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RESEARCH ARTICLE

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Assessment of spatiotemporal variability of water storage in Arabian countries using global datasets: implications for water resources management

Mohamed Saber, Sameh A. Kantoush and Tetsuya Sumi

Disaster Prevention Research Institute, Kyoto University, Uji, Kyoto, Japan

ABSTRACT
The Arab region is characterized by water scarcity, extreme droughts and floods. This paper aims to utilize the global datasets of rainfall, evapotranspiration (ET), Normalized Difference Vegetation Index (NDVI), Gravity Recovery and Climate Experiment (GRACE) satellites and Data Assimilation of GLDAS to assess the spatiotemporal variability of water resource components over the Arab region. The results indicate that the Terrestrial water storage (TWS) are declining in most of the countries over the analysis period (2002–2015). The long-term analysis indicates that 2008 was the driest year and a distinctive deflection point for a declining trend of TWS. Non-parametric trend analysis test of Man-Kendall showed that trend of rainfall, NDVI, ET are not statistically significant except in some regions. The highest TWS volume of about +1586.9 Million Cubic Meter was found in Sudan, evidenced by rainfall. The study provides a guide for stakeholders to manage water resources in all countries separately.

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KEYWORDS
Water resources management; GRACE; GLDAS; Arab region; NDVI; groundwater

Introduction

Water scarcity is a great challenge for human life, society, and the environment in the Arab region. An increasing gap between demand and water supply, due to the growth of population and urbanization, is hindering human development. Most of the Arabian countries are located in arid regions, where drought conditions result in water scarcity, and flash floods lead to disasters. This is considered one of the main challenges against any sustainable development in the Arab region. The recent droughts in the Middle East countries are adversely affecting the scarce water resources (Ragab and Prudhomme 2000; Şen et al. 2013). Over 60% of the water demands are covered by fossil groundwater of the Gulf Cooperation Council (GCC) countries (Al-Rashed and Sherif 2000). The average annual volume of rainwater in the Gulf countries is estimated at 205.93 billion m^3 (ACSAD 1997). Arab countries cover about 10% of the world's area but receive only 2.1% of its mean annual precipitation. Most of the region is classified as arid or semi-arid (desert), receiving less than 250 mm of rainfall annually (UNDP 2013).

Rainfall is considered one of the most important water resources in arid and hyper-arid regions, such as the Middle East and North Africa region (MENA) region, due to the limited water resources. As stated by (Almazroui et al. 2012), the observed annual rainfall in Saudi Arabia exhibits a remarkable declining trend of about 47.8 mm per decade over the analysis period of 1978–2009, with a relatively large interannual variability. Rainfall and temperature as main climatic parameters have been previously studied on the Arabian peninsula due to their importance as measures of the region's climate (Elagib and Mansell 2000; Lázaro et al. 2001; Islam, Langrish, and Chiou 2010; Almazroui et al. 2012). It was also stated (Donat et al. 2014) that changes in precipitation in the Arab region are generally characterized by a higher spatial and temporal variability and the trends are less significant.

The Gravity Recovery and Climate Experiment (GRACE) satellite data have been developed to monitor Terrestrial Water Storage (TWS) globally (Tapley et al. 2004). It has offered monthly gravity field solutions and has been used as an applicable tool to infer groundwater storage changes by subtracting contributions from other components (Tiwari, Wahr, and Swenson 2009; Rodell, Velicogna, and Famiglietti 2009; Famiglietti et al. 2011; Chen et al. 2014; Richey et al. 2015). The spatial variability of TWS is dependent upon and dominated by variations in surface water, and soil moisture (Rodell and Famiglietti 2001). The spatial resolution of the GRACE-TWS grid is one degree in both latitude and longitude (around 111 km at the equator) (Landerer and Swenson 2012). The GRACE data has been used in several applications including assessment of groundwater storage variability and dynamics (Rodell et al. 2007; Richey et al. 2015; Tregoning et al. 2012; Swenson and Lawrence 2015; Saber, Kantoush, and Sumi 2017; Saber et al. 2017).

Most of the previous studies addressed the water variability regionally, but this study focuses on spatial and temporal variability over the Arab region, and spatially at all countries as well as sub-regions. The demographic growth and climate change will deeply affect the water resources, as well as quality, in the MENA region (Conway 1996; Suppan et al. 2008; Alpert et al. 2008; Gao and Giorgi 2008; Evans 2008). The key capacities are also underdeveloped for adaptive governance to water shortages in Middle East region (Sowers, Vengosh, and Weinthal 2011).

Sustainable water management is hindered by data deficiency, water variability, and, in some cases, political situations.

CONTACT Mohamed Saber mohamedmd.saber.3u@kyoto-u.ac.jp

There are several reasons for focusing on the Arab region: (1) the region is located in the hyper-arid and arid zone which means very high variability of water components along with extreme drought and flooding, (2) the limitation of previous studies focusing on all countries separately, (3) the lack of observational and monitoring data. Therefore, proposing and developing good management strategies for the available water resources are urgently needed to overcome the water demand issues for the increasing population, industrialization, and urbanization. This can be achieved only by a comprehensive analysis of the water resource components to understand the spatial variability by utilizing the global data sets. The water resources in arid regions are mainly controlled by rainfall, groundwater, and evaporation changes. This paper aims to assess and evaluate the water resource variabilities in the Arabian countries using several global data sets, such as the Satellite Remote Sensing Data (Gravity Recovery and Climate Experiment; GRACE) and global land data assimilation (GLDAS), in addition to Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks-Climate Data Record (PERSIANN-CDR) rainfall data, global actual evapotranspiration, NDVI, and ET. The total water storage variability (rainfall, NDVI, ET, and groundwater) over the Arabian countries is analyzed spatially and temporally.

