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Impact of Climate Factors and Human Activities on Water Resources in the Aral Sea Basin

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Abstract: The Aral Sea in Central Asia plays an essential role in the socio-economic development of the region. During the last six decades, there has been remarkable changes observed in the water level and areal extent of the Aral Sea Basin; however, the causes behind these changes are unclear. This study quantifies the impacts of climatic and anthropogenic drivers on Aral Sea and the contributions made by these drivers to the variations observed in the Aral Sea Basin. The spatial and temporal seasonal variations in groundwater budget have been analyzed using the total water storage (TWS) of the basin from 2002 to 2015. The results from this study revealed significant increases in the the mean air temperature, precipitation, and potential evapotranspiration rate from 1960 to 2015 in the Aral Sea Basin. The TWS time-series shows a statistically significant declining trend of about 2 to 4 cm per year presented by the surface water storage. Based on the average monthly values of TWS, March 2005 presented the highest anomaly ~7.85 cm, while October 2008 showed the lowest anomaly ~8.22 cm between 2002 to 2015. The groundwater level indicates a small increasing trend of approximately 0.05 cm/year during the study period. Furthermore, the negative relationship between water level, climatic, and anthropogenic factors showed that these factors projected critical impact on the water level fluctuations within the Aral Sea Basin.

Keywords: Aral Sea Basin; climate change; anthropogenic factors; TWS; groundwater

1. Introduction

The global economy depends on water resources, especially in the socio-economic development of any country [1]. The ongoing and future climate change is reported to have serious impacts on global water resources [2]. Especially, the Aral Sea (AS) basin of Central Asia (CA), as reported by numerous studies, will gradually become drier in the coming years, thus decreasing the availability of freshwater resouces that can hinder the sustainable development of the region [3,4]. Furthermore, changes in land use, such as irrigation and urban settlement, can also affect the distribution and availability of freshwater resources, as shown by several studies for the AS basin in CA highlighting the human driven disturbances [4–6]. Hence, assessing the impacts of climate and anthropogenic changes on the change status of water in the AS basin is critical for effective water administration and management in the future in order to ensure sustainbility of freshwater resources [7].

Irrigation activities for wheat, rice, and cotton productions in CA commonly depend on the AS [8]. Besides, the population of CA has tripled from 24 million in 1960 to 72 million in 2015 [9]. Amudarya and Syrdarya are the two rivers known as major water resources in the AS and, among these two, AS has been marked as the fourth largest close boundry lake in East Asia after Caspain Sea. Due to these reasons, the groundwater level has been decreasing, especially during the spring season, causing the so-called "secondary salinization" of the soil in the region [10,11]. Monitoring changes in the status of terrestrial water bodies like the AS is essential for the effective management of water resources and related ecological services [12].

Deng and Chen (2017) found that water resources are under stress due to the climate change in CA [13]. The rising trend in temperatures and precipitation variability has increased in many parts of the world [14]. Moreover, climate change has led to greater variablity in the river runoff [7] with the gorwing frequency observed in drought episodes in numerous parts of the world [15]. Therefore, these variations may translate into increased water resource shortages, consequently affecting the socio-economic development underlined by the increasing regional conflicts over water resources in CA [16].

Prior studies have quantified the decrease of TWS and water levels in the AS basin [17,18]. However, little focus has been paid to the contribution of climate and anthropogenic factors to the disappearance of the AS starting from 1960s and going on until today. Therefore, in this study, we intend to analyze the contributions of climate change and human effect to the shrinkage of the AS and its basin. We have illustrated the study area, data, and methods used in this paper in Section 2. In the subsequent third section, we have presented the results based on our analysis of the trends found in the water levels in the AS basin and the responses of water level to climate and anthropogenic drivers. Finally, the the results of the study have been discussed in detail in the fourth section, along with the summary and conclusion remarks.

2. Materials and Methods

2.1. Study Area

Central Asia is located in the hinterland of the Eurasian continent and it has a unique landscape that features expansive but fragile mountain-oasis-desert ecosystems, as presented in Figure 1a. It is one of the driest areas in the world [19,20] and it is characterized by low vegetation coverage. The vegetation that does survive in this zone is mainly dependent on soil water as well as shallow groundwater from precipitation and glacier/snowmelt water in the mountains. The region is home to two deserts, named Kara-Kum and Kyzyl-Kum [15].

