Supplementary Materials: Cropping Intensity in the Aral Sea Basin and Its Dependency from the Runoff Formation 2000–2012. *Remote Sensing* 2016, *8*, 630

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1. Regional Scale Mapping—Visual Analysis of MODIS NDVI Time Series

Temporal NDVI signatures of the following land cover types in the Aral Sea Basin (ASB) were analyzed in MODIS data 2000–2012: Wetlands, bare land, water surfaces, natural vegetation and rainfed agriculture (in mountainous regions), low vegetation, rice cropping systems. Only the last class refers to cropland. All other classes were targeted to separate non-cropland or rainfed agriculture from the irrigated cropland extent.

The major observations are schematized at the example of single pixels in Figure S1 and can be summarized as follows:

- Wetlands can alter their appearance every year: Inundation phases (indicated by periods of NDVIs below zero) change with periods of varying vegetation cover. In some years, vegetation- and water-free years or years of vegetation cover similar to summer crops period can also occur. Having information of one year only, wetlands could be erroneously mapped as cropland, low vegetation or bare land (compare Figure S1a,b with Figure S1d,e).
- Water is characterized by fluctuating NDVI values, mostly below 0 (Figure S1c) [1].
- Bare land has distinctly low NDVI values throughout the year and also can have very sparse vegetation in spring (after snow melt, Figure S1d)
- Years without any crop growth can be followed by one or more years with crop cultivation as observed for the rice cropping systems in the Kyzyl-Orda region in Kazakhstan (Figure S1f).
- For rainfed agriculture and natural vegetation (in mountainous locations), NDVI peaks are observed to be highest during almost the first half of year due to the spring rain and snow-melt. During the extremely arid summer months, those areas get dry. This effect can be seen from the decreasing course of the NDVI values following spring time (Figure S1g). Having data of one year only, a separation between rainfed and irrigated winter wheat would be impossible. The inclusion of multiple years allows to reduce such confusion: one year of summer crops with higher NDVI during the dry season clearly indicates the possibility of irrigation water supply to the respective area (pixel).

Thus, the analysis of typical repetitions of signals, respectively, the course of NDVI throughout the year, combined with expert knowledge of the region, enables to distinguish irrigated from rainfed cropland, and other natural vegetation classes occurring in the ASB.

