type indicates soil contours and their areas in the soil map [1], dash stands for no data.

Thus, based on Landsat imagery, contour-by-contour estimate of the effect of natural and anthropogenic factors on the soil cover in steppe basins demonstrates a high reliability of the remote data necessary for creating a system of soil-ecological monitoring.

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