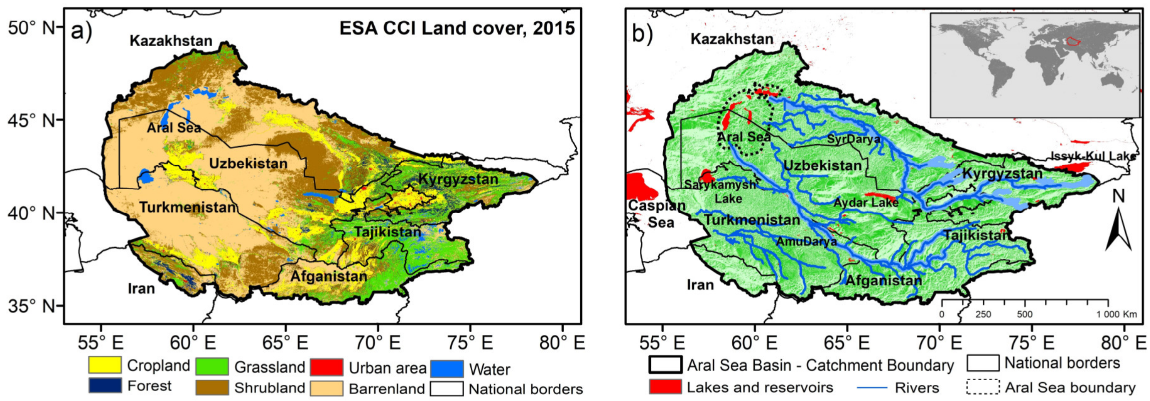

Figure 1. Study area: (**a**) land use map for the year 2015, showing the Aral Sea (AS) basin; (**b**) study area of AS basin with river tributaries present within the basin along with lakes and reservoirs.

The AS basin considered for this study, as presented in Figure 1b, majorly comprises of two main rivers, Amu Darya and Syr Darya. These two rivers originate from the Pamirs and Tian Shan Mountains [21] and run through the territory of CA and Afghanistan. The Amu Darya is 2400 km long and it is geographically located in the south of the AS basin, with the coverage of the basin area of more than 300,000 km^2 [22–24]. The Syr Darya is approximately 2500 km, the longest river in CA and ranks the second in terms of water runoff [25]. The bedrock composition is made of schist with quartzite layers while in the north the river terraces are compose of gravel, sand and loess [26].

AS basin is located in the heart of CA; the mountains present in the southeastern corner of the Basin prevent the flow of warm wet air currents traveling from Indian and Pacific Ocean to enter the Basin [27]. Therefore, the basin is characterized in the climatic range of continental desert and grassland region. Figure 1 shows the land use land cover map of the AS basin for the year of 2015. The figure highlights that the major portion of the basin comprises of barren land, which makes agricultural infrastructure difficult in this region. Irrigation activities for crop production are most commonly used within the respective region [28,29].

2.2. Dataset

The datasets that have been used for this study include monthly climate data (temperature and precipitation) from Climate Research Unit (CRU-TS, v4.00) reanalysis, with spatial resolution 0.5-degree [30]; monthly Total Water Storage (TWS) data from the Gravity Recovery and Climate Experiment (GRACE) datasets with the 1-degree spatial resolution [31]; soil moisture (SM) for the depth (0–200 cm) from Global Land Data Assimilation System (GLDAS) with the 1-degree spatial resolution [32]; annual land use land cover data from the European Space Agency (ESA) Climate Change Initiative project (CCI-v2.0.7), with a spatial resolution of 300 m [33]; and, population density data from United Nations—Food and Agriculture Organization (FAO) database based on the country level statistics (http://fao.org/statistics/en/).

2.3. Method

This paper used three versions (GSR, JPL, and GFZ) of the GRACE dataset. Noise makes a major contribution to GRACE to a high degree and hence Stokes coefficients in line with Gaussian smoothing [34–36] has been employed to suppress the high degree of noise variations from the dataset before using it for our analysis [37].

Datasets covered the period 1960–2015 with different temporal resolutions, which were adjusted, analyzed, and predicted using the linear regression method. The linear regression method is utilized to analyze the spatial and temporal trends of different climatic variables for growing and non-growing seasons. A pixel-to-pixel spatial trend has been plotted for climatic variables (temperature, precipitation, and evapotranspiration) and hydrological variables (GRACE TWS, Soil moisture and Ground water storage) with the significance ($p \leq 0.05$). Variations in groundwater level were calculated from two independent observations made as part of the GRACE mission and GLDAS model developed by NASA's Goddard Space Flight Center. Annually averaged ground water was estimated by the terrestrial water balance approach [38] for 13 years (2002 to 2015).

The time series of climatic parameters (temperature, precipitation, potential evapotranspiration, and soil moisture) within the AS basin has been analyzed with two periods of vegetation cover for CA; the growing season consisting of six months (April to September) and the non-growing season comprising of six months (October to March) due to the freezing temperature prevalent through the winter months in the region. After conducting the trend analysis, Pearson's correlation method has been used to study the relationship between different climatic and hydrological parameters with GRACE TWS for growing and non-growing seasons in order to study the impacts of different climatic and anthropogenic variables on lakes water levels over differential periods in order to quantify the extent of contributions by these variables.

3. Results

3.1. Climatic Variations over the AS Basin from 1960 to 2015

Figure 2 presents the temporal variability observed in the climatic paramters between 1960 to 2015 within the AS basin. The results obtained from studying different time series presented varying trends. Temperature showed a significant increase in temperature while potential evapotranspiration revealed minor but significant trends during both the growing and non gorwing period from 1960 to 2015. Contrarily, precipitation presented a minor but not significant trend during gorwing season and slightly increasing significant trend during non gorwing season over the Basin. Soil moisture demonstrated increasing trend for both gorwing and non growing periods, with high significance for the fomer one during 1960–2015. There are many indications that, since the early 1960s, the large-scale atmospheric circulation has been changing. During this period, the tendency towards the increase of the meridional circulation was evident e.g., [39,40] over CA. These trends should reflect the basic long-term air temperature variability that is related to the general regional climate changes and, hence, contributing to the Aral Sea's desiccation [41,42].

