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Detecting Vegetation Trends from NDVI Trend Analyses in Syrdarya Province, Uzbekistan

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Detecting Vegetation Trends from NDVI Trend Analyses in Syrdarya Province, Uzbekistan

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Cover: salinized soil, Uzbekistan (photo: Joachim Lent)

ABSTRACT

Vegetation trends can be detected using NDVI trend analysis. As vegetation productivity is linked to land degradation, one might use these NDVI trends as an indication of land degradation. In the highly irrigated areas of Uzbekistan, land degradation, and, more specifically, salinization, is considered to be a widespread problem, affecting crop productivity and subsequently the livelihoods of the rural population. Since the monitoring efforts of land degradation deteriorated after the dissolution of the Soviet Union, the usage of remote sensing images in these monitoring efforts might be the new way to help identifying degrading areas and thereby contributing to the development of sustainable rehabilitation measures. In this particular study, three different NDVI trend analyses have been applied to Landsat images of the Syrdarya province. Furthermore, farmers in the study area have been interviewed to reveal the link with their own yield observations and their perceptions on the presence of land degradation. Even though the three trend analyses provided similar, mainly positive, vegetation trends in the study area, no overlap with the farmers' perceptions on yield and land degradation could be found.

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1 INTRODUCTION

The Central Asian Republic of Uzbekistan is well-known for the much-documented desiccation of the Aral Sea, i.e. "one of the world's largest environment disasters" (Johansson, Aimbetov, and Jarsjö 2009, p. 287). The development of large-scale irrigation systems since the 1950s (Figure 1) is considered to be the main causal factor in this shrinking (Sokolov 1999). However, the environmental consequences of the water extraction for irrigation have not limited themselves to the lake shrinkage only. About 50% of the enormous irrigated agricultural areas in Central Asia are found to be affected by salinity (Bucknall 2003). This form of land degradation, negatively impacting crop productivity (Dubovyk et al. 2013a), reduces the incomes of the rural Uzbek population (Abdullaev, Giordano, and Rasulov 2007, Dubovyk et al. 2012) and can be considered as an alarming problem in a country where 19% of the GDP is contributed by the agricultural sector (WORLD BANK 2013).

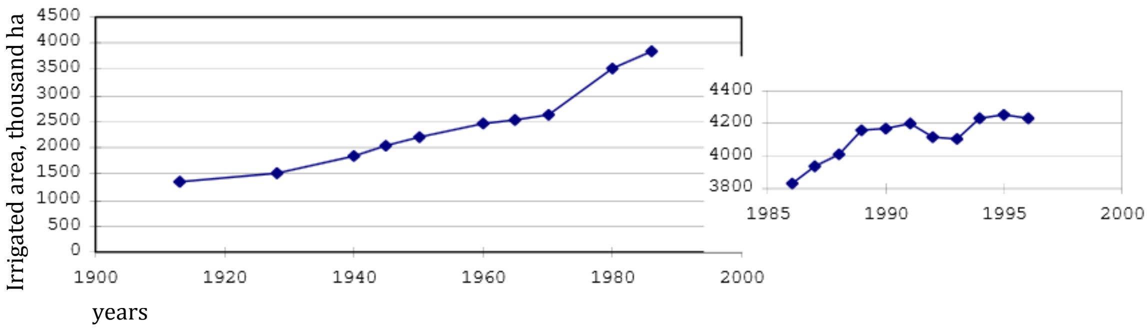

Figure 1: Evolution of irrigated area in Uzbekistan (Sokolov 1999)

During the Soviet times, the construction of these enormous irrigation systems coincided with the set-up of special programs focussed on the monitoring and assessment of land degradation. However, after the dissolution of the Soviet Union in 1991, these programs, mainly using soil samples for their assessments, seem to have collapsed as well (Platonov, Noble, and Kuziev 2013). According to Dubovyk et al. (2013b) there is currently a lack of information and little confidence in the existing degradation maps for land managers to deal with the land degradation in the irrigated areas. Multiple authors (Dubovyk et al. 2013b, Platonov, Noble, and Kuziev 2013) have highlighted the promising possibilities of remote sensing and geographical information systems in the monitoring and assessment of land degradation, though. It is stated to be "extremely cost-effective with a higher degree of spatial accuracy" compared to soil sampling (Platonov, Noble, and Kuziev 2013, p. 97).

In the abovementioned context of an urgent need for information on land degradation in Uzbekistan, a research on the trend changes of remotely-sensed vegetation data in the Syrdarya Province in Uzbekistan has been executed. Such a trend analysis is assumed to designate areas of changing vegetation cover and to thereby help identifying areas of land degradation.

1.1 CONTEXT

Most studies show that the exploitative land-use practices (Dubovyk et al. 2013b) and "insufficient irrigation management" (Dubovyk et al. 2012, p. 1) in the irrigated areas of Uzbekistan have resulted in the widespread presence of land degradation. However, the fact that Uzbekistan's irrigated areas have a predominantly arid climate seems to worsen the situation:

according to the study by Gao and Liu in 2010, such arid regions are known to have a “lower natural resilience against anthropogenic pressure” (as cited by Dubovyk et al. 2013b, p.167).

It is important to note that most studies on land degradation in this region have focussed on the magnitude and the trends of land degradation and have only to a limited degree been able to relate possible causes of land degradation to the observations (Dubovyk et al. 2013a). According to Evans et al. (2004), knowledge on exactly these causes are crucial to develop the most suitable strategy to combat land degradation, though. On the other hand, the identification of land degradation only is considered to already be a useful step in the direction of combatting land degradation (Platonov, Noble, and Kuziev 2013) as “detection and characterizing change over time is the natural first step toward identifying the driver of the change” (Verbesselt et al. 2010, p. 106). Moreover, one must take notice of the fact that the current state of information on land resources and related socio-economic data is considered as poor (UNDP 2004). Such limited data availability hinders the effort to link the observed trends to possible causes.

Land degradation is highly related to the vegetation biomass over time; according to the United Nations Convention to Combat Desertification (UNCCD), land degradation can be defined as a “reduction or loss of the biological or economic productivity and complexity of rainfed cropland, irrigated cropland, or range, pasture, forest and woodlands” (UNCCD 2012, p. 6). It is therefore argumentative to measure the vegetation productivity, which is commonly the case in land degradation studies (de Jong 2012, Wessels, Van Den Bergh, and Scholes 2012). For example, Dubovyk et al. (2012) have used the remotely sensed Normalized Difference Vegetation Index (NDVI) data to determine land degradation in the Khorezm region of Uzbekistan. In general, vegetation indices, like the widely used NDVI, have proven to represent the biomass productivity. In arid regions like Uzbekistan, the NDVI data in particular, have shown a good correlation with vegetation productivity (Nicholson 1994). An analysis of these indices over time can therefore help detecting land degradation (Dubovyk et al. 2012). It is important to note, though, that a degraded but stable area won’t be indicating any land degradation, as the NDVI trend is likely to be neutral.

Despite the fact that remote sensing has a long history in the area of change detection, the digital detection of change remains “a difficult task to perform”(Coppin et al. 2004, p. 1566) and there seems to be only a limited amount of different trend analysis methods that can detect change of time series (Verbesselt et al. 2010).

1.2 Problem Statement

Uzbekistan encounters widespread land degradation in its irrigated lands, negatively impacting crop productivity and subsequently the livelihoods of the rural population. Currently, there is a lack of reliable monitoring efforts that can help identifying degrading areas and can thereby contribute to the development of sustainable rehabilitation measures.

2 RESEARCH OBJECTIVES

Following from the abovementioned problem statement, this research aims to contribute to a better understanding of land degradation in Uzbekistan by detecting and mapping vegetation trends from NDVI trend analyses in the Syrdarya province in Uzbekistan and by exploring its plausible link with land degradation. Such an understanding can ultimately be an important first step in the combatting and prevention of land degradation.

In order to contribute to this main research objective, the following detailed research objectives have been formulated:

1. Detect and map NDVI trends from satellite imagery using multiple trend analyses;
2. Gather farmers' knowledge about the yield trend in their plots;
3. Obtain a basic idea on the state of land degradation and its link with the vegetation trend in the case-study plots.

3 STUDY AREA

This research focuses on the highly irrigated Syrdarya province of Uzbekistan (Figure 2). The province, owing its name to the famous river that is the main water source of the region, has a strong continental climate with limited rainfall in spring and winter (Noble, Ul Hassan, and Kazbekov 2005). Due to the present irrigation infrastructure, limited rainfall does not play a role in the current cropping pattern though: the water-demanding cotton and winter wheat are the main crops in the province. As explained before, this irrigation practice is related to an enormous downside: the province is known to cope with high levels of salinization. In 2000, salinization affected on average 85.7% of the province's irrigated lands (Egamberdiyeva, Garfurova, and Islam 2007). Figure 3 shows a somewhat heterogeneous pattern of this high level of salinization in the province though. Furthermore, the province is affected by the presence of wind erosion, limiting crop production (Noble, Ul Hassan, and Kazbekov 2005).

Both the manageable distance from the field to the working space in the capital Tashkent and the presence of land degradation issues in the area have resulted in choosing this region for this particular research on vegetation degradation and its link with land degradation (Alim Pulatov, personal communication, September, 2013).

