Land use analysis of Lake Khanka basin using remote sensing data

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Abstract. The paper presents results of the analysis of the land use map compiled for transboundary Lake Khanka Basin using remote sensing data and geoinformation systems. The map reflects the distribution of 12 land categories in Lake Khanka basin in 2017 (arable land, abandoned arable land, paddy field, abandoned paddy field, shrubs and sparse growth, forest land, open pit, settlements, meadows and pastures, wet meadows and marshes, water bodies, forest cuttings and fire sites). The data of land use structure in the whole Lake’s watershed, in its Russian and Chinese parts are given. Data on the distribution of different land categories in the administrative territories of the rank of districts (Russia) and counties (China) are also presented. The analysis of land use structure showed that about 50 % of the Chinese part of the basin is covered by anthropogenically transformed natural complexes. The share of such lands in the territory of Russia amounts to 28 %. Agriculture is the most important factor in the change of natural complexes in Lake Khanka basin. Before early 1990s, the area of farmland had increased in the basin on both sides of the border, after that there was a significant reduction in cultivated lands, which had lasted for 10 years in the territory of China and for 20 years in Russia. Over the past decade, the area of cultivated areas in the basin and adjacent territories has extended again, which indicates an increase of anthropogenic impact and requires serious attention to monitoring of the ecological state of lands in the basin.

1. Introduction
The transboundary Lake Khanka basin is located in the territory of the Primorsky Krai of the Russian Federation and Heilongjiang Province of China. Being the largest freshwater reservoir of the Russian Far East and the entire eastern Asia, the lake is of great value in terms of rich biodiversity of its flora and fauna, and, at the same time, it is an important agricultural region of the Primorsky Krai and entire Far Eastern Russia. During the past 20 years, the lake and its basin often became the object of various scientific studies. The main topics of most research are the pollution of the lake waters and its surrounding territories [1–5] and significant fluctuations in the lake water level [6–9]. Both of these topics form a complex of geocological problems [10], which are closely related to anthropogenic impact on the territory.

To understand the current conditions and consequences of economic activity within the transboundary basin, actual data on the land use are needed. The source of unified spatial data that reflect the information on natural features, economic use and anthropogenic changes of transboundary objects...
are the Earth remote sensing data (RSD). The goal of this article is to analyze the structure of the present day land use within the transboundary watershed of Lake Khanka using remote sensing data.

2. Materials and methods

The mapping of present-day land use of Lake Khanka basin was performed using multiband space imagery from Sentinel-2 (spring 2017) and Landsat-8 satellites (autumn 2016). The outlines of forest areas were obtained after automatic classification of autumn images with trained system; the boundaries of water bodies were calculated using the modified Normalized Difference Water Index (NDWI) [11]. After that, the resulting contours (forests and water bodies) were combined and served as a “skeleton” of the spatial information layer. The Sentinel-2 images were processed by the visual expert interpretation using highly-detailed basic layers provided by the Internet cartographic services (Google Maps, Yandex Maps, Bing Maps, etc.). Other types of land resources and their use were also digitized using these sources.

The work resulted in the creation of an up-to-date map (scale 1 : 100000) of land use for Lake Khanka basin, which displays the spatial distribution of 12 land categories in 2017 (Figure 1). This allowed the calculation of the areal characteristics for each category of land and the analysis of the structure of land use in the basin in general, in its Chinese and Russian parts, as well as in the context of individual municipal districts (Russia) and counties (China). The data on agricultural land categories were compared with statistical materials and analyzed in terms of long-term trends in the land development in the basin.

3. Results and discussion

Lake Khanka is located in the central part of the Khanka Lowland in the western part of the Primorsky Krai. The Russian-Chinese national border runs across the lake and its northern part, and its watershed is located in the territory of China. The lake is characterized by substantial long-term cyclic fluctuations of the water level and the area of its water surface can vary significantly, from 5010 km² to 3940 km² [6]. In this analysis, the area of Lake Khanka basin is calculated equal to 24855 km² (including the area of the lake equal to 4372.35 km²), of which 20941 km², or 84 % is located in the Primorsky Krai.

The Russian part of Lake Khanka is located in the territory of 10 municipal districts and 2 urban districts of the Primorsky Krai. Another part of the basin is located in China, in Heilongjiang Province in Mishan and Hulin Counties of the Jixi Region, including a small area (55 km²) in Dongning County and Suifenhe City of the Mudanjiang Region (Figure 1). This paper analyzes the structure of land use in 6 municipal districts and the Spassk-Dalny Urban District, which are completely or almost completely (more than 80 % of the territory) located within Lake Khanka basin, as well as the land use in Mishan County, with 46 % of the territory lying within the lake watershed (Table 1).

