Relationship between climate and land cover change in Aral Sea Basin

Asiya Tureniyazova[1] *and Timur* Berdimbetov[1,*]

[1]Nukus branch of Tashkent University of Information Technologies named after Muhammad-al Khorezmi

Abstract. In the past several decades, substantial changes were observed in Central Asia's land cover. Water-sensitive Central Asia has experienced an increase in farming and expansion of urban areas. These are considered the main reasons for water level reduction in the Aral Sea. The disappearance of the Aral Sea has not only affected the climate of the region but also caused regional land cover changes. In this article, we analyse the temporal variation of the Normalized Difference Vegetation Index (NDVI) and its correlation with climatic variables in the territory of the Aral Sea Basin from 1982 to 2015 using Global Inventory Modelling and Mapping Studies (GIMMS) and Moderate Resolution Imaging Spectroradiometer (MODIS). The results indicate that the mean annual NDVI value recorded a weak positive trend of 0.0023/10a over the last 34 years. The Hurst index is used to test whether the tendency observed in past can be extrapolated in the future or not. Our results showed, the Hurst exponent indicates that the vegetation dynamic trend was consistent, which means that NDVI values will continue to rise in the future. During the study period, precipitation and surface soil moisture increased in the growing season, which affected the temperature during the non-growing season.

1 Introduction

All Central Asian (CA) countries (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan) are far from the oceans [1]. Compared to other regions, in CA, air temperature continuously rises over the past several decades [2]. In the arid and semiarid regions of CA, ecosystems and, in particular, vegetation, are highly related to local climate variations [3]. Similarly, the carbon cycle transformation, which is of vital importance to global vegetation variations, plays a major role in the increase of vegetation in the Central Asian region [4]. Sustainable development of the Aral Sea Basin is a challenge due to the progressing problems in the region such as the declining Aral Sea water extent and rise of temperatures [5]. The main causes are identified as geographical location, and economic instability [6].

---

[*] Corresponding author: timur.berdimbetov@tea.ac.cn

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

Monitoring and analysing the region's land cover and vegetation cover change can give hints for future decision-making and beneficial use of natural resources.

To date, vegetation variability in response to climate change is still poorly studied, especially over CA [7]. Previous studies investigated the relationship between NDVI and other factors [8, 9] and the results of the study show that one of the key factors that control NDVI change is the terrestrial ecosystem carbon cycle. There is a positive correlation between NDVI and precipitation in arid and semi-arid areas in the Central Asian region [10]. Also, the influence of drought on vegetation changes in the CA region has been analysed, with a positive correlation between the vegetation and the SPEI drought index (Standardized Precipitation Evapotranspiration Index) in most regions in the period 2000-2012 [11]. Liangliang et al. analysed the human impact on vegetation change in CA, analysing the rapid development of oil and natural gas extraction in the southern part of the Kara-Kum Desert and the Southern Ustyurt Plateau, mainly through Google Earth software [12-14].

In the 60s of the 20th century, water volume in the Aral Sea, which had a major impact on climate in CA, began to decline. There are several reasons for the water level reduction: not efficient management of water resources of two major transboundary rivers of the region, Amu Darya and Syr Darya; rapid increase of population; intensive cropland degradation; construction of hydropower and irrigation structures. All of them became sources of environmental threats [5, 15, 16].

Dependency and intensity of vegetation change in function of temperature and precipitation are significant and vary among different land cover types [13, 17]. Previous studies show the only relationship between annual vegetation change and climate factors in the territory of the Aral Sea, but do not account for seasonal changes separately [1, 6, 18-20]. It is essential to investigate current and retrospective changes in different vegetation types in relation to seasonal climatic changes and anthropogenic activities in the Aral Sea Basin. The aim of our study is an analysis of land cover change in the Aral Sea basin and its impact on climate variables (air temperature, precipitation, and surface soil moisture) in different time periods (1982-2015 and 2000-2015) and in different time scales using NDVI data.

2 Materials and methods

2.1 Datasets

We obtained the two NDVI data set: GIMMS (Global Inventory Modelling and Mapping Studies) based on the daily data record from the NOAA's Advanced Very High-Resolution Radiometer (AVHRR; a spatial resolution of 0.05° and a monthly interval for the period from 1982 to 2015; https://ecocast.arc.nasa.gov/data/pub/gimms/3g.v1/) and MODIS (Moderate Resolution Imaging Spectroradiometer, from 2000 to 2015, https://lpdaac.usgs.gov/dataset_discovery/modis).

The GIMMS data set is an improved version of the AVHRR data, with the necessary adjustments taking into account image geometry, volcanic aerosols, and other effects not related to the change of vegetation itself [21]. Currently, satellite images of medium spatial resolution (such as MODIS) are available for free from the Internet. MODIS image processing products (NDVI) were used to track changes in land cover [22]. MOD13C2 products contain raster layers of Normalized Difference Vegetation Index (NDVI) values with a spatial resolution of 0.05° and a time resolution of monthly time-step from 2000-2015.