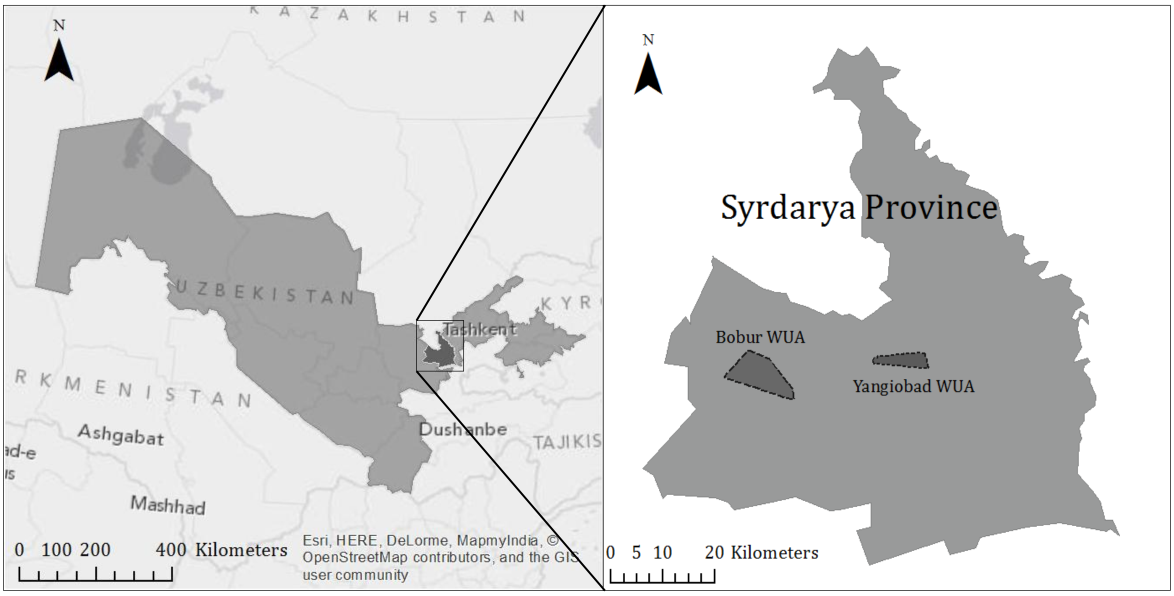

Figure 2: Study area

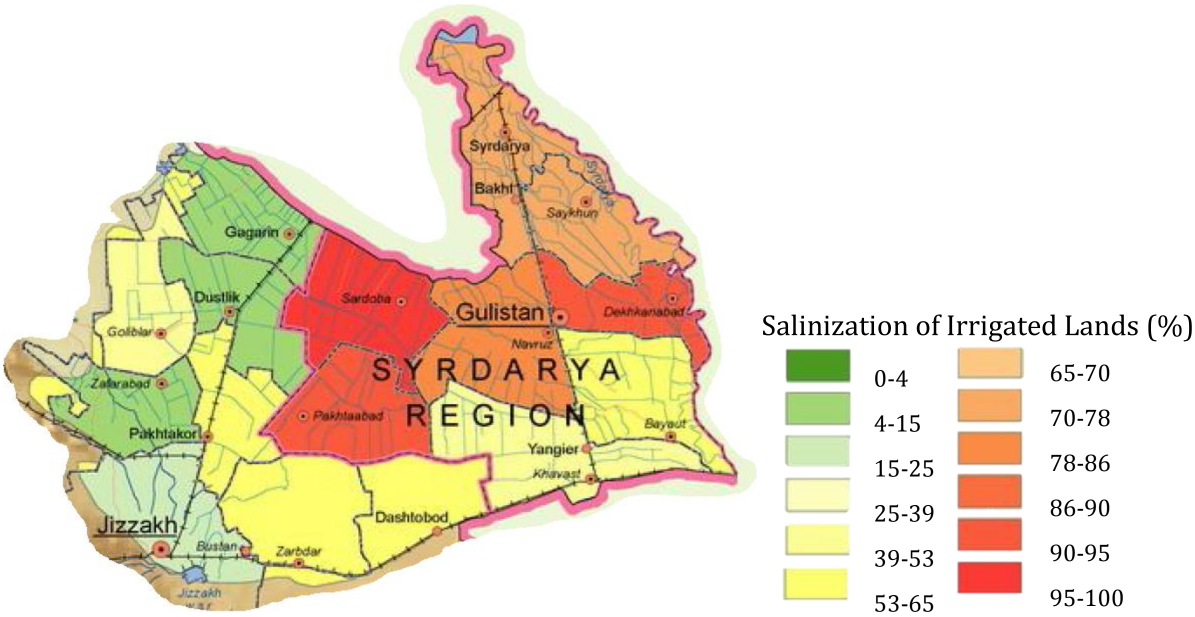

Figure 3: Salinization of irrigated lands in Syrdarya province (UNDP 2008)

Two smaller areas within the Syrdarya province, representing the Yangiobod- and Bobur Water User Association (WUA), have been the object of research (Figure 2). The selection of these two WUAs has not been a random selection, though. These two WUAs have been previously researched (Alim Pulatov, personal communication, September, 2013) and contact information of the farmers could therefore easily be obtained. The Yangiobod WUA is located in mid-Syrdarya, the so-called old zone (EcoGIS Center 2009) and it covers an area of about 2000 ha. The Bobur WUA, on the other hand, is located in the 'newer' Eastern part of the province and covers about 6000 ha. Interviews with farmers have been conducted in both WUAs.

4 METHODOLOGY

In order to reach the 3 detailed objectives of this research, two main methodological steps have been taken: a trend-analysis of the satellite imagery to detect and map vegetation trends and farmer interviewing to gather farmer's perspectives on the vegetation degradation and its plausible link with land degradation.

4.1 TREND-ANALYSIS

IMAGE DATA COLLECTION

The freely available (earthexplorer.usgs.gov/) Landsat Surface Reflectance L7 ETM+ images covering the Syrdarya province (Path 154, Row 32) have been downloaded for the period from the year 2000 onwards. These downloaded images have already passed through an atmospherically correction using the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) and therefore represent readily available reflectance values. According to Tian et al. (2013, p. 4257) these Landsat images are "suitable to capture vegetation changes". Especially in this local-scale study, the usage of Landsat images is considered to be more convenient than the usage of, for example, MODIS images. Notwithstanding the fact that the 16-day composite MODIS images have limited cloud cover effects (Knight et al. 2006), its spatial resolution of 250 meters is unsuitable for this study in which the case-study plots have an average size of only about 20 ha. The spatial resolution of the Landsat images (30 meters) on the other hand, enables the identification of cover change that is related to the scale of land management practices (Cohen and Goward 2004).

Following the procedure by Tian et al. (2013), images with an estimated cloud cover of more than 10% were discarded, leading to a total of 95 suitable images over 13 years (varying from 3 to 9 images per year): Figure 4 shows the temporal coverage of the selected images. Both images in the growing season (April-September) (Ibragimov et al. 2007) and images in the so-called dormant season (October-March) are represented in the time series.

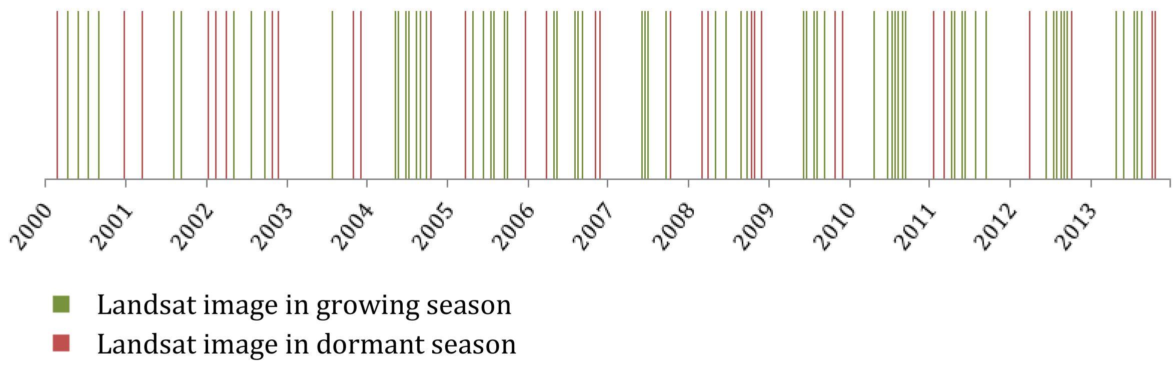

Figure 4: Selected Landsat images over time, representing both images in the growing season (April-September) and in the dormant season (October-March)

It is important to note, though, that the Landsat images representing the days from June 2003 onwards have been affected by the failure of the Scan Line Correcter (SLC-off). These images show missing scan lines on the edges. Fortunately, largest part of the Syrdarya province is located in the centre of the tile.

Further processing of the images has been executed in the open source R statistical software environment. The nature of this software, as an alternative to GIS software, offers the possibility to “implement, test and modify algorithms easily” (Goslee 2011, p. 2).

NDVI TIME SERIES

Before creating the NDVI time series, all downloaded images have been rasterized and cropped for both study areas, thereby saving calculation time in the further processing. To create NDVI images, the default NDVI equation for Landsat bands has been applied to the newly created rasters:

$$NDVI = \frac{(band\ 4 - band\ 3)}{(band\ 4 + band\ 3)}$$

By stacking these individual NDVI rasters and by making a link to the corresponding acquisition dates of the satellite imagery, time series have been created. Despite of the fact that the time series are likely to contain extreme values and gaps, no further smoothing or interpolation has been applied. This is mainly because this particular time series processing is likely to make the trend analysis more complex (Kandasamy et al. 2013).

TREND ANALYSIS AND VEGETATION TREND MAPPING

Before going into the complexity of trend analyses, the time series of a handful of randomly selected cells have been visually inspected first. A visual inspection of these graphs has helped to assess whether the time series would be appropriate for trend analyses. Furthermore, the time series of the average NDVI values within the case-study plots have been plotted to help understanding the NDVI dynamics.

There is a range of different trend analyses available. However, most analyses are based on a simple linear regression of NDVI data (De Beurs and Henebry 2004, de Jong et al. 2011). Therefore, this linear regression analysis has been applied to both study areas in this research as well. A linear regression analysis of the time series results in an equation of a regression trend line, explaining the relation between time and NDVI values:

$$y = \alpha + \beta x$$

β represents the slope of the regression line and is an indication of the trend: a positive slope is indicating a positive trend. All slope values have been plotted to create a vegetation trend map of both WUAs. These maps bring the areas with a negative vegetation trend to the attention, which might represent land degradation. It is important to note, though, that in essence one measures vegetation degradation (de Jong 2012) and a negative trend can also be found due to a crop change, which does of course not necessarily relate to land degradation. Furthermore, these found trends are not necessarily significant. It is therefore considered to be important to test these slopes for significance (de Jong et al. 2011). Using the analysis of variance (ANOVA), all slopes of the case-study plots[1] were tested to check whether they significantly differed from 0

[1] Note, only the slopes of the case-study plots were tested for significance, thus not the whole area of both WUAs .

(based on a confidence level of 90%). This significance test was used to create an attached vegetation trend map with only significant trends.

