

MAPPING OF THE CURRENT STATE AND LONG-TERM CHANGES OF AGRICULTURAL LANDS IN THE VOLGA DELTA

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ABSTRACT

Landsat satellite imagery covering the period from 1970s to present and topographic maps have been used for map creation. Topographic maps were used for formation of a base field boundary layer, while Landsat imagery-based multi-seasonal colour composites served as a basis for thematic map contents. Agricultural arable lands categories and the dynamics of field abandonment are shown on the created map. Calculations made on the map revealed that in 2014 the category of fallows was attributed about 82% (1326 km²) area of arable land of the delta. A half of these fields was abandoned during the period since the mid-1990s to the mid-2000s.

1 INTRODUCTION

During the period from 1965 to 1987 the area of arable lands in the Russian Soviet Federative Socialist Republic (RSFSR) remained rather stable at the level of 133-134 million hectares. Significant part of these areas was dropped out of agricultural use as a result of agrarian reform of 1990s. The Russian Agricultural Census 2006 stated that the total area of abandoned arable lands in the Russian Federation was about 40 million hectares (Agroecological, 2008). These areas were set aside and fell within the category of fallows. Now they are undergone transformations under the influence of different natural and anthropogenic factors. In some cases, the abandonment of arable lands improves the state of ecosystems and biodiversity recovery owing to restoration of original vegetation, soil fertility and ecological functions (reforestation in non-chernozem zone is an example). But the abandonment of agricultural lands located in arid regions of Russia mostly causes degradation processes of different types: desertification, soil salinization, halophytic vegetation overgrowth, especially at previously irrigated sites. Thus, the inventory, the agroecological assessment and ranking of fallow lands are of high importance when specifying the activities on reclamation and melioration of these lands in returning them into the agricultural use.

2 TEST SITE

The Volga Delta represents a region of special interest, as it is a natural oasis in the semiarid climate zone owing to the river's waters covering a huge catchment area, located mainly in the temperate climate zone with sufficient moisture (Figure 1). The climate is characterized by high summer temperatures and low precipitation rate.



Figure 40: The location of the Volga River delta

With regard to other coastal territories, the Volga River delta abounds with natural resources. This territory was actively used for farming and fishing during centuries. The efficient use of the agro-climatic resources and the success of plant cultivation at this arid region are highly dependent on the water supply. The Volga Delta area has undergone significant changes in the last decades. These changes have been driven by both environmental and socio-economic factors.

The expanding of arable lands here in 1950s was accompanied by extensive irrigation. By the middle of 1960s the most of arable lands was protected from spring tide by dams and moats, and cultivated fields were watered by pumps. Due to extensive growing of water-melons, vegetables and rice during the Soviet period this region was called “all-union garden”.

Among natural changing factors of greater importance was the dramatic Caspian Sea level rise of more than 2.5 m between 1977 and 1996 and its following stabilization at a new higher mark. This resulted in a water table rise that led to abandonment of agricultural fields at the lower delta area.

Economic reforms of 1990s and lapse in subsidy for agriculture caused the next stage of changes that resulted in the abandonment of the most previously irrigated areas. As long as these unused agricultural fields were protected from spring tide, they were exposed to desertification, i.e. dehydration and degradation in various ways

including such processes as shrub overgrowth and soil salinization. At present the fallow lands differ in their state depending on natural conditions, primarily the water availability and duration of abandonment period (Barmin, et al., 2006; Golub et al., 2012). The intensity and velocity of these changes demand to monitor the territory and effective land use management for sustainable development. Assessment of capabilities for land resources should be carried out taking into account their current state and conditions.

3 DATA USED

Cartographic and remote sensing data as well as different available sources of information were used for map creation to display the differences in agricultural land use, current state and duration of the abandonment period in the Volga River delta.

Cartographic data: Topographic maps at scale 1:100 000 produced in the USSR in 1970-80s. These topographic maps were used to create a base map of agricultural field boundaries needed for further thematic attribution. It should be noted that as a rule the topographic maps show only the averaged terrain state over an uncertain period but not on a particular year. However, the main advantage of these maps is their high geometrical accuracy and the reliability of objects displayed that allowed us to use them for our purposes.

Remote sensing data was the main information source used for determining thematic map contents. This data type is presented by Landsat satellite imagery taken from USGS archive (URL: <http://earthexplorer.usgs.gov/>). The archive contains imagery available from 1975. The first Landsat satellites were used for the multispectral observations with a spatial resolution of 80 meters. 30-m resolution satellite survey was carried out since 1984 (Landsat-5 Satellite and subsequent). As a significant part of the Volga Delta agricultural lands have a small size and cannot be distinguished well on the 80-m resolution imagery, data captured before 1984 were not used.

