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Supervised Classification and Change Detection of Agricultural Land Use in the Forest Steppe Zone of West Siberia Using Multitemporal Satellite Imagery

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List of Acronyms

BMBF	Bundesministerium für Bildung und Forschung
NIR	Near Infra Red
NDVI	Normalized Differenced Vegetation Index
TA	Test Area
UG	Untersuchungsgebiet

Abstract

After the collapse of the Soviet Union in 1991, severe changes in land use, especially the abandonment of farmland, have taken place in many regions of the Russian Federation.
In order to detect the current land use in the Forest Steppe Zone of Russia a supervised maximum likelihood classification was applied to Landsat images from 2009. A supervised classification as well as a calculation of the NDVI with Landsat images acquired in 1987 (Test Area I) / 1989 (Test Area II) were also performed in order to investigate the dynamics of agricultural land use changes with a focus on areas used as arable land. This study is connected to the BMBF-research project SASCHA (Sustainable land management and adaptation strategies to climate change for the Western Siberian corn-belt) and was carried out at two test areas (TA) located in the Tyumen region**.** The key idea was to develop an instrument for further investigations within the SASCHA project and to improve the understanding of ongoing land-cover changes in Russia.
In contrast to scientific publications and reports of national authorities which declared a great decrease of agriculturally used areas, the decline of cropland in the test areas is not as dramatic as presumed. While in TA I 7.89 % of the cropland has been lost, in TA II the cropland even expanded by 9.94%. The position of the study regions within the fertile and still agriculturally high productive forest steppe as well as their close distance to Tyumen, which is the commercial centre of Western Siberia reasons these outcomes. Higher economical productivity and better soil qualities in the district around TA II compared to TA I explains divergent trends in the test areas. The outcome of this study implies that the alteration of agricultural land use in Russia after the breakdown of the Soviet Union varies on a small scale and that the assumed drastic changes cannot automatically be transferred to all regions of the country.

Keywords: change detection, land use change, remote sensing, Russia, satellite images, supervised classification, Tyumen

Zusammenfassung

Der Zusammenbruch der Sowjetunion im Jahre 1991 führte zu gravierenden Landnutzungsänderungen, vor allem der Aufgabe von Ackerland in vielen Regionen der Russischen Föderation. Um die aktuelle Landnutzung in der Waldsteppenzone Russlands zu detektieren wurde eine überwachte Maximum Likelihood Klassifikation mit Landsatbildern aus 2009 durchgeführt. Zur Beobachtung von zeitlichen Landnutzungsveränderungen, die Ackerflächen betreffend, wurde neben einer überwachten Klassifikation zudem eine Berechnung des NDVI mit Landsatbildern aus den Jahren 1987 (Untersuchungsgebiet I) / 1989 (Untersuchungsgebiet II) durchgeführt.
Diese Studie kooperiert mit dem Forschungsprojekt SASCHA (Nachhaltiges Landmanagement und Anpassungsstrategien an den Klimawandel für den Westsibirischen Getreidegürtel) und fand in zwei Untersuchungsgebieten (UG) in der Region Tyumen statt. Die Grundidee war eine Grundlage für weitere Untersuchungen innerhalb des SASCHA-Projektes zu schaffen sowie das Verständnis über voranschreitenden Landnutzungswandel in Russland zu verbessern.
Im Widerspruch zu wissenschaftlichen Veröffentlichungen sowie Berichten nationaler Behörden, ist der Rückgang von Ackerflächen in den Testgebieten nicht so erheblich wie angenommen.

Während die Ackerfläche im UG I um nur 7,89 % abnahm hat sie im UG II sogar um 9,94 % zugenommen. Diese Ergebnisse können durch die Position der Untersuchungsgebiete innerhalb der fruchtbaren und immer noch agrarisch hoch produktiven Waldsteppe sowie ihrer geringen Entfernung zu Tyumen, dem wirtschaftlichen Zentrums Westsibiriens, erklärt werden. Höhere wirtschaftliche Produktivität sowie bessere Bodenqualitäten in dem Gebiet um UG II im Vergleich zu dem Gebiet um UG I, können divergente Trends zwischen den Untersuchungsgebieten begründen. Das Ergebnis dieser Studie zeigt, dass der Wandel in der Landnutzung Russlands im Zusammenhang mit dem Zusammenbruch der Sowjetunion kleinräumig sehr variiert und die angenommenen drastischen Änderungen nicht auf alle Teile des Landes angewendet werden können.

<u>Stichwörter</u>: Änderungsdetektion, Fernerkundung, Landnutzungswandel, Russland, Satellitenbilder, Tyumen, überwachte Klassifikation

Обобщение

После распада Советского Союза в 1991 году в землепользовании происходили серьезные изменения, в частности, отказ от сельскохозяйственных угодий во многих регионах России. Для того, чтобы определить текущее использование земли в лесостепной зоне России, была использована контролируемая классификация максимального правдоподобия (изображения Landsat, 2009 года). Контролируемая классификация так же, как и расчет нормализованного относительного индекса растительности (NDVI) по снимкам Landsat, полученным в 1987 (пробный участок I) / 1989 (пробный участок II) годах, также применялись для того, чтобы отследить динамику изменений в фокусе сельскохозяйственного использования земель (земледелие). Это исследование связано с проектом САША (SASCHA) (Устойчивое землепользование и стратегии адаптации к климатическим изменениям для территории Западносибирского кукурузного пояса).

Тест был проведен на пробный участках (пу) в Тюменской области. Основная идея данного проекта заключается в желании проследить за текущими изменениями почвенно растительного покрова России. Результаты теста оказались не столь драматичны, как предполагалось.

В то время как на пу I 7,89 % пахотных земель были потеряны, на пу II пахотные угодья даже расширились до 9,94 %. Более высокие экономическая производительность и качество почв вокруг пу II в сравнении с пу I объясняется разными тенденциями на территориях исследования. Отсюда следует главный вывод: некорректно утверждать, что резкие изменения в системе российского землепользования после распада Советского Союза происходили одновременно во всех регионах страны.

<u>Ключевые слова</u>: выявление изменения, дистанционное, зондирование, изменение в землепользовании, контролируемая классификация, Россия, снимки со спутника, Тюмень

1 Introduction

Land use plays an important role in environmental changes with regards to sustainability linked to socio-economic developments as well as it has an impact on natural resources like soils, vegetation, water resources and biodiversity (LAMBIN et al. 2000, TURNER 1994). Especially agricultural activities are a significant factor within the global carbon cycle (BONDEAU et al. 2007, PIELKE et al. 2007, KURGANOVA et al. 2010, TILMANN et al. 2001). Monitoring land cover changes can help us to understand how these processes affect climate change and global biochemistry (LAMBIN et al. 2000).

This study is part of the research project 'SASCHA – Sustainable land management and adaptation strategies to climate change for the Western Siberian corn-belt', funded by the framework programme 'Research for Sustainable Development' (FONA) and the funding measure 'Sustainable Land Management' (LAMA) of the Federal Ministry of Education and Research (BMBF).

SASCHA develops sustainable land use and adaption strategies to climate change by investigating interactional effects of climate and land use changes on resources and ecosystem functions in the pre-taiga and forest steppe (SASCHA 2011).

Two of three test areas of the SASCHA project were objects of this study. They are situated in the forest steppe zone in Western Siberia which is of global significance considering the ecological relations highlighted above. SHENG et al. (2004) found out that the peatlands of the Western Siberian plane contain about 70.21 Petagrams of carbon. At the same time, the province Tyumen, where this study was carried out, is a centre of Russia's gas and oil production (SHAHGEDANOVA 2008, WEIN 1999).

Land use in Russia changed because of a great institutional transformations after the breakdown of the Soviet Union in 1991 (LERMANN et al. 2004). This collapse led to serious changes in Russia's agricultural system. The development from a state-directed economy into a capitalistic system had severe consequences for the agricultural land use (KLÜTER 1992, MEINEL 2002, WEGREN 2011). Huge areas of land were abandoned (IOFFE 2005, IOFFE et al. 2008). Thus, FRUEHAUF (2011) noticed a decline of 61% in agricultural production in Russia between 1991 and 2000. Other land use studies in Russia, Kasachstan (HÖLZEL et al. 2002, DE BEURS & HENEBRY 2003, DE BEURS et al. 2003, KÜMMERLE et al. 2011, MEINEL 2002,) or Latvia (MADDOCK 1995) confirm the decreasing trend in the use of agricultural land in former countries of the Soviet Union after 1991.

Regarding the Tyumen region, there is not much information about current developments in expansion and trend of agricultural use. To give an instrument for further land management and environmental strategies, there is a need for information about the transformations of land use after 1991 as well as the current land use.

The global aim of this work is to imbed the region around Tyumen into movements of Russian land use and answer the question whether there really is a decline of agricultural area in the test areas after 1991. Therefore this study focuses on the automatic satellite image classification of current land use in order to produce a tool for further investigations in this area as well as the detection of changes in arable land use. Furthermore remote sensing as a tool for monitoring changes in land use will be discussed.

2 Methods

2.1 Test areas

The two study areas are located in the western part of West Siberia, in the southern part of the Tyumen Oblast[1] (figure 1) which covers an area of about 16000 km².

Figure 1. Location of the test areas

TA I (Test Area I) includes the city *Omytinskiy* (Омутиский) (56°27'N/67°35'E), TA II (Test Area II) lies to the south of the city of *Ischim* (Ишим) (56°06'N/69°30'E). Each of the study sites covers a 20 x 20 km area (40000 ha). They are situated to the south east of Tyumen (57°09'N/65°31'E), which is the largest city and the administrative centre of the Tyumen Oblast with a population of about 600000 inhabitants.

Geographically TA I and II belong to the Western Siberian Lowland. The topography is characterized by a flat surface. TA I lies 120 m, TA II 110 m above sea level. The bedrock consists of Palaeozoic rocks, which are overlain by Mesozoic and Cenozoic sedimentary consisting of Quaternary sands and other aeolian and fluvial deposits. These Quaternary

[1] Type of administrative division in countries of the former Soviet Union

deposits range from 200 to 250 m thickness covering the West Siberian Lowland (KORONOVSKY 2002, VOLKO & OLIUNIN 1993).
The soils are mostly chernozems (SMOLENTSEVA et al. 2002, ZAMOTAEV 2002). Further soiltypes in the test areas are gley soils, black alkali soils and phaozems (COMMITTEE FOR GEOGRAPHY AND CARTOGRAPHY OF THE MINISTRY FOR ECOLOGY AND RESOURCES OF THE RUSSIAN FEDERATION 1992). The climate for the Tyumen region is continental with a -17.05°C mean temperature in January to a +18.07°C mean temperature in July, giving an annual mean temperature of -1.02°C (RUSSIAN FEDERAL SERVICE FOR HYDROMETEROLOGY AND ENVIRONMENTAL MONITORING n.d.). Annual precipitation lies around 500 mm (RUSSIAN FEDERAL SERVICE FOR HYDROMETEROLOGY AND ENVIRONMENTAL MONITORING n.d., SHAHGEDANOVA 2002).
TA I and TA II belong to the dry midlatitudes. Depending on temperature and aridity in these ecozone several types of steppe can be differentiated. The natural vegetation in both test areas is forest steppe. The landscape is dominated by grassland of weather grass (*Stipa-Festuca*) communities, which are then broken up by islands of trees (SCHULTZ 2002). Land is mainly used for agriculture and extensive farming. Cropland, mostly planted with spring wheat as crop, meadows and pastures are the most common types of land use. The region around the test areas is with 2.18 persons/km² sparsely populated (WEIN 1999).