Besides a simple linear regression analysis, the Mann-Kendall trend analysis has been applied to the time series of all four case-study plots. This analysis is, contrary to the simple linear regression analysis, non-parametric (Abarghouei et al. 2011). It is one of the most widely used non-parametric trend tests (Jamali et al. 2012). For example, Dubovyk et al. (2012) have used this specific analysis to determine vegetation trends. A more detailed explanation of the Mann-Kendall trend analysis can be found in box 1. Where β represents the trend in the simple linear regression analysis, Kendall's tau (τ) does that for the Mann-Kendall test: Kendall's tau represents the correlation. Again, positive τ values represent a positive trend and vice versa. It is important to note, though, that "the Mann-Kendall test is an indicator of the strength and direction of a trend but it is insensitive to its magnitude" (Pérez-Hoyos et al. 2010, p. 24). Vegetation trend maps of all four case-study plots have been created. These trends have also been tested for significance (based on a confidence level of 90%) and, again, an extra map with only significant trends has been created.

Box 1: Mann-Kendall trend analysis

Even though linear regression is a widespread method to identify trends in time series, there are many assumptions influencing the slope (De Beurs and Henebry 2004) which leads to the idea that "messy environmental data would make it difficult to use parametric procedures" (Hipel and McLeod 1994, p. 853). In this respect, nonparametric tests like the Mann-Kendall trend test have been developed. Nowadays, these tests are widely used for the detection of hydrologic and climatological trends (Karmeshu 2012). According to Karmeshu (2012), the Mann-Kendall test knows two main advantages: the distribution of the data does not necessarily have to be a normal distribution and the test is not sensitive for abrupt breaks. Furthermore, the test is considered to be resistant to outliers (Neeti and Eastman 2011). This is related to the fact that the outcome of the Mann-Kendall test cannot say anything about the magnitude of the trend (Gagnon and Gough 2005, Hipel and McLeod 1994), rather only whether a positive or a negative trend is present and how 'strong' this trend is (ITRC (Interstate Technology & Regulatory Council) 2013). The trend test determines whether the data increases or decreases between two subsequent data points in time and values an increment with 1 and a decrement with -1 (which shows that the magnitude of change does not play a role). The sum of all these increments and decrements results in the Mann Kendall Statistic S (Karmeshu 2012); a positive trend will be detected when the data increases more often than they decrease over time and vice versa (Helsel and Hirsch 1992). Closely related to the Mann Kendall Statistic S is Kendall's tau (τ) (Hipel and McLeod 1994); "it is essentially a scaled measure of S" (ITRC (Interstate Technology & Regulatory Council) 2013, p. 91):

$$\tau = \frac{S}{n(n-1)/2}$$

This formula, in which n denotes the number of measurements, will have results ranging from -1 to 1 and because of this, ITCR (2013) promotes the usage of Kendall's tau rather than the Mann Kendall Statistic S. It is interesting to note, though, that due to the fact that this trend test cannot say anything about the magnitude of trends, multiple authors have considered the test to be applicable for exploratory data analysis only (Hipel and McLeod 1994).

In order to enable a quick overview of the general trend per case-study plot, the mean values of both trend indicators, β and τ, have been calculated. These mean values can also be used for a comparison of the trends of the four case-study plots. Furthermore, the mean percentage of NA in a dataset has been calculated per case-study plot. This gives an idea of the effect of the abovementioned missing scan lines and might say something about the quality of the image.

It is likely that NDVI time series show changing trends (de Jong et al. 2011), due to changing management practices for example. However, the abovementioned trend detection approaches do not consider a changing trend; they rather tend to average the trend in the studied period. The BFAST (Breaks for Additive Seasonal and Trend) approach, on the other hand, can "robustly detect changes" in time series (Verbesselt et al. 2010, p. 106). All time series of the four case-study plots have been checked for having one major break in the trend. Detecting these changing trends is one step, but, naturally, it is most important to identify the type of change that is present. The BFAST package in R has enabled the possibility to classify the trends in all four case-study plots, using the following classes:

- monotonic increase;
- monotonic decrease;
- monotonic increase (with positive break);
- monotonic decrease (with negative break);
- interruption: increase with negative break;
- interruption: decrease with positive break;
- reversal: increase to decrease;
- reversal: decrease to increase.

The first two classes represent the trends without any changes, though. It is likely that these two type of trends overlap with the trends that have been detected with the other trend analyses.

4.2 Farmer Interviewing

Due to all sorts of expected errors in the above-mentioned trend calculations, it is desired to compare the calculated vegetation degradation pattern with the actual vegetation trend in the case-study plots. Farmer interviews have been used as a means to make this comparison. The information that farmers can provide on the actual observed trend in the yield over time enables one to discuss the correctness of the calculated map. The yield is in this case assumed to be representative of the biomass productivity, which can easily be linked to the measured NDVI.

Most interesting, though, is the fact that these interviews can help revealing the expected link between the vegetation degradation and the presence of land degradation (Stocking and Murnaghan 2000). Oftentimes, this link is automatically accepted without much questioning. However, according to Stocking and Murnaghan (2000), this is an invalid assumption as vegetation degradation might occur without the presence of land degradation (for example due to a changing climate). And vice versa: the presence of land degradation negatively affects the productivity of the field, however, it does not necessarily affect production. The so-called "masking of land degradation" (Stocking and Murnaghan 2000, p. 60), e.g. the use of extra fertilizer, might even increase yields. In order to grasp the link between the observed vegetation degradation and the actual presence of land degradation, farmer perspectives on the present land degradation and the link to their yields have been acquired. Actually, Van Lynden and Kuhlmann (2002) consider farmer interviews to be "an excellent way to assess land degradation at the field level". Moreover, farmer interviews are known to be more quick and simple than complex physical measurements (Stocking and Murnaghan 2000).

The structured interview, available in English, Russian and Uzbek language (Annex), focuses on the perceived vegetation trend: farmers have been asked to provide information on the yield since 2005 (for the selected plot). They have been asked to draw a so-called trend line, a common tool in participatory appraisals (Geilfus 2008). Subsequently, farmers were asked to explain their observed trends and to assess the type and level of land degradation in their plots.

The interview has been tested with local (not from Syrdarya province) farmers first in order to check whether the questions and structure were well understood and to get an idea on the type of answers of the farmers, before going to the Syrdarya province. After this trial, 4 interviews with farmers of the case-study plots have been executed. An interpreter with a background in land degradation and English, Russian and Uzbek language skills has been involved in the interviewing exercise.

5 RESULTS

In this chapter, the vegetation degradation of both WUAs will be presented at first, followed by the results from a more detailed analysis of the vegetation trends in the case-study plots. Lastly, the results of the farmer interviewing will be presented.

5.1 VEGETATION TRENDS IN WUAS

Following from the abovementioned analysis of Landsat satellite images in R, a vegetation trend map of both WUAs could be produced. Figure 5 and Figure 6 show the vegetation trend pattern (represented by the slope of the linear regression trend through the time series, β) in the Bobur and Yangiobad WUA respectively. A negative slope represents vegetation degradation (browning), whereas a positive trend represents an increase of vegetation over the year (greening). It is important to note that the visualized NDVI trends are not necessarily significant trends. The mean β (slope) of the trends in the WUA areas is, as clearly visualized in both maps, positive (Table 1).

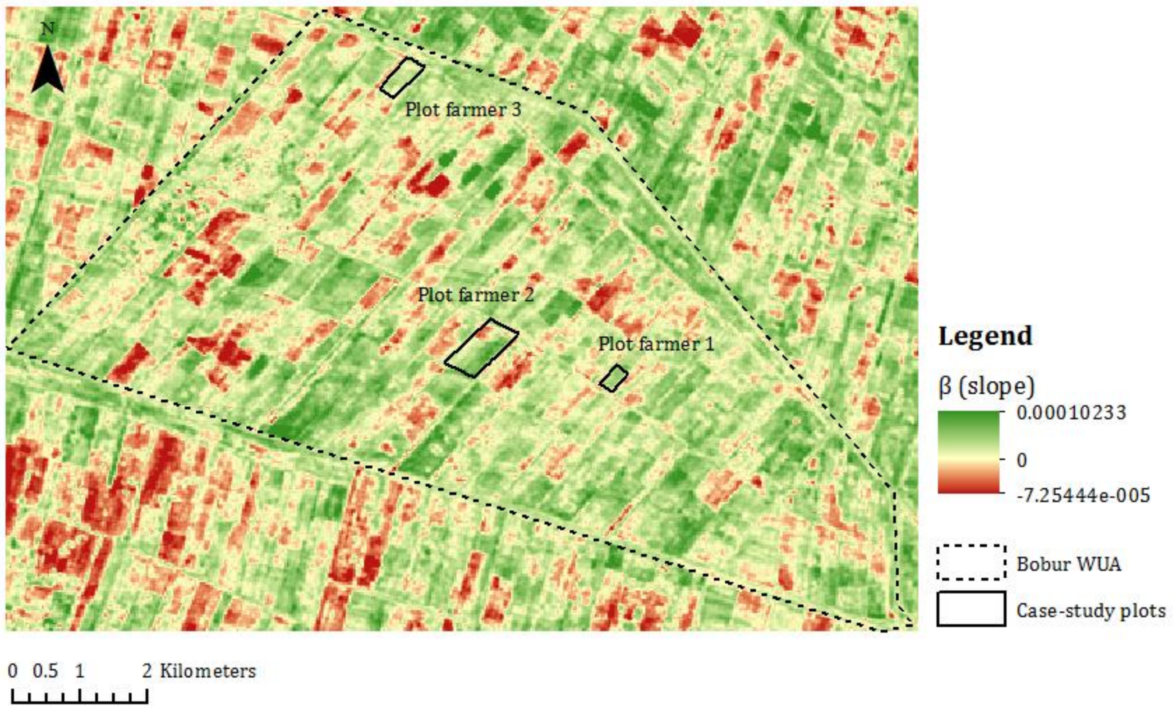

Figure 5: Vegetation trend map of Bobur WUA, represented by the slope of the linear regression trend through the time series (β)