The recently released annual land cover maps of the European Space Agency Climate Change Initiative (ESA-CCI, http://maps.elie.ucl.ac.be/CCI/viewer/download.php) from 1992 to 2015 partially overcame these resolution problems with a 300 m and long and consistent annual time series for all major land cover transitions (i.e., maps, including grasses, crops, and urban areas; ESA, 2017). Moreover, we used climate factors such as, temperature, precipitation, and soil moisture datasets [23]. The climate variability (air temperature and precipitation) Climatic Research Unit (CRU TS 4.0), University of East Anglia (https://crudata.uea.ac.uk/cru/data) received from the global meteorological net. The CRU dataset covers all land areas (except Antarctica) from 1901 to 2015 (at a spatial resolution of 0.5 by 0.5 degrees) and is based on monthly observational data from land meteorological stations across the world. Overall, it is generally in good agreement with other datasets such as GPCC [24]. This article uses soil moisture data from the Global Land Data Assimilation System (GLDAS, https://disc.gsfc.nasa.gov). Its resolution is 0.25x0.25 degrees, and layer depth is 0-10 cm [18].

2.2 Study area

In this paper, the study area concerned is the Aral Sea Basin. The Aral Sea located in CA has seen significant influence by anthropogenic load since the mid-20th century, leading to the desiccation of the Aral Sea [5]. The Aral Sea is a closed basin with a watershed area of almost more than 2 million square kilometres including the Amu Darya and Syr Darya river systems [25]. The Aral Sea basin mainly consists of four Central Asian countries (Kyrgyzstan, Tajikistan, Uzbekistan, Turkmenistan, and the southern part of Kazakhstan) and the northern part of Iran and Afghanistan (Figure 1). The region's water resources mainly consist of glaciers, lake water, runoff, and soil moisture. High altitudes, Tianshan, Pamir, and the glaciers in the Tibetan Plateau are the main sources of fresh water. Pamir glaciers play a significant role in the CA waters balance [26], and form the basis of the Amu Darya and the Syr Darya rivers flow. In the region, agriculture is the largest source of water resources [27], accounting for nearly 90% of the annual amount of water in this industry [26]. Water consumption in agriculture, along with the decline of the Aral Sea, caused serious environmental problems. From 2002 to 2009, the Aral Sea area fell by 62% [28].

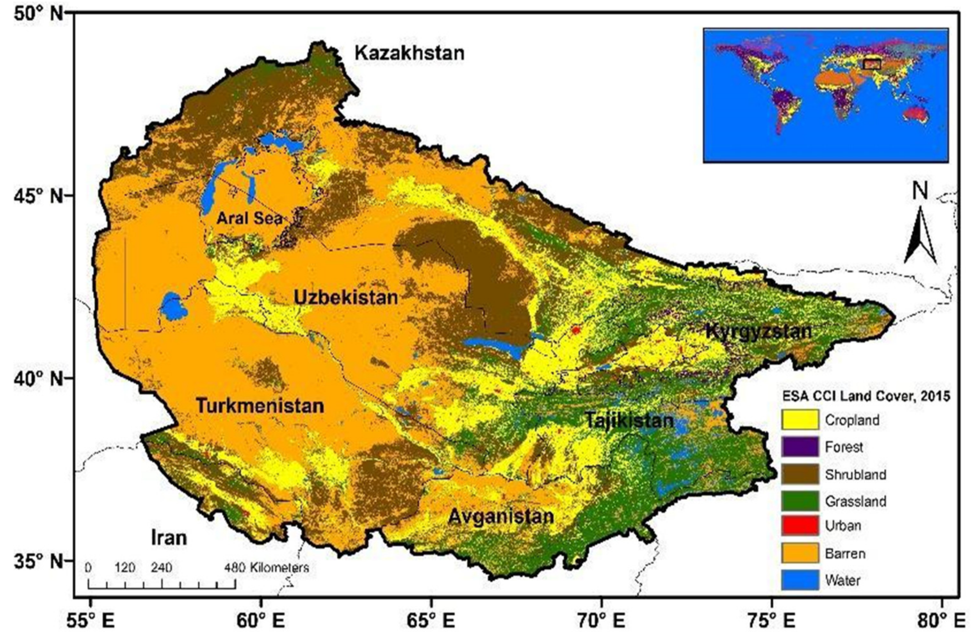

Fig. 1. Study area: Aral Sea basin's land use land cover map**.**

2.3 Method

Long-term trends in NDVI data were computed using linear regression method on annual and seasonal, growing (April-September) and non-growing (October-March), scales. The Hurst index is used to test whether the tendency observed in past can be extrapolated in the future or not [2]. Rapid changes in NDVI values in 1982–2015 were detected by the nonparametric Mann-Kendall (MK) method [3, 29]. Interdependence between NDVI and climate factors (temperature, precipitation, surface soil moisture) is represented by the correlation coefficients. All described methods were applied to the region as a whole and to different types of land cover separately (entire basin, cropland, grassland, shrubland, and desert area).

2.3.1 Hurst exponent.

Hurst exponent is a measure used in the analysis of time series. This value decreases when the delay between two identical pairs of values in the time series increases. For the first time, the Hurst index [30] was used in hydrology for practical purposes to determine the size of a dam on the Nile River under conditions of unpredictable rains and droughts observed for a long time. Nowadays, the Hurst exponent index, climatology, and vegetation change are widely used to measure the longevity of vegetation transformation in the continental sequence [31].