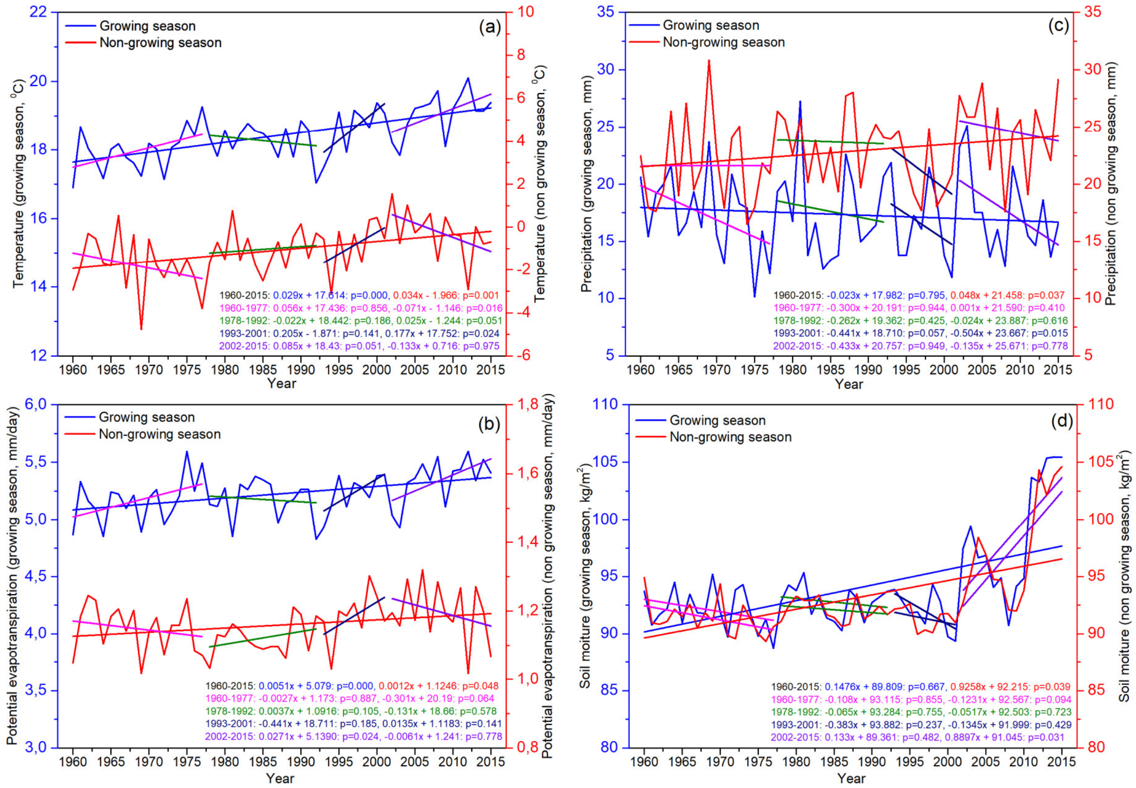

Figure 2. Time-series climatic condition within the AS basin between 1960 to 2015 for growing and non-growing periods. (**a**) Mean annual air temperature, (**b**) the total annual potential evapotranspiration, (**c**) total annual precipitation, and (**d**) soil moisture. The blue lines indicate the linear trends during the growing while the red lines present the linear fits for the non-growing season between the period 1960 and 2015.

Figure 2a indicates that the annual average temperature has increased from 1960 to 2015 with an inter-annual change value of 0.03 °C/year and 0.04 °C/year during the growing and non-growing period, respectively with p values < 0.05 for both seasons. The mean values of the temperature increased from −4 °C to +1 °C and +16.5 °C to +20 °C during the winter and summer seasons, respectively (Figure 2a). The results presented that the highest value for the mean temperature (t) during the growing season was observed during the year 2012, with the value of 20 °C, while the lowest value of mean temperature (t) of 16.5 °C was observed during two years that are 1960 and 1994. Similarly, for non-growing seasons the highest temperature (t) value of 1.8 °C was recorded in 2002, while the lowest temperature (t) value of −5 °C was presented by the year of 1969.

The average annual precipitation (PRE) during the growing season was 17.3 mm, and the non-growing season was 22.9 mm. The total annual precipitation from 1960 to 2015 during the growing season shows a slow decreasing trend over the study period, with −0.02 mm/year inter-annual change rate, as shown in Figure 2c. During the non-growing season, the annual precipitation shows a small increasing trend over the study period with 0.05 mm/year inter-annual rate of change. Over the study period, the maximum annual precipitation was recorded in 1969 with 30.8 mm, and the minimum annual precipitation was observed in 2001 with around 10.1 mm.

The change of trend in potential evapotranspiration (PET) in the AS basin shows a slight increase (Figure 2b). The trend of annual (PET) increase was 0.005 mm/year during the study period, and the maximum (PET) value was recorded in 2008, with 3.41 mm/day, and the minimum annual (PET) was observed in 1969, with around 2.95 mm/day. On average, 5.59 mm/day and 4.58 mm/day water was observed to have evaporated during the vegetation season (April–September) and the non-vegetated period (October–March), respectively.