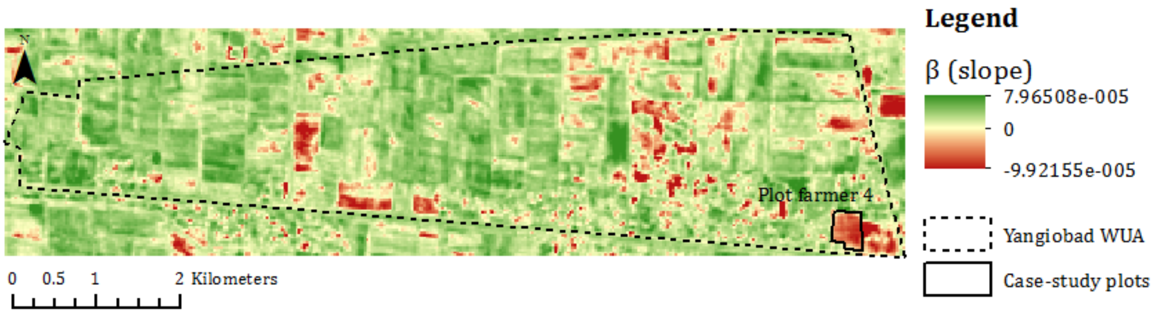

Figure 6: Vegetation trend map of Yangiobad WUA, represented by the slope of the linear regression trend through the time series (β)

Table 1: Mean slopes of vegetation trends

Plot	*Mean β (slope)*
Bobur WUA	1.080e-005
Yangiobad WUA	1.591e-005

5.2 VEGETATION TRENDS IN CASE-STUDY PLOTS

In this sub-chapter, a more detailed representation of the trends in the case-study plots is provided. For every case-study plot a time series of average NDVI values is plotted (Figure 7, 10, 13 and 16), thereby helping to understand the dynamics of the NDVI over time. Furthermore, the two different vegetation trends (simple linear regression and Mann Kendall trend) of all four case-study plots are presented (Figure 8, 9, 11, 12, 14, 15, 17, 18). Maps with only the significant trends are attached to the figures as well.

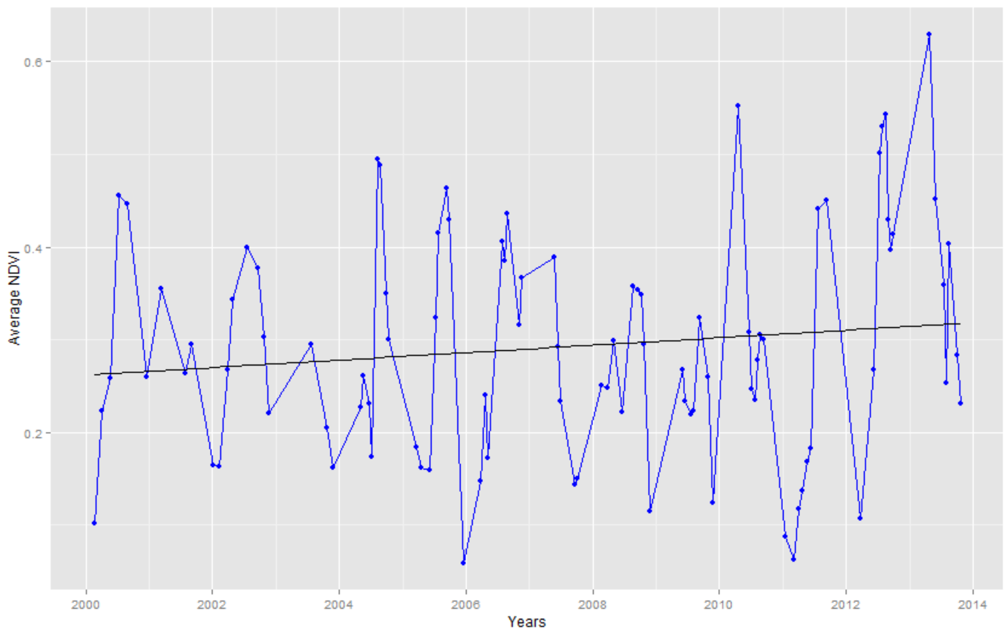

Figure 7: Time series of the average NDVI of case-study plot 1, including a linear trend line (black)

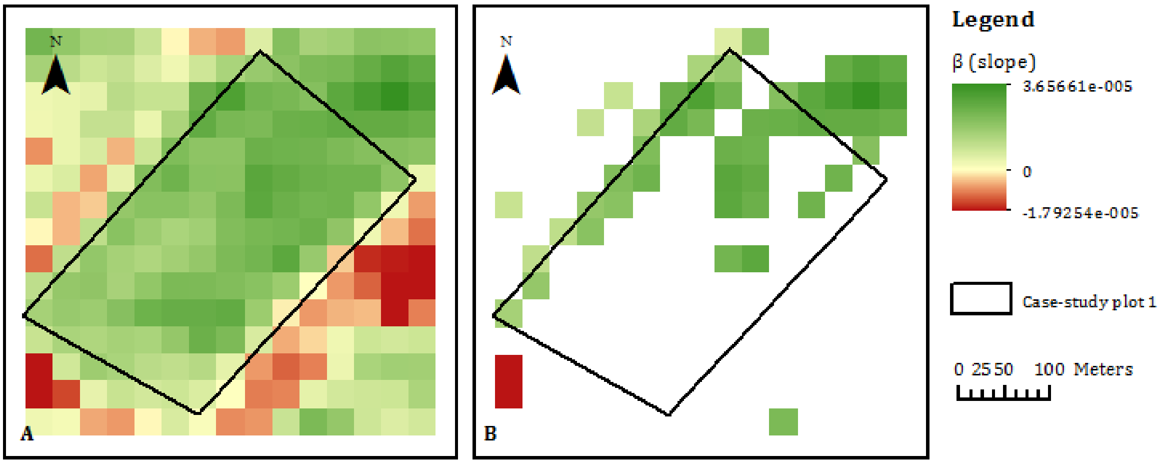

Figure 8: A- vegetation trend map of case-study plot 1, represented by the slope of the linear regression trend through the time series (β), B- significant vegetation trend map (p-value < 0.1)

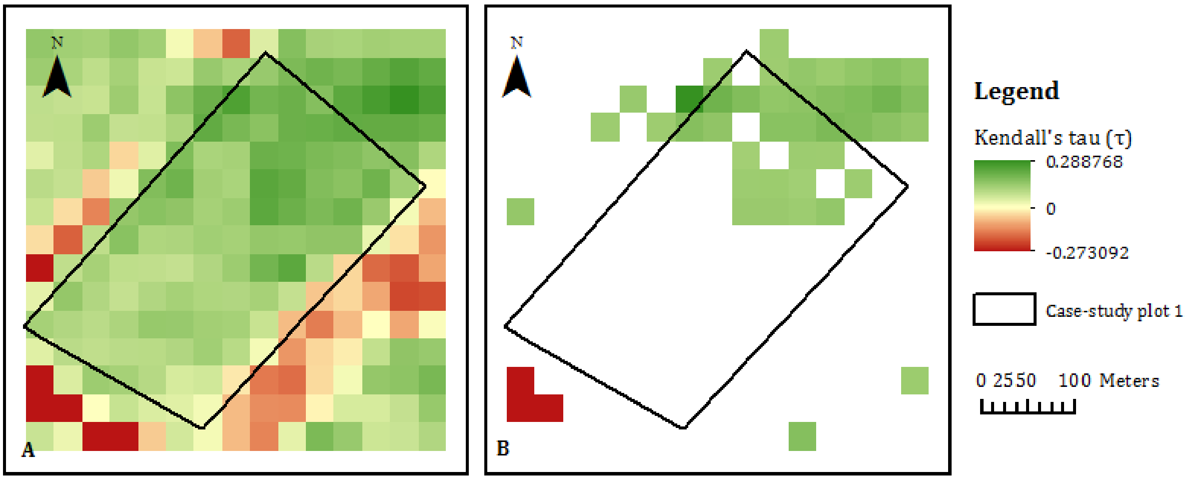

Figure 9: A- vegetation trend map of case-study plot 1, represented by Kendall's tau (τ), B- significant vegetation trend map (p-value < 0.1)

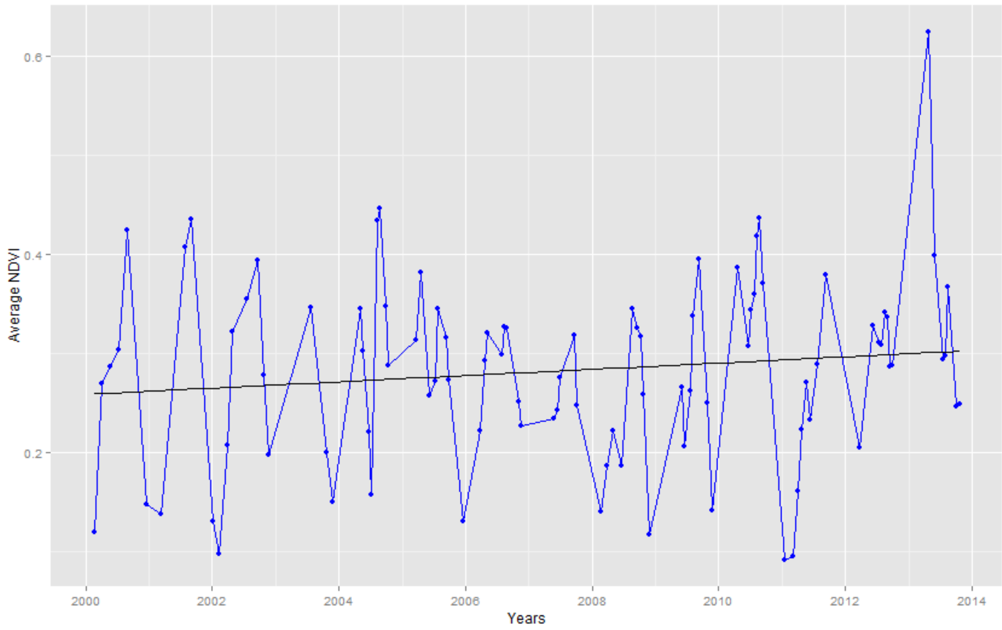

Figure 10: Time series of the average NDVI of case-study plot 2, including a linear trend line (black)