According to the interpretation of satellite images, in 2017, the total area of farmland (arable land and paddy fields) in the basin amounted to 451 thousand hectares, or 18.1 % of the territory, another 10.4 % falls on abandoned paddy fields [12]. The category of lands with the highest specific gravity is forest areas, which occupy 29.2 % of the watershed. The share of water bodies (rivers, canals, lakes, reservoirs) in the land structure is estimated at 17.9 %. Another 20 % of the watershed is covered by meadows, hayfields, pastures (10.9 %) and wet meadows, marshes (9.6 %). The remaining 4 categories of land (shrubs and sparse growth; open pits, abandoned mining areas; settlements, agricultural infrastructural objects, industrial and processing facilities; forest cuttings, fire sites) occupy less than 4 % of Lake Khanka watershed area.
A distinctive feature of the land use structure in the Chinese part of the basin is a high share of paddy fields and arable lands, which in total cover 44.4% of the territory. At the same time, the area of paddy fields is 2.2 times larger than dry arable land. If to exclude water bodies when calculating the structure, the share of arable land will increase up to 65.4% of the area in the Chinese part of the watershed. At the same time, the proportion of abandoned fields and abandoned paddy fields is very small (Table 1). It also should be noted that a relatively large share of wet meadows and marshes have been preserved here, probably due to existence of the Xinkaihu Nature Biosphere Reserve.

In 2017, the share of farmland in the Russian part of Lake Khanka amounted to 13.2% and, in contrast to the Chinese territory, it was mainly dry arable land (Table 1). The largest areas of arable land are located in Khorolsky, Mikhailovsky, Spassky and Khankaisky municipal districts (69% of all arable land in the Russian territory); they also contain a significant portion of abandoned fields (64.1%), which are typical for the Chernigovsky, Pogranichny and Kirovsky districts (a total of 29% of this category of land). In the Russian part of the basin, the area of paddy fields is almost 3 times smaller than in the Chinese part. Most of them are located in the Khorolsky, Spassky, Khankaisky and Chernigovsky municipal districts (97% of all farmland and 84% of abandoned rice fields).

Forest lands occupy quite sufficient part of the Russian territory of Lake Khanka basin (Table 1). The largest forest lands are located in the Pogranichny, Mikhailovsky and Spassky districts (29.3%, 17.7% and 16.3% of the entire category). The Pogranichny District is distinguished by the largest areas of shrubs and sparse forests, as well as forest cuttings and fire sites (40.6% and 51.4% of the related categories of land). The Khankaisky and Khorolsky districts (19.2% and 15.5%, respectively) are leading in terms of forest cuttings and fire sites. The proportion of land categories represented by various meadows and marshes in the Russian territory is estimated at more than 22%. A significant contribution to the preservation of wetlands belongs to the Khankaisky State Biosphere Nature Reserve, whose sections are located in the Khankaisky, Khorolsky, Chernigovsky, Spassky and Kirovsky municipal...
districts, and in the Lesozavodsky urban district. Here, 91.6 % of all wet meadows and marshes are located in the Russian part of Lake Khanka basin. The Pogranichny District is notable for meadows, hayfields and pastures, which amount to 30 % of all lands of this category, as well as the Khankaisky, Khorolsky and Mikhailovsky districts (a total of 45 % of meadows and pastures).