2.2 Satellite data

All satellite data used were Landsat Thematic Mapper images (TM 4 and 5) (supplement A) that were downloaded from http://glovis.usgs.gov/. They have a spatial resolution of 30 m per pixel in 7 bands (1^{st} 0.45-0.52 μm; 2^{nd}: 0.52-0.60 μm; 3^{rd} 0.63-0.69 μm; 4^{th} 0.76-0.90 μm; 5^{th} 1.55-1.73 μm; 6^{th} 10.40-12.50 μm (120 m pixel size); 7^{th} 2.08-2.35 μ (ALBERTZ 2007)). Selection criteria were no cloud cover at image acquisition date and the acquisition date itself. All images used were taken in May, because this is the period of the year where differences between areas of cropland and grassland are greatest. While cropland is freshly ploughed at this time the grassland already show a dense vegetation cover. Due to these criteria and limited availability, pictures were taken from 2009 (TA I: 29.05.09, TA II: 15.05.09) to classify the current state of land use. To detect differences over time between the state before the breakdown of the Soviet Union in 1991 and the current state pictures from 1987 (TA I, 17.05.87) and 1989 (TA II, 16.05.89) were used.
Processing was done using all reflective bands. The satellite imagery was handled with the software ERDAS Image 2011. Further data processing was handled in ArcMap.

2.3 Data processing

2.3.1 Georeferencing and collecting ground truth data

All subscenes were geo-referenced to a Universal Transverse Mercator projection. Three (TA I and TA II in 2009, TA I in 1987) of four scenes were provided at level 1T which

means pictures offer systematic radiometric and geometric accuracy by incorporating ground control points with employing a Digital Elevation Model for topographic accuracy (USGS 2009). For all images this Landsat reference at level 1T was used as base reference.
For the scene of TA II in 1989 the reference was done by generating control points from the other Landsat scene of TA II in 2009. At some points generating control points was difficult because the scene did not show acceptable fix points. Furthermore all pictures reveal aberrations from topographic maps in a range of one to three pixels. However, for an evaluation of changes in land use on the landscape level these small aberrations are not significant. The classifications of 2009 were additionally geo-referenced with Russian topographic maps (scale 1:100000).
In both test areas ground truth data for the supervised classification was collected. At 26 locations in TA I this data was acquired. Because of logistical conditions collecting ground truth data for TA II was only possible at eleven points. Coordinates with associated information about land use were taken with a Garmin GPS and administered with Map Source and applied in ArcMap.

2.3.2 Classification of the current state

The aim of an image classification is to automatically categorize all pixels in an image into land cover categories (LILLESAND & KIEFER 1994). Therefore, at the locations where ground truth data (training data) was collected areas of interest (AOI) were created. These AOI polygons were converted into parametric files presenting the spectral signatures of the training data (in case of parametric files these are the statistical parameters of the pixels) (ERDAS 2010).
These files were used to do an automatic supervised classification of land use in 2009. For this, a statistically-based maximum likelihood classification was applied. Based on the statistical parameters of the specified classes from the training data, this method calculates the likelihood, with which every pixel in the image belongs to these classes. Every pixel is than assigned into the class with the highest likelihood (ALBERTZ 2009, RICHARDS & JIA 2006). The detected classes can be found in the results (chapter 3.1). Areas sizes of *Cropland*, *Grassland* and *Forest* have been computed in ArcGIS.

2.3.3 Classification of the former state

For the detection of the areas of agricultural use in 1987 and 1989 only arable land (*Cropland)* was classified. Two different methods were applied:
To detect these areas a supervised classification with focus on cropland was done first. The classification was done as described in chapter 2.3.2 by generating signature files from areas of interest without ground truth data but manual interpretation of the image by the processor.
The second approach to detect *Cropland* was the calculation of the Normalized Differenced Vegetation Index (NDVI). This index is the difference of the near infra red (NIR) and the red band divided by their sum (NDVI = NIR-RED/NIR+RED) and points out areas

that have high reflectance in the near infra red (HUETE et al. 1997, NETZBAND et al. 2007). The result is an image with values between zero and one (ALBERTZ 2009) where areas of sparse to none vegetation correspond to lower values (MYNENI et al. 1995). By manual checking of these values converting the result into a pseudocolour image the threshold of the reflectance of cropland was observed. This was done by the known natural range cover of acres and comparison of the result with the satellite image. Using the 'Model Maker' in ErdasImage this pixel range was extracted to get just the areas used as *Cropland*. Finally, the results of both methods were compared using ArcGIS. Areas, where both methods classified pixels as *Cropland*, were signed as *Cropland* in 1987 respectively 1989. Sizes of the arable areas in the different years have been also computed in ArcGIS.

2.3.4 Accuracy assessment

For all classifications an accuracy assessment was done by generating stratified random points for the classified images, using the accuracy assessment application in Erdas Image. Per class 50 points were taken (CONGALTON 1991). The reference points were digitized manual on screen. On this basis an error matrix was produced for each result presenting the overall accuracy, the users and producers accuracy as well as the kappa coefficient.

3 Results

Two different thematic maps for each test area have been produced: land use classifications in 2009 and arable land use in 1987 (TA I) and 1989 (TA II). By combining this data not ploughed grassland in 1987 (I) / 1989 (II) and 2009 was deduced. The corresponding maps as well as the satellite images are added in the supplement (B, A). For bigger maps (figures 2 & 4) see also the supplement (B).

3.1 Land use classification for 2009

For TA I seven and for TA II six land cover classes have been determined. *Cropland*, *Grassland*, *Forest*, *Water* and *Reeds* have been carved out in both classifications (table 1, figure 2). Further classes are *Roads and Settlement* as well as *Unknown* for TA I and *Fens* for TA II.

Table 1. Composition of land use in both test areas in 2009

Class	TA I * [ha]	%	TA II * [ha]	%
Cropland	11842.74	29.61	16501.59	41.25
Grassland	16670.34	41.68	11913.12	29.78
Forest	5689.89	14.22	7635.87	19.09
All other classes	5797.03	14.49	3949.42	9.87

* TA= Test area ≙ 40 000 ha

Cropland is characterized as bare ground which enfolds in 2009 29.61% of the whole area in TA I and 41.25% in TA II. *Grassland* can include meadows, pastures and fallows and covered in 2009 41.68% of TA I and 29.78% in TA II. *Forest* covers all kinds of woodland vegetation, mostly birches as well as coniferous (predominantly pine). It accounts for 14.22% in the first test area in contrast to 19.09% in the second test area. The remaining classes (TA I: *Reeds*, *Roads and Settlement*, *Unknown*, *Water*, TA II: *Fens*, *Reeds*, *Water*)

cover an area of 14.49% (TA I) and 9.87% (TA II). For TA I *Roads and Settlement* were also classified. In the picture of TA II this class could not be outlined. Because of similar pixel signatures as arable areas, sealed surface appears in the same class as *Cropland*. Trials with taking signatures of *Cropland* and *Roads and Settlement* from a picture of another date as well as from a layer stack of two different dates could not solve this problem.
There is one pixel group for TA I, marked in the classification as *Unknown*, that could not be identified satisfactorily. At some points pixels of the class *Roads and Settlement* were automatically classified incorrectly and put into this unknown class.

TA I **TA II**

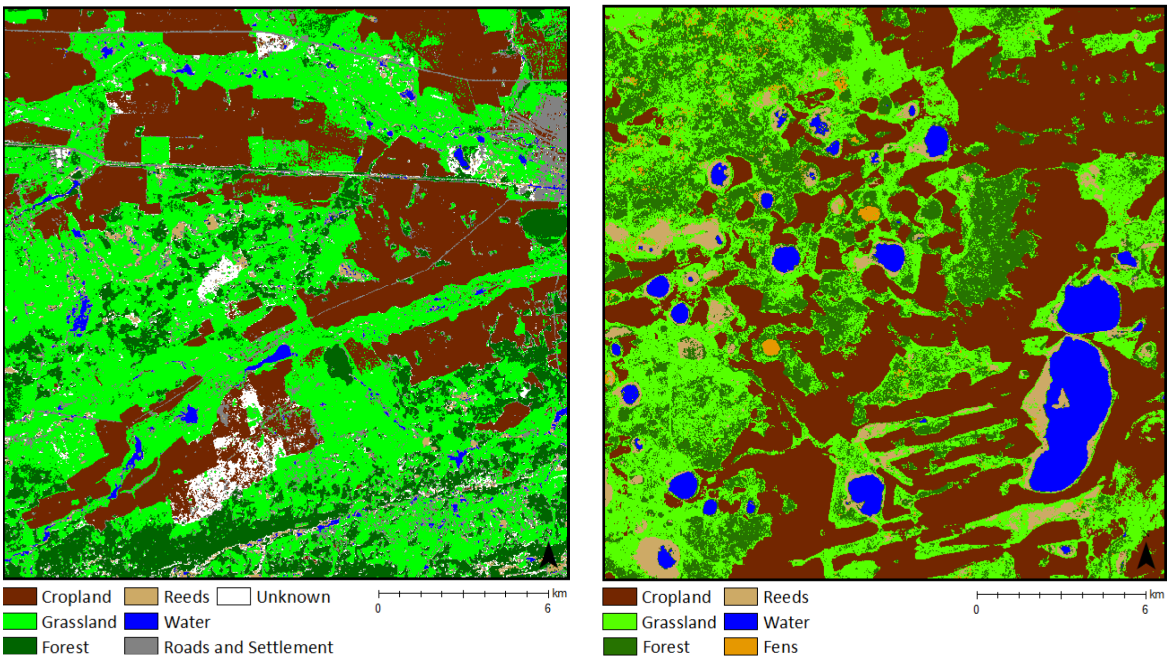

Figure 2. Land cover classification of the test areas for 2009

In contrast to TA I, TA II contains a further class named *Fens*. Although there were no ground-truth points for this class it could be identified because of its shape and by comparison to topographic maps.