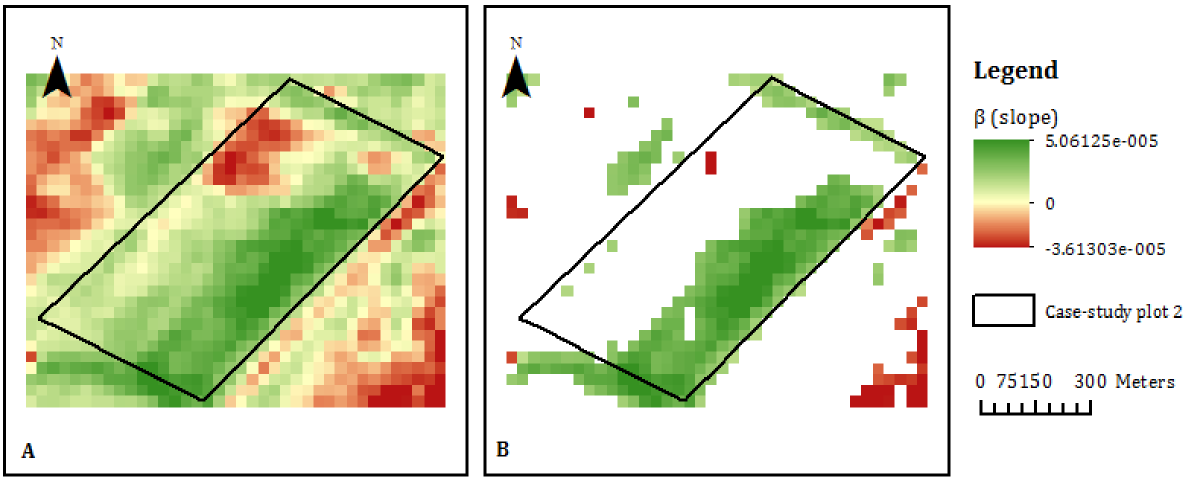

Figure 11: A- vegetation trend map of case-study plot 2, represented by the slope of the linear regression trend through the time series (β), B- significant vegetation trend map (p-value < 0.1)

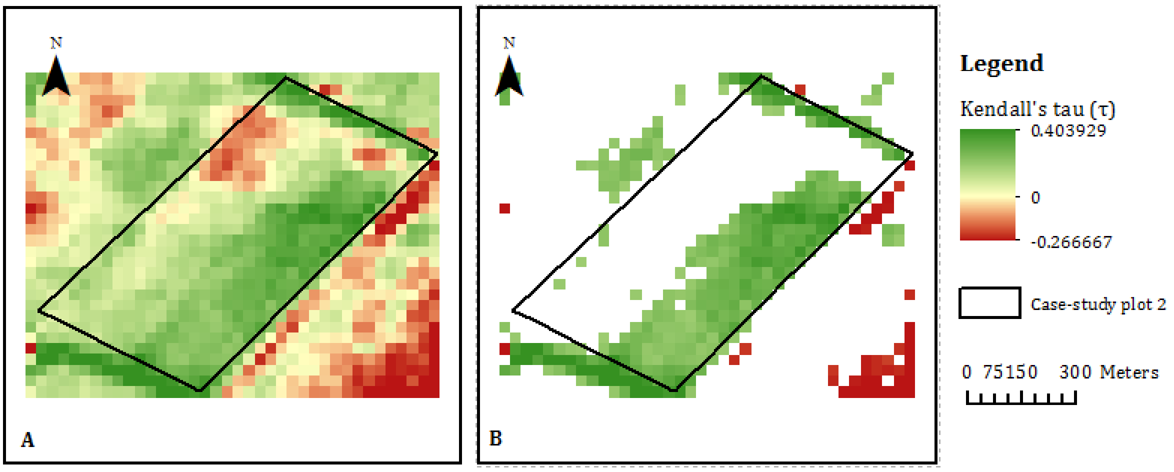

Figure 12: A- vegetation trend map of case-study plot 2, represented by Kendall's tau (τ), B- significant vegetation trend map (p-value < 0.1)

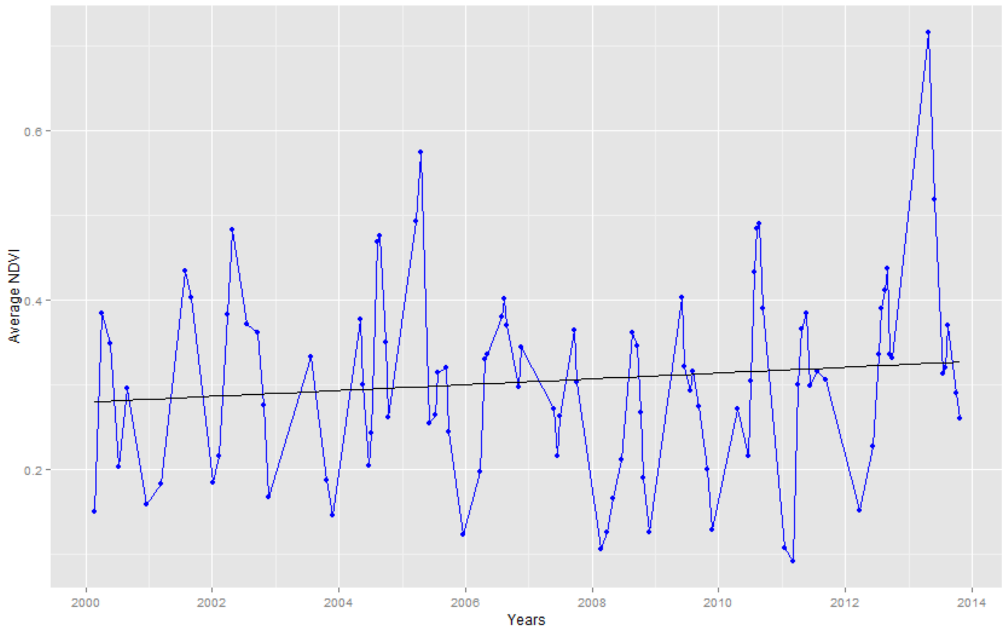

Figure 13: Time series of the average NDVI of case-study plot 3, including a linear trend line (black)

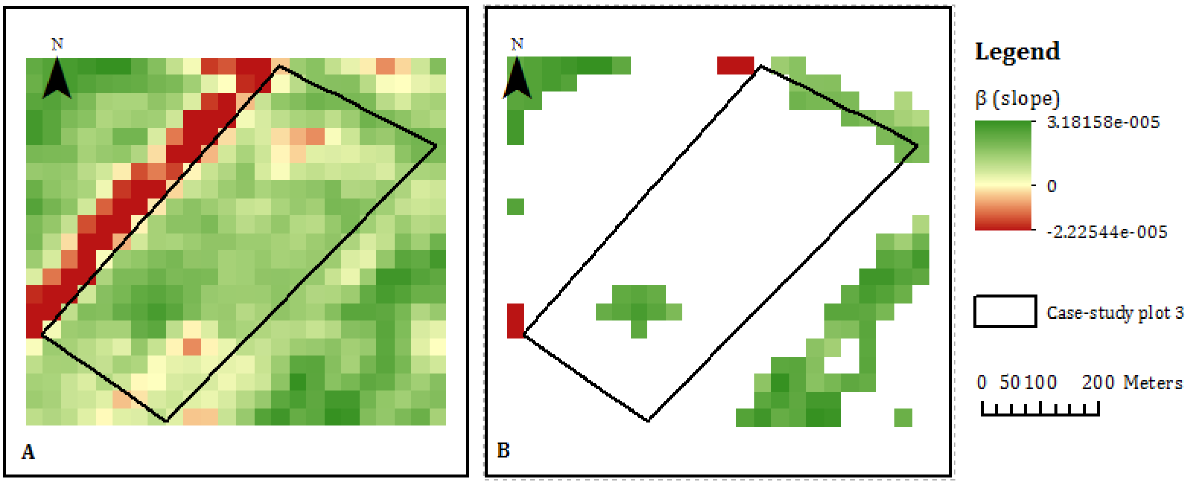

Figure 14: A- vegetation trend map of case-study plot 3, represented by the slope of the linear regression trend through the time series (β), B- significant vegetation trend map (p-value < 0.1)

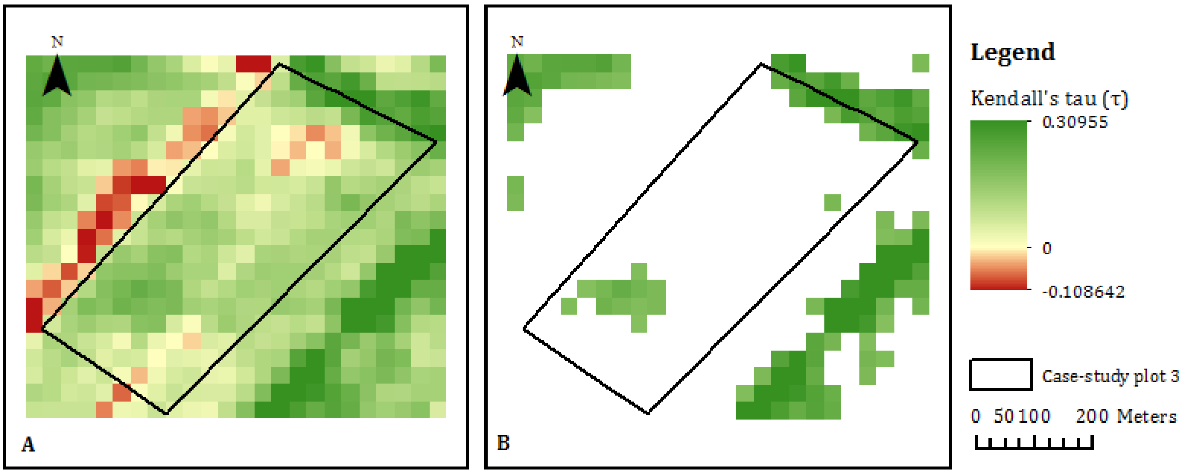

Figure 15: A- vegetation trend map of case-study plot 3, represented by Kendall's tau (τ), B- significant vegetation trend map (p-value < 0.1)

