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Wetland Distribution Trends in Central Asia

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Abstract
Anthropogenic activities and climate change contribute to the deterioration of wetlands worldwide with Central Asia (CA) being among the regions which are most severely affected. This study examined how the distribution of wetlands in CA has changed in the last two decades. Emphasis was put on inland wetlands protected as International Bird and Biodiversity Areas. Time series of maps of wetlands (i.e. reed beds) were created for the years 2000, 2005, 2010, 2015 and 2018. A supervised classification approach was applied using NDVI of MODIS satellite images with 1000m resolution for the respective years. Ground control points were acquired through fieldtrips to the lower Chu River, upper Ili River and Ili River Delta in Kazakhstan and the Amu Darya River Delta and the Lower Amu Darya State Biosphere Reserve in Uzbekistan. The applied method is not applicable for the classification of wetlands in northern Kazakhstan. The vegetation there is too alike to the wetland vegetation in terms of values and seasonality of NDVI. For the remaining part of the study area, the applied method delivers satisfying results. However, it is difficult to determine a general trend for most wetland areas since there is a large variability between years. This study marks a first attempt at examining wetlands in CA at a regional scale. The results provide a baseline for further, more detailed research through either fieldtrips or by using higher resolution remote sensing data.

Keywords: Phragmites australis, mapping, MODIS, remote sensing, NDVI.

Paper type: Research paper

1. Introduction

Since 1700 AD, there has been an average long-term loss of natural wetlands of 54 to 57 % globally even though it might have been as high as 87 %. A much faster rate has been the case for the 20th and early 21st centuries, with a loss of 64 to 71 % of wetlands since 1900 AD (Davidson 2014). Wetlands, including river systems, continue to be fragmented and degraded with negative impacts on ecosystem services (Leadley et al. 2014). Currently, there is no agreed global map of wetland ecosystems. Therefore, there is a growing need for accurate spatial mapping of terrestrial surface water to support the management and conservation of wetlands and their related biodiversity and ecosystem services such as fresh water supply (Fluet-Chouinard et al. 2015; Ramsar Convention Secretariat 2016).

Central Asia is the region of the world with the most endorheic (i.e. closed) river basins with several thousand lakes (Aizen et al. 2007; Yapiyev et al. 2019; Yapiyev et al. 2017). The geographical region of Central Asia largely consists of dryland areas. Therefore, water is the major driver for the persistence of the current natural ecosystems and their associated biodiversity (Imentai et al. 2015). The sources for water in the drylands are meltwater from snow and glaciers in the mountains as well as from rainfall (Imentai et al. 2015). Vegetation trends are mostly driven by precipitation and temperature dynamics (Aralova et al. 2016). This also determines the possibilities for different types of land use. Rivers and inland water bodies are the major sources for fresh water in the semi-arid and arid regions (Klein et al. 2014). This goes in line with the most productive and diverse ecosystems being located along the rivers (Ogar 2003), which are reed beds (Thevs et al. 2007) and riparian forests (Thevs et al. 2012). Thus, water bodies and wetlands are of high ecological and economic importance. Moreover, wetland vegetation plays a key role in the ecological functioning of wetland environments (Adam et al. 2010). Anthropogenic activities and climate change contribute to the deterioration of terrestrial water resources worldwide with Central Asia being among the regions which are most severely affected (Yapiyev et al. 2019). Climate change has been causing significant changes of the water bodies in Central Asia altering precipitation and evaporation (Lioubimtseva and Henebry 2009). The mountain ranges of the Tian Shan and Pamir-Alai, mainly in Kyrgyzstan and Tajikistan, have been showing a significant decline in glacier and snow-covered areas. This is primarily caused by warmer temperatures through to the month of September in the glacial-nival zone. There has been a significant warming, especially during the winter season in the northern foothills of Tian Shan (Klein et al. 2014). This warming trend not only results in a higher evaporation in the basin oases, but also in a significant retreat of glaciers in the mountainous areas. Wang et al. (2018) modelled a decrease of the glacier 2D area by 404 km² (- 8.1 %) and of the 3D area by 516 km² (- 7.9 %) between 1989 and 2015 for the Central Tien Shan in Northwest China, Kazakhstan and Kyrgyzstan. Shifts of seasonal runoff maxima have already been observed in some rivers, and it is expected that summer runoff will further decrease in these rivers if precipitation and discharge from thawing permafrost bodies do not compensate sufficiently for water shortfalls (Yu et al. 2019). However, once the tipping point of the glacier melting in the headwater region will be reached, a reduced runoff into the rivers is expected which will largely affect the wetlands (Imentai et al. 2015; Kuenzer et al. 2015). In this respect, a continued monitoring in the future is recommended. Water abstraction, mainly for irrigation, and hydropower generation have negatively influenced the water bodies. Water abstraction has made lakes and wetlands shrink and vanish whereby the construction of reservoirs and accelerated glacier melting let to the formation of new water bodies and wetlands. Ecological problems such as land desertification, salinization, degradation of vegetation, and biodiversity loss are strongly connected to water shortage and lake surface decrease (Figure 1) (Bai et al. 2012; Lioubimtseva et al. 2005; Saiko and Zonn 2000). Many studies have revealed dramatic ecological, morphological, and areal changes of different inland water bodies and lakes in the past decades (Klein et al. 2014).

Figure 1. Salinization at Lake Sudochie, Uzbekistan. Salinization is an ecological problem linked to lake surface decrease. As the water moves back, salt accumulates (white parts) and shrubs (red *Tamarix* spec. seedlings) replace reed beds.

Next to water abstraction and glacier melt, several further threats to wetland biodiversity have been described for the Ili Delta and southern Lake Balkhash, i.e. fires ignited by local herders, logging for fuel wood collection, overfishing, overgrazing, water pollution (Imentai et al. 2015). Thus, accurate datasets and time-series of water bodies and wetlands could improve our understanding of natural variability and human interaction in Central Asia. An accurate spatial detection and monitoring of wetlands is important for the assessment of actual driving forces in the past, present and future. This information is essential for future political activities and decisions in terms of sustainable land and water management (Klein et al. 2014). Especially river deltas are highly dynamic systems for which a thorough understanding of the general settings and intra-annual as well as long-term dynamics has been described as crucial for an informed management of natural resources (Kuenzer et al. 2015).

This study tries to fill the gap of the lacking information about the spatial distribution of wetlands in Central Asia by using low-resolution remote sensing data. The overall goal is to examine how the distribution of wetlands has changed between the years 2000 and 2018, i.e. to examine general trends and to identify areas at risk. This study is seen as a first step in the field of analysing wetland changes across Central Asia, as it reveals areas in which wetlands decrease and increase, respectively. In this first analysis, changes will not be quantified as areas given in hectares. In the context of the situation of wetlands in Central Asia as explained above, we created times series of maps of wetlands in Central Asia for the years 2000, 2005, 2010, 2015 and 2018.

2. Study area

The study region is comprised of the five former Soviet Union republics Kazakhstan (2,724,900 km²), Kyrgyzstan (199,900 km²), Tajikistan (143,100 km²), Turkmenistan (491,250 km²) and Uzbekistan (447,400 km²) which together are approximately 5.5 Mio km² in size (Klein et al. 2014). The area covered spans from the Caspian Sea in the west to the Tien Shan Mountains and China in the east, Russia in the north and Iran and Afghanistan in the south. The region is dominated mostly by gently hilly plains, flat lowlands and plateaus (Klein et al. 2014). A vast majority of the land lies below 200 m, yet there are as well massive mountain ranges rising up to 7,495 m at Ismoil Somoni Peak in the Pamir Mountains in Tajikistan (Aralova et al. 2016).

