Tapping the potential of Landsat archives for the monitoring of irrigated land use development in the lower Syr Darya catchment, Kazakhstan, 1984-2017

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Introduction

One important branch of the economy in the Republic of Kazakhstan is agriculture. After the break-up of the Soviet Union, processes like privatization of formerly state owned land and implementation of new organizational structures for land management and product delivery have intensified environmental problems such as land degradation, soil erosion, or decrease in biodiversity, and resulted in societal changes such as pauperization followed by migration (Institute Geographic 2010). In order to detect and explain spatial pattern of land use development (land degradation or cropland abandonment) in the rice cropping systems of the lower Syr Darya Basin, this research aims to identify hotspots of decreasing rice production through satellite remote sensing and time series analysis (1984-2017). One focus is set on the detection of the drivers with the help of linear statistical modeling of rice cropping intensity over time and secondary information integrated into geographical information systems (GIS). The maps and model outputs should assist for a implementation of countermeasures to prevent further land degradation or cropland abandonment and for a more efficient use of land and water resources.

Data and Methods

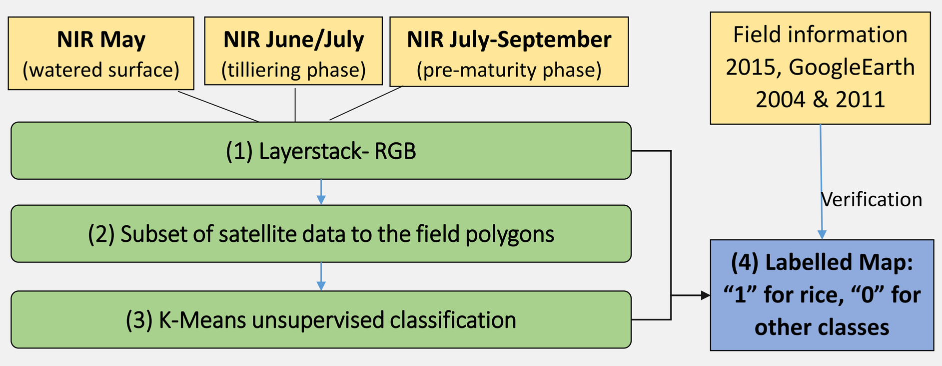


Figure 3: Workflow of rice field identification through three near infrared data sets (NIR) of Landsat

In total, 87 Landsat images of the period 1984-2017 were downloaded from the open USGS archive, prepocessed and analyzed. The download included Landsat 8 OLI data for the years 2013 to 2017, Landsat 7 ETM+ data for 1999 to 2006, 2009, and 2012 and Landsat 5 TM data for the remaining years. For 1985, 1995, and 1997, no data were available. Agricultural fields were digitized from Landsat data of 1984 and a cadaster map of 2000

The main purpose of the **classification of Landsat images** was to generate information for each field, which shows its usage for rice cultivation over time. The workflow is shown in Fig. 3. For each year, near infrared (NIR) bands of three acquisition dates that represent the three major growing phases (sowing, tillering and maturing) was stacked to one information layer (1). NIR indicates for instance the density of vegetation growth and allows for the demarcation of water surfaces during the sowing phase. Then, the raster data were masked to the field polygons (2) and an unsupervised k-means clustering with maximal five iterations and three classes was applied (3). The final labelling (4) occurred by visually interpretation of the RGB stacks (**Fig. 4a**). The pixel-based information (**Fig. 4b**) was aggregated to the field level using the majority rule (**Fig. 4c**, class assignment). A break-point analysis (BFAST, Verbesselt et al. 2010) was applied to the resulting time series of rice cropping area. Three **indicators of land use development** were calculated for the study area to describe the time series more in detail (**Tab. 2**).