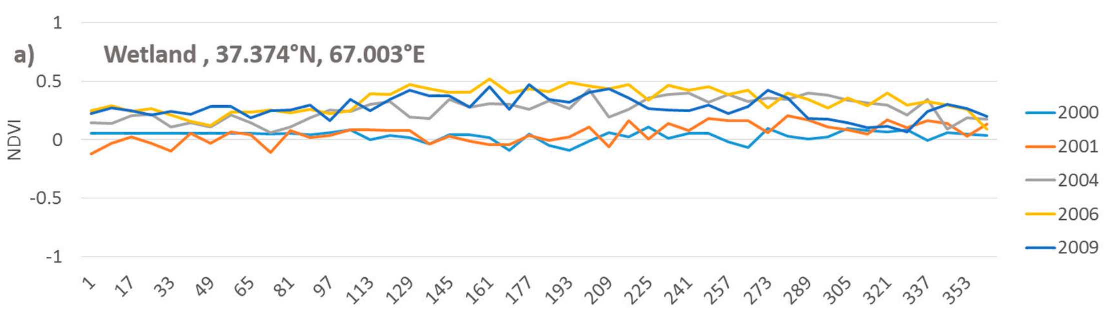

Figure S1. *Cont.*

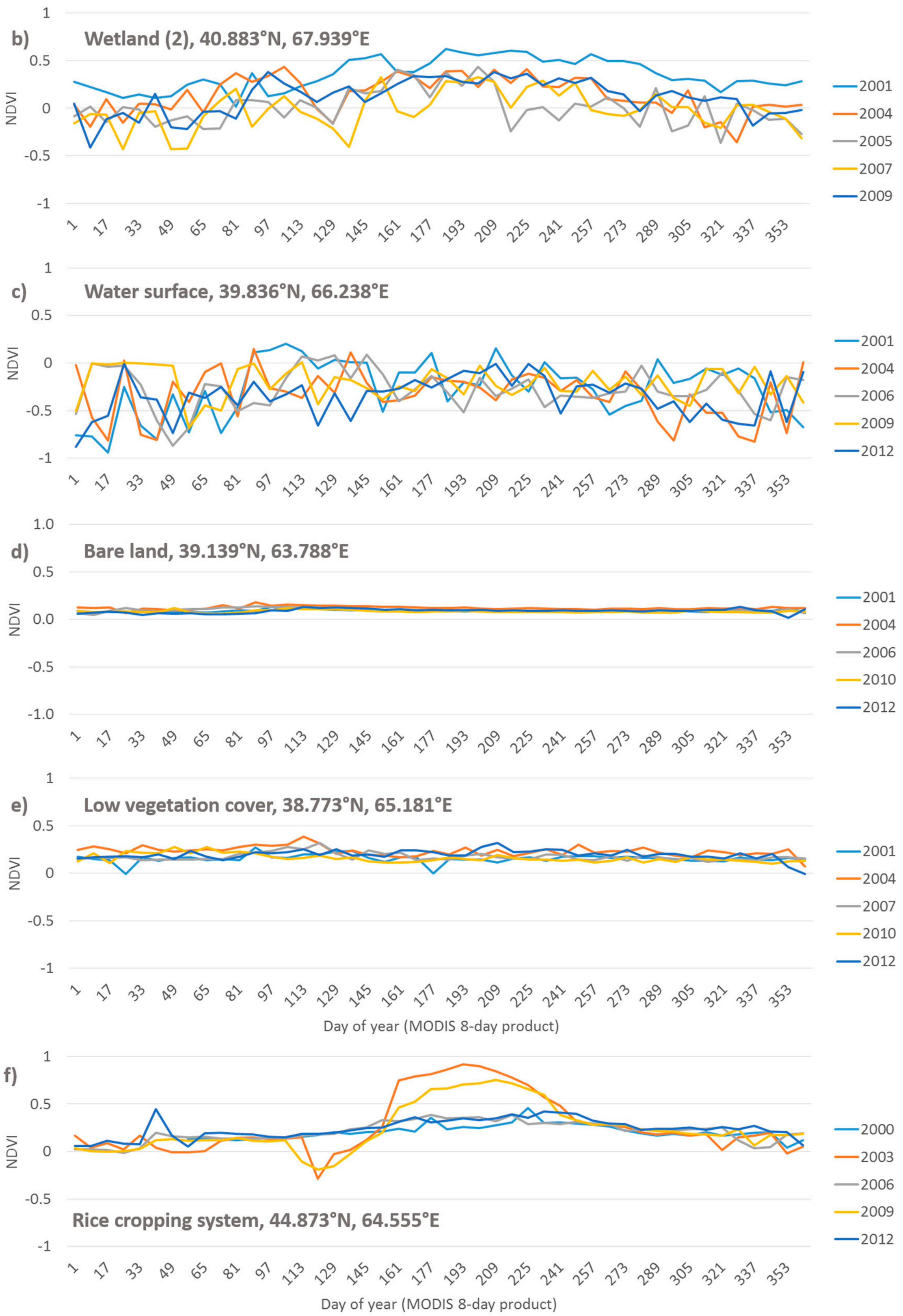

Figure S1. *Cont.*

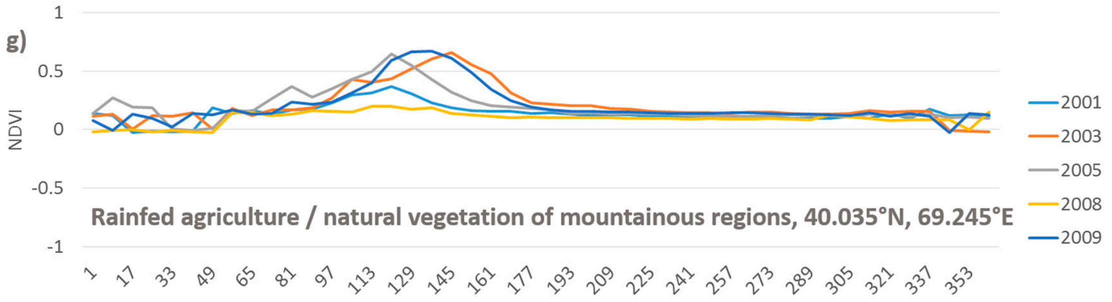

Figure S1. Annual NDVI time series of single MODIS pixels. For a better visibility, only five out of 13 (2000–2012) years are shown exemplarily: (**a**) wetland (example 1); (**b**) wetland (example 2); (**c**) water surface; (**d**) bare land; (**e**) low vegetation cover; (**f**) rice cropping system; and (**g**) rainfed agriculture (here wheat) and natural vegetation of mountainous regions. Two wetland examples were selected to show the variability of NDVI courses in this class.

2. Regional Scale Mapping—Rule Sets for Generating Annual Indicator Layers

The rules for generating the indicator layers from annual MODIS NDVI time series comprised (i) observation periods (e.g., spring-summer transition, vegetation period, etc.) and (ii) threshold values, which were applied to metrics (e.g., average, minimum, range) of the MODIS-NDVI time series within these periods (Table S1). This combination of observation periods and threshold values was extracted from expert-based visual inspections of the time series (Figure S1). They resembled each other but also varied among the classification zones (CZs, Figure 3).

For instance, vegetation green-up in few upstream locations (CZs 1 + 5) occurred earlier than in others because of the fact that water takes a couple of weeks to reach the downstream irrigation systems. This influenced the selection of the start dates for the respective periods. The desert regions of Kara Kum and Kyzyl Kum in the downstream Amu Darya catchment and the Turkmen water supply zone (CZs 7 + 8) are characterized by bright soils and reduced crop coverage. There, minima and maxima of NDVI peaks, and minimum average NDVI levels during the vegetation period were reduced to avoid underestimations of MR-iCE.