**Table 1.** Land use in the Russian and Chinese parts of Lake Khanka in 2017, km².

| Land category / type                        | Khan-kaisky District | Kho-rolsky District | Chere-nigovsky District | Spassky District | Pogranichny District | Mikhailovsky District | Total in Russia | Mishan County | Total in China | Total in the watershed area |
|---------------------------------------------|----------------------|---------------------|-------------------------|-----------------|----------------------|-----------------------|----------------|--------------|----------------|-----------------------------|
| Arable field                                | 332.0                | 476.5               | 257.5                   | 350.1           | 222.0                | 440.1                 | 2323.1         | 533.4        | 536.8          | 2859.9                      |
| Abandoned fields                            | 311.1                | 224.6               | 139.1                   | 359.7           | 150.0                | 144.7                 | 1617.8         | 25.9         | 26.3           | 1644.1                      |
| Paddy fields (arable in 2017)               | 153.5                | 136.2               | 51.9                    | 91.9            | 6.9                  | 1.4                   | 448.7          | 1056.7       | 1200.0         | 1649.2                      |
| Abandoned paddy fields                      | 154.8                | 183.2               | 56.9                    | 370.3           | 29.3                 | 3.5                   | 911.7          | 27.6         | 32.3           | 943.9                       |
| Forest land                                 | 1090.2               | 259.8               | 718.2                   | 1129.1          | 2030.7               | 1226.1                | 6937.9         | 241.5        | 316.3          | 7254.2                      |
| Shrub and sparse growth                     | 50.0                 | 29.7                | 27.8                    | 23.5            | 138.7                | 57.3                  | 341.9          | 2.6          | 3.9            | 345.8                       |
| Forest cuttings and fire sites              | 25.9                 | 21.0                | 9.3                     | 3.7             | 69.4                 | 2.0                   | 135.1          | -            | 0.1            | 135.2                       |
| Meadows and pastures                        | 461.8                | 380.0               | 183.0                   | 220.2           | 800.8                | 367.7                 | 2692.2         | 26.5         | 27.4           | 2719.6                      |
| Wet meadows and marshes                     | 69.4                 | 164.4               | 276.7                   | 707.3           | 1414.4               | 153.3                 | 1943.3         | 425.3        | 452.4          | 2395.7                      |
| Settlements                                 | 30.4                 | 61.5                | 56.9                    | 102.8           | 29.9                 | 45.3                  | 353.8          | 50.6         | 58.3           | 412.1                       |
| Open pits and mining sites                  | –                    | 5.9                 | 3.7                     | 4.2             | 0.3                  | 18.5                  | 32.7           | 2.2          | 2.2            | 34.9                        |
| Water bodies, including Lake Khanka         | 21.6                 | 14.4                | 5.7                     | 59.9            | 0.7                  | 7.8                   | 3202.4         | 1256.5       | 1258.6         | 4461.0                      |
| In total in the district/county/basin       | 2700                 | 1957                | 1787                    | 3423            | 3620                 | 2330                  | 20941          | 3649         | 3915           | 24855                      |

Notice: *including data of the Spassk-Dalny Urban District*

In general, the structure of land use in the Chinese part of Lake Khanka basin indicates a significant anthropogenic impact on ecosystems. Deeply changed and transformed natural complexes including arable lands, including abandoned fields, paddy fields, abandoned ones, settlements, open pits, forest cuttings and fire sites cover 47 % of the territory. If to exclude the area of the lake from the calculations of the land structure included in water bodies, the share of anthropogenically transformed lands will increase up to 70 %. The situation is more positive in the Russian part of the basin compared to the adjacent Chinese territory, and the proportion of transformed ecosystems amounts at 28 % of the total area. Among the municipal districts of the Russian part of the basin, the Khorolsky District has the most unfavorable land structure (31 % of the district is covered by anthropogenically transformed ecosystems, another 21 % is abandoned paddy fields).

Since the beginning of active settlement and economic development of the Khanka lowland in the second half of the 19th century, the agricultural activity was and still remains one of the main factors of transformation of Lake Khanka environment. The problems of water and soil pollution and anthropogenic impact on the hydrological regime of the lake are related, to a large extent, to the development of agriculture in the second half of the 20th century. The second aspect of the impact results from the creation of irrigation systems for growing rice in the lake basin and the artificial regulation of
the water flow by transferring water from the Mulinghe River [13]. In this regard, the analysis of the farmland dynamics is an important part of the land use study in Lake Khanka basin.

![Graph showing farmland dynamics](image)

**Figure 2.** The dynamics of farmlands in the Russian part of Lake Khanka and Mishan County over the past 25 years, tsh ha [14–16].

The historical data analysis of the dynamics of farmlands in the Russian part of Lake Khanka and Mishan County showed that before the early 1990s there was an increase in the farmland areas on both sides of the border. This indicator reached its maximum in the Russian territory in 1990, amounting to 450 thousand hectares, whereas in Mishan it amounted to 271 thousand hectares in 1993, respectively. Along with an increase in farmlands that began in Mishan County in 2000, and their continued decrease in Russia, in 2010 the area of farmlands on both sides of the border had the closest values (Figure 2). However, during the following 7 years, the dynamics of farmlands was the opposite. In Mishan, the area under cultivation slightly decreased, but it increased in the Russian part of the basin. After 2017, there was an insignificant increase in arable land area in the Russian territory, while in Mishan County, according to statistical data, the farmland area increased by twofold over 2 years, reaching 320 thousand hectares in 2019 [16].