Figure 2d presented linear regression trends of soil moisture (kg/m^2) for AS basin from 1960–2015 for the growing and non-growing season. The changing trend observed in soil moisture showed slight increasing trend 0.15 (kg/m^2)/year during growing season and a steep increase of 0.93 (kg/m^2)/year during the non-growing period. The maximum soil moisture value recorded was in 110.43 kg/m^2, and the minimum in around 88.74 kg/m^2.

Figure 3 presents the spatio-temporal trends maps of different climate variables (temperature, precipitation, potential evapotranspiration and soil moisture) for growing and non-growing seasons over the AS Basin region for the period of 55 years (1960–2015). The study area has presented a significant increase in mean temperatures during growing season over the entire region with the highest values observed over the north-west regions and southwest regions covering major areas of Kazakhstan and Turkmenistan, respectively, as presented in Figure 3a. Similarly the trends that were observed during the non-growing seasons revealed increase in mean temperatures distributed significantly over Kyrgyzstan in north east, Tajikistan in south east, Afghanistan in the south and Turkmenistan in the south west, with the value ranging between 1.4–1.8 °C. Figure 3c presents extreme decreases in precipitation over the AS for the growing season, where the most significant decrease has been found over the north most region of Kazakhstan and south west region of Turkmenistan with value ranging from −6 to −9 mm/year. Contrasting to the growing season, the non-growing season revealed an increase in precipitation over the basin, which has been found to be significant over the regions of north-west parts of Tajikistan, southeastern parts of Uzbekistan, and southwest parts of Kazakhstan.

Potential evapotranspiration (Figure 3e) during the growing season revealed an increasing trend, which has been found to be significant over the entire western part of the study region covering the south western parts of Kazakhstan, west region of Uzbekistan and north western region of Turkmenistan. While the potential evapotranspiration increased during the non-growing season was found to be significant covering the regions of south west of Kazakhstan, AS lake, and north-west parts of Uzbekistan, ranging between 0.3–0.5 mm/day. The potential evapotranspiration showed non-significant extreme decreases over the entire southern most parts of the AS Basin.

Soil moisture (Figure 3g) during the growing season presented an increase in soil moisture values at (0–200 cm) depth, which have been the most significant over the north west regions covering major areas of Kazakhstan, north west Uzbekistan, and parts of north Turkmenistan, respectively, with the highest increasing value ranges between 15–25 kg/m^2 with smaller area patches found near east Uzbekistan. The trends that were observed during the non-growing seasons (Figure 3h) revealed an increase in a similar region, like the growing season results of soil moisture majorly distributed over north western regions of the study area with patches of increased near east Uzbekistan. The decreasing values in soil moisture have been found for both the growing and non-growing season been found over the regions of Afghanistan and South Turkmenistan. The results revealed varying degrees of heterogeneity based on the spatio-temporal trend analysis of the climatic parameters for the study area.

The spatio-temporal maps presented significant increasing trends for both potential evapotranspiration and soil moisture over the north and north west region of the basin for growing season. Likewise, for the non-growing season, both PET and SM showed significant increasing trends over the northwestern regions of the basin. The soil moisture and precipitation feedback vary across different geographical and climatic conditions depending upon the region's energy balance.

There has been a negative feedback mechanism found to exist in dry soils/regions. The negative soil moisture-precipitation feedback depends on soil moisture-evapotranspiration correlation, where, in dry regions, evapotranspiration is soil moisture limited [43]