Study area

The Arab region covers an area about 13,781,751 km^2. It consists of 22 countries, as shown on the map, excluding Comoros (Figure 1). The Arab world, also known as the Arab nation, consists of the 22 Arabic-speaking countries of the Arab League. The population has increased by the rate of 8E+6 person every year from 2002–2015 (WorldBank 2017).

Based on the report of the Intergovernmental Panel on Climate Change (IPCC 2008), it is expected that MENA region, over the next century, will experience declining rainfall (10–25%), declining soils moisture (5–10%), declining runoff (10–40%), and increasing evaporation (10–20%) (IPCC 2008). Generally, water management has suffered from poor accountability (both external (service users) and internal (within resource management and service delivery organizations)). In March 2007, the World Bank report concluded that water is scarce and needs a management strategy to find engineering solutions; to improve water management, accountability needs to be deliberately promoted; and to improve water management, policies outside the water sector are often as important as those within the sector (WorldBank 2007). Groundwater resources in most Arab countries are also threatened by pollution from agricultural, industrial, and domestic activities. 'Over the last two decades, irrigated areas in Gulf countries grew 100–300 percent. Irrigation water is often used inefficiently, without considering the economic opportunity cost for urban domestic and industrial purposes' (UNDP 2013).

In East Africa and the Maghreb states, mean annual temperatures are likely to exceed 2° degrees Celsius (°C) with maximum projected increases up to 6°C – by the year 2100.4, based on the representative concentration pathways RCP 2.6 and RCP 8.5, respectively (Team, Pachauri, and Meyer 2014) . According to the International Panel on Climate Change (IPCC) Fifth Assessment Report (AR5), most of the MENA region is expected to become hotter and drier (Intergovernmental Panel on Climate 2014). Also, the region is particularly sensitive to extreme climates such as heavy rainfall, flash floods, rising sea levels, and droughts, which are on increasing under climate change (Intergovernmental Panel on Climate 2014)

Methodology and data processing

In this study, several global data sets were used (Table 1) to analyze the changes in water resource components over the whole Arab region due to the limitation of observational data. The analysis was conducted based on the whole region, countries, and sub-regions to deeply understand the spatial variability of the hydrological parameters over the region.

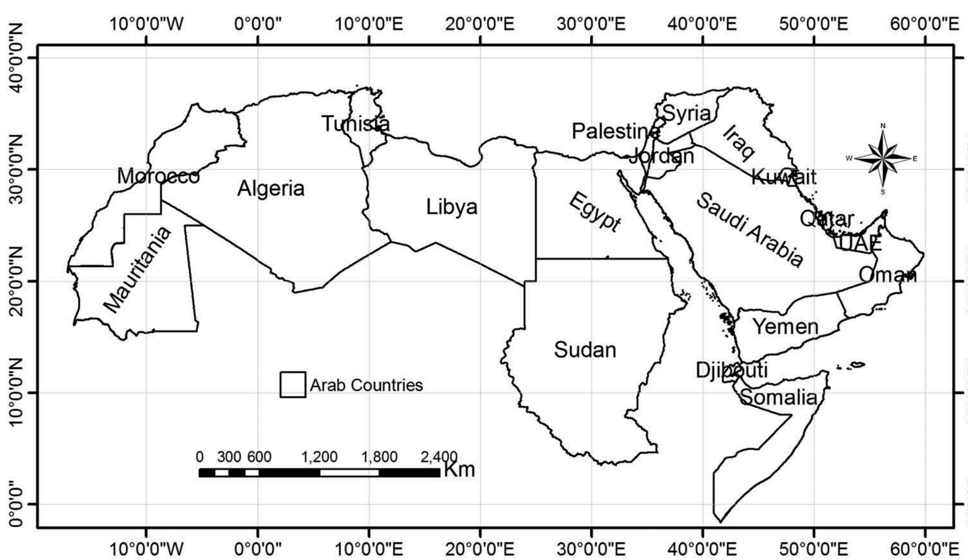

Figure 1. Location of the Arabian countries.

Table 1. The global data used in this study.

Global Data		Type	Temporal Resolution	Spatial Resolution	Time Span
1	PERSIANN-CDR	Precipitation	Daily	25 km	1983–present
2	NDVI	Normalized difference vegetation index	Annual	1 km	2001–2012
3	Actual evapotranspiration	Evapotranspiration	Annual	1 km	2000–present.
4	GRACE	Total Water Storage	Monthly	~100 km	2002–2015
5	GLDAS	Soil Moisture	Monthly	100 km	2002–2015

Precipitations data

For the rainfall analysis, PERSIANN-CDR (Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks-Climate Data Record) was used to understand the spatial and temporal variability over the region. It was developed by the Center for Hydrometeorology and Remote Sensing (CHRS) at the University of California, Irvine (UCI). It provides global daily rainfall estimates (Ashouri et al. 2015) and provides daily precipitation data with a spatial resolution of 0.25 degrees from 1983 to the near-present.

Normalized difference vegetation index (NDVI)

A Moderate Resolution Imaging Spectroradiometer (MODIS) based global 1-km maximum green vegetation fraction (MGVF) dataset was used in this analysis (Broxton et al. 2014). It was developed based on climatology data of the moderate resolution imaging spectroradiometer (MODIS) normalized difference vegetation index and land-cover type, which removes the associated biases with unusual greenness and inaccurate land-cover classification for each year.

Actual evapotranspiration

The ET is the combination of transpiration and evaporation. Actual evapotranspiration was developed based on the operational simplified surface energy balance (SSEBop) model (Senay et al. 2013) from 2003 to the present. The SSEBop setup relies on the simplified surface energy balance (SSEB) approach with unique parameterization for operational applications (Senay et al. 2013). Annual actual evapotranspiration (ET) is obtained from the early warning of USGS database website (https://earlywarning.usgs.gov/fews/product/458).