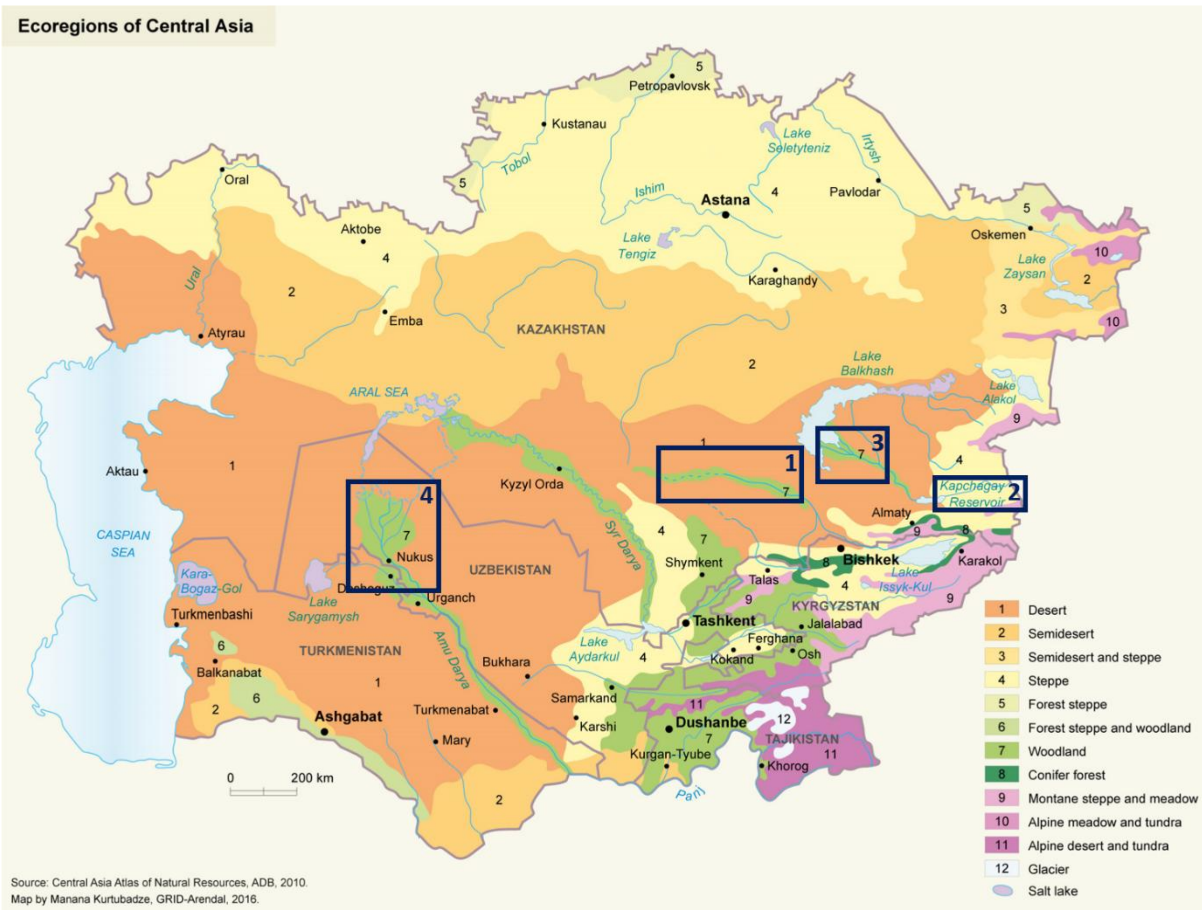

Figure 2. Ecoregions of Central Asia. Rectangles show the regions where fieldwork was carried out: 1 – Lower Chu River, 2 – Upper Ili River and Charyn River, 3 – Ili River Delta, 4 – Amu Darya River Delta and Lower Amu Darya State Biosphere Reserve (adapted from Outlook on climate change adaptation in the Central Asian mountains 2017).

The biggest part of the territory of Central Asia is occupied by steppe and desert ecosystems with sparse vegetation and closed to open shrublands (Ogar 2003). The mountainous regions

(Altai, Tien Shan, Pamir) are dominated by montane grasslands and shrublands as well as temperate coniferous shrublands (Aralova et al. 2016). The wetland vegetation in Central Asia consists of reed beds, riparian forests (Tugai), halophytic meadows, desert meadows, and shrub vegetation according to the Russian vegetation classification (Ogar 2003). Among these, reed beds are the most dominant. They are either periodically or permanently submerged and host mostly species-poor vegetation dominated by *Phragmites australis* (common reed) (Ogar 2003). The growing season of vegetation in the study area lasts from April/May to September/October being controlled by the key variables temperature and precipitation (Klein et al. 2012).

Central Asia has a temperate to sharp continental arid to semi-arid climate with very hot and dry summers as well as very cold winters (Aralova et al. 2016; Lioubimtseva and Henebry 2009). A strong north-south gradient exists regarding temperature and precipitation, as well as a gradient from lowlands to high mountains. The yearly mean precipitation differs among the vegetation zones, varying between 80 and 150 mm/year in the desert region, ranging from 200 mm/year in the southern to 400 mm/year in the northern steppe and lying between 600 and 800 mm/year in the mountainous zones (Klein et al. 2014).

3. Materials and methods

Wetlands in the study region were mapped through the Normalized Difference Vegetation Index (NDVI) of the Moderate Resolution Imaging Spectroradiometer (MODIS) for the years 2000, 2005, 2010, 2015 and 2018. The wetlands were mapped using a supervised classification approach. MODIS images from the year 2018 served as the basis against which acquired groundtruth data were related, in order to develop the decision tree for the supervised classification. For the wetland mapping, the focus was on mapping the areas with reed since these are the most productive wetland ecosystems in Central Asia.

3.1. Remote Sensing as a tool for mapping wetlands

Remote sensing techniques offer timely, up-to-date, and relatively accurate information for creating datasets for the sustainable and effective management of wetland vegetation (Adam et al. 2010). Although optical sensors cannot acquire imagery during clouded conditions, coarse resolution sensors with daily data acquisition, such as MODIS, can provide a good and affordable alternative to radar data with limited accessibility. MODIS data of 250 m spatial resolution has been used by several researchers to map water bodies, floods, and inundation dynamics (Kuenzer et al. 2015). MODIS VI data provides an option to determine wetland plant phenologies, to study wetland response to environmental changes, or to classify vegetation types (Petus et al. 2013; Sims and Colloff 2012; Zhao et al. 2009).

Figure 3. Wetland vegetation types. Submerged reed (l.) and non-submerged reed (r.) are the two wetland vegetation types which were examined in this study.

Remote sensing of wetland vegetation is challenging (Adam et al. 2010). One major challenge in distinguishing between vegetation types in complex environments such as wetlands, is the fact that commonly different vegetation types may possess the same spectral signature in remotely sensed images (Xie et al. 2008). One example for this is the similar signature for wetland vegetation and irrigated agriculture. Another challenge is dealing with so called mixed pixels, i.e. one pixel which covers two or more different vegetation types to be classified. Applications of per-pixel classifiers to images dominated by such mixed pixels often do not deliver satisfying results, i.e. produce inaccurate classification (Adam et al. 2010).

There have been numerous studies that have used mostly higher-resolution optical data sets (0.6 m to 30 m) to map and characterize wetlands in Europe, Australia and the United States of America, mostly for habitat assessments and inventory studies for nature conservation (Landmann et al. 2010). Fine-scale and multi-temporal imagery provide significant improvements in the detail and accuracy of wetland hydrology and wetland vegetation heterogeneity. However, there is also argumentation that the accurate characterization of wetlands over larger areas was found to be largely confined by the low temporal revisit frequencies even when high resolutions imagery was used (Landmann et al. 2010). For the characterization of wetland dynamics, time-series satellite imagery at 250 to 1000 m spatial resolution is suggested in a combination with passive/active synthetic aperture radar (SAR) data and other ancillary data about topography, climate, and soil. By applying big-data technology for sample datasets and by classifying massive satellite imagery by using the classification tree method, the accuracy of wetland map products can be further enhanced (Hu et al. 2017). In turn, accurate wetland datasets are indispensable for generating polices on wetland conservation and appropriate land uses, global climate change studies, and biodiversity conservation (Hu et al. 2017). For future global wetland datasets, a hierarchical and flexible structure of wetland classification systems aligning with the Ramsar wetland definition has been recommend (Hu et al. 2017).

Klein et al. (2014) resumed that medium-resolution data of 1 km x 1 km can be effectively used to detect areal extent of inland water bodies on a continental scale with high temporal resolution, documenting past conditions of water bodies and allowing analysis about driving forces and observed alterations as shown through a study on changes of water bodies in Central Asia from 1986 to 2012.

The NDVI has been applied successfully to quantify photosynthetic activity and to measure vegetation dynamics in many biomes (Petus et al. 2013). For the Great Artesian Basin in Australia, the NDVI extracted from QuickBird satellite images showed a good correlation with wetland vegetation cover (White and Lewis 2011). The NDVI is herein used as an indicator of semi-aquatic and aquatic vegetation activity within wetlands in the dry season (Landmann et al. 2010). Using NDVI under high biomass conditions can be limited by the so-called asymptotic saturation effect. Yet, this is not of concern for the arid landscape of Central Asia because exceptionally high biomass conditions are not encountered within this study area (Adam et al. 2010).

3.2. Data sources

3.2.1. Remotely sensed data

This study was carried out using the NDVI band of the MODIS product MOD13A3 V6 acquired from the website https://earthexplorer.usgs.gov/. Central Asia, i.e. the five countries looked at in this study, is entirely covered by eight tiles (h21v4, h21v3, h22v5, h22v4, h22v3, h23v5, h23v4, h23v3). The files were converted from hdf-format to GEOTIFF using the software Modis Reprojection Tool (Dwyer and Schmidt 2006). All tiles were projected into WGS84/UTM (Universal Transverse Mercator) zone 42N for further processing. Images were downloaded for the months April through October to cover the vegetation period. The winter season outside of the vegetation period was not considered since most of the water bodies are frozen and thus not applicable for the presented approach (Klein et al. 2014). Shapefiles with the boundaries of the five countries were downloaded from Diva GIS (http://www.diva-gis.org/). A digital elevation model of Central Asia was obtained from the NASA Shuttle Radar Topography Mission (SRTM). Shapefiles for the Important Bird and Biodiversity Areas (IBAs) in Central Asia were provided upon request by the BirdLife International Global Office in July 2018. The analysis was done using the two open source GIS software QGIS Desktop (versions 2.18.28 and 3.4.3, including the Google Satellite Plugin) and GRASS GIS (version 6.4.3).