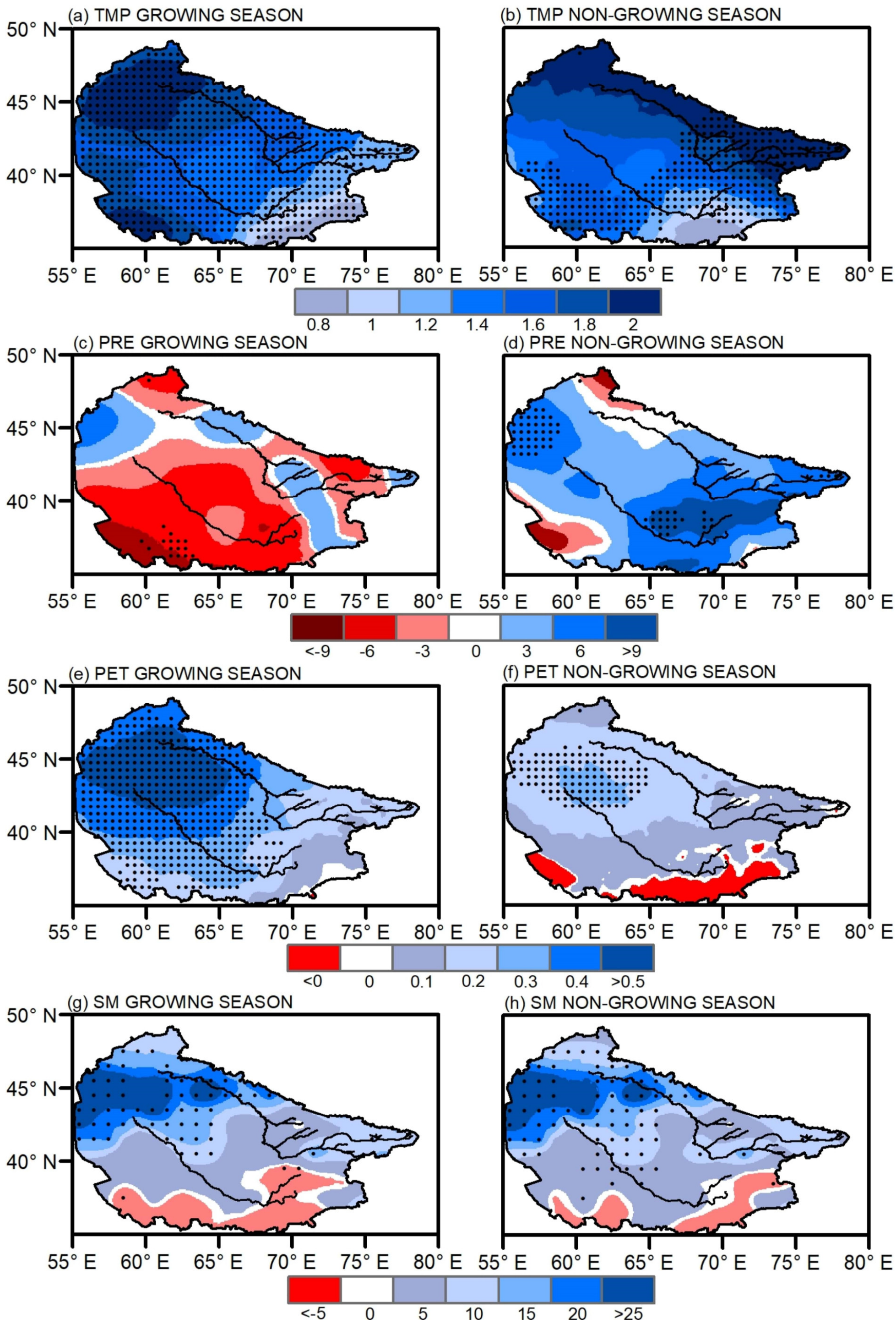

Figure 3. Spatial-temporal trends of different climate variables (**a**,**b**) temperature (TMP) (**c**,**d**) precipitation (PRE) (**e**,**f**) potential evapotranspiration (PET) and (**g**, **h**) soil moisture (SM) for growing season (Apr, May, Jun, Jul, Aug, Sep) and non-growing season (Oct, Nov, Dec, Jan, Feb, Mar) respectively from 1960 to 2015 with black dots presenting areas with significant changes over the years.

3.2. Water Balance in the AS Basin

The GRACE TWS and GLDAS SM datasets are analyzed and explained in Section 3.2 in order to quantify the variation of groundwater condition within the AS basin. Figure 4 illustrates the spatial distribution of trends of the GRACE water equivalent depth throught the time series of TWS from 2002 to 2015. We also calculated the three solutions from the three processing centers (CSR, JPL, and GFZ) where all three presented almost identical spatial patterns; hence, only one processing center has been used in Figure 4a. The plotted times series JPL and CSR showed the same patterns, with significantly decreasing trend of 2–4 cm per year. Similarly, the GFZ solution also shows a decreasing trend of around 2 cm per year over the study area. The maps presented in Figure 4a–c present the spatial trend distribution of GRACE TWS, soil moisture, and ground water, respectively, for AS basin. The total soil moisture time series (Figure 4b) shows the moisture quantity of 0–200 cm depth of soil layer, derived from GLDAS dataset for the growing and non-growing seasons. The spatial heterogenerity revealed that the TWS (Figure 4a), has significantly decreased in the west and north west and south west parts of the basin, with the value ranging as low as −2 to −4 cm/year from 2002 to 2015; similarly, ground water also presented a declining rate through the spatial maps with significant decreases in the western parts of the basin and significant increases observed over the north and middle of the AS basin. While, TWS and groundwater presented significant declines over the west and north west parts of basin contrarily soil moisture presented a significant increasing trend over the same region. Figure 4c represents the estimated annual average of groundwater levels. It has been quantified that 85% of the basin area suffered losses in groundwater. Still, small parts of the southern area near the mountainous and irrigated cropland region showed an increase in the groundwater levels (Figure 4c).