A list of Landsat imagery used is given in Table 1. We tried to select at least 3 cloudless images covering the whole crop season (spring-autumn) for each representative year. It was important for our study to have imagery taken in May-June (high water period) to distinguish leveed fields and flooded areas. The additional use of imagery taken in July (different stages of crops growth) and in August-September (harvesting) was necessary for cultivated fields and fallow lands discrimination.

It should be noted that for some years the archive contained least amount of images and this applies especially mid-1990s and mid-2000s in our case. Nevertheless, the used data set can be considered as sufficient to catch the trends in land use changes due to the availability of data gathered in the most major periods: the Soviet, after the collapse of the Soviet Union, and current.

Table 1: Landsat imagery

Year	Month, day
1984	April 12, June 24, July 1, July 10, September 3
1986	May 20, June 21, July 23, August 24, September 9
1987	June 17, July 26, August 27
1988	May 10, June 27, July 29
1989	June 5, July 7, August 24
1993	May 16, June 8, August 4
1998	May 30, June 6, June 15, August 18, September 19
2002	April 22, June 25, July 20, August 12, September 29
2007	May 14, May 30, June 15, July 17, August 2
2008	May 25, June 10, June 17, July 12, September 5
2009	June 4, June 20, July 6, August 7
2010	May 31, July 9, July 18, August 10, September 4
2011	May 25, June 26, July 12, July 28, August 13
2013	May 30, June 15, July 1, July 17, August 2
2014	May 1, May 17, June 2, July 4, July 20

4 METHODS

Map creation was done in two stages.

As the first stage a vector map (just contours) of agricultural lands cultivated in 1970s was created using topographic maps. Leveed fields, irrigation canals, rice paddies and fish ponds were shown on the maps by special symbols. It is clearly seen while comparing topographic maps with actual Landsat imagery that the field location remained almost unchanged.

At the second stage the agricultural land state and properties were determined based on remote sensing data analysis. Color composites made up of multi-seasonal Landsat imagery (R – the beginning, G – the middle, B – the end of the growing season) were used as a main source of data which allowed revealing Land Use/Land Cover (LULC) patterns (Figure 2). Near infrared band (0.76-0.90 μm) was used as the most informative for the synthesis because the vegetation cover, including agricultural one, has the highest reflectivity in this band, so the contrasts between water bodies, vegetated areas, crops and bare land are the greatest.

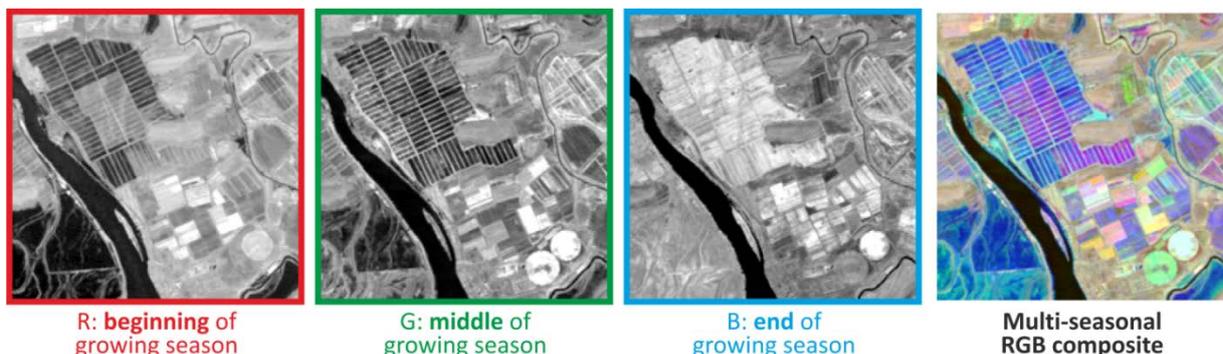


Figure 2: Multi-seasonal image synthesis for LULC patterns revealing

The types of agricultural land use were defined by the imagery taken in 2014. Fishponds can be recognized most accurately: as a rule, they have a rectangular shape and dark tone (almost black), with no changes during growing season. Arable lands are identified quite well too: as fishponds they have in general a regular shape but they are displayed in different colors according to the crops phenological stages in different seasons.

Panchromatic imagery with the highest resolution (15 m) was used for allotments detection. These objects are located around Astrakhan city and differ from it by low-rise building type and high percentage of woody vegetation.