3.2 Arable land use in 1987 (TA I) / 1989 (TA II)

The two methods produced slightly differing results (table 2, figure 3). For TA I the supervised classification brought out 18000.72 ha of *Cropland* in comparison to 17243.64 ha from the NDVI. That makes a difference of 1.89%. In TA II the NDVI characterized with 13892.31 ha 2.6% more as *Cropland* than the supervised classification with 12853.35 ha.
The NDVI shows in TA I a values margin from -0.06 to 0.13. TA II shows a range from -0.01 to 0.03. Beside the fact that the range of the NDVI which was identified as C*ropland*, includes in TA II also some pixels from the class *Reeds*, interpretation of these values by comparison with the results of the supervised classification and a consideration of the

satellite image as well as consulting the results of the accuracy assessment (see chapter 3.4) showed that C*ropland* could be confidently identified. The intersection of the two

Table 2. Detection of areas of arable use for 1987 (TA I) and 1989 (TA II) by two different methods

		TA I* [ha]	%	**T A II*** [ha]	%
1987 (I) / **1989** (II) **	1 Supervised Classification	18000.72	45.00	12853.35	32.13
	2 NDVI	17243.64	43.11	13892.31	34.73
	Intersect of method 1 and 2	14999.58	37.50	12524.13	31.31

* TA = Test Area ≙ 40000 ha   ** Use of different detection methods

methods produced an area of 14999.58 ha in 1987 (37.50%) for TA I and 12524.13 ha (31.31%) in 1989 for TA II for as arable land used area.

TA I **TA II**

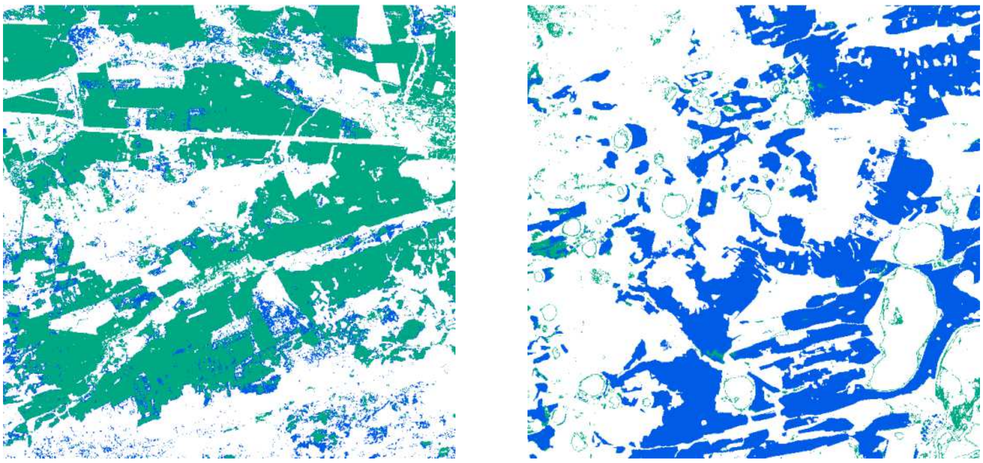

Figure 3. Identification of areas of arable use in 1987 / 1989 by calculation of the NDVI (turquoise) and a supervised classification (blue).

3.3 Changes in arable land use

The most striking feature is the decrease of cropland in TA I from 37.50% to 29.61% indicating a decline of 7.89% of area for arable use. In contrast to this result arable use expanded in TA II from 31.31% to 41.25% which is an increase of 9.94%

Table 3: Changes in the extent of arable land use between 1987 (TA I) / 1989 (TA II) and 2009

TA*	Cropland [%]		**Change in Extent** [%]	Unchanged Area** [%]
	1987 (IA I) / 1989 (IA II)	2009		
I	37.50	29.61	**- 7.89**	23.24 (9295.02 ha)
II	31.31	41.25	**+ 9.94**	28.98 (11590.65 ha)

* TA = Test Area ≙ 40 0000 ha, ** Cropland in 1987 (IA I) / 1989 (IA II) and 2009

(table 3). *Unchanged Area*, which means the area that was used as *Cropland* in 1987 respectively 1989 and 2009, is with 11590.65 ha in TA II higher than in TA I with 9295.02 ha.

TA I **TA II**

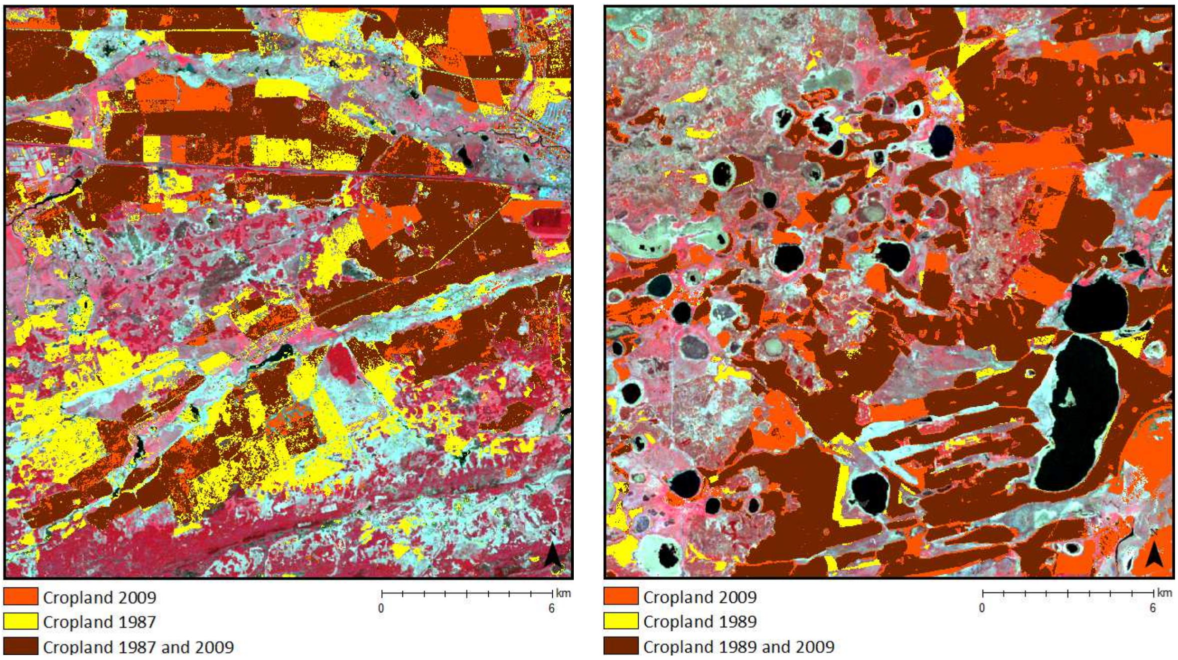

Figure 4. Cropland in the test areas in 1987 / 1989 and 2009 (background: satellite image, false colour composite NIR/R/GR (bands 4/3/2)

3.4 Accuracy assessment

The accuracy assessment shows clearly that all of the results fulfill an overall accuracy higher than 85%. The classifications for the former state of the test areas reached better results than the supervised classifications for 2009 (table 4).

Table 4. Overall accuracy and kappa statistics of all classifications for the images of 1987 / 1989 and 2009

	Method	TA	Overall Classification Accuracy [%]	Overall Kappa Statistics
2009	Supervised Classification	I	89.4	0.85
		II	90.7	0.87
1987 (I) / 1989 (II)	NDVI	I	93.0	0.86
		II	96.0	0.91
	Supervised Classification	I	95.0	0.81
		II	98.0	0.95

For both test areas the overall accuracy of the NDVI calculation is three percentage points below the supervised classification for 1987 (TA I) / 1989 (TA II) (table 4). All of the user's and producer's accuracies for *Cropland* are within a range from 88.4% to 100.0% (table 5).

All classifications for TA II reached better results than those for TA I. For more detailed results of the accuracy assessment (error matrices, users accuracy and producers accuracy of the other classes) see the supplement (D).

Table 5: Producers and Users accuracy of all classifications for the class *Cropland* in 1987 / 1989 and 2009

	Method	Reference Totals	Classified Totals	Number Correct	Producers Accuracy [%]	Users Accuracy [%]
TA I	Supervised Classification for 2009	105	97	95	90.5	97.9
	Supervised Classification for 1987	42	45	41	95.0	88.4
	Calculation of the NDVI for 1987	40	43	38	95.0	88.4
TA II	Supervised Classification for 2009	110	113	110	100.0	97.4
	Supervised Classification for 1989	34	32	32	94.1	100.0
	Calculation of the NDVI for 1989	35	35	33	94.3	94.3

4 Discussion

4.1 Land use change

With its land policies and farm restructuring Russia underwent in the agricultural sector after the breakdown of the Soviet Union in 1991 many changes, that had consequences for the whole agrarian system (LERMAN et al. 2004). Previously funded by subsidies, the agrarian sector then collapsed because of a deficient efficiency in productivity hence the agricultural sector decreased after 1991 (LERMAN 2001).

This reorganization from a command to a free market economy led to farmland abandonment. Huge areas between 20 and 30 million hectares of cropland were given up (IOFFE 2005, IOFFE et al. 2008). IOFFE et al. cite in their work from 2008 the State Committee for Statistics that Russian agriculture is 40% lower in 2008 than in 1990. FRÜHAUF (2011) describes a decline in agricultural production between 1991 and 2000 of even 60%.

In the Tyumen Oblast the acreage of crops on farms of all categories decreased by 33.33% during 18 years from 1607.5 ha in 1991 to 1071.7 ha in 2009. The decrease of the single Rayons[2] within the Oblast is varying from 30.5 % (*Sladkowskii* Rayon) to 52.38 % (*Sorokinskii* Rayon) (THE TERRITORIAL OFFICE OF THE FEDERAL STATE STATISTICS SERVICE OF THE TYUMEN REGION 1996, THE TERRITORIAL OFFICE OF THE FEDERAL STATE STATISTICS SERVICE OF THE TYUMEN REGION a 2010). While the quality of soviet data often provides reasons to doubt (FISCHER 1992) Russian statistics after 1991 have been largely reliable (INOFFE 2005). This differing numbers of decreases in acreage of crops within the Rayons already indicate that Russia's agricultural development can differ in different regions of the country.