The main equations are as follows:

Let $x(t)$be some random variable considered at discrete time intervals $t_i$during the observation period τ is its mean value, and

$$S(\tau) = \sqrt{\frac{1}{\tau}\sum_{i=1}^{\tau} \quad [x(t_i) - \langle x(\tau)\rangle]^2} \qquad (1)$$

x - Standard deviation. Denote by

$$X(t,\tau) = \sum_{u=1}^{t} \quad [x(u) - \langle x(\tau)\rangle] \qquad (2)$$

The accumulated deviation of the values of the random variable$x(t)$ from its average value$\langle x\rangle$ over time t. The difference between the minimum and maximum values of $X(t,\tau)$ is called the span of, i.e.

$$R(\tau) = maxX(t,\tau) - minX(t,\tau), \quad (3)$$

Where $1 \leq t \geq \tau$. The considered range $R(\tau)$ obviously depends on the period τ and grows with it. The dimensionless $\frac{R}{S}$ ratio allows you to compare the span for different phenomena.

$$\frac{R}{S} = \left(\frac{\tau}{2}\right)^{H} \qquad (4)$$

In order to more accurately determine the indicator, the time series must be sufficiently long. The value of the Hurst index will change in the interval 0<H<1. Sequences for which H>0.5 are considered persistent - they retain the current trend, that is, an increase in the past is more likely to increase further, and vice versa. With a value of 0.5, a clear trend is not expressed, and at smaller values, the process is characterized by antipersistence - any tendency tends to be replaced oppositely.

3 Results and discussion

3.1 Temporal trend changes of NDVI

Results were classified into four classes for further time series analysis of NDVI change dynamics (Table 1). Time series vectors were built for two time periods and three-time scales. After removing harmonic and noise components, the linear least square method was used for calculating the trend. The abrupt trend change and the Hurst index value were calculated in the long-term period between 1982 and 2015. During 1982-2015, three vegetation types showed an upward trend with only one downward trend for desert areas. Particularly, cropland had the most upward trend 0.0059/10a with comparatively large fluctuations, which was related to the increasing agricultural activities; grassland also showed an upward trend with comparatively large fluctuations of 0.0055/10a. Shrubland experienced upward trends with comparatively small fluctuations 0.0007/10a, desert area showed a slightly decreasing trend -0.0012/10a, which resulted from the warm-dry trend of climate change in the southwestern part of Central Asia [32].

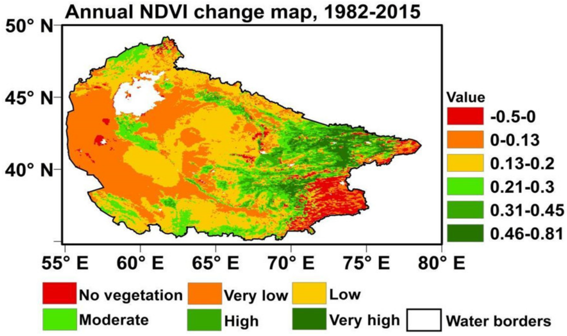

Fig. 2. Annual NDVI (from GIMSS) change in the ASB from 1982 to 2015.

Compared to 1982-2015, a high-positive trend belongs to the grassland region during the non-growing season 0.0164/10a; the abrupt change was observed in 2004, when the negative trend changes (-0.0129/10a) to positive (0.0205/10a). A relatively low negative trend was observed in the desert region(-0.0074/10a), there was no abrupt change in the area during the growing season, and NDVI values decreased continuously throughout the study period. Sharp fluctuations of NDVI values were in 1999, 2000, and 2002 years; and these dates trend is negative in almost all land cover types (Table 1). The Hurst index value is H>0.5 on the whole-time scale, which means that NDVI will continue to increase in the future, namely the NDVI values will continue to rise in the non-growing season, while the grassland, shrubland, and desert regions in the growing season are expected to decrease their vegetation index.

Table 1. Time series trend and abrupt changes of NDVI at different time scales during 1982–2015 (GIMMS) and 2000-2015 (MODIS) in Aral Sea Basin

Land cover	**Time scale**	**Trend changes of NDVI**					**Abrupt year**	**Abrupt changes of GIMMS NDVI**			
		GIMMS (1982-2015)			**MODIS (2000-2015)**			**Before the abrupt year**		**After the abrupt year**	
		H	**Slope (10-3)**	**Mean NDVI**	**Slope (10-3)**	**Mean NDVI**		**Slope (10-3)**	**Mean NDVI**	**Slope (10-3)**	**Mean NDVI**
The entire ASB	Annual	0.90	0.23	0.230	0.23	0.245	2003	0.84	0.230	-0.26	0.230
	Growing	0.72	0.15	0.220	0.60	0.304	2004	0.72	0.220	-1.07	0.220
	Non-growing	0.95	0.51	0.120	0.15	0.186	1994	0.76	0.130	-1.32	0.120
Cropland	Annual	0.91	0.59	0.317	0.39	0.319	1998	2.08	0.313	-1.70	0.322
	Growing	0.92	1.09	0.462	0.50	0.483	1998	3.55	0.473	-1.29	0.453
	Non-growing	0.78	0.41	0.172	0.43	0.152	2005	0.91	0.176	-4.48	0.166
Grassland	Annual	0.78	0.55	0.250	-3.62	0.234	2000	0.51	0.257	-2.28	0.243
	Growing	0.86	-0.60	0.373	-5.93	0.361	2000	1.99	0.379	-4.29	0.370
	Non growing	0.87	1.64	0.127	-0.76	0.106	2004	-1.29	0.133	2.05	0.111
Shrubland	Annual	0.81	0.07	0.203	1.24	0.171	2002	0.75	0.208	-4.85	0.198
	Growing	0.72	-0.14	0.232	1.19	0.174	2002	0.48	0.237	-4.90	0.227
	Non-growing	0.86	0.68	0.175	-1.27	0.167	2002	1.03	0.181	-4.80	0.170
Desert	Annual	0.95	-1,24	0.120	-0.30	0.102	2003	0.2	0.128	-1.01	0,107
	Growing	0.96	-0.74	0.119	-0.31	0.099	-	-	-	-	-
	Non-growing	0.85	0.19	0.121	-0.79	0.105	1995	0.13	0.129	-1.96	0.116