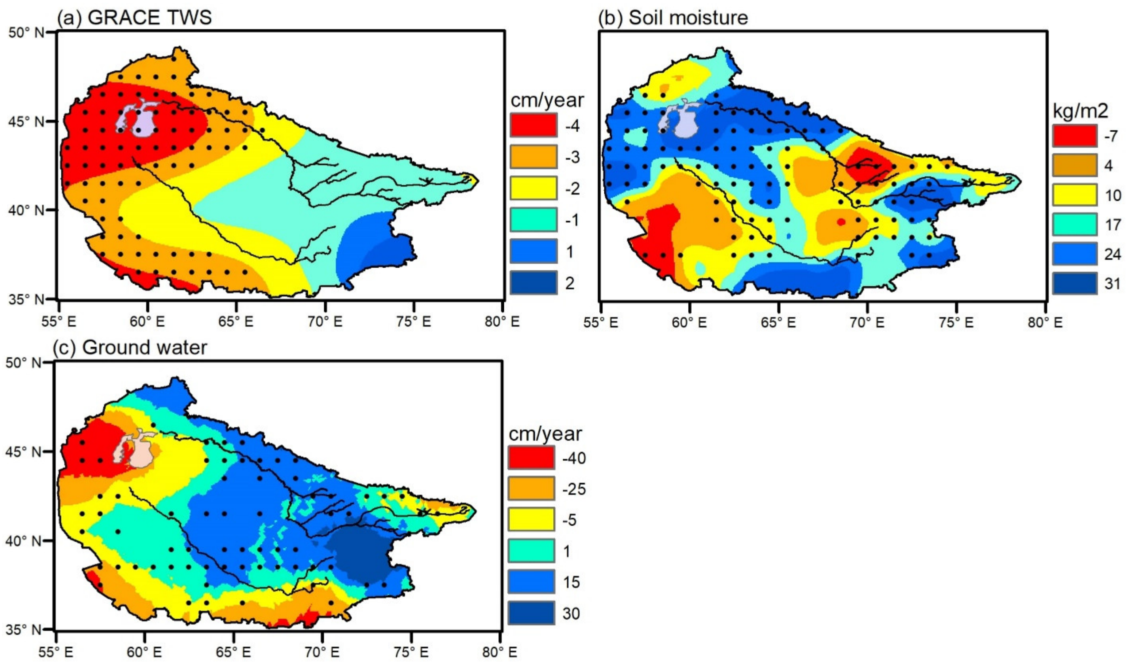

Figure 4. Spatial distribution of trend of the (**a**) GRACE TWS, (**b**) soil moisture, and (**c**) ground water from 2002 to 2015. Areas with a significant trends are denoted by a dot in each pixel.

The water flow is positive within the eastern part of the basin and it extends to the center of the basin [44]. The positive patterns observed within this region were due to the presence of water bodies, like Aydar Kul, Son-Kul and Tuzkan lakes, Bahri-Tojik, Toktogul, Kapchagay, Kuksaray, Shardara dam, and others. The volume of the basin from the center to the AS and Karakum is sharply decreasing and a strong negative trend is recorded in the south-western part of the AS basin. Similarly, the overall anomaly shows TWS shrinkage in the AS watershed, which can be ascribed to the declines that were observed in the glaciers of the Tian Shan and the Pamir Mountains, whereas the TWS shrinkage in the Tian Shan Mountains has dropped by −3.6 mm/a in 2003–2013, with themean water loss of −1.1 ± 0.64 Gt/ha being reported [45]. Similar results have been reported other studies [46,47]. The total glacier mass balance in the Pamir Mountain during the years 2002–2013 is −0.52 m w.e.i/year similar to [48]. The plotted times series JPL and CSR showed the same patterns, with significantly decreasing trend of 2–4 cm per year in Figure 2d. Similarly, the GFZ solution also shows a decreasing trend of around 2 cm per year over the study area.

The difference computed for the growing and non growing seasons based on the TWS has presented significant declines while the ground water storage showed almost negligible declining trends. The time series plot of the groundwater level in Figure 5b indicates an increasing trend of approximately 0.05 cm/year during growing season and 0.03 cm/year during the non-growing season respectively for 2002–2015.

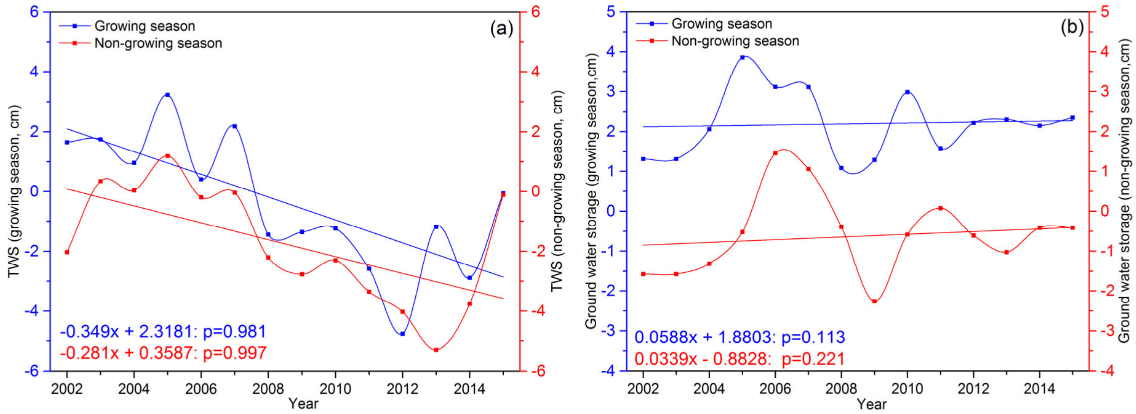

Figure 5. (**a**) Total Water Storage (TWS) linear regression and (**b**) ground water storage linear regression based on the AS basin values for growing and non-growing seasons, respectively, between the period of 2002–2015.