3.2.2. Ground truth data collected through field trips

In total, three different fieldtrips were carried out for marking ground control points (GCPs) to be used for the supervised classification (

Table I). For each GCP, the location in UTM coordinates was recorded with a GPS-device (Garmin eTrex® H and Garmin GPS 60). Alongside this, the surrounding vegetation type including an estimated ground coverage [%] of the main plant species was observed. Further, information about the terrain and the size of the area observed was noted down. At every GCP, photos of the vegetation type were taken. At some spots during the fieldtrips in Kazakhstan, photos were also taken using a drone to get an overview of the area and look beyond the edge of the reed thickets. Furthermore, a GPS photo tracker was carried at all times which recorded the location once every minute. At the end of the day, the coordinates were joined with the photos taken by camera. Therefore, a rough location of every photo taken during the trips was known, including those photos which were taken from the car window while driving. Besides the fieldtrips mentioned in

Table I, GCPs were marked using the photo tracker during trips to the Ili Delta in southeastern Kazakhstan in June 2018 and to the Korgalzhyn State Nature Reserve (including Lake Tengiz) in northern Kazakhstan in July 2018. The software EasyGPS (version 6.11.0.0) and GPS TrackMaker (version 13.0.0.600) were used to download the coordinates from the GPS-device. Furthermore, GeoSetter 3.5.0. was used for visualizing the photos with coordinates from the photo tracker.

Table I. Fieldtrips in 2018 for marking ground control points.

Date	**Location**
25th April - 1st May	Chu River (also Shu in Kazakh, Чүй/Chui in Kyrgyz), Kazakhstan; between the town of Moyynkum in the east and the village Zhaylaukol in the west, including the area north of the village Ulanbel.
21st - 25th May	Ili and Charyn (also Sharyn in Kazakh) Rivers, Kazakhstan; at the Ash Grove, a stretch of riverine forest along the Charyn River, at several spots along the upper Ili River eastwards from the town Shonzhy and at different locations westwards of the village Araltobe in the Ili Delta.
25th - 26th October	Delta region of the Amu Darya River, Uzbekistan; between the towns of Kungrad in the south and Muynak in the north. around Lake Sudochie, near the village Tokmak, in the wetlands eastwards of Muynak and in the remaining wetlands south of Muynak along the villages Shagyrlyk, Kyzylkhar and Shege as well as at a spot on the banks of the Amu Darya River further south.
27th October	Lower Amu Darya State Biosphere Reserve (including the former Badai Tugai Nature Reserve), Uzbekistan; about 80 km northwest of the town Urgench.

3.3. Mapping of wetlands in Central Asia

The mapping was done using a supervised classification approach (Figure 4). The NDVI is calculated from the surface bidirectional reflectance factors for MODIS near infrared (NIR = 648 nm) and red (RED = 858 nm) bands as follows: (NIR – RED)/(NIR + RED) (Huete et al. 2002).

First, the GCPs from the fieldtrips were used to mark the corresponding MODIS pixels with the respective vegetation type to create a training dataset. 13 different vegetation types were distinguished, which are: submerged reed, non-submerged reed, submerged reed and desert mixed, Tugai forest, Tugai forest and water mixed, Tugai forest and desert mixed, Tugai forest and steppe mixed, southern steppe, middle steppe, steppe connected to groundwater, shrubs, semidesert and desert. Then, the NDVI-values for the months from April to October 2018 at the marked pixels were analysed (Figure 12).

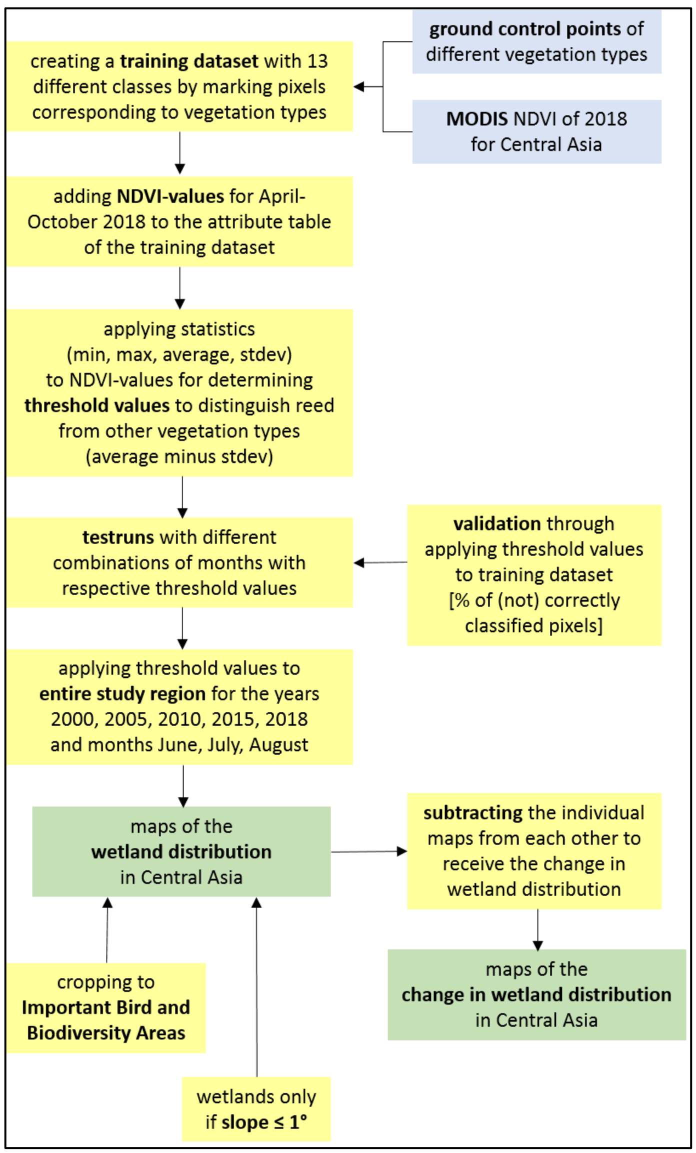

Figure 4. Process of mapping wetlands using a supervised classification approach**.**

The threshold values were examined towards distinguishing areas with reed from all other wetland vegetation types as well as steppe, semidesert and desert. As the threshold value for each month and vegetation type, the average minus the standard deviation was used. Several test runs were carried out to examine which combination of months and threshold values provided the best results. For validation, the values calculated by the different combinations were extracted for the training dataset with the different vegetation types. The percentages were calculated for the number of points which had been categorized correctly and not correctly (Table). Using a combination of the threshold values for June, July and August with an AND condition showed the best results.

The above threshold values were then applied to the years 2000, 2005, 2010, 2015 and 2018. Two challenges in mapping the wetlands in Central Asia are, that the NDVI for mountain forests and (irrigation) agricultural areas is similarly high as for reed thickets. Since in Central Asia, naturally forested areas aside from the Tugai forests are usually found in mountainous areas, a digital elevation model was used to exclude the forested areas. Any area being on a slope of 1 degree or more was categorized as not being wetland. Distinguishing between wetland areas and areas used for (irrigation) agriculture is difficult. To avoid this, the focus of this study was put on protected wetlands. Initially, the plan had been to focus on Ramsar sites. Yet, it turned out to be impossible to obtain shapefiles for the Rasmar-sites in Central Asia. Thus, the focus was put on Important Bird and Biodiversity Areas (IBAs). These are areas which have been identified by BirdLife International as being globally important for the conservation of bird populations using an internationally agreed set of criteria. Only IBAs indicated as “Wetlands (inland)” on the website http://datazone.birdlife.org/site/search (19-02-2019) were considered for this study. All resulting wetland maps were also cropped to the areas protected as IBAs by using the shapefile of IBAs as a mask. Focusing on IBAs draws the attention on those sites which are particularly valuable for nature conservation and thus hold priority in terms of future decision making. Some IBAs are as well Ramsar-sites.

To examine the change in wetland distribution over the years, the above results of the separate years were compared for the time periods of 2000-2005, 2005-2010, 2010-2015, 2015-2018 and 2000-2018. The four categories of change were: (1) wetland in both years = 1, (2) no wetland in both years = 2, (3) wetland in the first year and no wetland in the second year = 3 (decrease), (4) no wetland in the first year and wetland in the second year = 4 (increase).

4. Results

By using a combination of threshold values for June, July and August with an AND condition, 80 % of the training pixels for submerged reed and 65 % for non-submerged reed were classified as reed (Table II). For mixed pixels of submerged reed and desert, 16 % were classified as reed. These were all pixels from the mosaic landscape in the Ili Delta which had more than 50 % of the area covered by reed. The 14 % of points wrongly classified as reed were points near reed areas or pixels containing mostly shrubs with smaller amounts of reed.

For the 19 % of Tugai points wrongly classified as reed, it needs to be mentioned that those were all points in the Ili Delta and along the Upper Ili River where the landscape was a mosaic of patches covered by Tugai forest and patches covered by non-submerged reed. For the points marked in the Lower Amu Darya State Biosphere Reserve, which were purely Tugai forest vegetation, no single point was classified as reed. The same applies for those points in the mixed category of Tugai and water.

Table II. Validation for the ground control points. Pixels were classified as reed if the NDVI for June 2018 is higher than 4437 and the NDVI for July 2018 higher than 4707 and the NDVI for August 2018 higher than 4287.