Since Mishan County is not fully included in Lake Khanka watershed, it does not appear possible to estimate how such significant changes in farmlands affected the land structure in the Chinese part of the basin using only statistical data. Therefore, to assess these changes, an additional visual expert interpretation of the 2020 Sentinel-2 and Landsat-8 satellite images was carried out for Lake Khanka basin in order to delineate polygons of cultivated land including dry arable land and paddy fields.

According to the RSD, in the Russian part of the basin, the arable land area increased by 27.2 thousand hectares in 2020 compared to 2017, and paddy fields decreased by 5.9 thousand hectares. In general, the arable land expanded by 21.3 thousand hectares. In the Chinese territory, the arable land decreased by 3.9 thousand hectares, while the area occupied by rice fields increased by 1.2 thousand hectares. Therefore, to conclude, the total area of cultivated land did not increase, but decreased. This may mean that the main increase in the farmland areas in Mishan County in the period 2017–2019, reflected in statistics, occurred in the territory of the county, which is located outside Lake Khanka basin in the Mulinghe River watershed. However, considering the actual entity of the basins of Lake Khanka and the Mulinghe River [13], it is obvious that such a large-scale change in the area of farmlands in the county, if not directly, then indirectly, can affect the geocological state of Lake Khanka basin, primarily regarding water pollution and hydrological aspects associated with the functioning of irrigation systems.

4. Conclusion

The transboundary watershed of Lake Khanka, located at the Russia and China border, is a unique area that combines rich biodiversity and nature conservation importance with a high agricultural value. Active economic development of the Russian and Chinese parts of Lake Khanka basin in the second half of the 20th century has led to a significant transformation of landscape complexes and the deterioration in the state of the natural environment. The map of the current land use of the basin, compiled using the RSD, reflects the spatial distribution of 12 land categories and made it possible, on a unified basis, to carry out a comparative analysis of the land use structure of its Russian and Chinese
parts, to identify the features and characteristics of the distribution of different land categories within each of the national territories of the basin in 2017.

In general, the structure of land use in the Chinese part of Lake Khanka basin indicates a significant anthropogenic impact on its natural environment. Deeply changed and transformed ecosystems cover 47% of this territory. In the Russian part of the basin, the situation is more positive, the proportion of the transformed ecosystems accounts for 28% of the total area. Among the municipal districts of the Russian part of the basin, the Khorolsky District has the most unfavorable land structure.

The historical data analysis on the dynamics of farmlands in municipal districts of the Russian part of Lake Khanka basin over 120 years, and in Mishan County over 80 years has shown that before the beginning of the 1990s, on both sides of the border, the main trend was an increase in croplands. This was followed by a period of reduction in cultivated areas, which had lasted for 10 years in China and for 20 years in Russia. Currently, in the Russian part of the basin, a gradual expansion of cultivated areas continues, which began in 2010. In Mishan County, according to statistics, after a period of increase in cultivated areas from 2000 to 2010 and their slight decrease by 2017, in 2019 there was a sharp two-fold increase in the size of the total farmland area.

Based on the remote sensing data, the study of the dynamics of farmlands has shown that in 2020, their area in the Russian territory increased by 21.3 thousand hectares compared to 2017, and in the Chinese territory it decreased by 2.7 thousand hectares. Such a discrepancy between the RSD and statistical data, showing a significant increase in farmlands in Mishan County, may mean that the main increase in the area under crops took place in the half of the county which is located outside Lake Khanka watershed.

For a more complete understanding of the land use dynamics in transboundary Lake Khanka basin, in order to compare statistical data and remote sensing data, it is necessary to expand the land use map for the entire territory of Mishan County. To assess changes in the structure of land use in the basin, the satellite images of 2019–2020 are interpreted to obtain the information on changes in the area of all land categories in the basin, in addition to the previously obtained information on farmlands.

Due to the expansion of the area of farmlands observed in recent years and an increase in production in the agricultural sector, a map of the land use in Lake Khanka basin in 2017 can be useful for assessing anthropogenic change and transformation of ecosystems of the transboundary Khanka basin; for monitoring of the state of the natural environment; the development of recommendations and strategies for sustainable, environmentally balanced territorial development and planning of economic activities; for the development of functional zoning of the area under consideration.

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