The value of the decline of cultivated area in the whole Oblast is slightly lower than those discussed in the literature for the entire country. The cited values are not transferable to this study. Indeed, a decline in area of arable use is also illustrated in the first test area. Here, the decrease of cultivated land appears to be quite low with 7.89% in contrast to the numbers discussed before. In the second test area acreages of crops even increased

over a 20 year period by 9.94%. The results of this study indicate, that the decline of agriculturally used areas might be in some regions not as high as previously assumed.
Obviously, acreage in the test areas that is not used as *Cropland* anymore, is still used as *Grassland*. Indeed *Cropland* in TA I decreased but considering the proportion of the classes in both classifications of 2009 areas used for agricultural purposes, either intensive as *Cropland* or extensive as *Grassland*, remain the largest proportion of the area. Both test areas are situated within the forest steppe belt, where with its fertile soils and good climatic conditions huge areas of steppe have been ploughed in the 1950s (MEINEL 2002, WEIN 1999). WEIN (1999) entitles the cultivated area of Western Siberia to 17.5 million hectares, which underlines, even after the breakdown of the Soviet Union the remaining, global importance of Western Siberia as an agricultural area. Moreover the Tyumen region is one of the most profitable economical regions in the country (WEIN 1999). Both test areas are connected by a good network of transport routes to the commercial centre of Western Siberia. The close distance to Tyumen as well as their position within Russia's agriculturally favored region can be the reason for the consistent agricultural activities within the test areas.
Nevertheless there are differences in arable use between both test areas. Quite clear is that fields are abandoned where soil quality is poorer in comparison to other locations. In the first test area *Cropland* was given up predominately in areas with gley soils (COMMITTEE FOR GEOGRAPHY AND CARTOGRAPHY OF THE MINISTRY FOR ECOLOGY AND RESOURCES OF THE RUSSIAN FEDERATION 1992). Without draining these wet soils are not appropriate farmlands (SCHEFFER & SCHACHTSCHABEL 2008). Furthermore *Cropland* was abandoned on black alkali soils which are more difficult to cultivate than chernozems (SCHEFFER & SCHACHTSCHABEL 2008), on which the increase of areas of arable use in TA II occurred mainly (COMMITTEE FOR GEOGRAPHY AND CARTOGRAPHY OF THE MINISTRY FOR ECOLOGY AND RESOURCES OF THE RUSSIAN FEDERATION 1992).
These humus-rich soils belong to the most fertile grounds in the world (SCHEFFER & SCHACHTSCHABEL 2008). Partly they are degraded (COMMITTEE FOR GEOGRAPHY AND CARTOGRAPHY OF THE MINISTRY FOR ECOLOGY AND RESOURCES OF THE RUSSIAN FEDERATION 1992), but still with their high content of humus are fertile locations (SCHEFFER & SCHACHTSCHABEL 2008, ZAMOTAEV 2002). Different soil qualities in the test areas can be one explanation for the divergent trends in the study regions.
A further reason for the increase of *Cropland* in TA II can be a local established meat factory, named '*Plemzavod-Jubilei'* which ensures a demand for production here. In the regions *Ischim* and *Berdyuzhskom* this company cultivates its own crops as barley, wheat, peas and rapeseed. The bigger part of the harvest is processed into pig feed, the rest is sold. For 2011 *Plemzavod-Jubilei* declares a harvest of 33000 tons on 35373 hectares of arable land (PLEMZAVOD-JUBILEI 2011). This factory is also supported by governmental subsidies (DEPARTMENT OF AGRICULTURE TYUMEN 2010) which boosts the economical structure in the mentioned region. Also parameters like higher population and greater income in

[2] Administrative subdivision of Oblast

the agricultural sector in the region around TA II support this trend (THE TERRITORIAL OFFICE OF THE FEDERAL STATE STATISTICS SERVICE OF THE TYUMEN REGION a 2010, THE TERRITORIAL OFFICE OF THE FEDERAL STATE STATISTICS SERVICE OF THE TYUMEN REGION b 2010).

4.2 Classification

The results of image classifications are often insufficient (MARBLE & PEUQUET 1983). Generating training classes can improve such results (ALBERTZ 2009, KRONBERG 1985). Thus, the use of a supervised classification in this study to detect current and former land cover has been generally a success. The results of the overall accuracy assessment are satisfying with at least 89.4% (TA I, 2009). Furthermore *Cropland*, *Grassland*, *Forest* and *Water* show also sufficient values in users and producers accuracy. The calculation of the NDVI for identifying *Cropland* in 1987 and 1989 showed good results as well with values for overall accuracy over 90%. Additionally, the low deviation of the two methods for detecting former arable use indicates that these areas could be determined precisely. The overlap of the values of the NDVI for *Cropland* with *Reeds* in TA II could be caused by the fact that both classes contain bare ground surfaces which can explain same reflections.

Weaknesses of the classifications for 2009 are *Roads and Settlements* as well as *Reeds* for both classifications. Here, users and producers accuracy do not offer satisfactory results. In TA I there are some misclassifications between the classes *Roads and Settlement* and *Cropland*. In TA II *Cropland* and *Roads and Settlement* could not be differentiated. Identifying a class through a supervised classification depends on the spectral properties of the training class (ALBERTZ 2009). Ideally each class has a significant spectral signature. In reality this is not always the case. Thus, the same surface can appear different in several locations and show different reflections (KRONBERG 1985). This can lead to the mentioned misclassifications. Because of the small proportion of *Roads and Settlements* of the whole landscape (approximately less than 2 %), the significance of the results of the determined cropland is not affected.

The month of May turned out to be a good recording point for making out differences between vegetation covered areas and non covered surfaces as cropland.

The differentiation within classes like *Grassland* into meadows, fallows and pastures, *Forest* into different types of trees and *Cropland* into several crops was not an aim of this study and would have been difficult with the number of collected ground truth data. To get a more detailed separation of the classes for special research questions concerning individual ecosystems there should be at least one reference surface for each subclass (ALBERTZ 2009). Moreover a classification of one area from different acquisition dates within a year could be very helpful to differentiate within classes. For crops with characteristic seasonal changes, this is a common proceeding (ALBERTZ 2009).

However, the discrimination of riparian vegetation, areas with shrubs, wetlands, wet grasslands, reeds and fens for the denotation as well as for the correct classification have a need for further discussion. For summarizing these vegetation types, 'herbaceous wetland vegetation' could be a suggestion. In context of monitoring land use changes a further differentiation would be desirable. For a more specified description of these classes a further collection of detailed ground truth data at points with these vegetation types is recommended.

A weakness of the classification of 2009 in the first test area is the non successful classification of a big cluster of the class *Unknown*. A big cluster of these signature can be found in the northern part of the test area. The shape indicates that this is likely to be used for agricultural purposes. It is possible that further investigations within the subproject 'Analysis and Monitoring of land cover and current land use change' within the SASCHA project can proof this assumption. Because of the small proportion of this class in the entire landscape this result does not lead to a big reduction of the conclusions of this study.

4.3 Conclusion

In this work, it has been proven, that the supervised classification of multitemporal satellite images is an effective tool to quantify current land use as well as to detect changes in an altering environment. With high accuracy land use within the test areas could examined.

All in all the results of this study have shown, that the break-in of the agrarian production in Russia after the breakdown of the Soviet Union, which is described in the literature, is not that dramatic as assumed in the test areas. In between 20 years farmland declined in the first test area, but not as much as the reported numbers in the literature. Furthermore *Cropland* increased in the second area which suggests that Russia's agricultural development after the breakdown of the Soviet Union does not apply to all regions in the Russian Federation. Land use differs in between different locations, depending on conditions on the small scale (like soil quality and economical development) in a particular region of the country.

For a better understanding of the impacts caused by political and economical developments on land use further studies are necessary. Around 2000 the economical situation in Russia has stabilized again (INOFFE et al. 2008). Also statistical data (from 2005 to 2009) show that acreage of crops increased again after that time (THE TERRITORIAL OFFICE OF THE FEDERAL STATE STATISTICS SERVICE OF THE TYUMEN REGION a 2010).

To examine this development on scale of the test areas further investigations with images from that time are desired. It would be also interesting to know if the decline of cropland in TA II was constant between 1989 and 2009 or if an interim break-in of the agrarian production after 1991 did also take place there.

To put the results of this study into a context of a higher landscape level it would be useful to detect land use changes for the whole Tyumen Oblast. Further research on these topics will be done within the module 'Analysis and monitoring of land cover and current land use change' in the context of the framework of the SASCHA project.

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Supplement

A **Test areas**

B **Maps**

C **Overview - area sizes** (of detected classes)

D **Results of the accuracy assessment**

E **Used satellite imagery**

F **CD – Contents**

A Investigation Areas

TA I

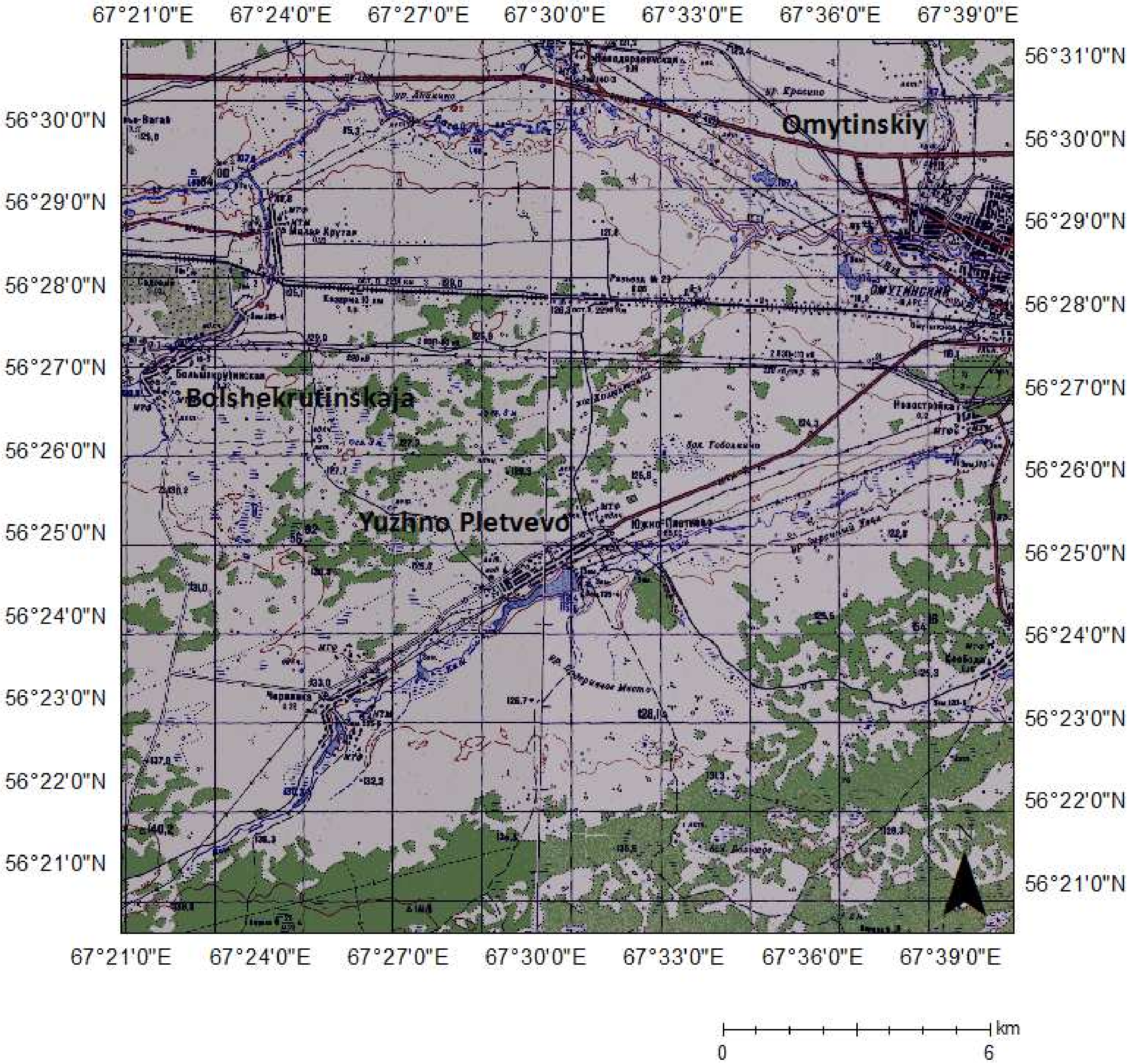

Figure A 1. Topographic map of TA I, source: Main Administration of Geodesy and Cartography under the USSR Council of Ministers (GUGK Mapping) (1985), scale 1:100000 (in Russian)