	Reed_wet	Reed_dry	Reed_wet_Desert_mixed	Tugai_Water_mixed	Tugai	Tugai_Steppe_mixed	Tugai_Desert_mixed	Steppe_south	Steppe_middle	Steppe_groundwater	Shrubs	Semidesert	Desert
No. of points classified as reed	324	33	9	5	8	3	3	0	5	22	11	0	0
No. of points not classified as reed	81	18	46	29	34	10	35	69	58	1	68	49	207
No. of points for vegetation type	405	51	55	34	42	13	38	69	63	23	79	49	207
No. of points classified as reed [%]	80	65	16	15	19	23	8	0	8	96	14	0	0
No. of pts. not classified as reed [%]	20	35	84	85	81	77	92	100	92	4	86	100	100

Several areas show changes in the distribution of wetlands which are visible in Figures 5-9. The biggest changes in the surface area of IBAs which contain wetlands have been summarized in Table .

Table III. Changes in the wetland extent of Important Bird and Biodiversity Areas in Central Asia.

Important Bird and Biodiversity Area	Country	Time period	Change
Zeyit–Kelif	Turkmenistan	2000-2005	increase on eastern side
		2005-2010	decrease
		2010-2018	increase
Lake Sarygamysh	Uzbekistan, Turkmenistan	2000-2018	slight increase
Lake Sudochye	Uzbekistan	2000-2015	increase
Zholdyrbas Lake	Uzbekistan	2000-2018	slight increase
Amu Darya floodlands near Termez	Uzbekistan	2005-2015	slight increase
Arnasay Lake System, Tuskan Lake, Aydarkul	Uzbekistan	2005-2015	increase

Water reservation of Northern Chu Valley	Kyrgyzstan	2000-2018	substantial increase
Tulek Valley	Kyrgyzstan	2000-2018	increase
Chardara Reservoir	Kazakhstan	2000-2018	decrease
Ili River Delta	Kazakhstan	2010-2015	substantial decrease
		2015-2018	increase
Lower Reaches of the Karatal River	Kazakhstan	2000-2018	increase
Tentek River Delta	Kazakhstan	2010-2015	decrease
		2015-2018	increase
Cherniy (Black) Irtysh Delta	Kazakhstan	2000-2018	decrease in the west, increase in the east with variations between the time spans
Western and northern foothills of the Kalba Range	Kazakhstan	2000-2018	large increase
Sarykopa Lake System	Kazakhstan	2000-2005	increase
		2005-2010	decrease
		2010-2018	increase
Korgalzhyn State Nature Reserve	Kazakhstan	2000-2018	increase
Delta of the Ural River	Kazakhstan	2010-2018	decrease
Kamysh-Samarskie Lakes	Kazakhstan	2005-2018	decrease
Kushum Lakes	Kazakhstan	2005-2018	decrease
Kazakhstan portion of the river Volga's Delta–Zhambay	Kazakhstan	2005-2015	decrease
		2015-2018	increase
Lesser Aral Sea	Kazakhstan	2000-2015	increase
Syr Darya Delta Lakes	Kazakhstan	2000-2018	fluctuations of increase and decrease

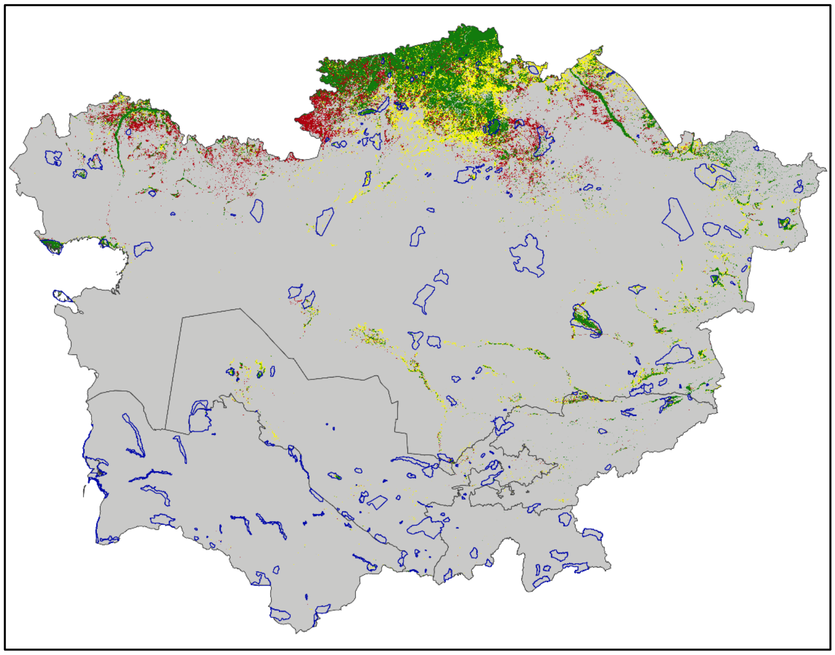

Figure 5. Results for mapping the change in the distribution of wetlands from 2000 to 2005. Green = wetland in both years, grey = no wetland in both years, red = wetland in 2000 but no wetland in 2005 (decrease), yellow = no wetland in 2000 but wetland in 2005 (increase). Grey lines = country borders, blue lines = boundaries of IBAs.

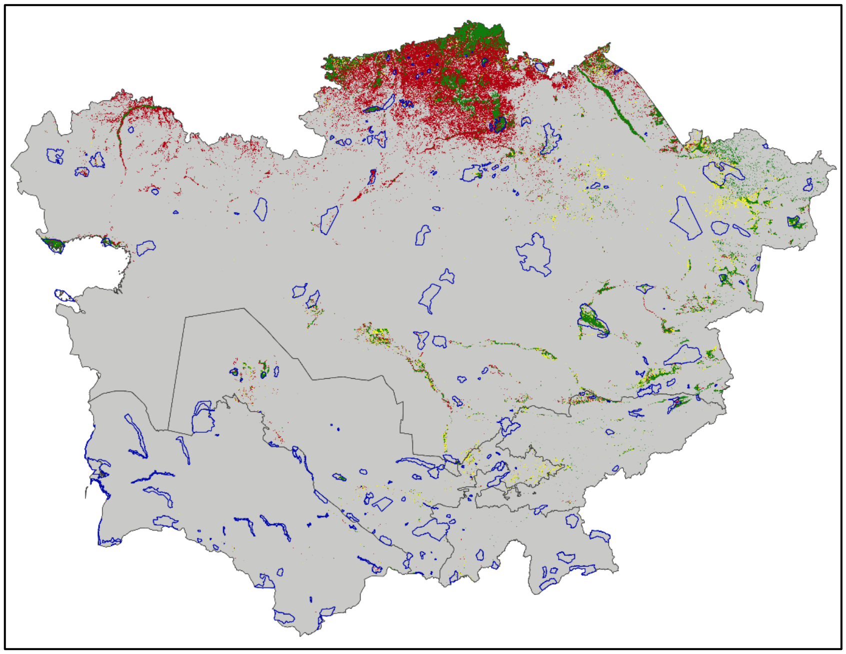

Figure 6. Results for mapping the change in the distribution of wetlands from 2005 to 2010. Green = wetland in both years, grey = no wetland in both years, red = wetland in 2005 but no wetland in 2010 (decrease), yellow = no wetland in 2005 but wetland in 2010 (increase). Grey lines = country borders, blue lines = boundaries of IBAs.

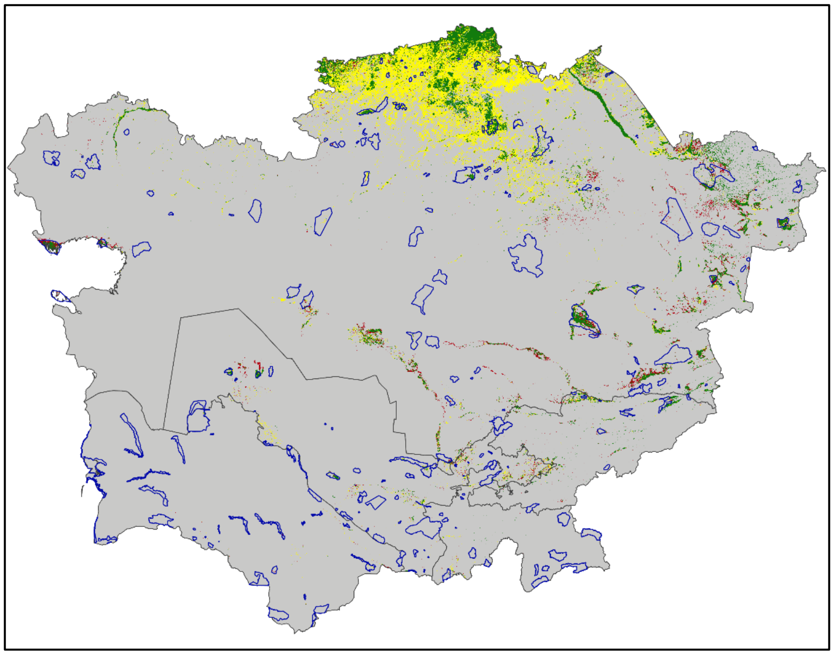

Figure 7. Results for mapping the change in the distribution of wetlands from 2010 to 2015. Green = wetland in both years, grey = no wetland in both years, red = wetland in 2010 but no wetland in 2015 (decrease), yellow = no wetland in 2010 but wetland in 2015 (increase). Grey lines = country borders, blue lines = boundaries of IBAs.