All the fields, which were contoured using topographic maps and not cultivated in 2014 were referred to the category of fallow lands. As a rule, these lands are represented in gray tones at the color composites due to the weak seasonal variations and, therefore, small changes in images brightness. For fields abandonment monitoring a series of multi-year color composites obtained from 1984 to 2013 were analyzed (Figure 3). The age of fallow lands was determined according to the period in which a field was cultivated the last time (Table 2). If any area was marked at a topographic map as a field, but none of the multi-temporal Landsat imagery has fixed an agricultural activity here, this fallow field considered as the oldest (the duration of abandonment period is more than 30 years). It should be noted that fields which were not tilled in 1970s (i.e. not displayed on topographic maps) but which were used at least once during the investigated period were also digitized and attributed in a proper way.

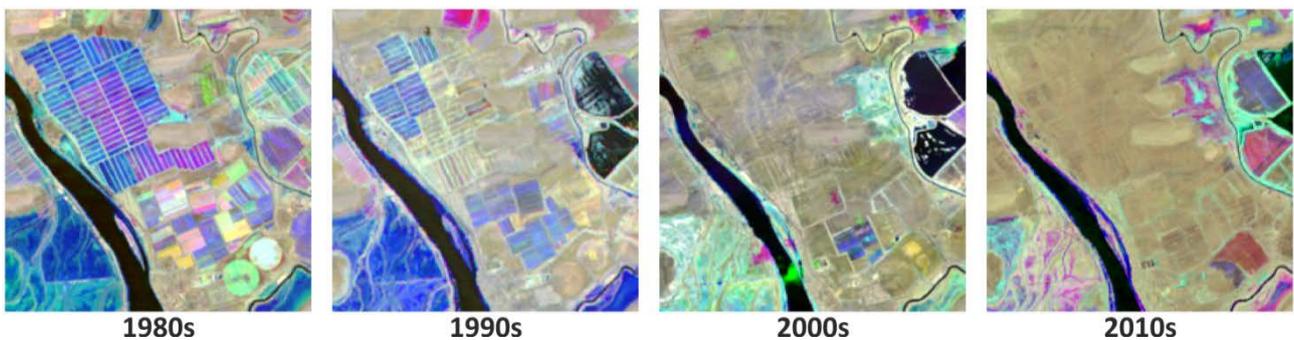


Figure 3: A series of multi-seasonal RGB composites for LULC change detection

Table 2: Fallow lands age revealing

Fallow land age in the map legend, years	Period of last field cultivation, years
1-5	2009-2013
6-10	2004-2008
11-20	1994-2003
21-30	1984-1993
>30	before 1984

The rest area was categorized in two classes: 1) flood-meadows and 2) natural grasslands, not or rarely flooded. To differentiate these two categories, an image taken at the peak of flooding (middle to end of May) was used.

5 RESULTS AND DISCUSSION

The main result of our study is the map “Agricultural lands use in the Volga River delta (RF) in 2014” at a scale of 1:250 000 (Figure 4). The map legend consists of two parts: agricultural lands and other areas and objects (water bodies, settlements and etc.). Agricultural lands in turn are categorized in three groups:

- 1) Lands, cultivated in 2014 (arable lands, fishponds, allotments);
- 2) Fallow or abandoned lands, classified by 5 categories according to the period of abandonment;
- 3) Flood-meadows and natural grasslands appearing partly as hayfields, pastures which serve spawning areas in spring tide periods.