GRACE and GLDAS

GRACE and GLDAS data were used to estimate the total water storage and groundwater storage changes over the Arab region. Thus, we used the scaled version of GRACE data processed and archived by Landerer and Swenson (Landerer and Swenson 2012) to assess the total water storage variability of the study region. The data of GRACE TWS is available at (1°×1°) spatial resolution and monthly temporal resolution, version RL05 (CSR). The corresponding scaling factors were provided for the correction of GRACE data errors (such as the leakage errors due to signal leakage from neighboring grids and measurement errors due to raw GRACE data processing). GRACE TWS estimates of the target region were corrected by multiplying the GRACE pixels by the corresponding scaling factors. Groundwater storage changes were analyzed and assessed at different scales in regional districts (Huang et al. 2015) and for watershed scale (Billah et al. 2015) with spatial areas in the range from 30 to 7000 km^2. Therefore, in the present study, GRACE TWS data and GLDAS data were used from October 2002 – September 2015, to estimate the groundwater anomalies of the Arab region.

GLDAS data was introduced and sponsored by NASA Goddard Space Flight Centre (GSFC) and the National Oceanic and Atmospheric Administration (NOAA) to calculate the variations in both ocean and land mass fluxes (Rodell and Famiglietti 2002; Rodell, Velicogna, and Famiglietti 2009; Rodell et al. 2004). GLDAS NOAH Ver. 1 were processed to estimate the TWS components (e.g. soil moisture, canopy water, surface runoff). It is available at spatiotemporal scales (1° pixel and monthly resolutions). The total soil moisture (SM) was estimated as the total summation of soil moisture values of four layers: (0–10, 10–40, 40–100, and 100–200 cm). The total SM and other components were then subtracted from GRACE TWS to calculate groundwater storage changes (Equation (1). The first step, GRACE TWS, was processed to estimate the variability of total water storage across the region and then the groundwater storage anomalies were estimated to assess the variability of the study area.

In order to evaluate the groundwater storage variabilities, the water components of GLDAS (such as surface, snow, and canopy water and soil moisture storage) were subtracted from the GRACE data (Equation (1)). The annual total average for all parameters was estimated first, then the anomalies were calculated by subtracting the average over the time period (October 2002 – September 2015) from every month value.

$$\Delta \mathbf{S_{GW}} = \Delta \mathbf{S_{TWS}} - (\Delta \mathbf{S_{SW}} + \Delta \mathbf{S_{SM}} + \Delta \mathbf{S_{cpy}} + \Delta \mathbf{S_{SWE}}) \quad (1)$$

where $\Delta \mathbf{S}$: is (the monthly, seasonal, or annual changes), SM: is soil moisture, SW: is surface water, cpy: Canopy water, SWE: Snow water equivalent and GW is groundwater storage.

Trend analysis

In this study, statistical significance trend analysis was performed on different hydrological parameters such as rainfall, Actual Evapotranspiration, and NDVI by using Mann–Kendall test (Mann 1945; Kendall 1975) while for the magnitude of trend was determined by non-parametric Sen's estimator method to know the positive and negative trend of time series data, and the point of changes was assessed by Pettitt's test (Pettitt 1979). Mann–Kendall Test is a statistical approach which can be used to check the null hypothesis of no trend versus the alternative hypothesis of the existence of monotonic increasing or decreasing trend of hydrological and hydro-climatic time series data. The significance of trend is statistically assessed using Z – value of Mann-Kendal trend test. A positive value of Z shows upwards (increasing) trend while the negative value indicates downward (decreasing) trend.

Results and discussions

The Arab region is characterized by high limitation and demand of water resources due to climatic conditions and increases of the population. The limited monitoring data is hindering many studies in the area. Thus, we discuss in this paper the potential use of global datasets to overcome such challenges to understand the spatial and temporal variation of water components (rainfall, NDVI, ET, total water storages, and groundwater) over the whole region considering all countries. The region was analyzed spatially and temporally based on the country and sub-regions. A trend analysis for rainfall, NDVI, and ET were conducted for all countries separately and also for the sub-regions. We assumed that the Arab region can be divided into four sub-regions: the whole Arab region (all countries), North Africa (Egypt, Libya, Tunisia, Morocco, Algeria, Djibouti, Mauritania, Somalia and Sudan), Western Asia (Jordan, Palestine, Syria, Iraq, and Lebanon), and Gulf countries or Arab peninsula (Bahrain, Oman, Kuwait, Qatar, Saudi Arabia, UAE, Yemen).

Total precipitation anomalies

In this part, we analyzed the rainfall for all countries by using PERSIAN-CDR. The total average of precipitation shows that Sudan, Mauritania, Djibouti, and Somalia received the highest quantity of precipitation between 2003 to 2015, while Egypt received the lowest annual average rainfall during the same time (Figure 2). From the temporal anomalies of total rainfall, there are two peaks for most of the countries, in 2007 and 2013, which means that the region received the highest rainfall during these 2 years (Figures 3 and 4). Over the whole region, the results show that 2007 had the highest average rainfall, and 2008 was the driest. It was found that Saudi Arabia experienced a significant decrease in rainfall from 1994 to 2009 (Almazroui et al. 2012), which aligns with this study's analysis that rainfall over Saudi Arabia declined in the first half of the analysis period. However, the trend starts to increase from 2009 until 2015. The rainfall anomalies over the whole Arab region and Gulf Countries show that there are two trends: before 2008, the rainfall decreased; but after 2008, the rainfall increased (Figure 3(a,b)). Also, 2007 and 2013 showed the highest level of average rainfall at both regions. The rainfall anomalies over the Western Asia countries are not changeable except the maximum increasing in 2007, but in North Africa, the general trend is decreasing over the region with very high variability temporally and spatially.