TA I

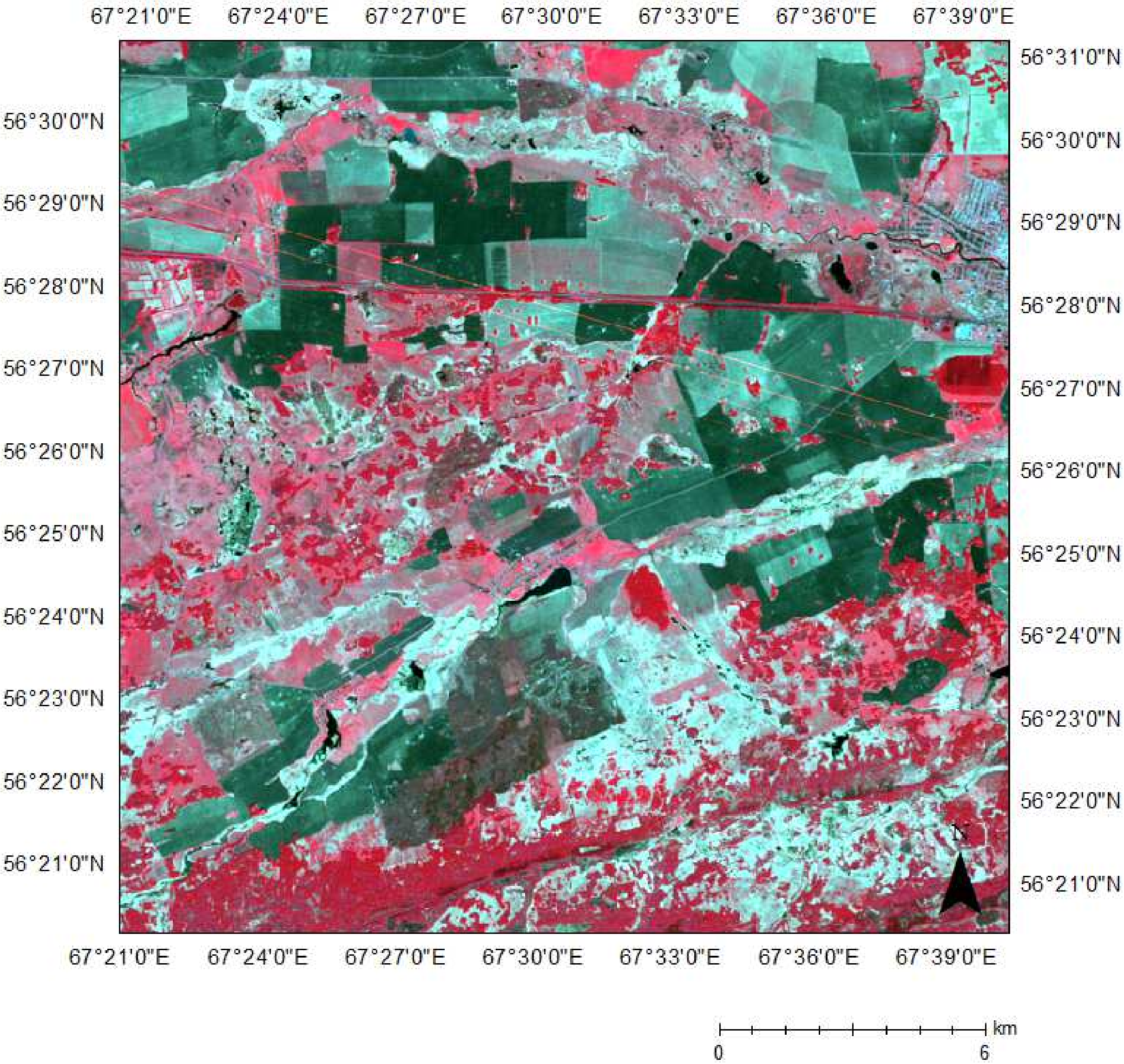

Figure A 2. Satellite image of TA I, source: http://glovis.usgs.gov/, image acquisition date : 29.05.2009, image-ID : L5159021_02120090529, sensor: Landsat 5, false colour composite NIR/R/GR (bands 4/3/2)

TA II

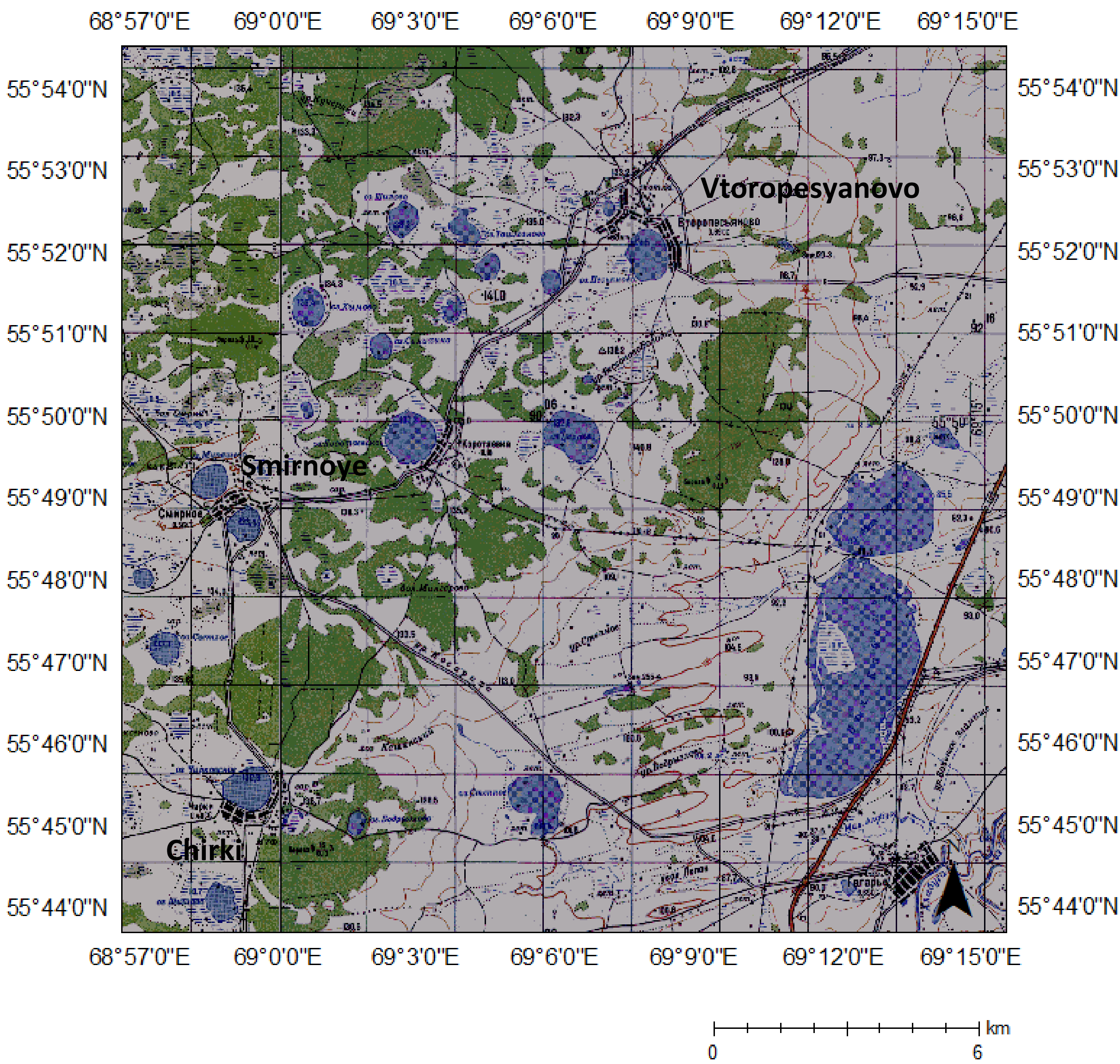

Figure A 3. Topographic map of TA II, source: Main Administration of Geodesy and Cartography under the USSR Council of Ministers (GUGK Mapping) (1985), scale 1:100000 (in Russian)

TA II

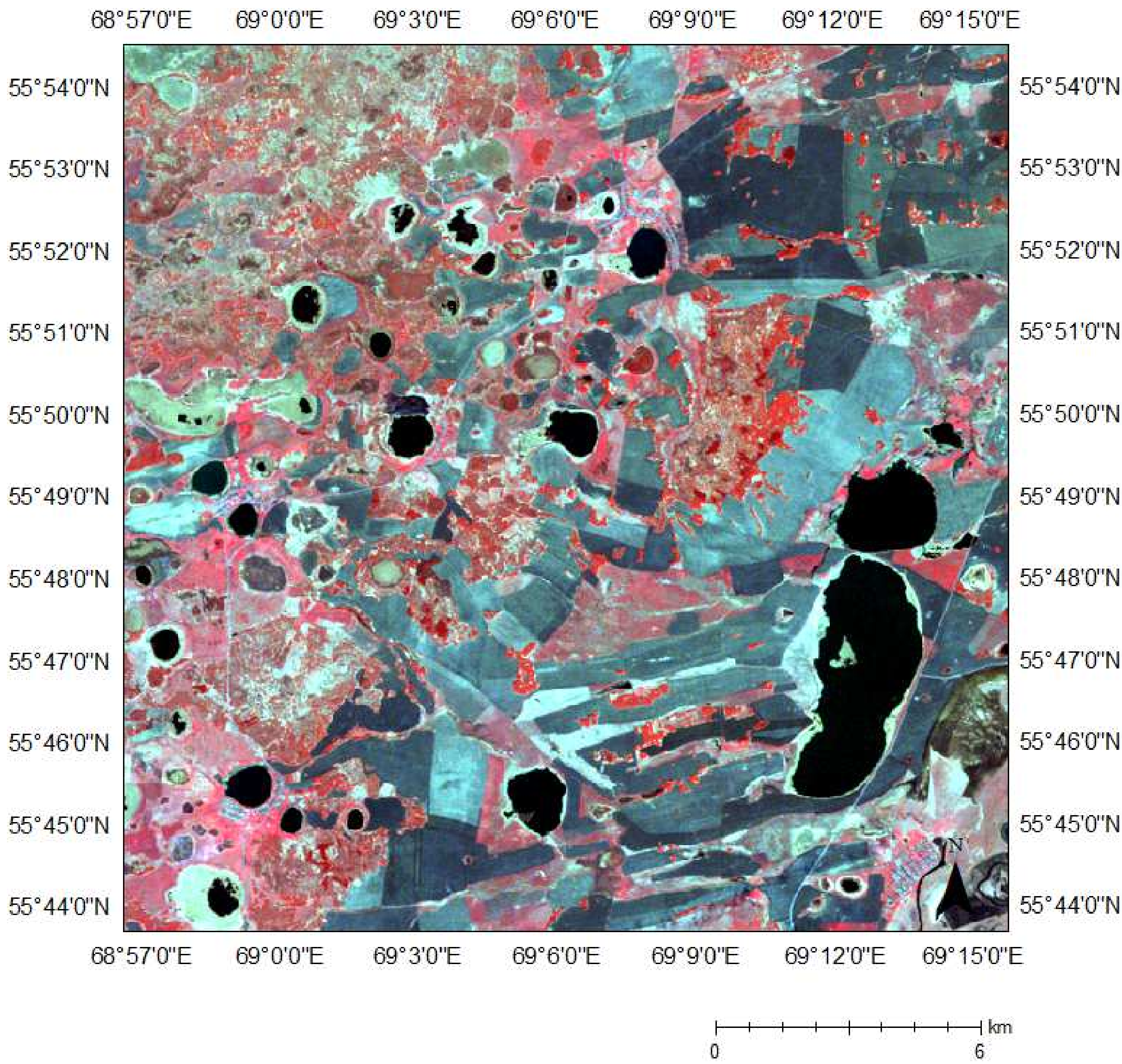

Figure A 4. Satellite image of TA II, source: http://glovis.usgs.gov/, image acquisition date : 15.05.2009, image-ID : L5157021_02120090515, sensor: Landsat 5, false colour composite NIR/R/GR (bands 4/3/2)