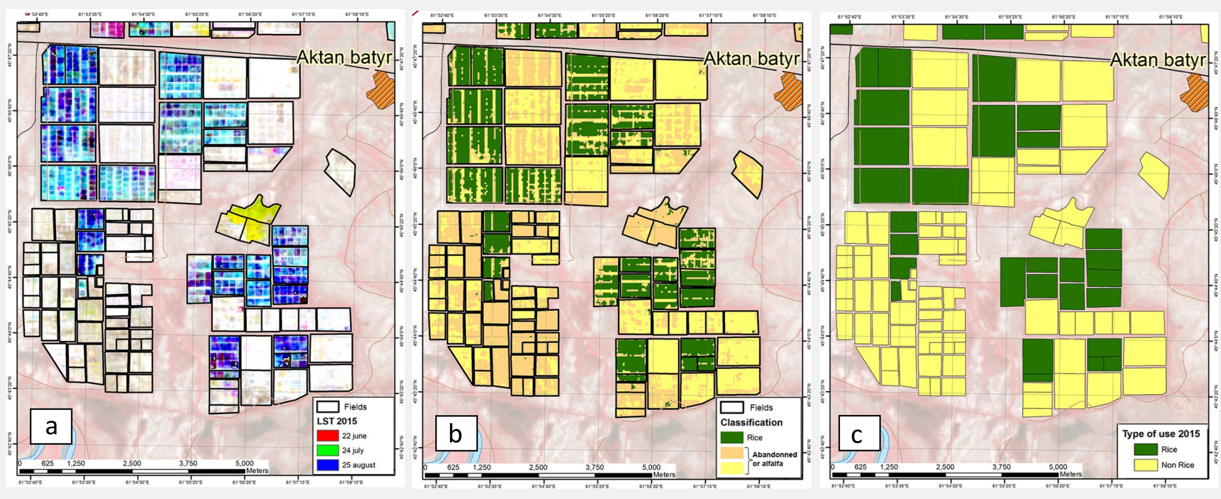


Figure 4: Example of the NIR-RGB composite image a subset showing the Aktan Batyr farm (a), the result of the K-Means classification and an initial labelling (b) and rice fields, in green color (c).

Table 2: Indicators of land use development.

Indicator	Description
Frequency of rice cultivation 1984-2017	Shows the rice intensity during the past three decades. It can be assumed that intensively used fields indicate good access to water, reduced degradation, and well-organized management (**Fig. 6a**).
Last year of rice cultivation	Points at spots that are still under production or abandoned (**Fig. 6b**).
Linear trend of rice cropping intensity	Trend of a five-year moving average of rice cropping intensity. Allows for the identification of field specific production decline or re-use. Calculated on the full time series (**Fig. 6c**) and for further analysis on periods identified by the break-point analysis.

A Classification and Regression TREE (CART, Breiman et al. 1984) was applied for the **derivation of drivers** that influenced the spatial pattern of the frequency of rice cultivation in the Kazalinsk region. The explanatory variables are summarized in **Tab. 3**.

Table 3: Explanatory variables for the CART analysis of the per-field rice cultivation frequency.

Explanatory variables	Description
Field size [m²]	Indicates on the area that can be prepared per time.
Field density [ha/2500ha]	Agricultural fields within an area of 2500 ha. Shows irrigation efforts at field level.
Soil type	Quality indicator: (1) water-affected, (2) hydromorphic, (3) arid, and (4) salt-affected soils
Nearest distance to river	Indicates the regularity of access to irrigation water and the economic efforts for irrigation
Nearest distance to settlement	Access to markets/transportation nodes and workers.

Discussion and Conclusions

Over the analyzed historical period (1984 – 2017), the areas of fields used for rice cultivation changed from year to year. The strong trends of rice crop area (decrease before 1999, increase after 2004) matches the national statistics of Kazakhstan and can be explained by economic transformation rather than by water scarcity or land degradation. Especially the years 2003 and 2004 are water rich but demarcate the lowest point of rice production in Kazalinsk. Based on the assumption that abandonment can be defined as a gap in rice production that lasts more than 5 years, 44,249 ha of the 69,033 ha of cropland are currently abandoned. However, significant positive trends of rice production (re-use of cropland) occurred on 11,029 ha since 2004. Annual rice maps produced by this study provide on the next step an opportunity to study the rice states and make yield estimation, water resource use, and other relevant issues that are critical for the region food security and human wellbeing.