3.2 Relationship between NDVI and climate factors

The climate change in its turn had a considerable impact on vegetation [9, 11]. Temporal and spatial variations in the relationship between vegetation dynamics and climatic factors have been reported in other regions. In this article, we analyse the relationship between

NDVI content changes in the Aral Sea Basin region and temperature, precipitation, and soil moisture, in three-time scales (annual, growing, and non-growing). The first analysis is the average monthly variability of NDVI and climate parameters in selected sites on the basis of land cover classification (Figure 3). In cropland areas in June, NDVI is more than 0.5 (Figure 3a), which is the highest value in the region, respectively, in this month the temperature is above 250C (Figure 3c) and the precipitation is about 40 mm (Figure 3d). In July, NDVI in alignment with values of precipitation and soil moisture (Figure 3e) decreases, whereas the temperature continued to rise during July (Figure 3c). During the year, NDVI in shrubland and desert regions is almost stable (0.1-0.2), but the amount of precipitation and soil moisture in these areas is very low and vice versa temperature shows high values especially in the summer (Figure 3).

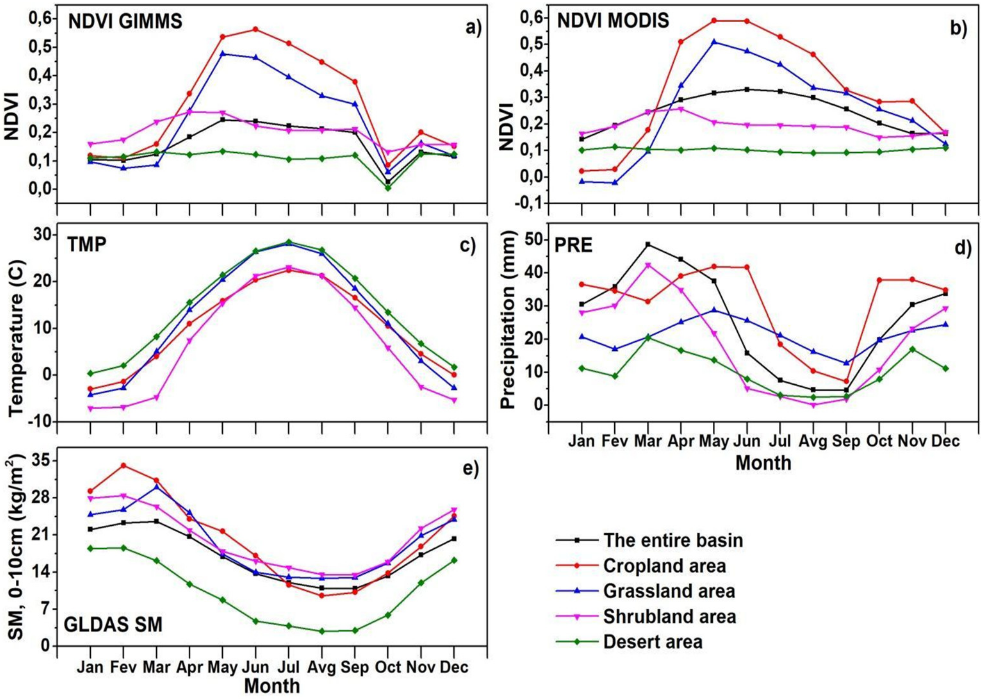

Fig. 3. The mean monthly GIMMS NDVI (a), temperature (c), precipitation (d), and soil moisture (e) from 1982 to 2015 and mean monthly MODIS NDVI (b) from 2000-2015 in the Aral Sea Basin.

The relationship between NDVI and climate parameters between 1982 and 2015 is given in Table 2. The GIMMS NDVI and temperature were significantly correlated in the cropland region, with a significant correlation in the annual (R=0.405, P=0.002) and non-growing (R=0.488, P=0.002) seasons. In the growing season, a significant negative correlation was observed in grassland, shrubland, and desert regions (R<-0.4, P<0.005). In all selected regions, a positive correlation between NDVI and precipitation (R>0.1) can be observed in the annual and growing season time scales. A significant correlation was observed in the study area, mainly in the grassland and shrubland regions (R>0.3, R<0.005). In the non-vegetative season, a negative correlation was observed between precipitation and NDVI in all selected areas. The coefficient of correlation between the GIMMS NDVI and the soil moisture in 1982–2015 corresponds to the scenario that lies almost between NDVI and precipitation.