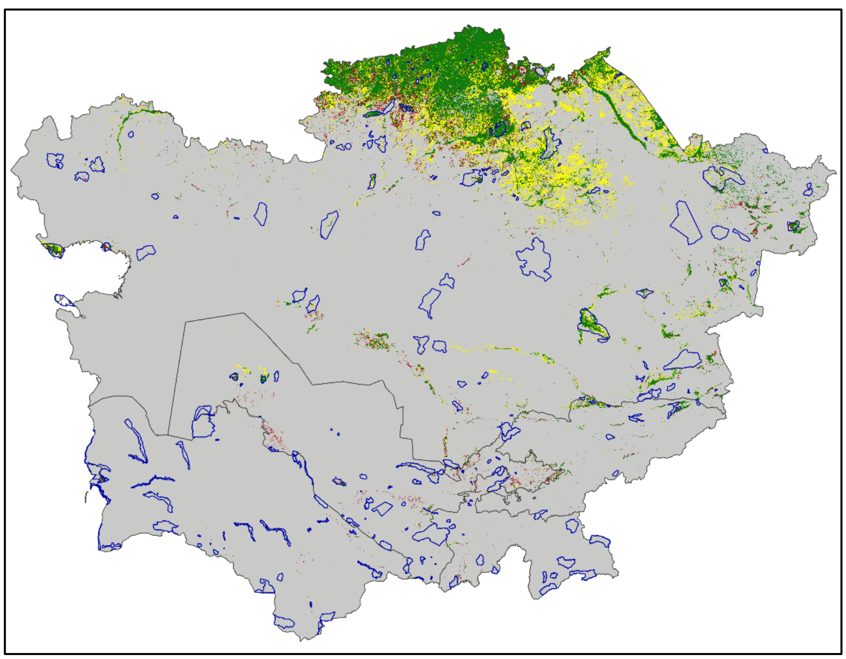

Figure 8. Results for mapping the change in the distribution of wetlands from 2015 to 2018. Green = wetland in both years, grey = no wetland in both years, red = wetland in 2015 but no wetland in 2018 (decrease), yellow = no wetland in 2015 but wetland in 2018 (increase). Grey lines = country borders, blue lines = boundaries of IBAs.

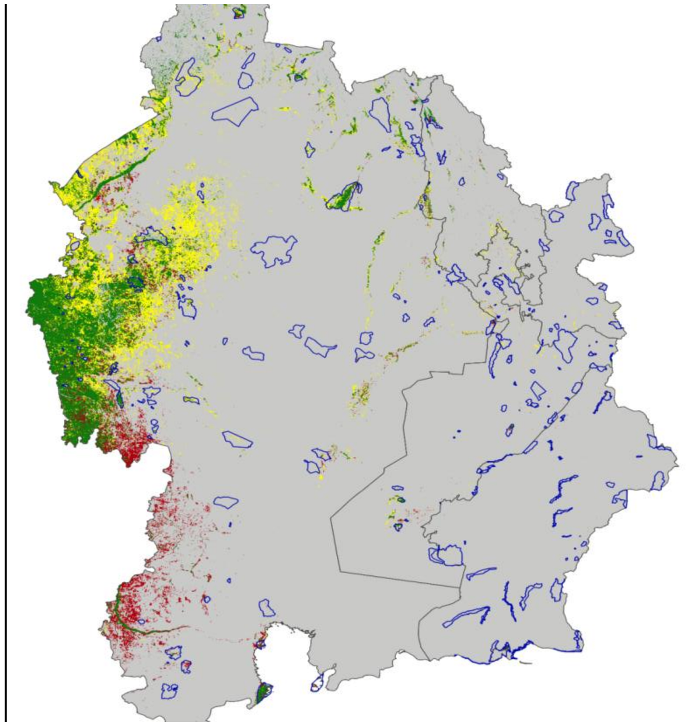

Figure 9. Results for mapping the change in the distribution of wetlands from 2000 to 2018. Green = wetland in both years, grey = no wetland in both years, red = wetland in 2000 but no wetland in 2018 (decrease), yellow = no wetland in 2000 but wetland in 2018 (increase). Grey lines = country borders, blue lines = boundaries of IBAs.

The Chu River, from the settlement Baytal westwards until its disappearance, shows large-scale increases in wetland area between 2000 and 2005, especially at its most western edge. Between 2005 and 2015 it reduces largely and then increases again (Figure 10).

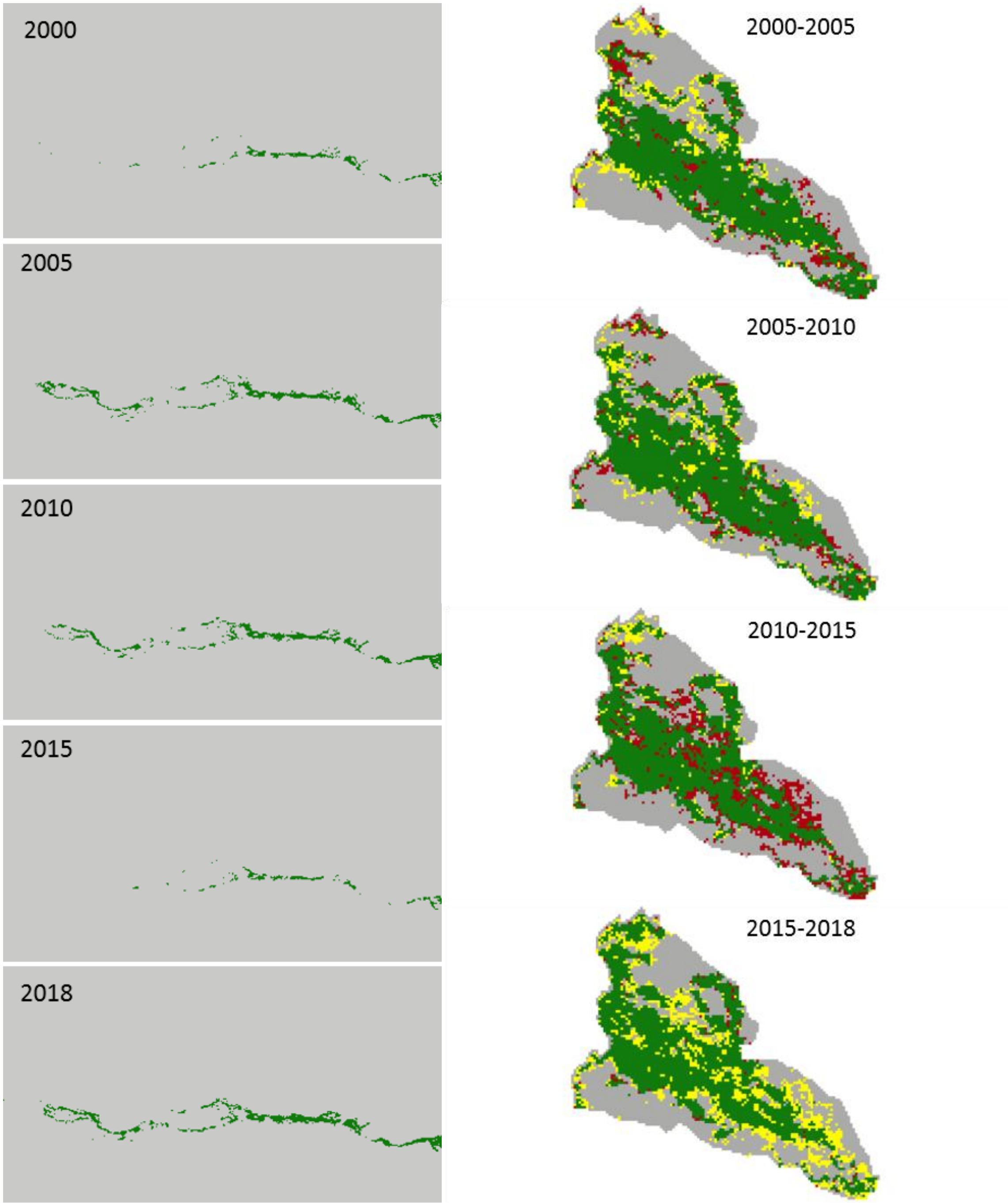

Figure 10. Wetland distribution of the Chu River from the settlement Baytal westwards (left); change of wetland distribution of the IBA Ili River Delta (right).

The northern part of Kazakhstan is largely classified as wetland (Figure 11).