While this study focused on changes at the district level, more studies are needed to understand the mechanisms at the regional scale (Kyzylorda oblast). Of particular interest are the drivers of rice field expansion in formerly abandoned areas (**Fig. 6c**) and the recovery of abandoned fields in the Kazalinsk region.

Study area

The Kyzylorda oblast is the main rice-growing region of Kazakhstan (**Fig. 1**). The region is located east of the Aral Sea (50 m - 200 m above sea level). The oblast area amounts to 226,076 km² and the population is about 766,417 (Institute Geographic 2010). The average size of one rice field that usually consists of +/- 25 checks (**Fig. 2**) is ~100 ha. The Kazalinsk rayon was chosen as study area. Its downstream situation makes it severely endangered to insufficient irrigation water in drought years. The main planting crop is rice. The recommended crop rotations differ with the soil conditions and include mainly fallow periods and alfalfa (**Tab. 1**).

A considerable recession of rice production occurred in the 1990s when the farmers had no machinery, fertilizers, nor finance to purchase them (Institute Geographic 2010a). Many fields have been abandoned. Until today, the main challenge for agricultural production in Kazalinsk is the deterioration of land reclamation conditions and irrigation and drainage systems.

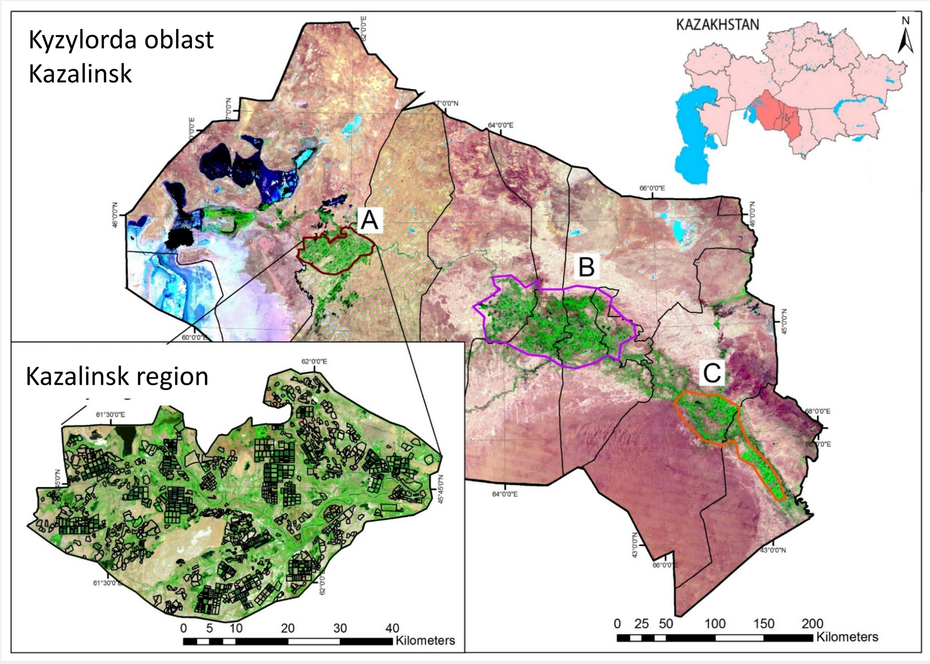


Figure 1: Irrigation schemes in the lower Syr Darya Basin: (A) Kazalinsk (study area), (B) Kyzylorda and (C) Chiiliysko-Zhanakorgan, background: MODIS image of 12-7-2015.