Table 2. Correlation coefficients between GIMMS NDVI and climate parameters in Aral Sea Basin over the period 1982-2015.

Land cover	**Period**	**Temperature**			**Precipitation**			**Soil Moisture**		
		Slope (10-1)	**Corr. NDVI&TMP**		**Slope (10-1)**	**Corr. NDVI&PRE**		**Slope (10-1)**	**Corr. NDVI&SM**	
			R	**P value**		**R**	**P value**		**R**	**P value**
The entire ASB	Annual	0.29	0.087	0.620	1.23	0.408	0.015	0.49	-0.296	0.084
	Growing	0.35	-0.269	0.119	-0.01	0.401*	0.000	0.21	0.383	0.023
	Non growing	0.22	0.247	0.153	3.15	-0.134	0.443	0.78	-0.534*	0.000
Cropland	Annual	0.40	0.405*	0.002	0.7	0.342	0.045	1.00	0.025	0.618
	Growing	0.48	-0.436*	0.000	-0.14	0.387	0.022	0.49	0.075	0.291
	Non growing	0.33	0.488*	0.003	1.65	-0.120	0.492	1.50	-0.021	0.771
Grassland	Annual	0.38	-0.177*	0.000	0.29	0.416*	0.000	0.11	0.265	0.124
	Growing	0.50	-0.216*	0.002	-0.27	0.445*	0.001	0.02	0.418	0.012
	Non growing	0.25	-0.115	0.512	1.25	-0.069	0.692	0.21	-0.126	0.471
Shrubland	Annual	0.32	0.086	0.624	0.00	0.325	0.057	0.13	0.171	0.326
	Growing	0.39	-0.476*	0.004	-0.68	0.326*	0.001	0.47	0.434*	0.005
	Non growing	0.25	0.383*	0.003	0.67	-0.102	0.558	-0.20	-0.105	0.549
Desert	Annual	0.32	-0.331	0.052	0.13	0.326*	0.000	0.42	-0.172	0.322
	Growing	0.44	-0.427*	0.000	-0.29	0.135	0.629	0.11	0.089	0.613
	Non growing	0.20	0.085	0.627	0.56	-0.075	0.294	0.74	-0.272	0.114

Note: * mean significance at P<0.005 level.

Table 3. Correlation coefficients between MODIS NDVI and climate parameters in Aral Sea Basin over the period 2000-2015.

Land cover	**Period**	**Temperature**			**Precipitation**			**Soil Moisture**		
		Slope (10-1)	**Corr. NDVI&TMP**		**Slope (10-1)**	**Corr. NDVI&PRE**		**Slope (10-1)**	**Corr. NDVI&SM**	
			R	**P value**		**R**	**P value**		**R**	**P value**
The entire ASB	Annual	-0.41	0.391*	0.000	0.86	0.259*	0.000	1.66	0.183*	0.000
	Growing	0.39	0.351*	0.000	-0.24	0.215	0.035	1.18	0.172	0.094
	Non growing	-0.93	0.457	0.006	2.31	0.303*	0.003	2.03	0.203	0.049
Cropland	Annual	-0.39	0.415*	0.000	-0.11	-0.014	0.850	2.91	0.062*	0.000
	Growing	0.43	-0.135	0.190	1.79	0.485*	0.000	2.70	0.091*	0.000
	Non growing	-0.93	0.403*	0.002	-1.43	-0.089	0.391	2.92	0.112*	0.000
Grassland	Annual	-0.25	0.465*	0.000	-4.21	0.204*	0.005	0.47	0.016*	0.000
	Growing	1.49	0.042	0.685	-7.77	0.413*	0.000	0.74	-0.056	0.008
	Non growing	-1.60	0.240	0.037	-1.38	0.045	0.665	0.03	0.024*	0.000
Shrubland	Annual	-0.45	-0.259*	0.000	0.95	0.431*	0.000	-0.06	0.268*	0.000
	Growing	0.57	-0.494*	0.000	-1.68	0.418	0.153	-0.58	0.095*	0.000
	Non growing	-1.16	0.458	0.006	3.59	0.136	0.007	0.29	0.165	0.110
Desert	Annual	-0.34	-0.254*	0.000	0.18	0.341*	0.000	0.23	0.227*	0.000
	Growing	0.78	-0.167	0.104	-1.93	0.169	0.106	0.27	0.235*	0.000
	Non growing	-1.12	0.369	0.159	2.15	0.240*	0.021	0.19	0.135*	0.005

Note: * mean significance at P<0.005 level.