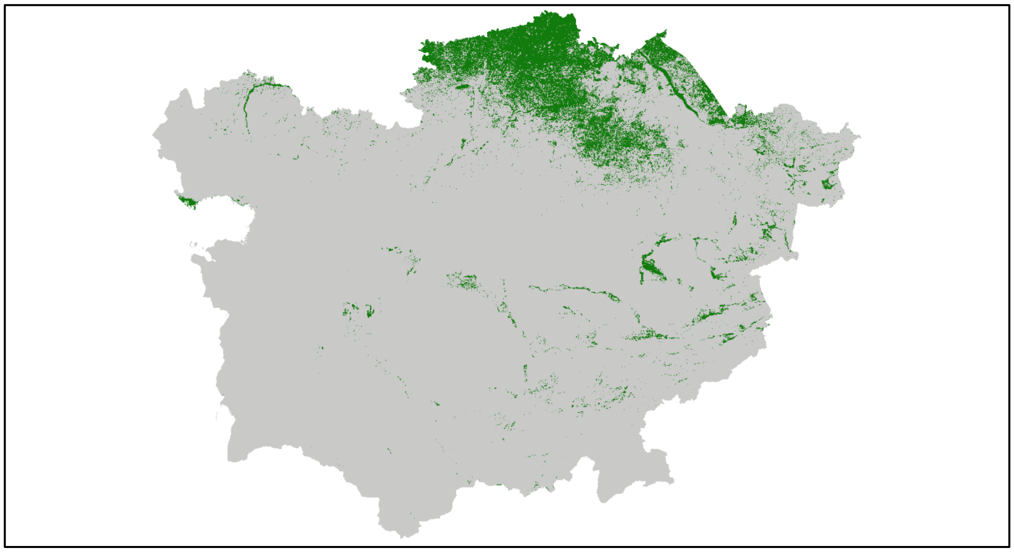

Figure 11. Results for mapping the distribution of wetlands in Central Asia in 2018. Green = wetland, grey = no wetland.

5. Discussion

The results of this study provide baseline information about the locations of wetlands in Central Asia where changes have occurred. Thus, the results can be used as an indication on which sites should be prioritized in terms of further research or closer observation through either fieldtrips or by using higher resolution remote sensing data. For example, the three IBAs Delta of the Ural River, Kamysh-Samarskie Lakes and Kushum Lakes showed a continuous decline from 2000 to 2018 and thus should be further investigated (see Table III).

It is difficult to determine a general trend for most wetland areas since there is a large variability between the years. For example, the Chu River shows larger wetland coverage for the years 2005, 2010 and 2018 but substantially smaller coverage for the years 2000 and 2015 (Figure 10). This reflects the total amount of precipitation from 1st February to 31st May at the weather station in Almaty, Kazakhstan for the respective years. The total amount of precipitation during this period was 365mm in 2005, 343mm, in 2010 , 280mm in 2015 and 280m in 2018 (https://rp5.ru/; for 2000, there was no data available). At the weather station in Taras, Kazakshtan, the total amount of precipitation was 223mm in 2005, 223mm in 2010, 103mm in 2015 and 122mm in 2018.

Similarly, the IBA Ili River Delta shows irregular fluctuations of increase and decrease for the different time segment (Figure 10). A general trend is not discernible. To get a better idea of how the variability between years looks like, applying the calculations for each year between 2000 and 2018 would be necessary. It would also be helpful to compare a very dry year with a very wet year to examine the amplitude of variability. Calculating change between two years only, or for time steps with leaving out years in between as was done in this study, is always prone to misinterpretation as the risk of picking a very dry year as the second year can show a severe reduction in the wetland size even though the general trend might be different, and vice versa (Perennou et al. 2018). Long-term, slow changes (e.g. the impact of declining precipitation on wetland extent) are difficult to detect under such highly variable conditions (Perennou et al. 2018).

The decline of wetland surface area of the IBA Chardara Reservoir for 2010 to 2015 is likely linked to the construction of the Koksaray Reservoir further downstream of the Syr Darya River. It was built between 2008 and 2011. Thus, probably water was directed to Koksaray Reservoir which had previously remained in Chardara Reservoir. Klein et al. (2012) observed a dramatic rise in the water surface area of the Chardara Reservoir from 2000 to 2009. They related the uncontrollable growing of the reservoir to increased water discharge from snow melt. Generally, the areal extend of Chardara Reservoir strongly differs from year to year depending on the accumulated snow in the winter in the mountains feeding the Syr Darya's catchment as well as on the water discharge controlled by Kyrgyzstan and the amount of water discharged from Chardara onto Uzbekistan's Arnasai depression (Klein et al. 2012).

The drastic desiccation of the Aral Sea caused by overexploiting of the water resources is and has been a widely discussed topic and is known as an environmental disaster (Micklin 2016). Unsustainable water withdrawal for irrigation and intense agriculture from both of the tributaries of the Aral Sea, the Amu Darya and Syr Darya Rivers, resulted in the size of the Aral Sea to shrink dramatically since the 1960s (Micklin 2016). A significant decreasing trend in snow cover duration and an earlier start of snow cover melting for the Amu Darya basin has been observed (Zhou et al. 2013). In 2005, the construction of the Kok-Aral dike by the Kazakh government in conjunction with the World Bank was completed intending to save the Small Aral Sea (Klein et al. 2014). The results of this study show an increase in wetland area in the south near the dike.

This study focused only on mapping the reed beds leaving out other wetland vegetation types. For mapping Tugai forests a higher resolution would be more appropriate since the remaining Tugai forests usually grow as strips (sometimes less than 200 m wide) along the rivers. In few cases (such as in the Lower Amu Darya State Biosphere Reserve) the Tugai forests are several square kilometres in size and can be detected with a resolution of 1000 m. In general, when the landscape is highly fragmented, the issue of mixed pixels in moderate or low resolution imagery can be problematic (Landmann et al. 2010). Aggregating land cover categories into less numerous classes, such as in this case to combine submerged reed and non-submerged reed, can increase thematic map accuracy, and thereby reducing the classification errors (Perennou et al. 2018).

The applied methods do not provide satisfying results for the northern part of the study area, i.e. northern Kazakhstan. Extensive areas were classified as wetlands even though the area is mostly covered by steppe and forest steppe vegetation (Figure 2). For example, the IBA

Alekseevskie steppe pine forests was entirely classified as a wetland area, even though it is "an assemblage of dry meadow herbage and Fescue-Feather-Grass vegetation between stands of coniferous forest and occasional groves of birch" (BirdLife International 2019). A similar situation is the case for the IBA Amankaragay Forest. The NDVI-values for the ground control points of wet reed and those of the steppe north of the Tengiz-Korgalzhyn Lakes System were very similar, not only in terms of the values but also in terms of their development throughout the growing season (Figure 12). The climate graph for Kokshetau in northern Kazakhstan shows the highest amounts of rainfall in the summer with a peak in July (Klein et al. 2014). This results in the steppe vegetation in those areas to stay green until autumn. Accordingly, the NDVI-values are also relatively high for these areas even in August and September. For the remaining part of the study area, when excluding mountainous areas, the applied methods provide satisfying results in respect to detecting reed beds. As mentioned above, the agricultural areas were avoided by focusing on the IBAs. To make statements outside of the IBAs and without knowing the area, more steps need to be taken in order to distinguish the reed beds from the agricultural areas. This could be done by taking into account more MODIS bands to test whether both vegetation types differ significantly in any of these.

The limitations of the applied methods were: (1) Small wetlands were not detected due to the low MODIS resolution of 1000 m x 1000 m; (2) The magnitude of change was not detected (Perennou et al. 2018); (3) Fluctuations within years were not detected since only images of a few years within the time span were included (Klein et al. 2014); (4) Ecosystem quality, e. g. impact of water quality, cannot be assessed by only using MODIS data (Bekturganov et al. 2016; Perennou et al. 2018; Törnqvist et al. 2011).

6. Conclusion

The results of this study provide a baseline by providing the locations where larger scale changes in wetlands have occurred in Central Asia from 2000 to 2018. These can be used as an indicator on where to carry out further and more detailed research through either fieldtrips or by using higher resolution remote sensing data, e.g. quantification of area losses, mapping of other wetland vegetation types such as Tugai forest, biodiversity monitoring, water quality assessment etc. If shapefiles of Ramsar sites in Central Asia become available in the future, the resulting maps of wetlands can be cropped to these areas as well to observe changes in additional protected areas.

The applied methods do not provide satisfying results for the classification of wetlands in the northern part of the study area, i.e. northern Kazakhstan. The general vegetation there is too similar to the wetland vegetation (i.e. *Phragmites australis*) in terms of values and seasonality of NDVI. For the remaining part of the study area, the applied methods deliver satisfying results. However, it is difficult to determine a general trend for most wetland areas since there is a large variability between the years.

The next step could be to apply the same method to all years from 2000 to 2018 to get more insight about the variation within years. Furthermore, comparing a relatively wet year with a relatively dry year could show the amplitude of variation. Both will also assist in examining general trends. To make a general statement about the wetlands in Central Asia, other techniques can be applied to distinguish between reed beds and agricultural areas, i.e. eliminate the agricultural areas from the maps. Similar action can be taken to get better results for northern Kazakhstan.

The temperature increase in Central Asia is above global average. This will continue to increase evaporation in the drylands and decrease the amount of snow and ice in the mountainous areas. To observe how this will affect the distribution of water and wetlands respectively a continuous monitoring should be carried out.