NDVI anomalies

NDVI annual data of MODIS-based global 1-km was used. The general trend of NDVI over the analysis period was increasing, which means the agriculture activities are increasing due to population growth; this consequently affects the water resources in the region, including surface and groundwater. The highest NDVI values were recorded in 2008 and the precipitation was the lowest this year, which means that the usage of groundwater was very high and caused a dramatic decline in the water resources availability, especially groundwater (Figures 5 and 6). However, based on the increasing trends of NDVI over the whole Arab region and Gulf Countries (Figure 5(a,b)), there is very high spatial variability from one country to the others. For instance, NDVI increased over time in some countries, such as Iraq and Syria, but decreased in other countries, such as Morocco and Tunisia. Also, Libya, Tunisia, Syria, and Saudi Arabia have the highest total NDVI, while Somalia and Lebanon have the lowest. In 2008, there a remarkable increasing in NDVI for all regions. NDVI is increasing at both Gulf and Wester Asia Countries, but the last showing much more increasing in the general trend. NDVI at North Africa is highly changeable with no specific trend. This can be linked with the same year of 2008 as the total water storage over the region estimated by GRACE and GLADAS data was dramatically declining (See Figure 9).

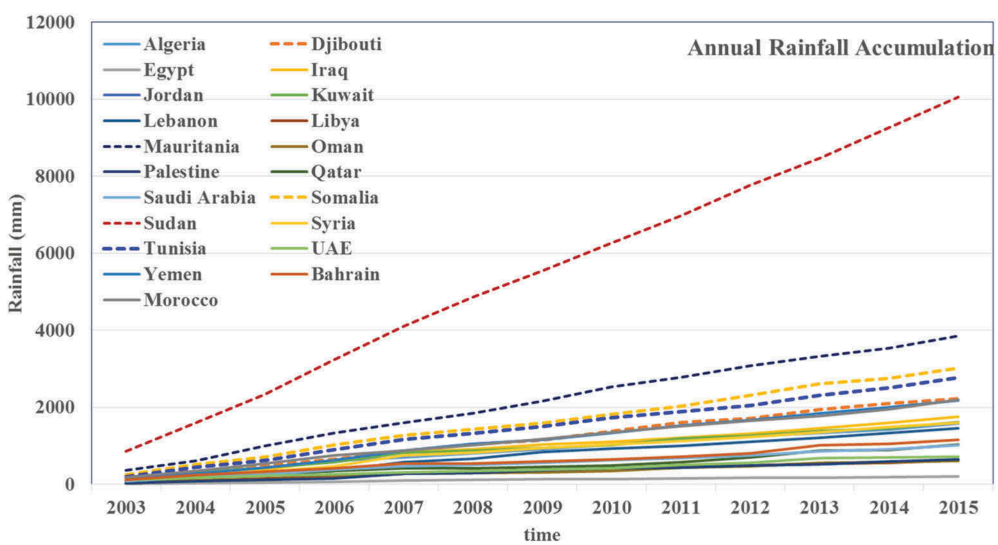

Figure 2. Rainfall accumulation of the Arab countries from 2003 to2015.

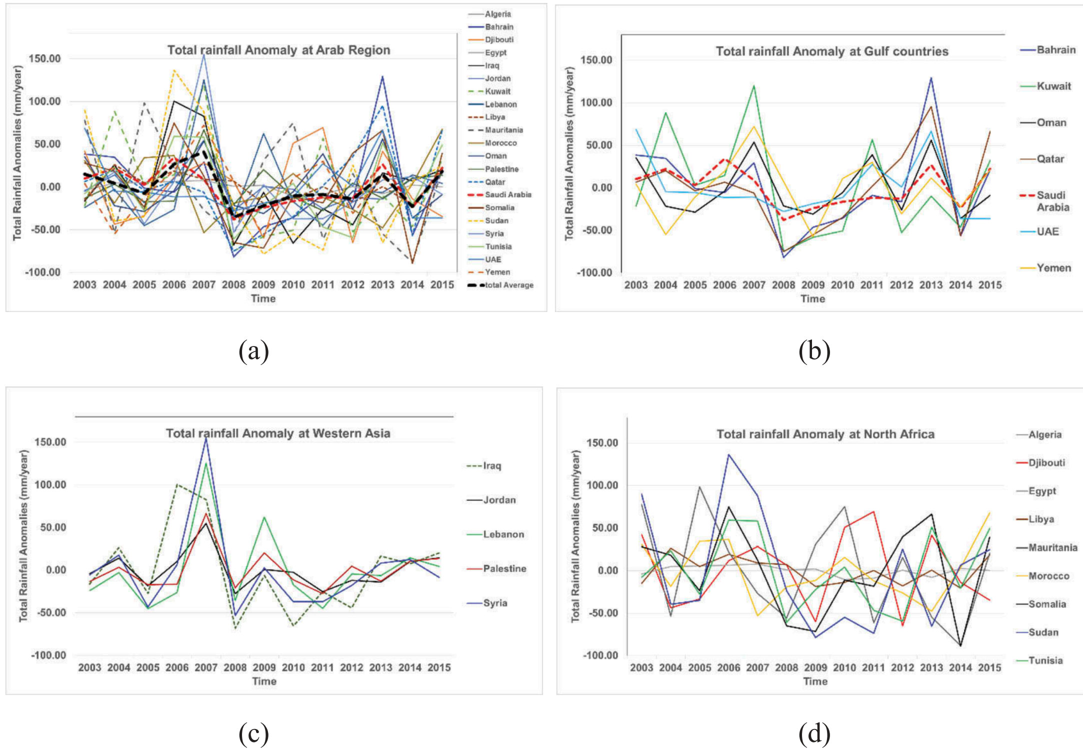

Figure 3. Rainfall anomalies of the Arab countries showing the temporal variability from 2003 to 2015.