B Maps

TA I

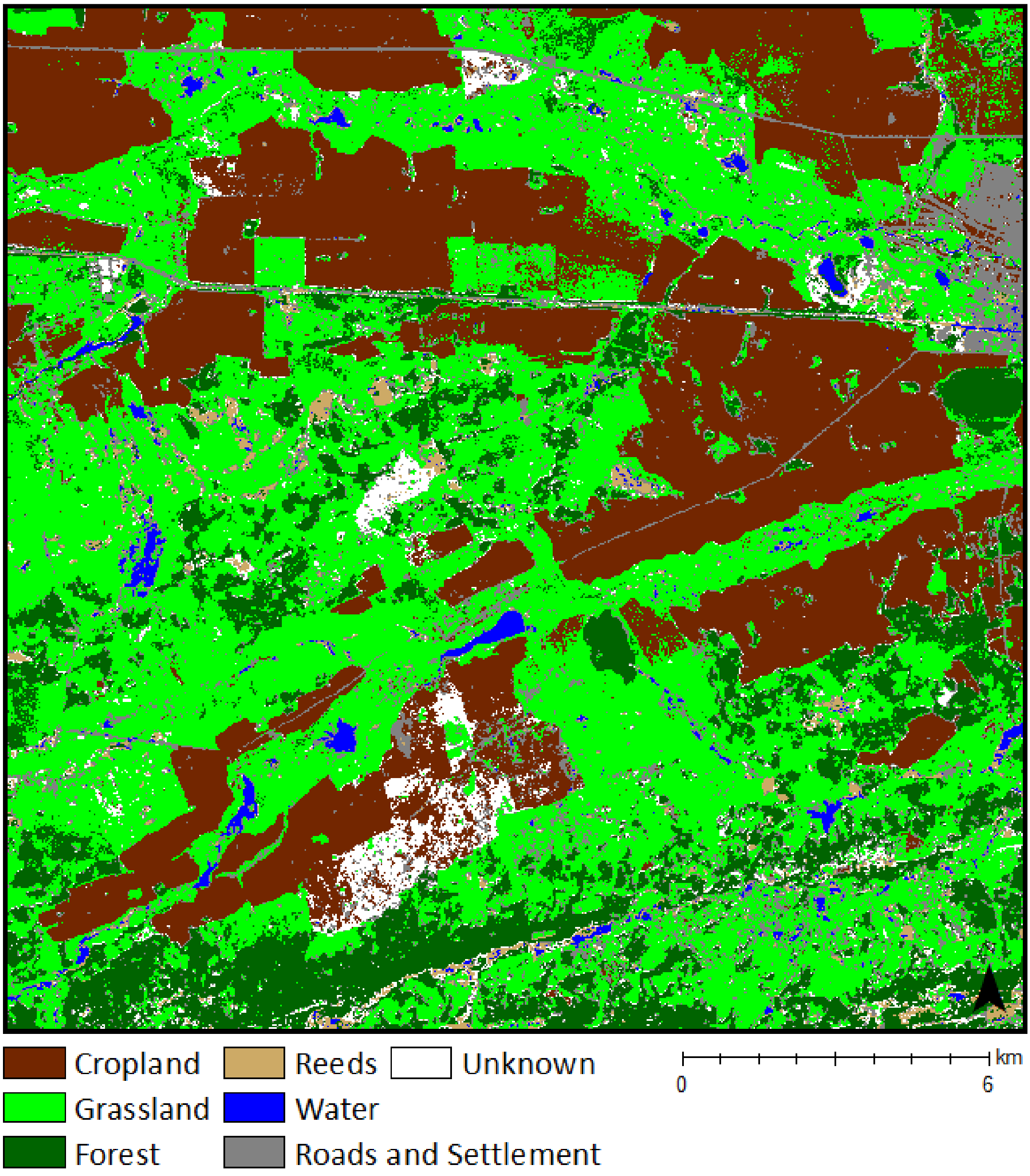

Figure B 1. Land use classification for 2009

TA I

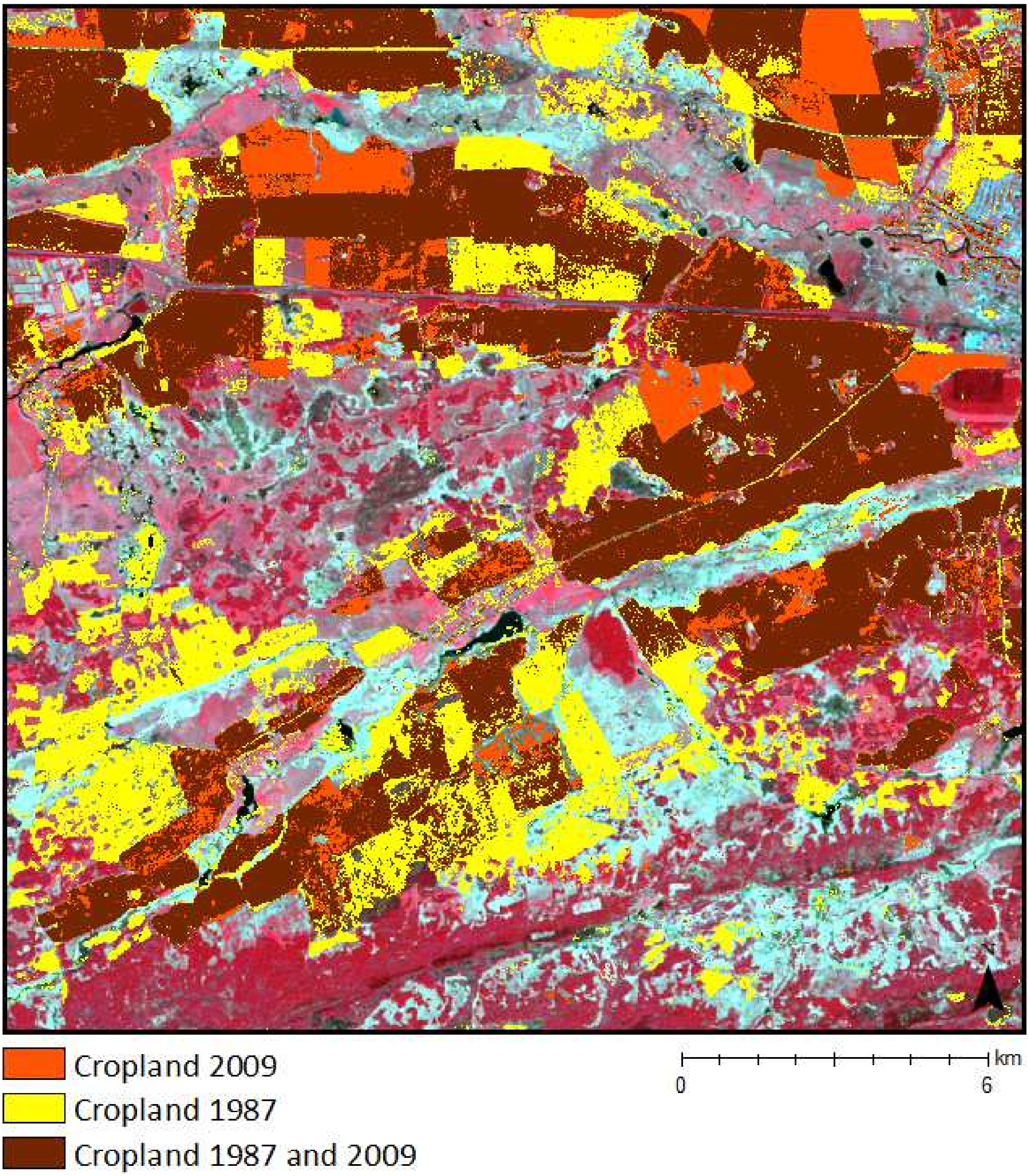

Figure B 2. Agricultural land use between 1987 and 2009, background: satellite image, false colour composite NIR/R/GR (bands 4/3/2)