Groundwater has presented higher levels for 2005 and 2007 during growing season at 3.85 and 3.12 cm/year, respectively. Comparatively, river water consumption for irrigation was found to be higher at 73 km^3/year during these years for the territory of Uzbekistan [49]. Figure 5 presented contrasting results between GRACE TWS and ground water levels; this could be attributed to various factors, including inefficient irrigation transport system, anthropogenic modifications, and increased evapotranspiration, which, in combination, has resulted in extensive surface water loses. The soil moisture might not necessarily translate into surface water availability as the groundwater after infiltration has lesser probability of reaching to the lake or reservoirs, which cannot aid the recovery process, causing a difference in the water budget of the region [44].

3.3. Factors Affecting to Water Level Change

Figure 6 shows the influence of climatic and anthropogenic factors on the water balance fluctuations within the basin area and Tables 1–4 present the correlation. The urban population growth for the four countries being covered with the AS basin has been presented in Figure 6a, from 1060 to 2015. A total of three land cover classes were categorized based on ESA land cover dataset, namely cropland area, urban area, and AS surface area (Figure 6b) from 1992 to 2015. Over this period the population has increased in all countries around CA while the results of three land-use classes showed a rapid increasing trend in urban and cropland areas, with a dramatic decrease observed in the AS water surface area over 23 years of land cover change (1992–2015). The irrigated cropland area has shown steep extension from 9,700,000 km^2 to 9,925,000 km^2, from 1998 to 2007.

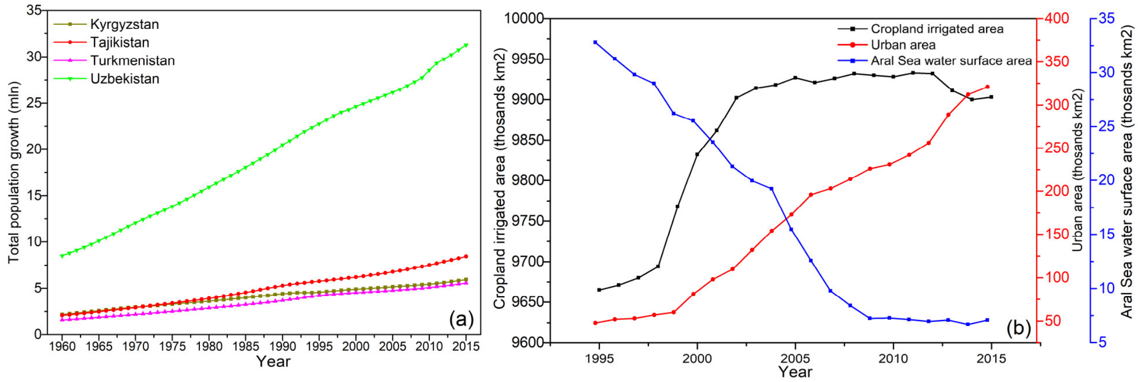

Figure 6. (**a**) Population growth, (**b**) area change of land cover classes within the AS basin region.

There has been a drastic increase of 60% observed in the expansion of irrigated arable land from 1962–2002 over the study region [50]. There was a 5.2% (over half a million hectares) overall increase in irrigated land observed between 1992 to 2002 [51]. By 1988, the total with withdrawals reached 125% of the annual average water resources [52]. Such drastic land use changes not only affected the river runoff and area of lakes, but also made significant changes to evapotranspiration and precipitation interactions over this region.

Table 1. Correlation between AS surface water and variables (1960–2015).

Year	Variables	Correlation Lake Surface Water and Variables	
		Corr. Coef.	*p*-Value
1960–2015	Temperature	−0.606 *	0.000
1960–2015	Precipitation	−0.103	0.452
1960–2015	Potential evapotranspiration	−0.470 *	0.000
1960–2015	Soil Moisture	0.013	0.926
1960–2015	Population	−0.995 *	0.000

Note: * mean significance at $p < 0.005$ level.

Table 1 shows the relationships of climate and antropogenic variables with water surface area fluctuations. Land surface temperature and water level has a significant negative correlation (−0.6, $p < 0.005$). Increasing air temperatures results in the higher evaporation rates (PET), which causes a shrinkage in the surface water level. The anthropogenic factors in terms of population growth demonstrate a strong statistically significant negative relationship with the terrestrial water levels within the basin (−0.99, $p < 0.001$).

Likewise, an increase in population results in an increase in urban settlement areas, which presented a negative correlation (Table 2) with surface water levels (−0.97, $p < 0.001$). The growth of the population results in the intensified food demand; therefore, the extension of cropland area has shown a significant negative correlation −0.86 ($p < 0.005$) with lake water surface.

Table 2. Correlation between AS surface water and variables (1995–2015).

Year	Variables	Correlation Lake Surface Water and Variables	
		Corr. Coef.	*p*-Value
1995–2015	Crop area	−0.857 *	0.001
1995–2015	Urban area	−0.971 *	0.000

Note: * mean significance at $p < 0.005$ level.

In Table 3, the correlation of AS water level with GRACE TWS and Estimated Ground water has been presented, where the former has shown significantly high positive correlation.