The mean positive correlation between annual MODIS NDVI and temperature (R>0.3, P<0.005) in cropland, grassland, and the entire basin, negative significant correlation (R<-0.2, P<0.005) in shrubland and dessert. During the non-vegetative season, a significant correlation (R>0.2, P>0.005) was observed in the cropland area between NDVI and temperature, with a highly significant positive correlation (R=0.403, P=0.002) in the whole basin and other selected areas (Table 3). Between MODIS NDVI and precipitation, only a positive correlation R>0.1 was recorded in selected regions during the growing season. In the non-growing season, a non-significant negative correlation and weak positive correlation can be seen in selected regions. NDVI MODIS positively correlates with soil moisture (R>0) in all selected regions (excluding grassland in the growing season) in all three-time scales.

Table 4. The statistics of the correlation coefficient between mean GIMMS NDVI and climate data factor in the Aral Sea Basin over the period 1982-2015.

Category	Correl. range	Correl. area	Temperature			Precipitation			Soil Moisture		
			Annual	**Growing**	**Non-growing**	**Annual**	**Growing**	**Non-growing**	**Annual**	**Growing**	**Non-growing**
High positive correlation	>0.2	area %	14.4	1.3	35	2.9	10.9	0.3	6	4.2	10.2
		area th. km2	348.7	32.4	847.4	71	263.5	6.1	145.4	102.6	248
Moderate positive correlation	0.2 - 0.1	area %	23.2	11.3	36.8	18.4	28	5.3	13.8	19.8	13.4
		area th. km2	561.5	273.7	889.9	446	677.1	127.7	333.6	479	325
Low positive correlation	>0	area %	32	27.2	20.9	37.2	31	21.7	27.9	36.4	22.3
		area th. km2	774.4	658.8	506.8	900.1	750.1	525	675.7	881	538.8
Low negative correlation	–0.1 - 0.00	area %	19.9	27.5	5.3	30.2	20	30.4	27.9	29.3	27.9
		area th. km2	482.5	664.9	127.7	731.8	484.5	735.9	675.7	709.9	675.7
Moderate negative correlation	–0.2 - –0.1	area %	8.3	20.3	1.3	8	6.5	28.1	17	7.1	21.9
		area th. km2	200.7	490.6	30.4	194.6	158.1	681.1	410.5	171.1	530.3
High negative correlation	<-0.2	area %	2.2	12.4	0.8	3.2	3.6	14.2	7.4	3.2	4.2
		area th. km2	52.7	300	18.2	77	87.2	344.6	179.6	77	102.6

Table 5. The statistics of the correlation coefficient between mean MODIS NDVI and climate data factor in the Aral Sea Basin over the period 2000-2015.

Category	Correlation range	Correlation area	Temperature			Precipitation			Soil Moisture		
			Annual	**Growing**	**Non-growing**	**Annual**	**Growing**	**Non-growing**	**Annual**	**Growing**	**Non-growing**
High positive correlation	>0.2	area %	39.6	9.3	64.8	60.8	69.2	32.2	29.6	75.7	23.2
		area th. km2	958.6	225.5	1569.3	1471	1674	779.1	715.9	1832.4	560.5

Moderate positive correlation	0.2 - 0.1	area %	22.9	2.9	11.5	9.1	10.4	7.8	22.5	11.6	17.5
		area th. km2	553.1	70.3	278.9	220.2	251.6	189.1	545.5	281.3	424.6
Low positive correlation	>0	area %	18.1	4	7.3	9	7	13.1	20.8	6.3	11.6
		area th. km2	438.8	97.2	176.9	218.2	170.5	317.9	502.9	153.4	280.3
Low negative correlation	−0.1 - 0.00	area %	13.2	5.3	4.8	4.5	4.9	21.7	14.4	1.8	16.8
		area th. km2	320.2	128.3	116.6	110.1	118.5	525.7	349.4	42.6	407.7
Moderate negative correlation	−0.2 - −0.1	area %	4	12.3	4	3.2	3.2	19.9	6.7	2.5	15.1
		area th. km2	95.7	297.9	95.7	76.9	76.9	482	161.9	59.7	365.2
High negative correlation	<-0.2	area %	2.2	66.2	7.6	13.5	5.3	5.2	6	2.1	15.8
		area th. km2	54.1	1601.3	183.2	326.2	128.9	126.7	144.9	51.1	382.2

The NDVI and climate parameters were analysed on each grid scale in order to more accurately determine the interdependence (data are not shown). Table 4 shows the statistical analysis of the distribution of correlation value of pixels by region from 1982-2015. According to the results of the analysis, high-positive correlation between NDVI and temperature in the non-growing season was in 35% of the region, a moderate positive correlation was in 36.8%, in the growing season, a negative correlation was recorded across most of the region, low negative in 27.5% and moderate negative correlation in 20.3%.

In the growing season, NDVI and precipitation were positively correlated in most parts of the region, high positive in 10.9%, a moderate positive in 28%, and a low positive correlation in 31%. NDVI with soil moisture correlates with low positivity in 36.4% of the total area and in 19.4% correlation is moderately positive during the growing season. Between NDVI and temperature, a high positive correlation is recorded in 64.8% during the non-growing season and, in the growing season, NDVI correlates with precipitation and soil moisture respectively in 75.7% and in 69.2% of the total area in 2000-2015 (table 5). During the non-growing season, NDVI correlates not only with temperature but also with precipitation and soil moisture; a positive correlation was found between each pair in 52.7% of the total area. NDVI (1982-2015, 2000-2015) correlates most commonly with precipitation vegetation season in the selected regions, the impact of soil moisture is also noticeable on the annual scale. NDVI has a negative or weak positive correlation, in the growing season, with temperature.