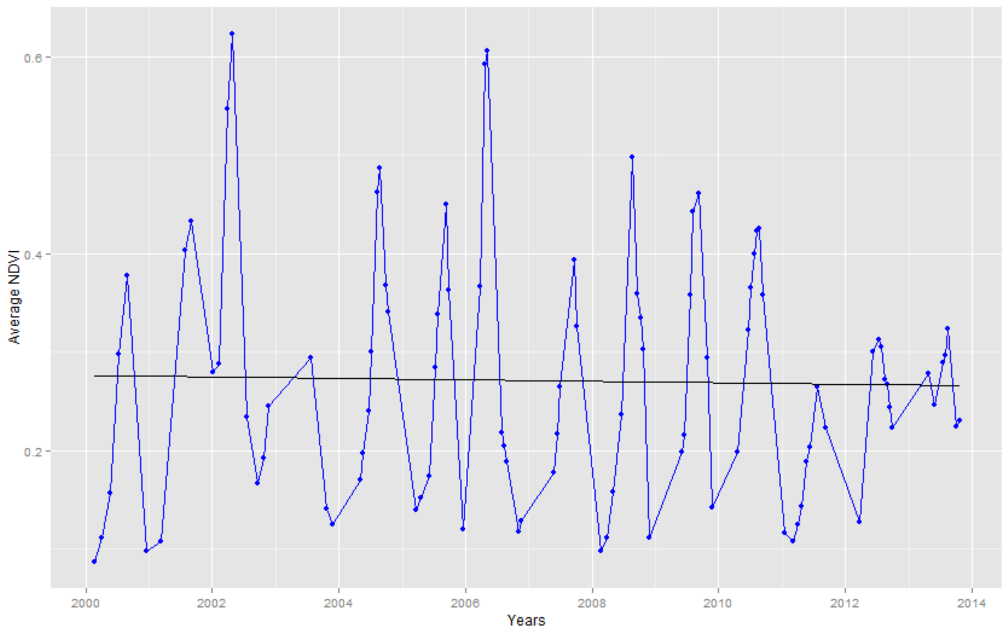

Figure 16: Time series of the average NDVI of case-study plot 4, including a linear trend line (black)

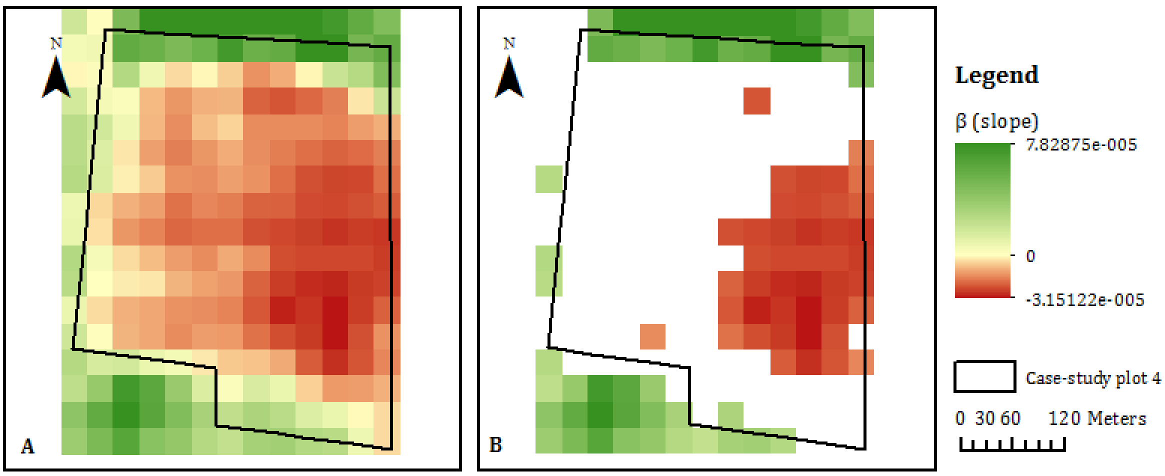

Figure 17: A- vegetation trend map of case-study plot 4, represented by the slope of the linear regression trend through the time series (β), B- significant vegetation trend map (p-value < 0.1)

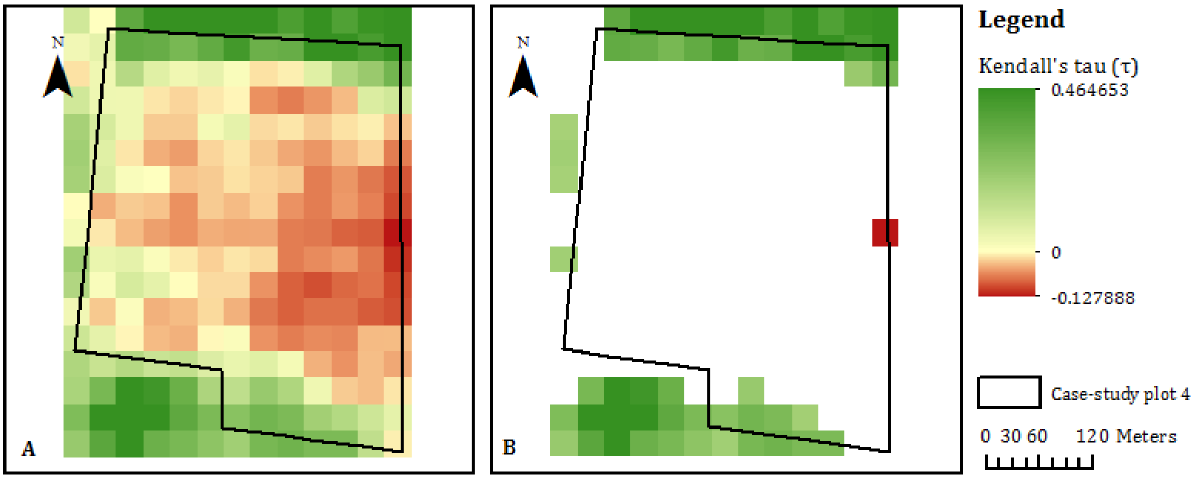

Figure 18: A- vegetation trend map of case-study plot 4, represented by Kendall's tau (τ), B- significant vegetation trend map (p-value < 0.1)

As can be observed from the maps, all three plots in Bobur WUA (case-study plot 1-3) show a relatively positive vegetation trend for both trend analyses, contrary to case-study plot 4 in Yangiobad WUA. This plot seems to be the subject of strong vegetation degradation. However, when calculating the means of both trend types in the case-study plots (Table 2), the mean τ (Kendall's tau) of case-study plot 4 is still positive. It is important to note, though, that the calculated trends in this plot are, but a few, not significant. Table 2 also provides the mean percentage of NA in a dataset, showing that the trend maps of case-study plot 4 are based on most data and that this plot does not seem to be affected by the missing scan lines of the Landsat satellite.

Table 2: Mean slope, Kendall's tau and percentage of NA in dataset of all case-study plots

Plot	*Mean β (slope)*	*Mean τ (Kendall's tau)*	*Mean percentage of NA in dataset*
Case-study plot 1	2.053 e-005	0.096	15.0 %
Case-study plot 2	1.707 e-005	0.110	16.0 %
Case-study plot 3	1.152 e-005	0.069	16.6 %
Case-study plot 4	-8.610e-006	0.009	1.3 %

Since it is not clear from the abovementioned trends whether they are purely negative or positive or whether there is a changing trend, the BFAST approach has been applied to all four case-study plots, resulting in the following maps (Figure 19). These maps represent the different type of trends, including trends that are found to contain a changing trend in the time series. It is important to realize that some pixels in the plots are not representing any change due to missing data in the time series.

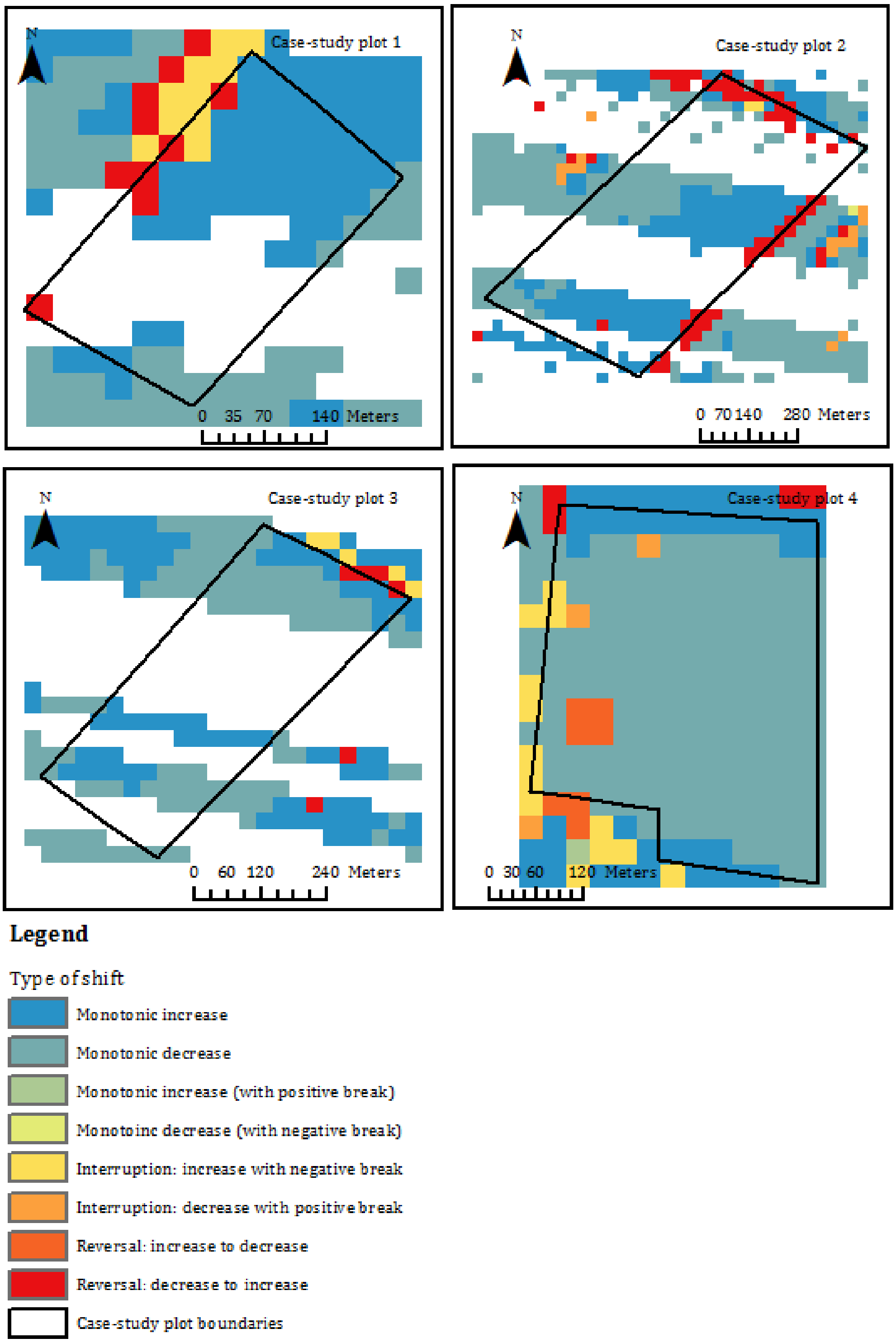

Figure 19: Classified trend types in all four case-study plots

Figure 19 shows that most trends in the four case-study plots represent a monotonic trend, i.e. no changing trend direction nor any 'jumping' breaks. Regarding these monotonic trends, it is most noticeable, though, that there seem to be more pixels representing a negative trend (monotonic decrease), compared to the resulting maps of the other two trend analyses (Table 3). Furthermore, most trends that *do* contain a change (both an interruption and a reversal), are mainly located at the edges of all plots. Figure 20 shows an example of a plotted time series of a pixel with such a changing trend. In this case, the trend represents a reversal from an increasing- to a decreasing trend.