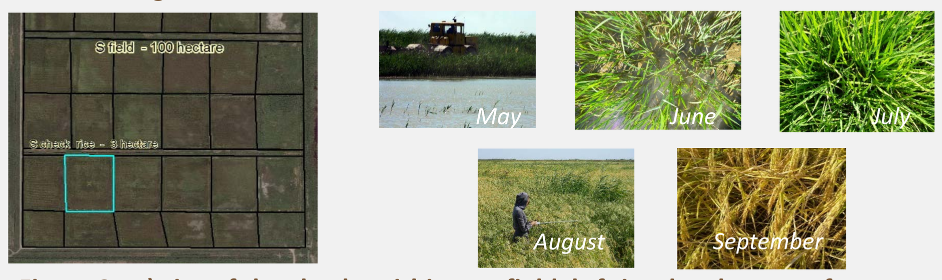


Figure 2: a) size of the checks within one field, b-f rice development from sowing over tillering and maturing to the pre-harvest situation.

Table 1: Recommended crop rotations in Kyzylorda oblast (Abuov et al. 1967).

Field states	Years 1	2	3	4	5	6	7	8
Old arable lands, highly infested	Alfalfa mixed with spring crops	Only Alfalfa	Only Alfalfa	Rice	Rice	Fallow (ameliorative field)	Rice	
Meadowlands, not infested	Alfalfa mixed with spring crops	Only Alfalfa	Only Alfalfa	Rice	Rice	Fallow (ameliorative field)	Rice	Rice
Fertile lands with close underground water table	Alfalfa mixed with spring crops	Only Alfalfa	Rice	Rice	Fallow (ameliorative field)	Rice		

Legend: red = Alfalfa mixed with spring crops; yellow = Only Alfalfa; green = Rice; blue = Fallow (ameliorative field)

Results

For verification of the rice field classification we used the historical images for 2004 and 2011 provided by GoogleEarth (**Tab. 4**). The overall accuracy is 91.6%.

Table 4: Verification results of the rice field identification based on GoogleEarth historical images

Year	Correct rice	False rice	False non-rice	Correct non-rice	Sum Correct	Sum False
2004	30	12	2	74	104	14
2011	37	0	3	44	81	3

The development of the rice cropping area in Kazalinsk (**Fig. 5**) shows a constant but moderate decline during the late Soviet era (-1991) and in the post-Soviet time, which is followed by a sharp decline between 1999 and 2004. Afterwards, a moderate increase of rice area can be observed. The breakpoint and trend analysis (BFAST) confirms this result.