The reason why we can see that NDVI changes over the years was to control the temperature in the non-growing season, correlation with temperature is always positive in all selected regions. Former studies of monthly temperature variability show that temperature was the main factor determining NDVI from June to September in the CA region. It was pointed out that there was a significant positive correlation between NDVI and temperature in the plains and mountainous regions of Central Asia in September [9]. Taking into account that the Aral Sea basin is a large part of the Central Asian region, we can see the results obtained in this article corresponds with the previous results. In the Central Asian region, using correlation analysis of the time series of NDVI and precipitation, a controversial dependency was detected, i.e., weak positive correlation in the summer and winter seasons (R<0.25), negative correlation in the spring and autumn seasons [3].

4 Conclusions

This article analyses the land cover change process based on NDVI and the impacts of climate parameters in the Aral Sea Basin in two time periods (1982-2015, 2000-2015). The average temporal NDVI trend indicated a weak increase in all time scales in the Aral Sea Basin region between 1982 and 2015. The areas of significant trend (increase and decrease together) accounted for only 3.27% of the total area in annual GIMMS NDVI over 34 years. During the growing and non-growing seasons, areas of a significant trend are also very small, 4.51% and 1.52% of the total area respectively.

The abrupt NDVI trend was mostly observed after the year 2000. The Hurst index is higher than 0.5, so the trend of NDVI can be reliably extrapolated to the near future.

We compared two datasets GIMMS and MODIS NDVI after 2000 years and found a big difference between these two datasets. Spatial distribution of MODIS NDVI shows higher density than GIMMS NDVI, especially in the non-growing seasons.

Between 1982 and 2015, the NDVI and temperature recorded negative correlations ($R<-0.2$) in all selected regions (excluding cropland areas) during the growing season. Both datasets of NDVI recorded positive correlations in all selected regions with precipitation ($R>0.2$) and soil moisture ($R>0.08$) in two time periods. During the non-growing season, NDVI recorded a high positive correlation with temperature ($R>0.35$), and weak positive correlations (excluding cropland) in all regions ($R>0.04$). In 1982-2015, trends of climate variables, hydrological parameters, NDVI, and its impact in all three-time scales along the basin were rising. In the spatial distribution of the correlation between NDVI and climate variables in 1982–2015, the NDVI positively correlated with precipitation that accounts for 69.6%, and with soil moisture in 60.4% area of the total area, whereas with the temperature only 39.8% of the area exhibited a positive correlation during the growing season. In the non-growing season, NDVI recorded a positive correlation with temperature, which accounts for 92.7% of the area, the negative correlation of NDVI with precipitation occupies 72.7%, and with soil moisture occupies 54% of the total area. In the growing season, 86.6% of the region recorded a positive correlation of NDVI with precipitation, 93.6% with soil moisture, and only 16.2% with temperature from 2000 to 2015. During this time period, non-growing seasonal NDVI and temperature had a positive correlation of 83.7%. According to the results of the temporal and spatial correlation analysis, the surface soil moisture was more affected by the MODIS NDVI change during the growing and non-growing seasons. Hence, in the Aral Sea Basin area during the two-season period, NDVI changes mainly under the control of precipitation and surface soil moisture in the growing season, and under temperature control during the non-growing season. The increased area of NDVI residuals occupied 52.75% of the Aral Sea Basin from 1982 to 1999. Between 2000-2015 years, the area of the positive residual trend of annual NDVI occupied a smaller area than in 1982-1999 years and accounted for 42.24% of the study area.

Acknowledgments

We are grateful to the Nukus branch of Tashkent University of Information Technologies named after Muhammad Al-Khwarizmi for providing the opportunity to work on this study.

References

1. T. T. Berdimbetov, Z-G. Ma, C. Liang, and S. Ilyas, *Impact of Climate Factors and Human Activities on Water Resources in the Aral Sea Basin*, Hydrology. **7**, (2020)