Table 3: Different proportions of negative trends in all case-study plots

Plot	*% cells representing a decreasing trend using BFAST**	*% cells representing negative trends using linear regression*	*% cells representing negative trends using Mann Kendall*
Case-study plot 1	43%	20%	20%
Case-study plot 2	59%	47%	29%
Case-study plot 3	52%	14%	10%
Case-study plot 4	79%	61%	50%

* *proportion cells representing a monotonic decrease of cells representing both monotonically increasing and decreasing trends (note that the BFAST maps have a considerable amount of cells with no value or another type of trend)*

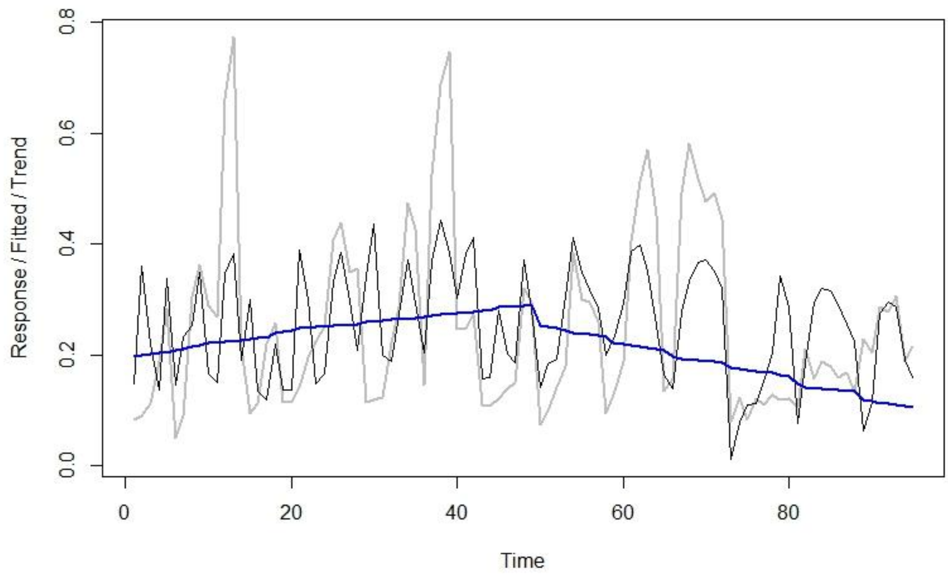

Figure 20: NDVI time series case-study plot 4, pixel #120. The grey graph represents the original NDVI data, the black line the fitted data and the blue line the trend.

5.3 FARMER PERSPECTIVES ON VEGETATION AND LAND DEGRADATION TRENDS

In this sub-chapter the (limited) results of the farmer interviewing will be presented. First of all, all farmers have been asked to sketch a trend line of their yield from the specific case-study plots. It is important to note that the farmers of case-study plot 3 and 4 have only recently been farming on the plot and could therefore not estimate the yield before 2011. This resulted in the following figure, showing that most farmers have actually noticed a positive yield trend:

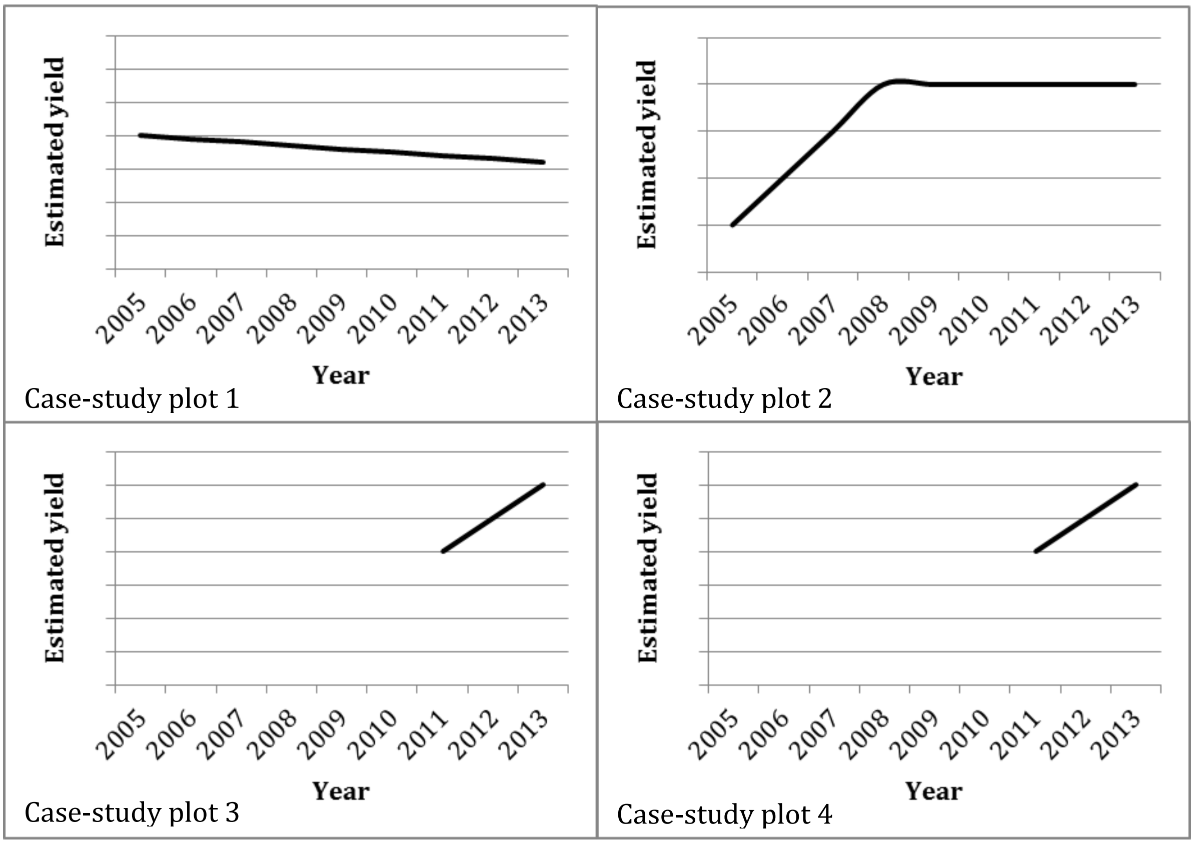

Figure 21: Estimated yield over time by the farmer of the four case-study plots

All farmers that seem to experience a positive yield trend, have related their increasing yield to improved management practices, including the application of fertilizers. The farmer on case-study plot 1 (experiencing a decreasing yield) has indicated the salinization to affect his yields on this particular plot.

Even though, most yield trends are considered to be positive, a high yield or even an increasing yield does not necessarily indicate an absence of land degradation. This has been confirmed by the outcomes of the interviews: all four farmers do experience one or multiple types of land degradation on their plots, despite their positive yield trends (Table 4). Clearly, salinization is the main malefactor, being recognized by all four farmers.

Table 4: Observed forms of land degradation by farmers from the four case-study plots

Land Degradation	*Plot 1*	*Plot 2*	*Plot 3*	*Plot 4*
Salinization	V	V	V	V
Compaction, crusting or sealing		V	V	
Decreasing soil organic matter	V			V
Water degradation	V	V		

The farmer interviewing has resulted in some more useful information about the perception of land degradation by the four farmers. These results have been summarized in box 2.

Box 2: Additional results farmer interviewing

According to the interviewed farmers, salinization has been the result of a high groundwater level and the sealing of the soil. Some have even made the next step, by relating this to the failing drainage system. According to the farmer of case-study plot 1 only 35% of the collectors in the area are working, which, as has been stated by the farmer of case-study plot 3, might be the effect of the fact that the system has not been cleaned for over 30 years.

Regarding different levels of salinization in the region, all four farmers were giving a similar explanation for this phenomenon. They have linked the level of salinization to the topography of the plot in the irrigation system: when the plot is located next to a (proper working) drainage system, the salinization is likely to be much less than a more distant plot. Furthermore, the flatness of the plots was indicated to be a factor in the level of salinization: when irrigating an uneven field, containing sinks, ponding takes place, increasing the level of salinization.

Furthermore, farmers have been asked for their ideas on how to increase their yields in the future. They mentioned both the improvement of the drainage systems and the application of more fertilizers and chemicals as solutions.

6 DISCUSSION

In this chapter, first, the results will be interpreted and a link to the research objectives will be made. Secondly, the reliability and the validity of the research methods that have influenced these results will be discussed. These two concepts refer to the influence of non-systematic and systematic mistakes on the results, respectively.

6.1 INTERPRETATION OF THE RESULTS

The vegetation trends that have been detected in both study areas (Bobur and Yangiobad WUA) show an average positive trend. However, it must be noted that the areas show a heterogeneous pattern of both increasing and decreasing NDVI values. This is consistent with the results of a vegetation degradation research in another highly irrigated area in Uzbekistan in which the spatial distribution of the different trends was described as “highly variable” (Dubovyk et al. 2013a, p. 4782).