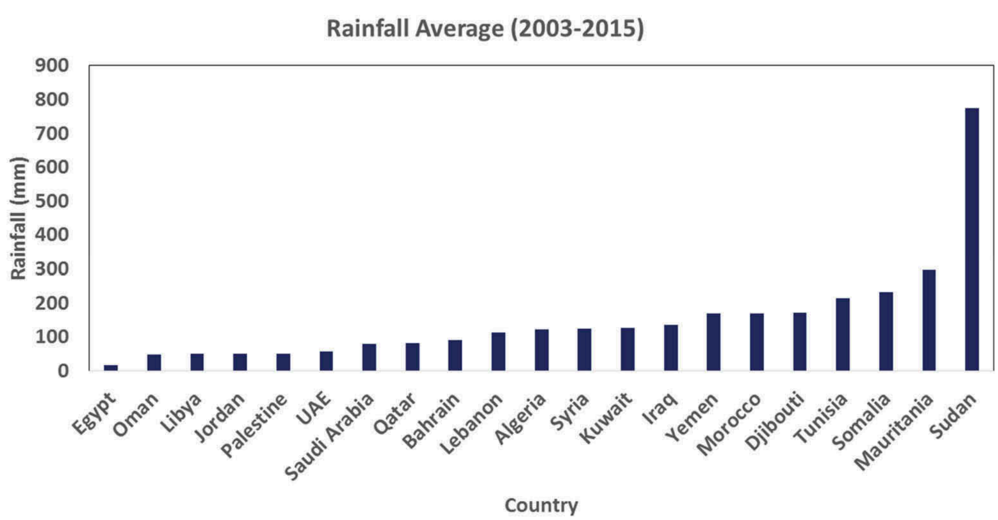

Figure 4. Annual average rainfall of the Arab countries from 2003 to 2015.

Actual evapotranspiration

In this section, the annual actual evapotranspiration (ET) were estimated for all the countries, and sub-regions. The actual ET is highly variable from one country to the other; for instance, in Saudi Arabia, the ET is declining, as shown in Figure 7 (in red) and is increasing in Sudan (the blue dotted line). Kuwait (green line) is very changeable from 1 year to the next, as shown in 2010 and 2008 (very high ET) versus 2009 and 2011 (very low ET). The results also exhibit that the Gulf countries, such as Kuwait, Qatar, Saudi Arabia, and Bahrain, are characterized by the highest ETs, while Lebanon and Mauritania have the lowest. Kuwait exhibits a very high temporal variability from 1 year to the next (Figure 8). The average of ET at the whole Arab region, Gulf countries, Western Asia countries is decreasing but in North Africa is increasing, however, there is no a significant trend of change in general. The year of 2008 is also showing high changes in ET over most of the countries and sub-regions.

Trend analysis

The results of Man-Kendal test (MKT) and Sen's slope (SS) approach showed that for the rainfall data, there is no any

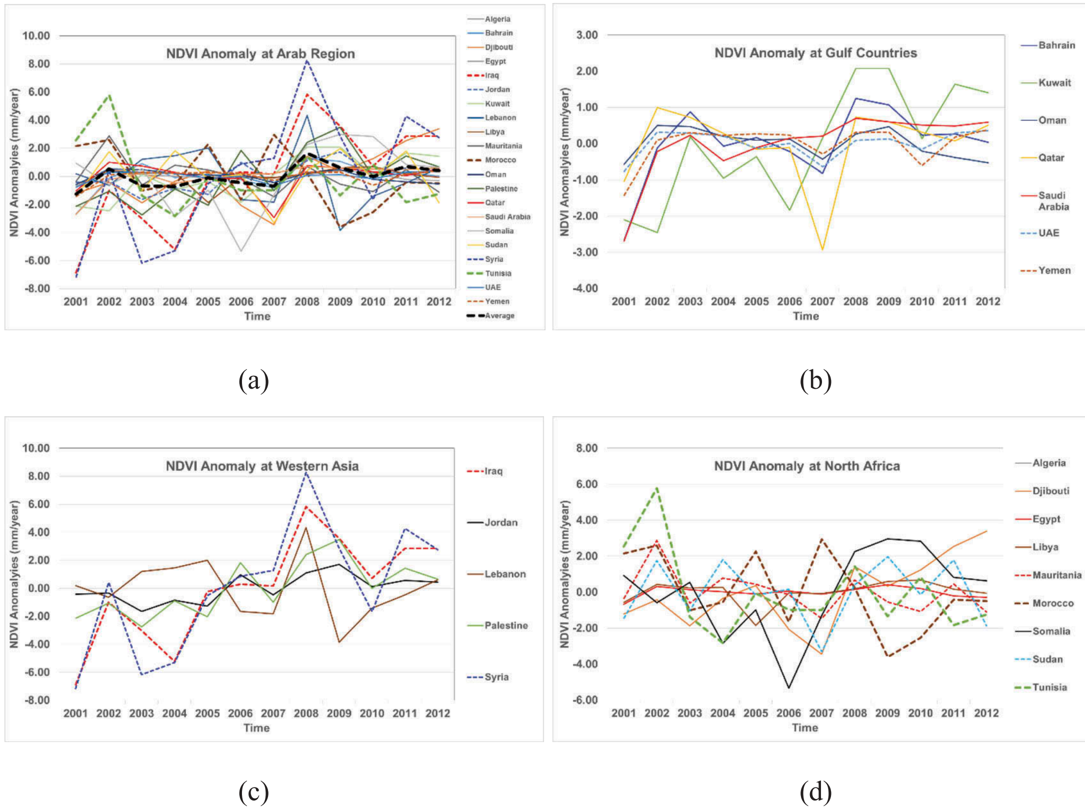

Figure 5. NDVI Anomalies of the Arab countries, showing the variability from 2001 to2012.