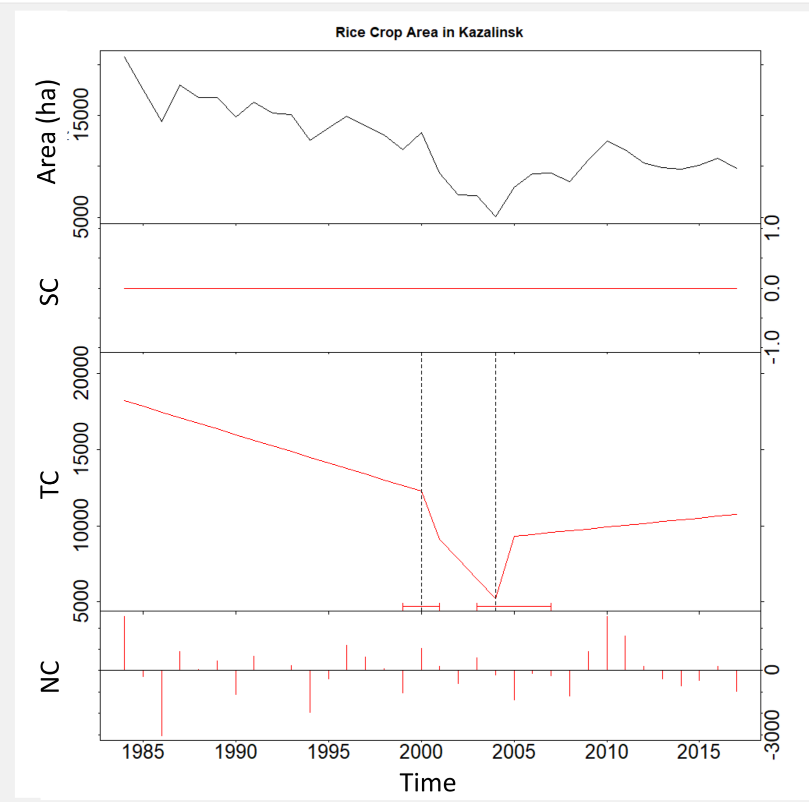
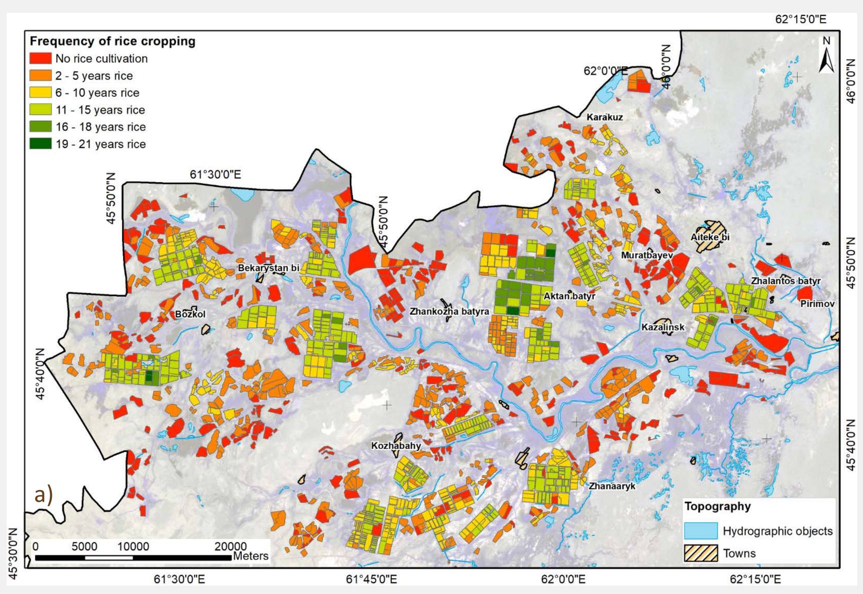


Figure 5: Rice area development in Kazalinsk 1984-2017 (upper line), and Results of the BFAST, SC = fitted seasonal component, TC = fitted trend component, NC = Noise or Reminder Component



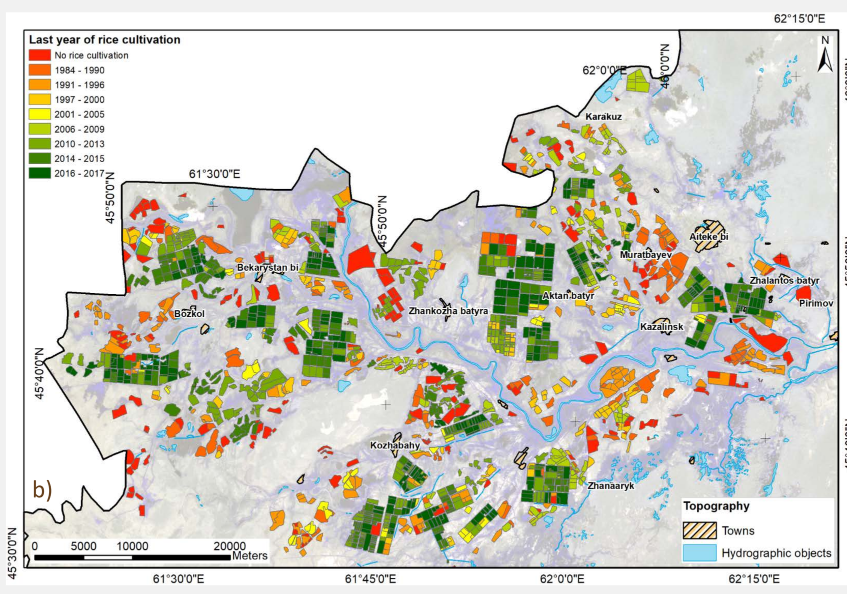


Figure 6: a - The number of years a field was used for rice cropping (1984-2017) , b - The last 5-year period a field was used for rice production (1984-2017) ; c – the trend of rice usage (per field) 1984 – 2017, blue outline color identifies fields with significant trend (< 0.05). The background map is a subset of the Landsat image June 2015 false color composite (red-green-blue = band 5-4-3); transparency: 70 %.