7. Acknowledgments

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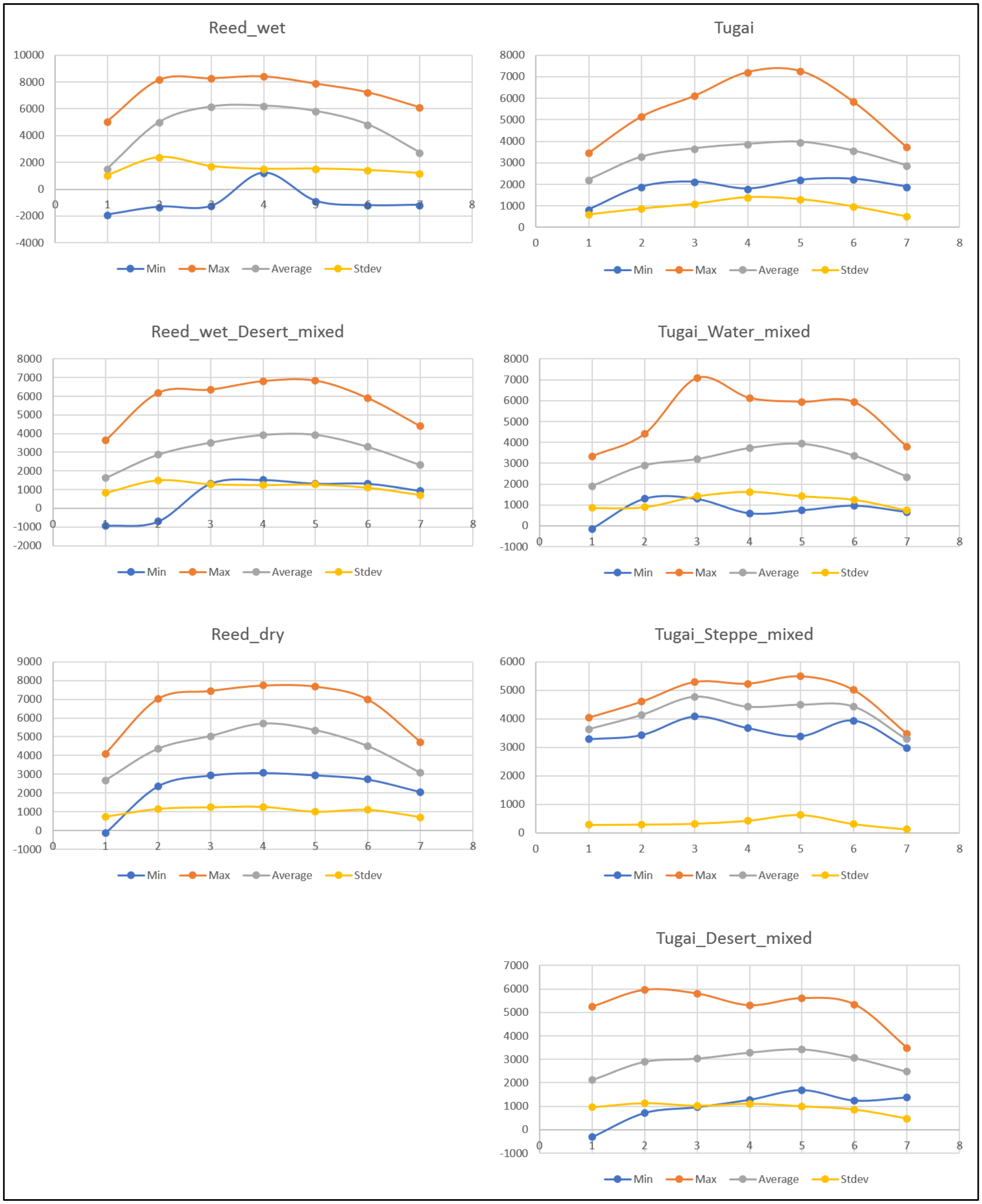
9. Appendix


Reed_wet
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Tugai
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Reed_dry
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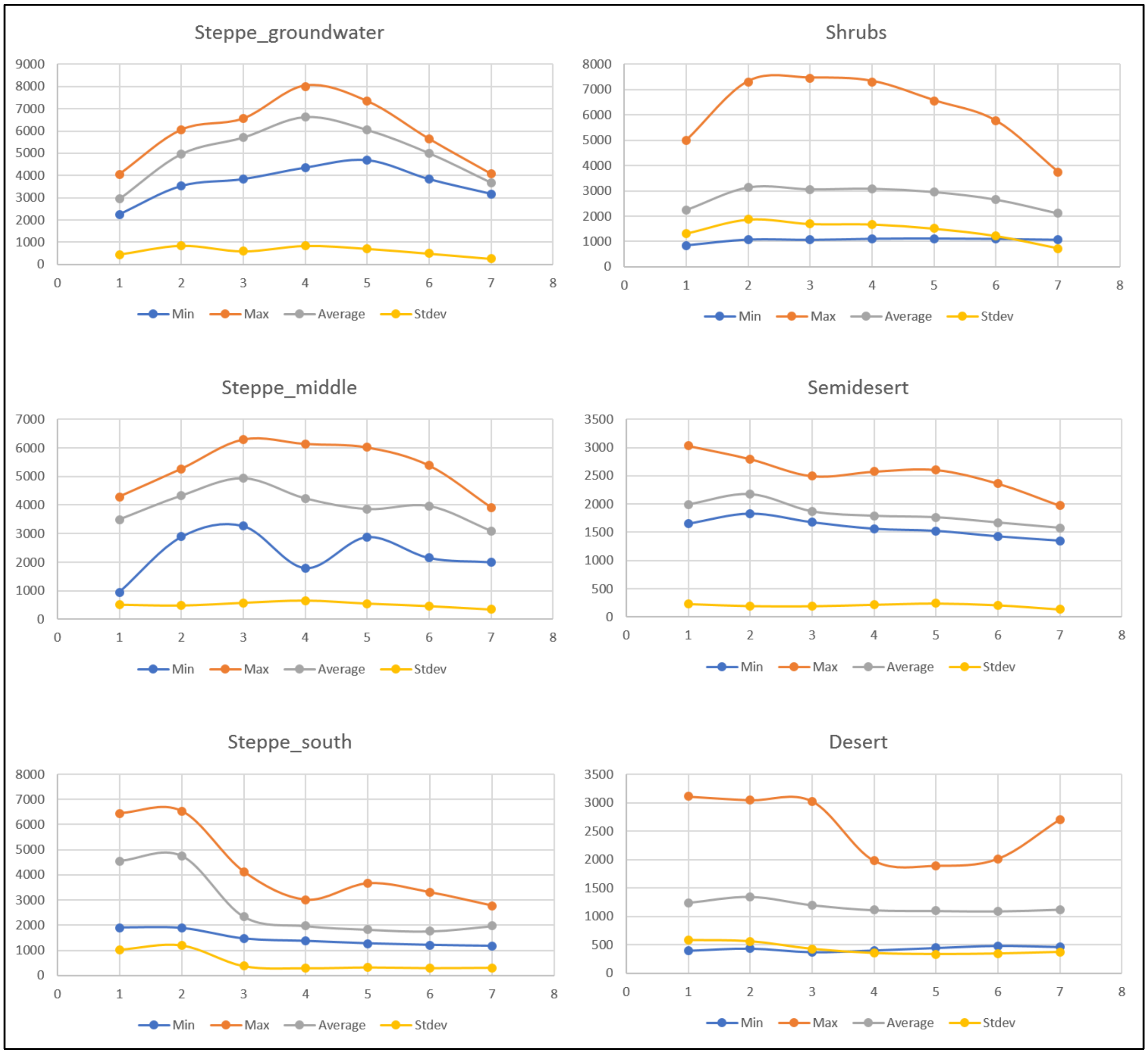

Figure 12. NDVI-values for the training pixels of different vegetation types for the months from April to October.

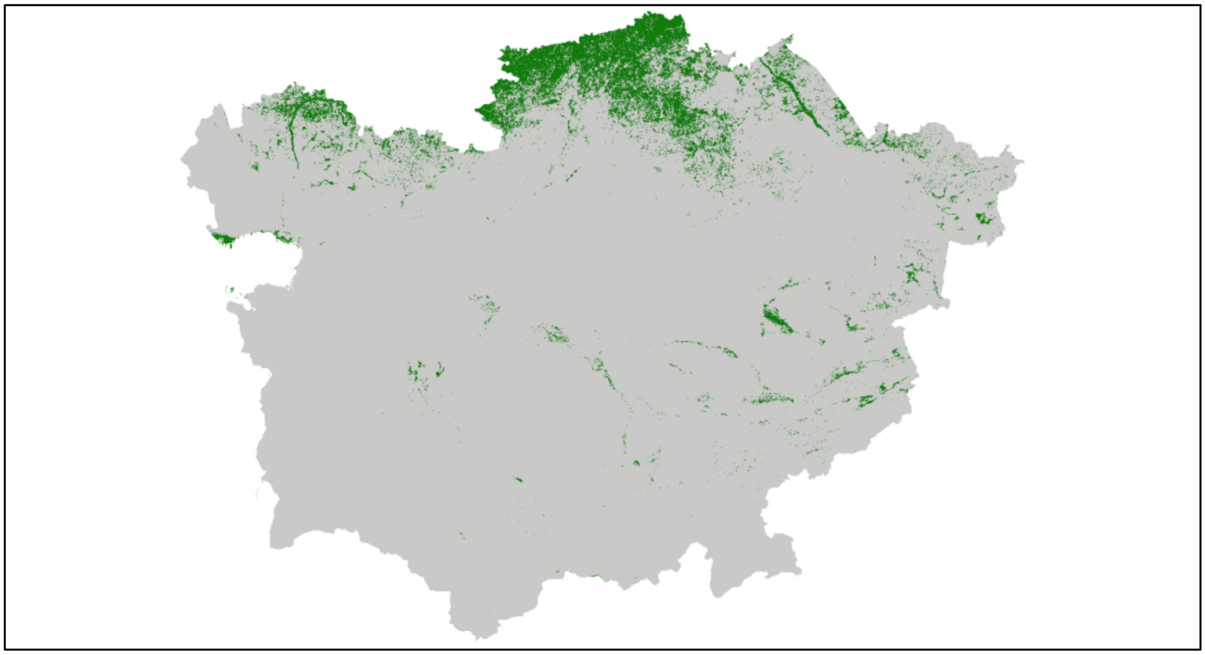

Figure 13. Results for mapping the distribution of wetlands in Central Asia in 2000. Green = wetland, grey = no wetland.