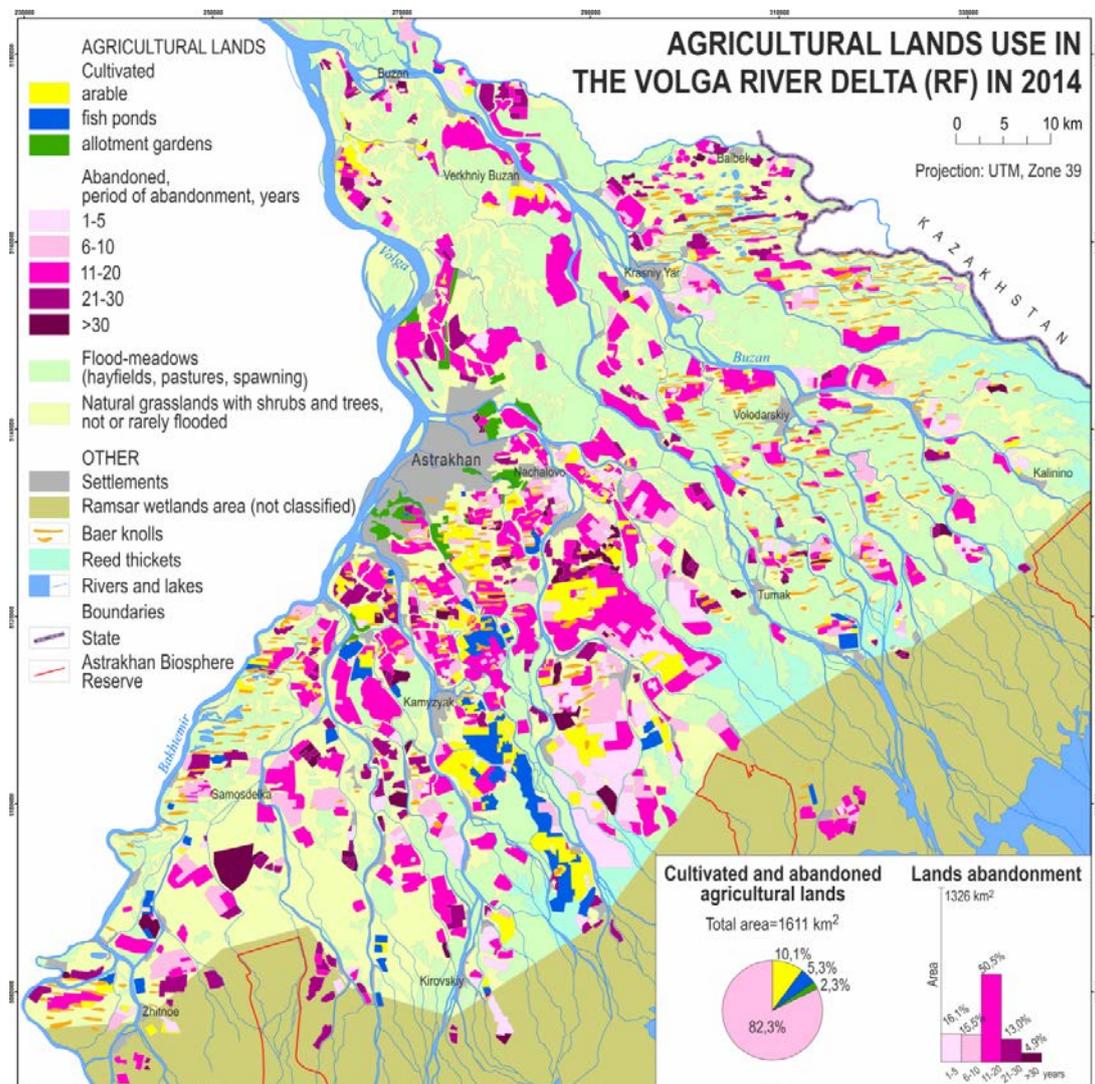


Figure 4: The map “Agricultural lands use in the Volga River delta (RF)” in 2014 (reduced)

Map creation in a GIS environment provided to make the subsequent quantitative estimation with ease. Some computations were done using the map. The total area of agricultural lands in the Volga Delta in 2014 was about 1611 km² (excluding the area of flood-meadows and natural grasslands). A land use structure is shown in Table 3.

Table 3: The area of agricultural lands in 2014

Categories of agricultural lands	Area, %	Area, km ²
Arable lands	10,1	163
Fishponds	5,3	85
Allotments	2,3	37
Fallow lands	82,3	1326
Total	100	1611

The agricultural land abandonment was observed throughout the whole studied period, but it was irregular. Table 4 represents the fallow lands distribution by their age: it can be clearly seen that the process of abandonment was the most active after the collapse of the Soviet Union.

Table 4: Fallow lands distribution in 2014 according to their age

The age of fallow land, year	Area, %	Area, km ²
1-5	16,1	213
6-10	15,5	206
11-20	50,5	670
21-30	13,0	172
>30	4,9	65
Total	100	1326

Additionally, it is important to note some general trends in the delta’s agricultural land use, which became clear through comparative image analysis. As compared with land abandonment these processes are spreading locally:

- 1) Conversion of fields to fish ponds and their alternation year by year in the direction to the south of Kamyzyak town (Figure 5a);
- 2) Conversion of fields into allotments around Astrakhan city (Figure 5b);
- 3) Reduction in size of cultivated fields up to 1 hectare that makes the process of fields identification by 30-m resolution imagery rather difficult (Figure 5c).