Wetland indications were given by (i) severe water inundation periods characterized by extremely low NDVI values; (ii) very high vegetation cover (mainly reed) in the spring-summer transition period, when winter crops are harvested and second crops are still in early vegetative phases (spring-summer transition period); or (iii) very high vegetation cover from spring until the end of summer (spring-summer transition + summer period). Very low annual average NDVI values easily pointed to water bodies and bare soils. The occurrence of rainfed agriculture and natural vegetation in the mountain regions was indicated by bare and very low vegetated summer periods (late autumn could show an increased average NDVI due to snow-cover). Since rainfed agriculture is typically practiced on slopes above 0.1° [2], another threshold was introduced for CZ 6, because in the Karshi steppe intensive wheat production occurs also in the intensively irrigated plain [3]. A wide NDVI range during the vegetation period characterized shooting of rice crops, because the NDVI signal typically increases from water to dense vegetation within very short time [4]. Average NDVI above the soil signal but without clear peak, which could be explained by a crop signal, were classified as low vegetation. Those MODIS-NDVI time series with reduced vegetation signals showing such a peak either in spring or summer were labeled indicative for cropland.

Table S1. Metrics, thresholds, and observation periods used for the calculation of annual indicator layers from MODIS NDVI time series in the different classification zones; Days of year (DOY) describe the start day of a MODIS compositing period (referring to the respective MODIS product identifier). Because the products are 8-day composites, the end of the observation period falls within the DOY plus seven days. TP = transition period.