TA I

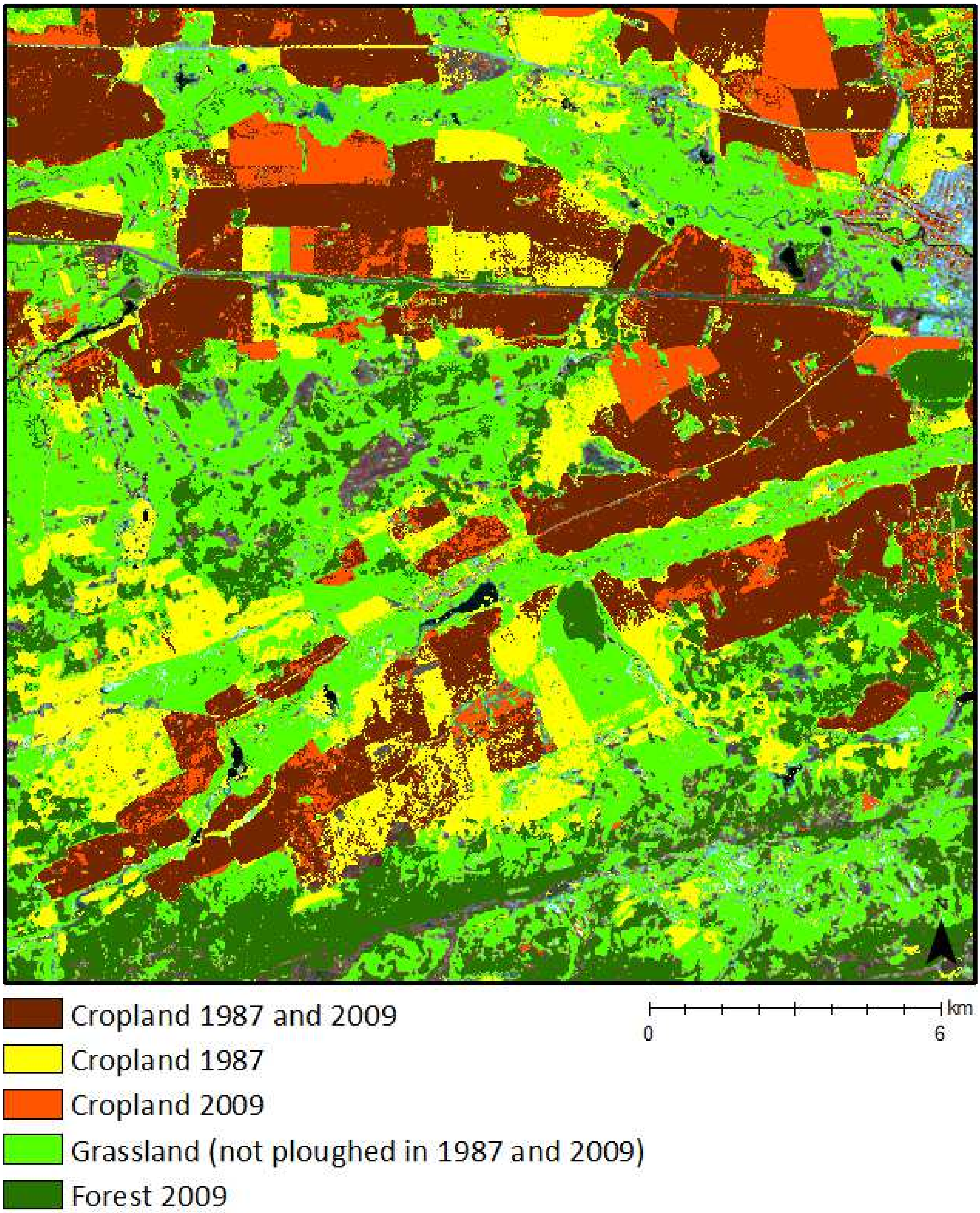

Figure B 3. Not ploughed grassland in 1987 and 2009, background: satellite image, false colour composite NIR/R/GR (bands 4/3/2)

TA II

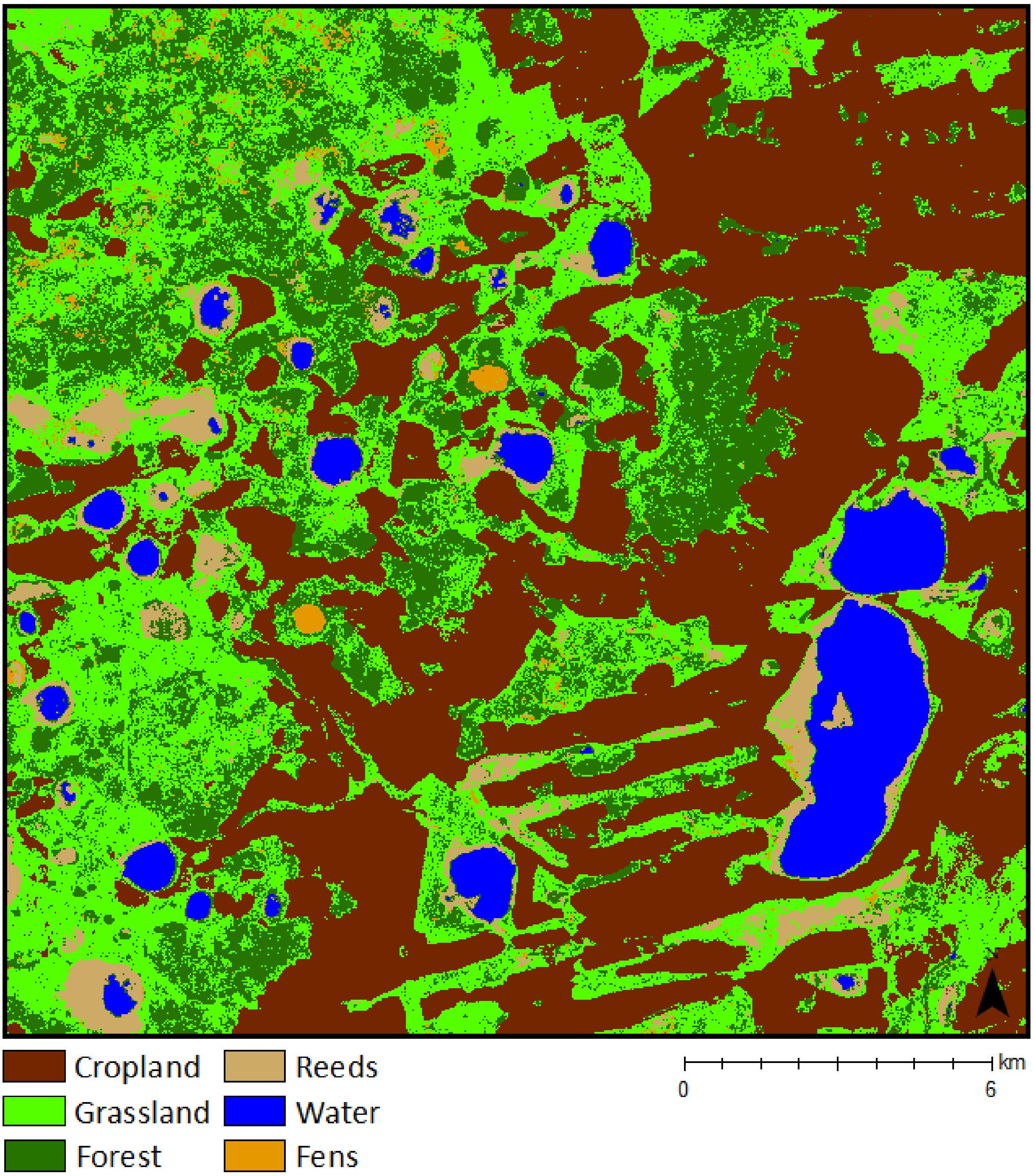

Figure B 4. Land use classification for 2009

TA II

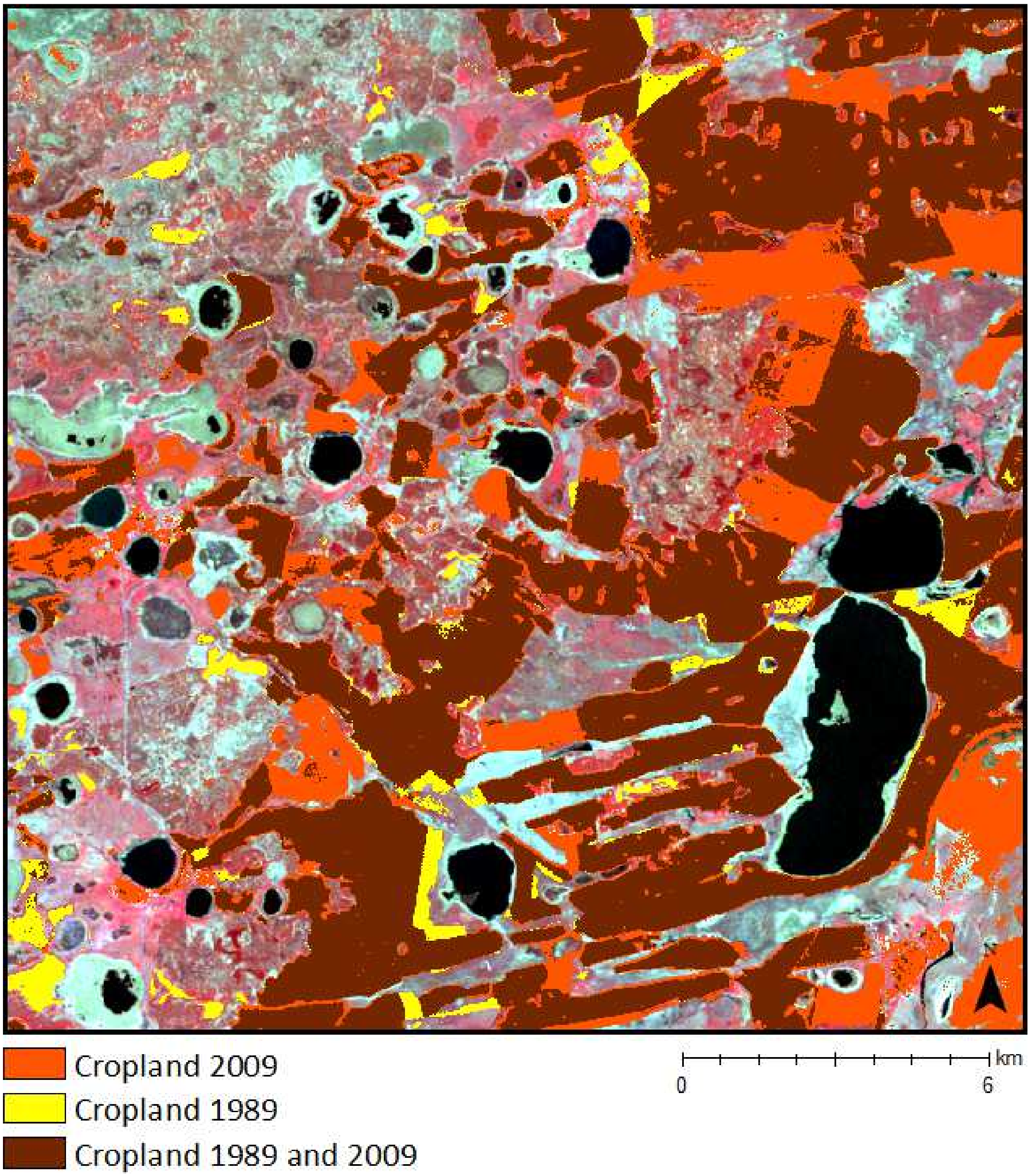

Figure B 5. Agricultural land use between 1989 and 2009, background: satellite image, false colour composite NIR/R/GR (bands 4/3/2)