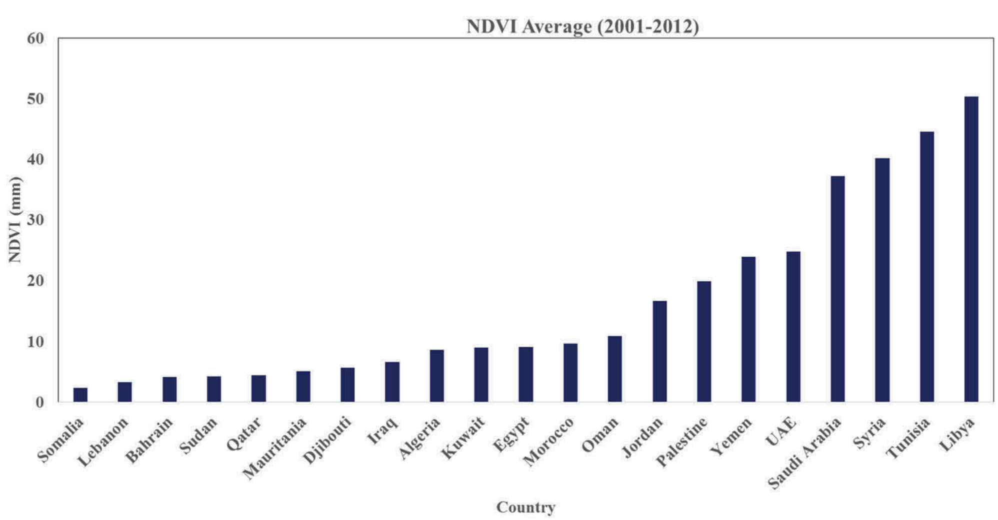

Figure 6. Annual average NDVI for the Arab countries from 2003 to 2015.

statistical significance trend for all countries except for Algeria (90%) with decreasing rate about 3.192 mm (Appendix A, Figure 1(a,b), Table 1). SS test showed that most of the countries and sub-regions are showing a declining trend of change, except (Lebanon, Palestine, Qatar, Syria, Yemen, and Western Asia Countries) showed an increasing trend. The maximum declining of rainfall was recorded in Mauritania and Sudan about 5.2 and 3.9 mm. Both Lebanon and Qatar showed the highest increasing rates of about 2.6 and 1.98 mm. The Total average of the Arab countries, North Africa, and Gulf countries are showing a declining trend of rainfall, but the west Asia countries is increasing.

Statistical significance trend for NDVI was found about 95% in many countries such as: Djibouti, Iraq, Kuwait, Palestine, Saudi Arabia, Syria, and the west Asia countries, and 90% significance level in Western Asia countries, Algeria, and Jordan (Appendix A, Figure 1(c,d), Table 2). Based on SS method, NDVI are increasing generally in Arab region, North Africa, wester Asia, Gulf countries, and most of the countries except (Egypt, Lebanon, Mauritania, Morocco, Oman, Qatar, Saudi Arabia, and

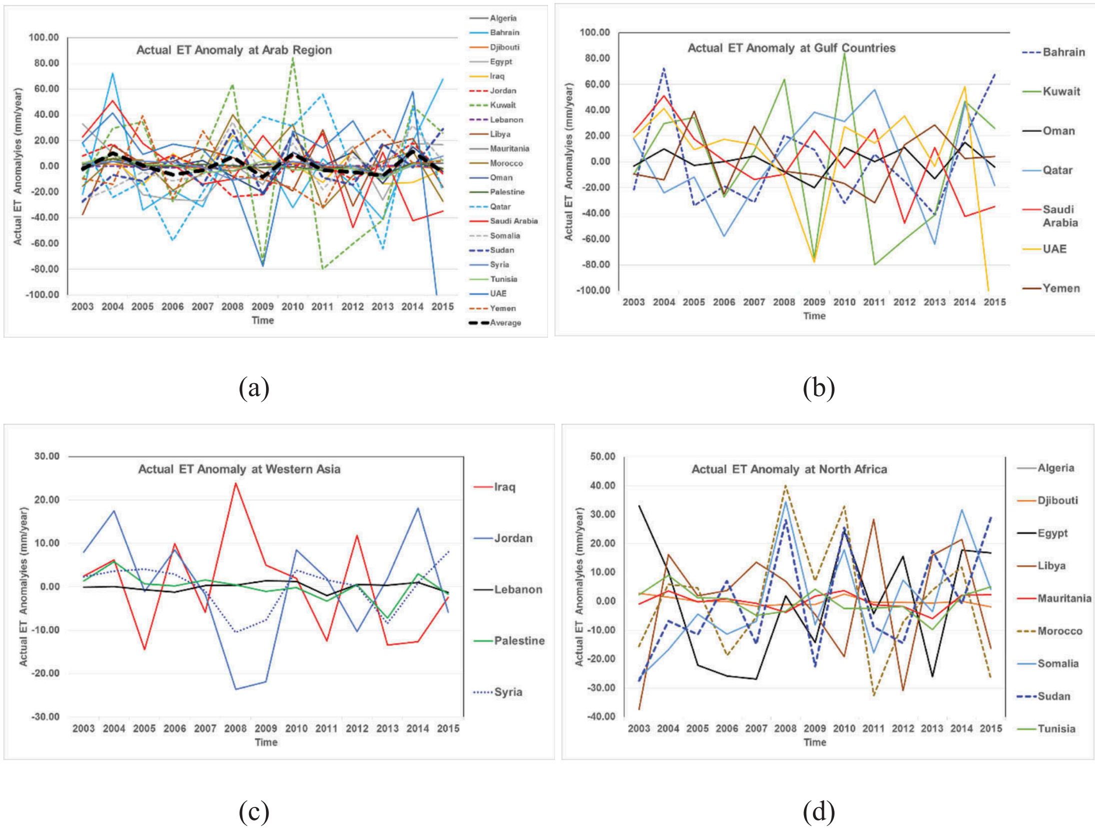

Figure 7. Actual ET anomalies of the Arab countries, showing the variability from 2003 to 2015.