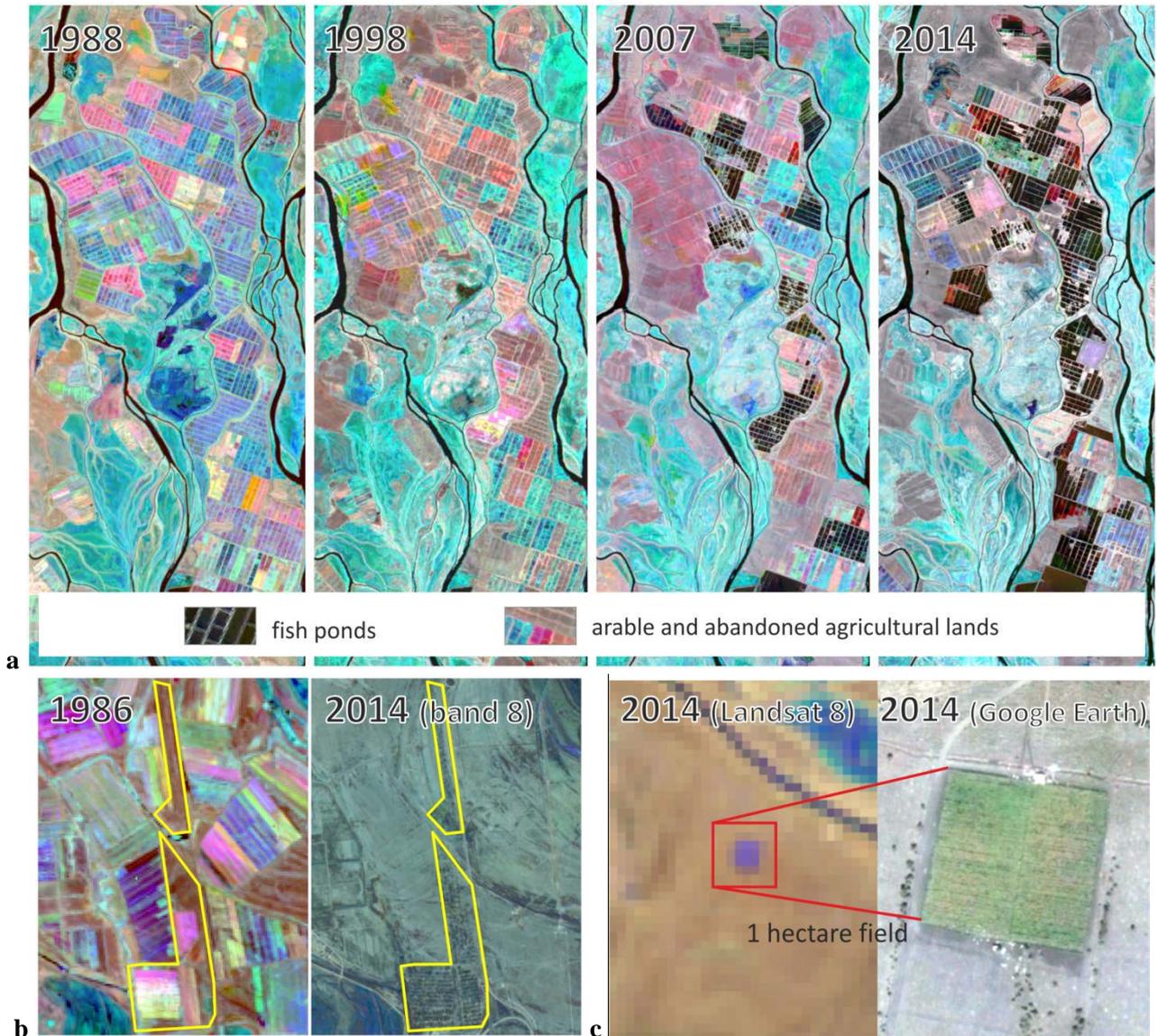


Figure 5: LULC patterns changes: a - conversion of rice paddies into fish ponds, b - conversion of fields into allotments, c - reduction in size of cultivated fields

6 CONCLUSION

Archive maps and present-day satellite imagery are the most valuable sources to analyse the land use dynamics within any territory due to their ability to cover a wide area using uniform symbols. Created map helps to reveal LULC changes in the Volga delta agriculture over the period from 1970s to 2014. Using GIS methods in map creation, it became possible not only to show the spatial distribution of agricultural lands and their dynamics but also to calculate some statistic parameters of changes.

This map is considered as a starting point for further study. It was created primarily manually using visual analysis in a GIS environment to reach the higher accuracy and reliability. Currently the map is used as a reference for evaluation of automatic methods in land use change revealing based on remote sensing data, and estimation of results.

Hereafter, we are planning to continue the study of the Volga delta agricultural lands. The degradation degree of abandoned agricultural lands will be the main point of the study based on remote sensing data captured by different sensors, including SAR, and ground truth data obtained in summer 2014. The expected result will be a map showing both the dynamics and current state of arable lands. The map will make possible to identify the relationships between the state of fallow fields, their age and natural conditions.

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