TA II

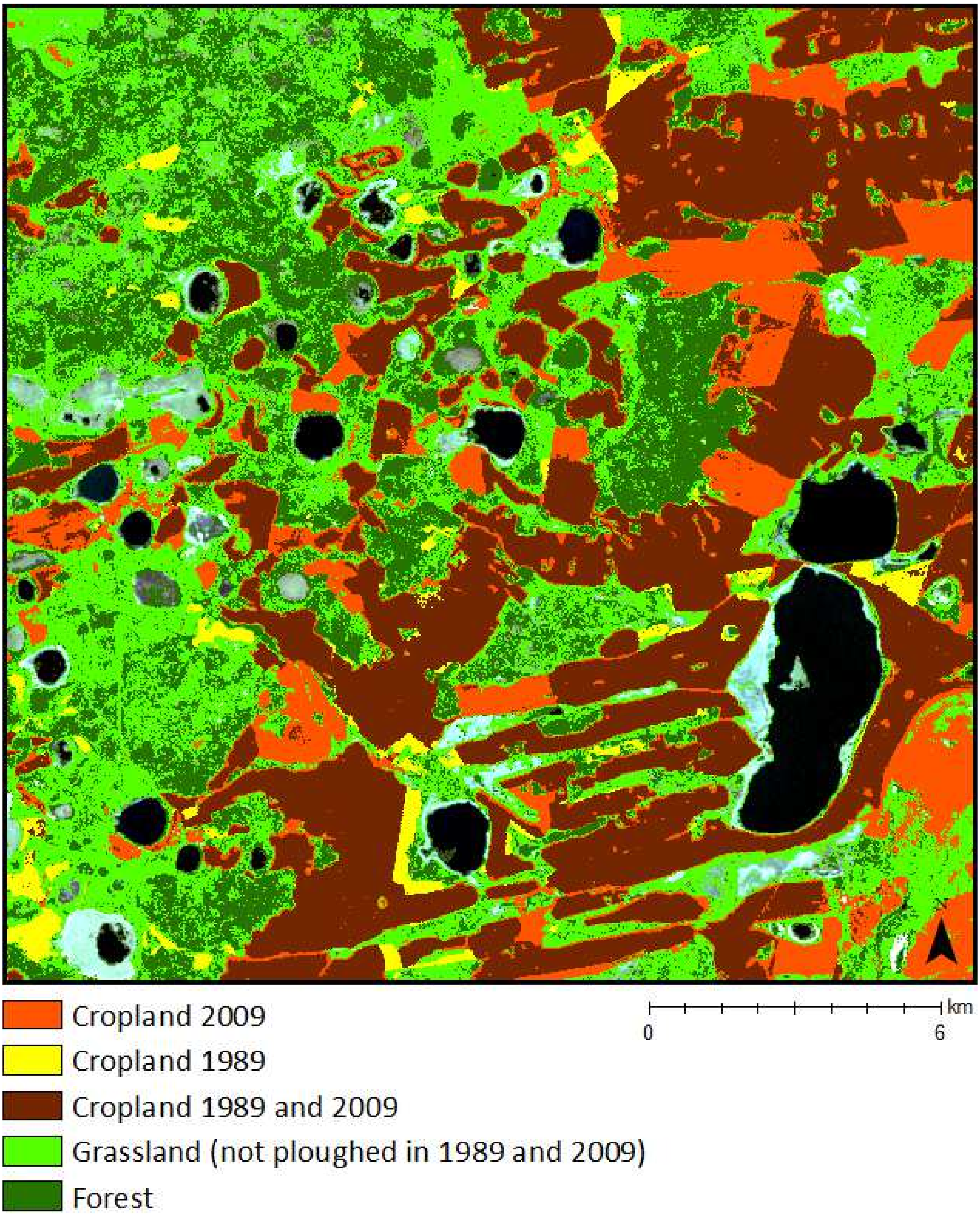

Figure B 6. Not ploughed grassland in 1989 and 2009, background: satellite image, false colour composite NIR/R/GR (bands 4/3/2)

C Overview - area sizes (of detected classes)

Table E 1. Area sizes of *Cropland* in 1987 (TA I) / 1989 (TA II) and *Cropland*, *Unchanged Area*, *Grassland* and *Forest* in 2009

			TA I [ha]	%	**T A II** [ha]	%
Cropland	**2009**		11842.74	29.61	16501.59	41.25
	1987 (TA I) / **1989** (TA II) *	1 Supervised Classification	18000.72	45.00	12853.35	32.13
		2 NDVI	17243.64	43.11	13892.31	34.73
		Intersect of method 1 and 2	14999.58	37.50	12524.13	31.31
Others	**Unchanged Area** (between 1987/89 and 2009)		9295.02	23.24	11590.65	28.98
	Grassland 2009		16670.34	41.68	11913.12	29.78
	Forest 2009		5689.89	14.22	7635.87	19.09

* Use of different detection methods **TA= Test area ≙ 40 000 ha

D Results of the accuracy assessment

TA I Supervised maximum likelihood classification 2009

Table D 1. Results of the accuracy assessment for the supervised classification for 2009

Class	Reference Totals	Classified Totals	Number Correct	Producers Accuracy [%]	Users Accuracy [%]
Cropland	105	97	95	90.5	97.9
Forest	50	50	48	96.0	96.0
Grassland	151	133	130	86.1	97.7
Reeds	9	11	9	60.0	81.8
Roads and Settlement	15	32	15	100.0	46.9
Unknown	10	17	6	60.0	35.3
Water	10	10	10	100.0	100.0
Totals	350	350	313		

Overall classification accuracy = 89.43%

Table D 2. Error matrix of the accuracy assessment for the supervised classification for 2009

Class	Cropland	Forest	Grassland	Reeds	Roads and Settlement	Unknown	Water	Total
Cropland	**95**	1	0	0	0	1	0	97
Forest	1	**48**	1	0	0	0	0	50
Grassland	2	1	**130**	0	0	0	0	133
Reeds	0	0	2	**9**	0	0	0	11
Roads and Settlement	2	0	12	0	**15**	3	0	32
Unknown	5	0	6	0	0	**6**	0	17
Water	0	0	0	0	0	0	**10**	10
Total	105	50	151	9	15	10	10	**350**

Table D 3. Kappa statistics of the accuracy assessment for the supervised classification for 2009

Class	Kappa
Cropland	0.97
Forest	0.95
Grassland	0.96
Reeds	0.81
Roads and Settlement	0.45
Unknown	0.33
Water	1.00

Overall kappa statistics = 0.8543

TA I Supervised maximum likelihood classification for 1987

Table D 4. Results of the accuracy assessment for the supervised classification for 1987

Class	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Cropland	42	45	41	97.62%	91.11%
Background	58	55	54	---	---
Totals	100	100	95		

Overall classification accuracy = 95.00%

Table D 5. Error matrix of the accuracy assessment for the supervised classification for 1987

Class	Cropland	Background	Total
Cropland	41	4	45
Background	1	54	55
Total	42	58	100

Table D 6. Kappa statistics of the accuracy assessment for the supervised classification for 1987

Class	Kappa
Cropland	0.9567
Background	0.8467

Overall kappa statistics = 0.8984

TA I Calculation of the NDVI for 1987

Table D 7. Results of the accuracy assessment for the calculation of the NDVI for 1987

Class	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Cropland	40	43	38	95.00%	88.37%
Background	60	57	55	---	---
Totals	100	100	93		

Overall classification accuracy = 93.00%

Table D 8. Error matrix of the accuracy assessment for the calculation of the NDVI for 1987

Class	Cropland	Background	Total
Cropland	38	5	43
Background	2	55	57
Total	40	60	100

Table D 9. Kappa statistics of the accuracy assessment for the calculation of the NDVI for 1987

Class	Kappa
Cropland	0.9123
Background	0.8062

Overall kappa statistics = 0.8560

TA II Supervised maximum likelihood classification for 2009

Table D 10. Results of the accuracy assessment for the supervised classification for 2009

Class	Reference Totals	Classified Totals	Number Correct	Producers Accuracy [%]	Users Accuracy [%]
Cropland	110	113	110	100.0	97.4
Fens	18	18	13	72.2	72.2
Forest	47	56	45	95.7	80.4
Grassland	87	83	74	85.1	89.2
Reeds	12	10	9	75.0	90.0
Roads and Settlement	5	0	0	---	---
Water	21	20	20	95.2	100.0
Totals	300	300	271		

Overall accuracy = 90.7 %

Table D 11. Error matrix of the accuracy assessment for the supervised classification for 2009

Class	Cropland	Fens	Forest	Grassland	Reeds	Roads and Settlement	Water	Total
Cropland	**110**	1	0	0	1	1	0	113
Fens	0	**13**	0	3	0	2	0	18
Forest	0	0	**45**	9	1	0	1	56
Grassland	0	4	2	**74**	1	2	0	83
Reeds	0	0	0	1	**9**	0	0	10
Roads and Settlement	0	0	0	0	0	**0**	0	0
Water	0	0	0	0	0	0	**20**	20
Total	110	18	47	87	12	5	21	**300**

Table D 12. Kappa statistics of the accuracy assessment for the supervised classification for 2009

Class	Kappa
Forest	0.77
Cropland	0.96
Fens	0.89
Water	1.00
Grassland	0.85
Reeds	0.70
Forest	0.77

Overall kappa statistics = 0.8699

TA II Supervised maximum likelihood classification for 1989

Table D 13. Results of the accuracy assessment for the supervised classification for 1989

Class	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Cropland	34	32	32	94.12%	100.00%
Background	66	68	66	---	---
Totals	100	100	98		

Overall classification accuracy = 98.00%

Table D 14. Error matrix of the accuracy assessment for the supervised classification for 1989

Class	Cropland	Background	Total
Cropland	32	0	32
Background	2	66	68
Total	34	66	100

Table D 15. Kappa statistics of the accuracy assessment for the supervised classification for 1989

Class	Kappa
Cropland	0.9135
Background	1.000

Overall kappa statistics = 0.8984

TA II Calculation of the NDVI for 1989

Table D 16. Results of the accuracy assessment for the calculation of the NDVI for 1989

Class	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Cropland	35	35	33	94.29%	94.29%
Background	65	65	63	---	---
Totals	100	100	96		

Overall classification accuracy = 96.00%

Table D 17. Error matrix of the accuracy assessment for the calculation of the NDVI for 1989

Class	Cropland	Background	Total
Cropland	33	2	35
Background	2	63	65
Total	35	65	100

Table D 18. Kappa statistics of the accuracy assessment for the calculation of the NDVI for 1989

Class	Kappa
Cropland	0.9121
Background	0.9121

Overall kappa statistics = 0.9121

E Used satellite imagery

Test area	Acquisition date	Image-ID	Sensor	Source
TA I 56°27’N/67°35’E	29.05.2009	L5159021_02120090529	Landsat 5	http://glovis.usgs.gov/
	17.05.1987	L5159021_02119870517	Landsat 5	http://glovis.usgs.gov/
TA II 56°06’N/69°30’E	15.05.2009	L5157021_02120090515	Landsat 5	http://glovis.usgs.gov/
	16.05.1989	L4157021_02119890516	Landsat 4	http://glovis.usgs.gov/

For all images the Landsat reference (level 1T) was used as base reference. The classifications of 2009 were additionally geo-referenced with topographic maps. All scenes were geo-referenced to a Universal Transverse Mercator projection.

[Coordinate system: WGS_1984_UTM_Zone_42N][Datum: D_WGS_1984]

F CD – Contents

- Data as shapefiles:

  - Boundaries of the test areas
  - Land use classifications for 2009
  - Land use categories
    - 2009 : *Cropland* / *Grassland* / *Forest*
    - 1987 (TA I) / 1989 (TA II) : *Cropland*

- Maps (.bmp)

- Satellite imagery (.img)

- This thesis (.pdf)

Affidavit

I hereby assert that this master thesis with the title 'Supervised Classification and Change Detection of Agricultural Land Use in the Forest Steppe Zone of West Siberia Using Multitemporal Satellite Imagery' is written by myself and that I did not use any other than the declared resources. All parts which are literally and logically taken from external sources within this work are marked as being external. Each figure or table without denoted source is created by myself.

Münster, 24th of April in 2012