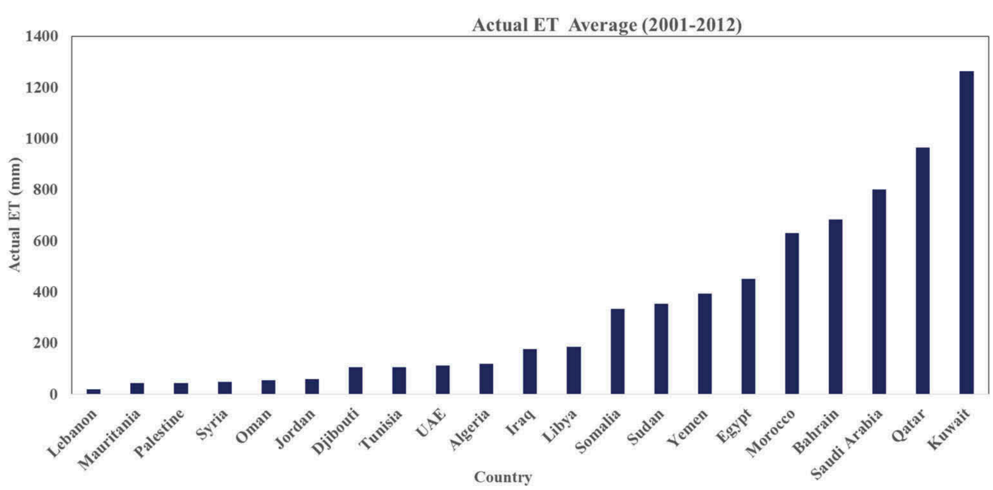

Figure 8. Actual ET average of the Arab countries, showing the drought variation from 2003 to 2015.

Tunisia). The maximum increasing trends of NDVI were recorded in Syria and Iraq, and the maximum declining trends were observed in Morocco and Tunisia.

The ET shows a declining trend in the Arab region, Wester Asia, and Gulf countries, but increasing in North Africa. A statistical significant trend of 95% was recorded only in Palestine, and 90% was observed in Djibouti, Saudi Arabia, and Somalia, but the other countries does not show a statistical significance trend (Appendix A, Figure 1(e,f), Table 3). The maximum declining rate of ET was observed in Saudi Arabia, but the maximum increasing trend was recorded in Qatar, Somalia and Sudan.

Total water storage anomalies

GRACE TWS were downloaded and processed to estimate the annual anomalies of total water storage over the study area between October 2002 and September 2015. Spatial and temporal analyses were conducted to understand the variability in the study region. Figure 9 shows the time series of Total Water

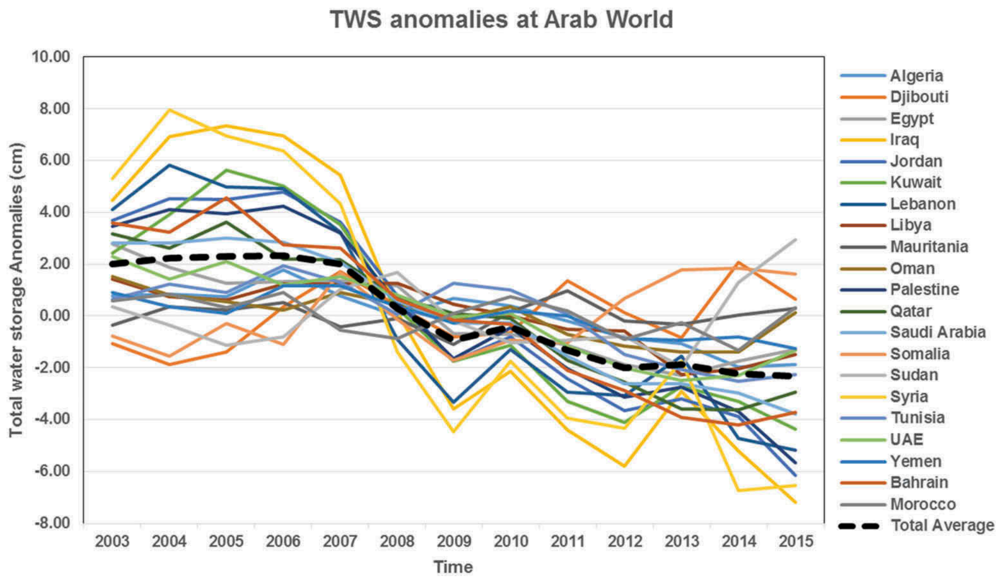

Figure 9. The TWSA estimated for all Arab countries, showing a declining trend in all the countries except four (Sudan, Somalia, Mauritania, and Djibouti).

Storage Anomalies (TWSA) for all Arab countries, indicating a remarkable declining trend of total water storage over the whole region, except for four countries (Sudan, Somalia, Mauritania, and Djibouti) as also shown in Figure 10. The declining water volumes (Figure 9), estimated based on the linear time series, varies from −10775.92 MCM in Saudi Arabia to −4.7 MCM in Bahrain. Sudan is the country showing the highest increase in total water storage (about +1586.9 MCM), and Somalia shows the second highest (about 1099.3 MCM.) The most declining water storages were recorded from high to low as follows: Saudi Arabia, Iraq, Algeria, Libya, Egypt, Syria, and Jordan. It might be due to increasing in water demands and usage resulting of population growth in these countries. It was noted that there are two stages for the TWS variability based on the time series data; the first one was a stable stage (not highly changeable) from 2002 to 2008, but the second stage was highly changeable, showing a decreasing trend in all countries between 2008 to 2015 (Figure 9).