2. Z. Hu, C. Zhang, Q. Hu, and H. Tian, *Temperature Changes in Central Asia from 1979 to 2011 Based on Multiple Datasets*,* Journal of Climate. **27,** (2014)
3. Y. Gang, Z. Hu, and T. Tiyip, *Vegetation dynamics and its response to climate change in Central Asia,* Journal of Arid Land. **8**, (2016)
4. Z. Li, Y. Chen, W. Li, H. Deng, and G. Fang, *Potential impacts of climate change on vegetation dynamics in Central Asia*, Journal of Geophysical Research: Atmospheres. **120**, (2015)
5. P. Micklin, *The Aral Sea Disaster,* Annual Review of Earth and Planetary Sciences. **35**, (2007)
6. T. Berdimbetov, S. Ilyas, Z. Ma, M. Bilal, and S. Nietullaeva, *Climatic Change and Human Activities Link to Vegetation Dynamics in the Aral Sea Basin Using NDVI,* Earth Systems and Environment. **5**, no. 2 (2021)
7. X. Yuan, W. Wang, J. Cui, F. Meng, A. Kurban, and P. De Maeyer, *Vegetation changes and land surface feedbacks drive shifts in local temperatures over Central Asia,* Sci Rep. **7**, no. 1 (2017)
8. C. S. Potter, and V. Brooks, *Global analysis of empirical relations between annual climate and seasonality of NDVI*, International Journal of Remote Sensing. **19**, no. 15 (1998)
9. S. Piao, A. Mohammat, J. Fang, Q. Cai, and J. Feng, *NDVI-based increase in growth of temperate grasslands and its responses to climate changes in China,* Global Environmental Change. **16**, (2006)
10. N. Aitekeyeva et al, *Drought Risk Assessment in Cultivated Areas of Central Asia Using MODIS Time-Series Data,* Water. **12**, no. 6 (2020)
11. Z. Hu et al, *Climate changes in temperature and precipitation extremes in an alpine grassland of Central Asia,* Theoretical and Applied Climatology. **126**, no. 3-4 (2015)
12. L. Jiang et al, *Monitoring land sensitivity to desertification in Central Asia: Convergence or divergence?*, Sci Total Environ. **658**, (2019)
13. L. Jiang, J. Guli, A. Bao, H. Guo and F. Ndayisaba, *Vegetation dynamics and responses to climate change and human activities in Central Asia,* Sci Total Environ. **599-600**, (2017)
14. L. Jiang et al, *Monitoring the long-term desertification process and assessing the relative roles of its drivers in Central Asia*, Ecological Indicators. **104**, (2019)
15. P. Micklin, *"The Aral Sea Crisis and Its Future: An Assessment in 2006,",* Eurasian Geography and Economics - EURASIAN GEOGR ECON. **47**, (2006)
16. R. Ressl, and P. Micklin, *Morphological changes in the Aral Sea,* Satellite imagery and water balance model (2004)
17. Y. Sun, Y. Yang, L. Zhang, and Z. Wang, *The relative roles of climate variations and human activities in vegetation change in North China,* Physics and Chemistry of the Earth, Parts A/B/C. **87-88**, (2015)
18. T. Berdimbetov, Z-G. Ma, S. Shelton, S. Ilyas, and S. Nietullaeva, *Identifying Land Degradation and its Driving Factors in the Aral Sea Basin from 1982 to 2015,* Frontiers in Earth Science. **9,** (2021)
19. T. T. Berdimbetov, M. Zhu-Guo, S. Nietullaeva, and A. Yegizbayeva, *Analysis of Impact of Aral Sea Catastrophe on Anomaly Climate Variables and Hydrological Processes,* Elsevier, International Journal of Geoinformatics. **17**, no. 1 (2021)

20. S. Nietullaeva, B. Fayzullaev, A. Karimova, and N. Shaudenbayev, *An Investigation into the Hydro-Climate Processes Impacting Aral Sea Region in Central Asia,* Annals of the Romanian Society for Cell Biology. **25,** no. 4, (2021)
21. C. J. Tucker et al, *An extended AVHRR 8-km NDVI dataset compatible with MODIS and SPOT vegetation NDVI data,* International Journal of Remote Sensing. **26**, (2005)
22. X. Zhan et al, *Detection of land cover changes using MODIS 250 m data,* Remote Sensing of Environment. **83**, (2002)
23. A. Yegizbayeva, S. Ilyas, and T. Berdimbetov, *Drought Characterisation of Syrdarya River Basin in Central Asia Using Reconnaissance Drought Index,"* presented at the IGARSS 2022 - 2022 IEEE International Geoscience and Remote Sensing Symposium (2022)
24. I. Harris, T. J. Osborn, P. Jones, and D. Lister, *Version 4 of the CRU TS monthly high-resolution gridded multivariate climate dataset,* Sci Data. **7**, (2020)
25. R. Becker, and K. Zmijewski, *Estimating the Effects of Anthropogenic Modification on Water Balance in the Aral Sea Watershed Using GRACE*: 2003–12 Earth Interactions. **18**, (2014)
26. K. Unger-Shayesteh et al, *"What do we know about past changes in the water cycle of Central Asian headwaters?* A review Global and Planetary Change. **110**, (2013)
27. A. Lutz, P. Droogers, and W. W. Immerzeel, *Climate Change Impact and Adaptation on the Water Resources in the Amu Darya and Syr Darya River Basins* (2012)
28. A. Singh, A. Behrangi, J. B. Fisher, and J. T. Reager, *On the Desiccation of the South Aral Sea Observed from Spaceborne Missions,* Remote Sensing. **10**, (2018)
29. Q. Li, Y. Chen, Y. Shen, X. Li, and J. Xu, *Spatial and temporal trends of climate change in Xinjiang,* China Journal of Geographical Sciences. **21**, (2011)
30. H. E. Hurst, *Long-Term Storage Capacity of Reservoirs Transactions of the American Society of Civil Engineers.* **116**, (1951)
31. G. Jiapaer, S. Liang, Q. Yi, and J. Liu, *Vegetation dynamics and responses to recent climate change in Xinjiang using leaf area index as an indicator,* Ecological Indicators. **58**, (2015)
32. W. Hu, H. Liu, A. Bao, and A. M. El-Tantawi, *Influences of environmental changes on water storage variations in Central Asia, J*ournal of Geographical Sciences. **28**, (2018)