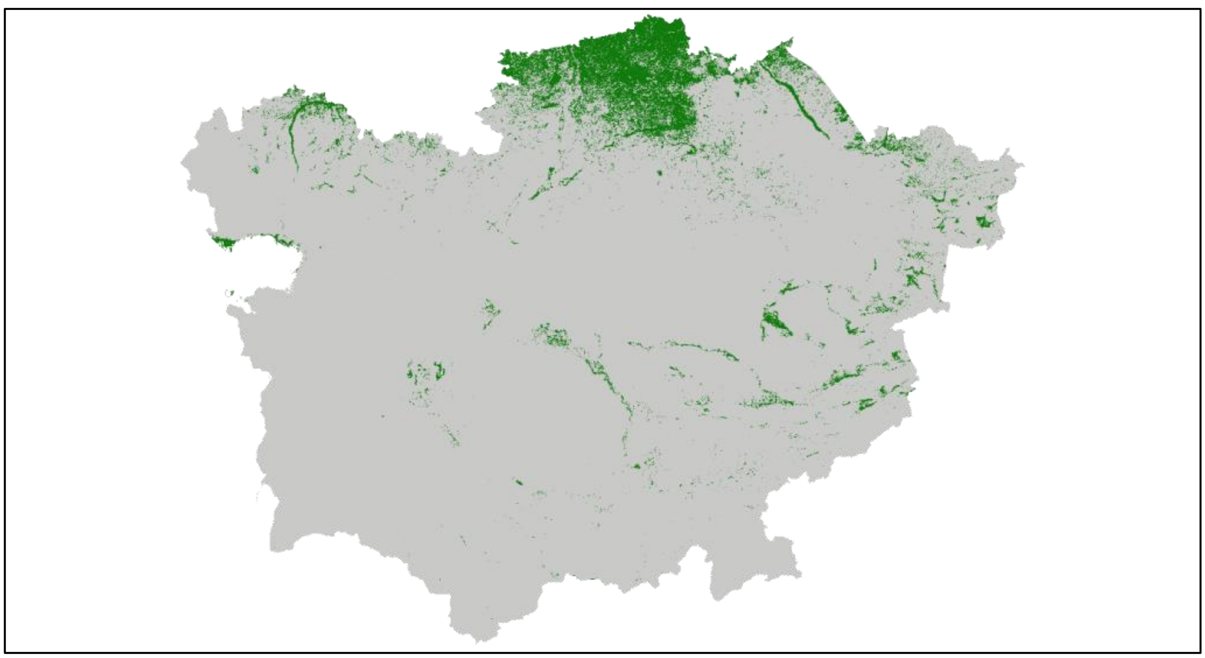

Figure 14. Results for mapping the distribution of wetlands in Central Asia in 2005. Green = wetland, grey = no wetland.

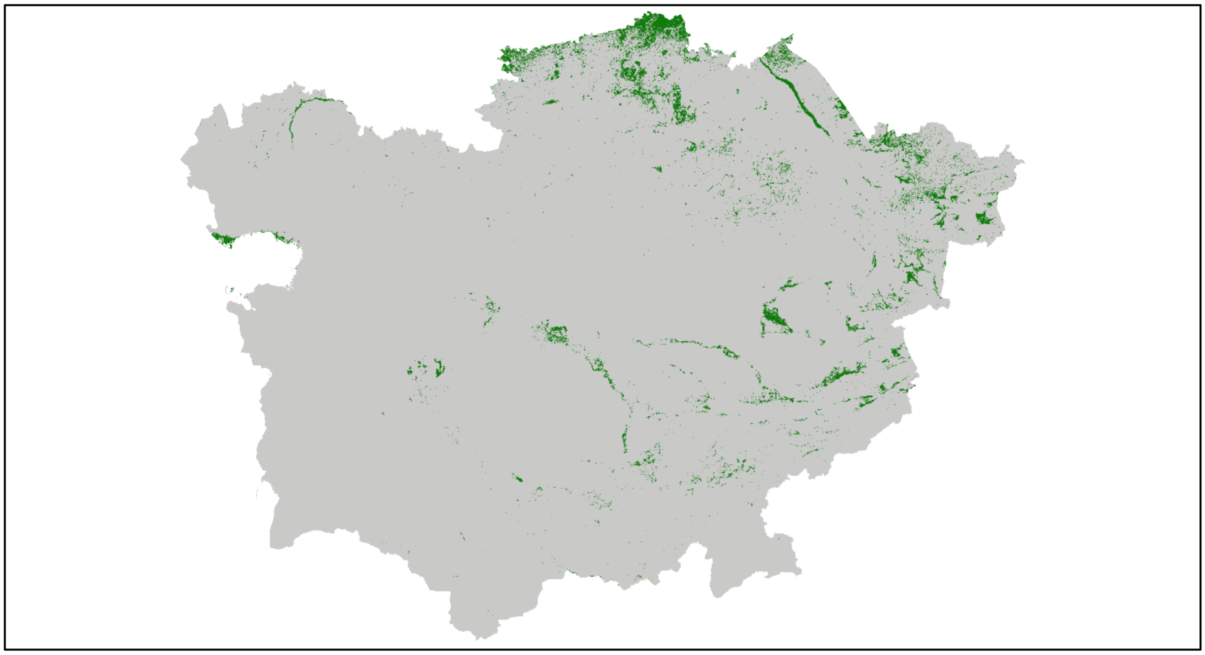

Figure 15. Results for mapping the distribution of wetlands in Central Asia in 2010. Green = wetland, grey = no wetland.

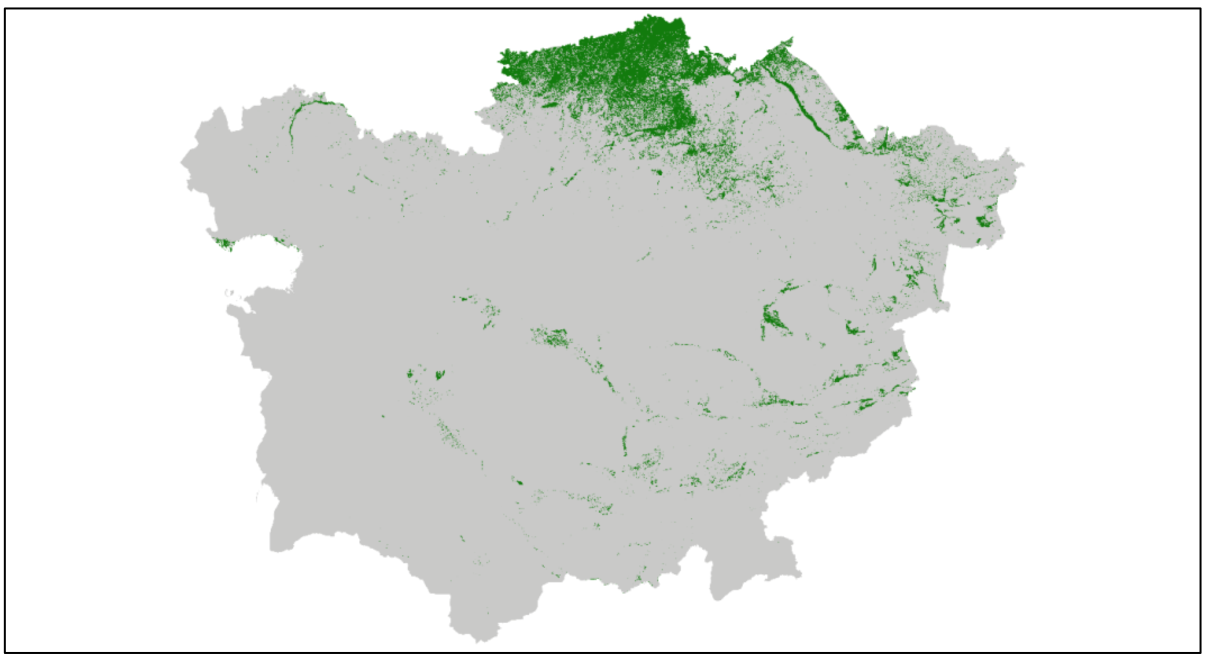

Figure 16. Results for mapping the distribution of wetlands in Central Asia in 2015. Green = wetland, grey = no wetland.