Mapping Indicators and Settings for Observation Periods		**Classification Zone**							
		Fergana	**Tashkent/ Syr Darya**	**Chardara, Aris**	**Kyzyl Orda**	**Upper Amu Darya**	**Zerafshan, Mid Amu Darya**	**Karakum Canal**	**Amu Darya Delta**
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Wetland indicators	Absolute minimum NDVI (indicating a flooding event)	−0.45	−0.40	−0.35	−0.45	−0.45	−0.42	−0.20	−0.43
	Minimal average NDVI for (early) spring-summer transition period (TP)	0.58	0.60	0.60	0.64	0.50	0.55	0.60	0.66
	Minimal minimum NDVI for (early) spring-summer (+summer) TP	0.53	0.56	0.55	0.53	0.48	0.51	0.50	0.49
	Initial DOY (spring-summer TP)	*137*	*129*	*137*	*145*	*137*	*145*	*145*	*145*
	End DOY (early spring-summer TP)	*185*	*185*	*185*	*185*	*185*	*185*	*185*	*185*
	End DOY (spring-summer TP)	*233*	*233*	*233*	*233*	*233*	*233*	*233*	*233*
	End DOY (summer period)	*281*	*281*	*281*	*281*	*281*	*281*	*281*	*281*
Water and bare soils	Max. annual NDVI average (water)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	Max. annual NDVI average (bare soil)	0.18	0.18	0.18	0.18	0.18	0.18	0.17	0.17
Bare summer (very low vegetation)	Maximum summer and autumn NDVI	0.35	0.30	0.33		0.35	0.27		
	Minimal slope inclination (°) *						0.10		
	Initial DOY (dry summer period)	*209*	*193*	*209*		*233*	*185*		
	End DOY (dry summer period)	*297*	*297*	*297*		*297*	*321*		
Rice shooting signal **	Range of NDVI increase				0.71	0.72			
	Start DOY (rice growing season)				*105*	*105*			
	End DOY (rice growing season)				*289*	*289*			
Low vegetation and crop indicators	Maximum of average NDVI (no crop)	0.36	0.32	0.32	0.35	0.35	0.32	0.25	0.26
	Start DOY (growing season: spring)	*97*	*97*	*97*	*97*	*97*	*97*	*97*	*97*
	End DOY (growing season: late summer)	*289*	*289*	*289*	*289*	*289*	*289*	*289*	*289*
	Minimum peak of NDVI (winter crop)	0.42	0.39	0.41	0.43	0.39	0.39	0.37	0.38
	Start DOY (early growing season)	*65*	*65*	*65*	*65*	*65*	*65*	*65*	*65*
	End DOY (early growing season)	*145*	*145*	*145*	*145*	*145*	*145*	*145*	*145*
	Minimum peak NDVI (summer crop)	0.43	0.42	0.42	0.42	0.41	0.42	0.38	0.40
	Start DOY (late growing season)	*193*	*193*	*193*	*193*	*193*	*193*	*193*	*193*
	End DOY (late growing season)	*281*	*281*	*281*	*281*	*281*	*281*	*281*	*281*

* this rule was introduced for CZ6 only, because the Karshi region located in that CZ has a strong focus on winter wheat production, i.e., it can also happen that wheat is repeatedly grown in that area. ** The separation of rice signals became only necessary in zones with a high risk of confusion between wetlands and rice.

3. Regional Scale Mapping—Threshold Values of Terrain Attributes

According to Gupta et al. [2], irrigated agriculture in the Aral Sea Basin is mainly practiced in flat terrain and locations at lower altitudes. Hence, two terrain attributes, slope inclination and altitude, were overlaid by Google Earth to extract thresholds above which irrigation was observed to be absent (Table S2).

Table S2. Threshold values of the terrain attributes above which no irrigated cropland can be found in the different classification zones (estimated by using Google Earth). Because of their location in the flat, inner Aral Sea Basin, terrain attributes were not required for classification zones (CZs) 4 and 8.

Maximal Threshold Values for Irrigation	**Classification Zone (CZ)**							
Terrain attributes	**Fergana**	**Tashkent /Syr Darya**	**Chardara, Aris**	**Kyzyl Orda**	**Upper Amu Darya**	**Zeraf-shan**	**Karakum Canal**	**Amu Darya Delta**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Altitude (m a.s.l.)	1300	1100	350		1300	1100	300	
Slope inclination (°)	3	1.8	0.6		2.9	2	1.5	

References

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