Table 3. Correlation between AS surface water and variables (2002–2015).

Year	Variables	Correlation Lake Surface Water and Variables	
		Corr. Coef.	*p*-Value
2002–2015	TWS GRACE	0.752 *	0.003
2002–2015	Ground water	0.131	0.671

Note: * mean significance at $p < 0.005$ level.

The correlation values computed between climate variables for two different time series (1960–2015 and 2002–2015) have been presented under Tables 1 and 4, respectively. The variables of temperature and potential evapotranspiration have shown higher correlation values (negative) with the surface water levels for the longer study period, while no significant correlation was found between GRACE TWS and the same variable for shorter time period. While, in Table 2, the anthropogenic variables presented extremely high correlations with lake water levels over the period of 20 years.

Table 4. Correlation between GRACE TWS and variables (2002–2015).

Year	Variables	Correlation GRACE TWS and Variables			
		Growing		Non-Growing	
		Corr. Coef.	*p*-Value	Corr. Coef.	*p*-Value
2002–2015	Temperature	−0.458	0.099	0.295	0.306
	Precipitation	0.420	0.135	0.403	0.153
	Potential evapotranspiration	−0.537	0.048	−0.039	0.894
	Soil Moisture	−0.279	0.335	−0.201	0.491
	Ground water	0.249	0.391	0.209	0.473

Note: * mean significance at $p < 0.005$ level.

The correlation computed between different variables and lake water levels revealed that the anthropogenic drivers have shown the most significant contributions to the correlation values.

Extensive Soviet programs towards cultivating cotton on a large scale during the mid-twentieth century started in the region with significant modifications being made to the natural system via canals, irrigation ditches, and reservoirs over the past half century. Soviet scientists knew that the shrinkage of the Aral Sea was a potential repercussion of this modification but proceeded with agricultural expansion anyway [53]. This unprecedented demographic change along with the climatic changes in terms of negative feedback mechanisms of soil moisture-precipitation and soil moisture-evapotranspiration interaction worsened in the region.

4. Discussion

In this paper, we analyzed the AS's surface water changes in association with climate and anthropogenic factors. We found that the annual water level within the basin has been decreasing since 1960. During the study period, the value of mean air temperature has increased between 0.4 to 0.6 °C, which facilitated evaporation, hence contributing to the decrease in water balance in the study region. The cumulative precipitation and soil moisture have shown a slight increase, which barely affects water level change within the AS.

Our analysis shows that, in the past 55 years, the population in CA countries has experienced rapid changes. The total population in the region has grown from 24 million in 1960 to 73 million in 2015. The population growth causes an increased demand of food and water availability in the region.

AS basins agro-infrastructural development is dependent on the Amu Darya and Syr Darya rivers water supply. The two major rivers not only supply the AS, but also feed the surrounding population and socio-economic activities. Furthermore, our analysis reveals that the change of air temperature and human activities along with water management practices had a strong effect on the hydrology of the AS basin [54]. The selected hydro-climatic and anthropogenic parameters have helped us to identify the rate of influence to water level change contributed by each variables.

In this study, we analyzed the collective contributions of climatic changes and human activities to the AS basins water resource dynamics using statistical analysis with remotely sensed and reanalysis datasets. Our results have indicated that the mean annual temperature in the AS basin from 1960 to 2015 significantly increased during the growing and non growing seasons. The total precipitation shows an increasing trend during the cold seasons and a decreasing one during the warm seasons. The GRACE and GLDAS dataset provide feasible information in groundwater change for those regions, which lack the ground observation instrumentation. A significant negative correlation has been revealed between water level and anthropogenic factors, which demonstrated high human pressure on the shared water resource of CA instigating transboundary conflicts and challenges.

The territory of Central Asia consists non-uniform geographical and climate zones. Hence, the regional water resources within different geographical zones in CA respond differently to varying climatic and land use changes. Therefore, we will try to analyze the effects of climatic variables on water resources based on different climate and geographic zones of the region in the future.

5. Conclusions

The results found from this study improves our understanding of the contributions made by climatic and demographic growth factors on the surface water flucations and hydrological dynamics of the AS basin. Through this study we analyzed the effects of climatic variability and demographic changes underlined by population pressure on CA's regional water resources. The dynamics defining the association between climatic and land use changes and water resources has been investigated in this research, which is crucial for sustainable water management and agriculture practices within this water scarce region.This study highlighted that the Aral Sea Basin suffered drastic surface and groundwater fluxes, especially after the region underwent extensive urban sprawl indicated by upsurges in population and irrigated cropland area under the study region. This study can prove to be beneficial for the policy makers, stakeholders, and land and demographic management practitioners for thorough and holistic actions to minimize and prevent further damage to this shared water resource of CA in the future. This could be used to strengthen the water and food security situation within CA, which mainly depends on the AS basin.

Author Contributions: All authors conceived the presented research; T.T.B. and Z.-G.M., developed the theory and performed the computations: T.T.B., C.L. and S.I., verified the analytical methods. M.Z., has supervised the findings of this work: T.T.B. and S.I. wrote the research findings: M.Z., T.T.B. and S.I. reviewed and edited and finalised the manuscript. All authors have read and agreed to the published version of the manuscript.

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