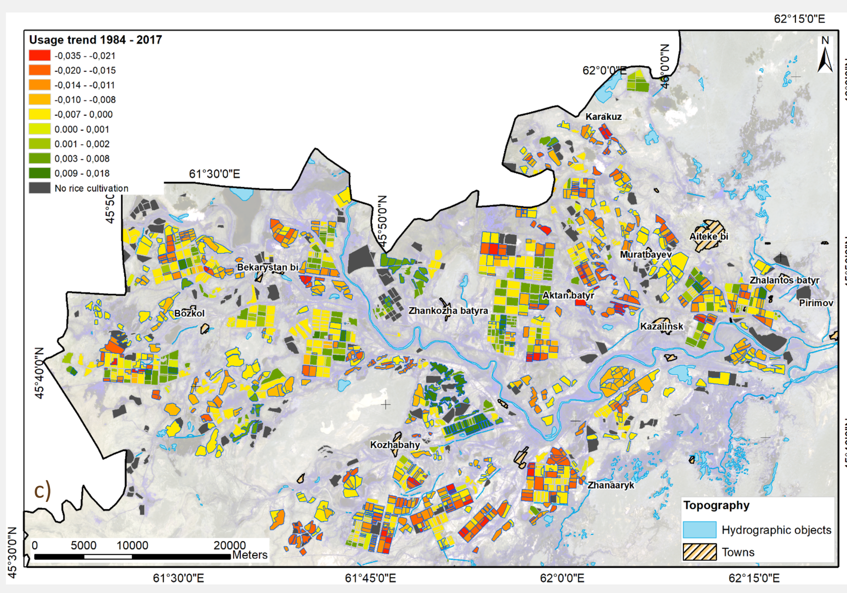


Fig. 6 highlights the rice production intensity and the temporal development 1984-2017 in space. The results highlight that fields that were seldom used for rice cropping (**Fig. 6a**) and that were used before 2000 only (**Fig. 6b**), are either small or occur in more fragmented parts of the irrigation system. Trends of re-use become visible in green colors mainly on fields that are often used for rice cultivation (**Fig. 6c**).

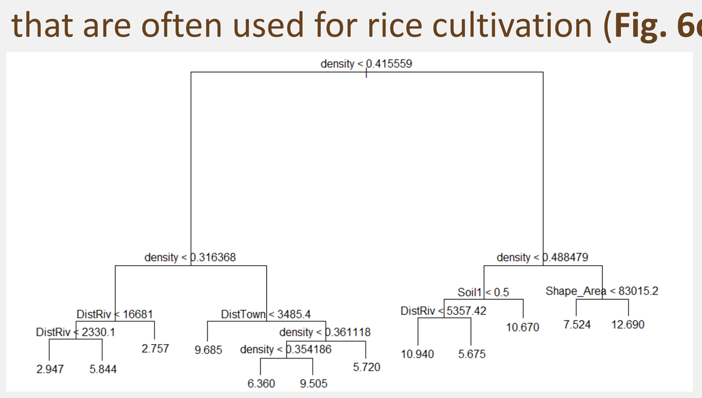


Figure 7: Classification and Regression Tree applied to explain the frequency of rice cropping 1984-2017

The driver analysis could explain 38.3% of the variance of the rice cropping frequency 1984-2017 (R^2 = 0.386). The regression tree (**Fig. 7**) shows that most relevant decisions that occur in the upper part of the tree are related to the indicator field "density". Increasing distance from the river ("DistRiv") or settlements ("DistTown") reduced the likelihood of rice cropping. The influence of the soils can be neglected.

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