When zooming into the four case-study plots, it is interesting to see that all three trend analyses present a similar pattern of positive and negative trends; this corresponding result strengthens the idea that the results are valid. Note, though, that most of the observed trends are not significant.

Despite the limited significance of most trends in the presented maps, the maps suggest that the yields in plot 1, 2 and 3 are positive and any land degradation (if present) does not affect biomass production. The map of plot 4, on the other hand, is presenting quite some negative vegetation trends, suggesting a decreasing yield and the possible presence of land degradation. The results of the farmer interviewing have helped to determine whether these suggested links with yield and land degradation approximate the (farmers’) truth; the observed trends in yield do not represent an obvious link to the trend maps as, for example, the farmer of plot 1 describes a negative yield trend, whereas the trend map shows strong and even significant positive trends in this particular plot. When making the link to land degradation, it is very important to note that even though vegetation/yield degradation is often used as an indicator of land degradation, land degradation can of course be present without any vegetation degradation. Land degradation clearly has an effect on a field’s productivity (i.e. “the inherent potential of a land system to produce crop yields” (Stocking and Murnaghan 2000, p. 11), however, the actual production might be unaffected due to compensating land management practices, e.g. the application of extra fertilizers. When interpreting the results of the farmer interviewing, this important distinction seems to be very relevant as all farmers have observed land degradation on their plots, independent of the type of yield trend. Moreover, as mentioned before, degraded, however stable areas won’t be identified by any trend analysis. This could mean that all four case-study areas are actually degraded (probably salinized) areas, however, due to its stable state, vegetation degradation won’t be present and trends won’t be identified. A similar kind of problem has been recognized by de Jong et al. (2011) who state that since the initial state is not known, a positive vegetation trend might represent a natural recovery from a drought, which can be considered as a misleading improvement when land degradation is still taking place.

6.2 RELIABILITY AND VALIDITY OF METHODS

TREND ANALYSIS

The different trend analyses have all been executed believing that they would be able to represent the vegetation degradation in the area. However, there are certain aspects of this methodology that threaten its reliability and validity. First of all, the usage of Landsat images should be linked to the fact that the satellite has a limited temporal resolution. Due to cloud cover effects, not all 16-day images were considered to be suitable and in the end, an average of about 7 images per year have been used for time series analyses. However, according to Bhandari et al. (2012), at least monthly images are required for detecting trends in vegetation. This indicates that the outcomes of the time series analyses are questionable and should be interpreted with care. Additionally, due to the missing scan lines, the time series miss even more NDVI data (Table 2). Special care should be taken for the interpretation of the outcomes of a non-parametric trend test like the Mann-Kendall trend test. When having only an average of 7 images per year, there is the possibility that all images are representing only one part of the growing season, which results in a distorted trend. For example, when all satellite images are representing the first half of the growing season, the NDVI is likely to mainly increase, i.e. an increment takes place between all data points, resulting in a high value of the Mann-Kendall Statistic S and Kendall's tau. Figure 4 shows that this is partly the case: there are definitely more satellite images representing the growing season than the dormant season. When checking the time series of average NDVI values in case-study plot 4 (Figure 16), one can also clearly observe more data points in the ascending lines of the seasonal peaks, suggesting that the Mann Kendall trend test might be corrupted for this particular plot. The other three case-study plots do not seem to have these unequally balanced data points, though. Moreover, the Mann-Kendall trend analysis might anyway falsely identify significant vegetation trends as the analysis assumes independent and randomly ordered data (Hamed and Ramachandra Rao 1998), whereas "NDVI time-series are characterized by outliers, seasonality and serial auto-correlation" (de Jong et al. 2011, p. 694). Regarding the detection of breaks in trends, it is important to note that the analysis used in this research (bfast01) could only detect one break in a time series. One should recognize that multiple breaks could actually be present, though. Furthermore, for a correct interpretation of the maps, one should realize that the current method of trend detection has not excluded non-agricultural lands. Contrary to de Jong et al. (2011), who masked all areas with NDVI < 0.1, inter alia roads, water and build-up areas are included in the trend maps. Despite of the fact that the study-areas are mainly covering agricultural lands, the maps might provide a slightly misleading image of trends due to this inclusion of non-agricultural areas.

FARMER INTERVIEWING

It has been clear from the beginning onwards that the farmer interviewing could never be a method of actual validation of the trend analyses: it has always been a method only to come up with a basic idea of the relation between the outcomes of trend analyses and the farmer's knowledge. Not only is the number of interviewees too small to be able to validate the outcome of the trend analyses, also the interviewing in itself knows some drawbacks. The reliability of interviewing can never be 100% reliable as the researcher and the translator are part of the measuring device and local and personal circumstances can influence the outcomes. Besides, farmer interviewing is considered to be unreliable as one never knows whether a farmer is telling the truth (Stocking and Murnaghan 2001).

The linking of the interviewing outcomes with the NDVI trend maps is considered to be tricky too. First of all, during the interviewing, farmers were asked to describe their yields, however, yields are not necessarily directly related to NDVI numbers (Benedetti and Rossini 1993): for example, the yielded part of the plant might decrease (e.g. the cotton flowers), whereas the total biomass of the plant remains stable over time. This doubtful correlation makes it therefore more likely to find non-corresponding results. Furthermore, farmers have been asked to describe their trends from 2005 onwards, contrary to the trend tests that analysed trends from 2000 onwards. This threatens the validity of the comparisons. Moreover, multiple farmers have not been able to provide yield information about the whole study period. This could mean that a farmer has observed a positive trend during the last 3 years, whereas over a longer period, a negative trend has been found. However, in this respect the BFAST method comes in handy, as it can detect multiple trend types in bigger time series. Lastly, due to limited information on the exact cropping calendar of the farmers, links between the yield and the detected trends of NDVI have been more difficult to make. For example, a farmer could have been cropping a new crop type that shows a lower NDVI, but at the same time actually provides a higher yield.

7 CONCLUSION

The study areas in Syrdarya province show a scattered pattern of both positive and negative vegetation trends. When zooming into four case-study plots, the trends of both the linear regression-, the Mann Kendall- and the BFAST analysis are considered to correspond with each other, making the validity of the methods plausible.

No immediate link with the observed yield trend was present, which might be a result of the validity and reliability issues in one of the methods.

In all four case-study plots land degradation, mainly salinization, was considered to be taking place, however, no clear link with nor the calculated vegetation trends nor the observed yield trends could be made.

8 RECOMMENDATIONS

Considering the aforementioned lack of reliable monitoring efforts, this research has been an attempt to, inter alia, demonstrate the value of remote sensing for these efforts. However, due to circumstance, the research has been subject to multiple pitfalls. By identifying these pitfalls in the discussion, it has been possible to develop the following recommendations for future research and/or monitoring efforts:

First of all, clearly, the link to land degradation could not directly be made from NDVI time series. Therefore, it is recommended to include other information sources in the assessment of land degradation (de Jong 2012). Wessels et al. (2004), for example, included rainfall data as to not take natural climate variability into account and only consider human-induced land degradation. The farmers' identification of the presence of water degradation (i.e. drought) shows that in these irrigated areas, it might be interesting to focus not only on rainfall, but also on irrigation water availability. Furthermore, it is recommended to include a detailed documentation of land management practices in the area in order to avoid the false identification of trends: e.g. one can detect a stable trend, suggesting no land degradation, whereas actually the increasing application of fertilizers has masked the land degradation.

Furthermore, the quality of farmer interviewing in this particular research did not meet the requirements to actually validate any of the found trends. However, validation is considered to be "crucial for remote sensing studies" (de Jong 2012, p. 35) and it is therefore recommended to improve the interviewing strategy and investigate the exact relation between farmers' knowledge and the outcomes of the trend tests.

Regarding the trend tests for time series, it is recommended to use the seasonal Mann Kendall trend test instead of the standard Mann Kendall trend test that has been used in this particular research. The seasonal Mann Kendall trend test computes increments and decrements between data from comparable seasons, i.e. "January data are compared only with January, February only with February, etc." (Helsel and Hirsch 1992, p. 338), thereby taking seasonality into account.

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ANNEX

Farmer interview (10-15 minutes)

General information

1. Date interview:

2. GPS location:

3. Name farmer:

4. Age farmer:

5. Total land size (ha):

Specific plot information

6. Land size (ha):

7. Soil type (official):

8. Soil bonitet:

9. Years of ownership (since when):

10. Crop types since 2005:

11. Cropping calendar:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2005												
2006												
2007												
2008												
2009												
2010												
2011												
2013												

Vegetation trend

12. Yield information available:

Year	Yield (tonnes)
2005	
2006	
2007	
2008	
2009	
2010	
2011	
2012	
2013	

13. No yield information available/ limited:

-> *show example of graph and trend line and explain principles*
-> *ask to draw trend line of yield over time (since 2005)*

14. Reasoning behind the observed trend:
(*think about climate, crop change, management, fertilizers, pests and degradation)*

<u>Land degradation</u>

-> *explain concept of land degradation and different types of land degradation (show pictures)*

15. Do you think land degradation has an effect on crop growth? Yes / No

16. Do you observe land degradation on your plot? Yes / No

17. If yes: what type of land degradation do you observe?
□ soil erosion by water
□ soil erosion by wind
□ salinization
□ compaction, crusting or sealing
□ pollution
□ decreasing soil organic matter
□ nutrient depletion
□ water degradation (e.g. drought)

18. Which type of land degradation has the biggest effect on crop growth?

19. Land degradation trend
-> *show example of graph and trend line and explain principles*
-> *ask to draw trend line of observed types of land degradation (since 2005)*

20. Reasoning behind the observed degradation:
(*considering salinization, think about drainage system, groundwater level)*

Differences in area

-> show NDVI trend map of the area and point to the different trend types

21. Do you experience different trends in yield in the area?

22. If yes: what do you think can be the reasons for these differences?

23. Do you observe different levels of land degradation in the area?

24. If yes: what do you think can be the reasons for these differences?
(think about location, management, soil type)

Future

25. Future yield trend
-> ask to draw trend line of predicted crop yield

26. Future degradation trend
-> ask to draw trend line of land degradation

27. Reasoning behind yield trend:

28. Reasoning behind degradation trend:

29. What options do you see to increase the crop yield (and if applicable, decrease degradation)?
(think about innovations, new crop types)