Groundwater storage anomalies

The groundwater storage variability was also conducted by using GRACE and GLDAS data. The results of the time series analysis revealed that the groundwater storage changes (Figure 11) from 2002–2015 declined in all countries except Somalia and Djibouti. Saudi Arabia was the highest user of groundwater and showed the largest decline in groundwater volume (about −18437.2 MCM from 2002–2015); and the lowest user was Bahrain, where groundwater storage decreased by about 4.3 MCM. Groundwater shortages from 2002–2015 show

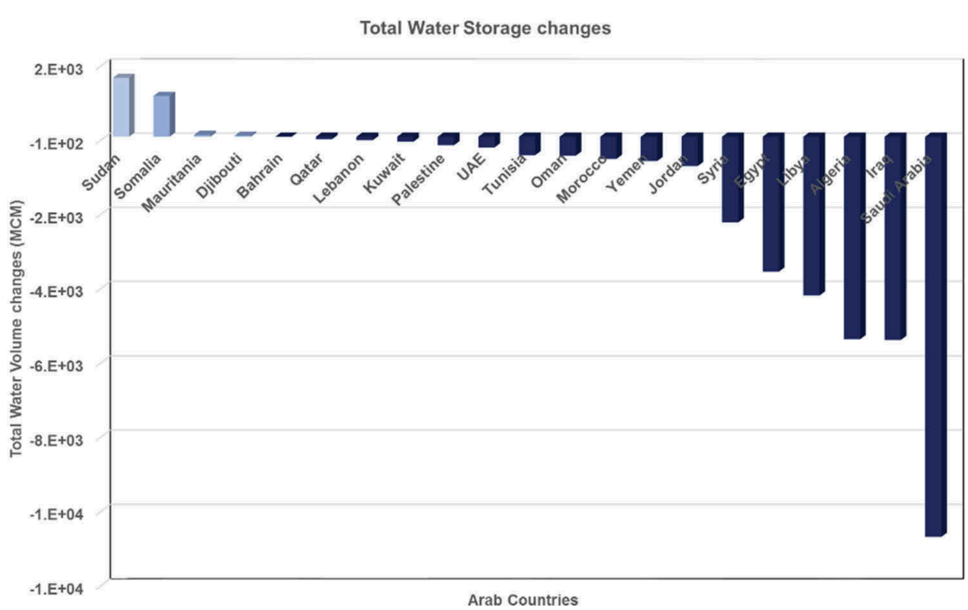

Figure 10. The accumulated TWSA estimated from October 2002 to September 2015 showing a decreasing in the water storage in most of the Arab world except Sudan, Somalia, Mauritania, and Djibouti.

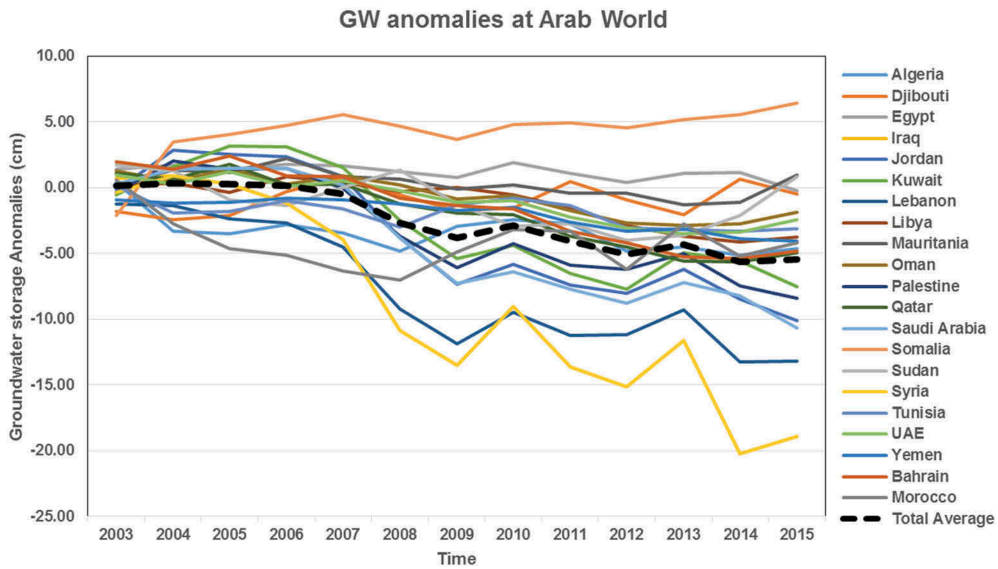

Figure 11. Groundwater storage anomalies estimated from October 2002 to September 2015 for all Arab countries, showing a declining trend in all countries except Somalia and Djibouti.

high variability from one country to the next (Figure 12). The highest levels of groundwater use are ordered from high to low as follows: Saudi Arabia, Iraq, Algeria, Libya, Egypt, and Syria.

Spatiotemporal variability of total water storage and groundwater

Spatial distribution maps for total water storage and groundwater anomalies were developed to investigate the changes from one country to another. Figure 13 shows that TWSA from 2002–2015 was variable between regions. For instance, the northeastern part of the Arab region exhibited an increase in TWSA from 2002 to 2007 while between 2007 and 2015 it experienced a decreasing TWSA. On the other hand, the western and southern regions exhibited a decreasing TWSA from 2002–2007 but started to increase between 2008 and 2015 (Figure 13). In the case of groundwater storage anomalies (Figure 14), it was noted the spatiotemporal variability is remarkable in most of the countries. In Saudi Arabia, Syria, and Iraq, groundwater was decreasing gradually from 2002 to 2006; however, after 2006, it dramatically decreased until 2015. In South Sudan, the situation is different as we noticed that groundwater was increasing or stable during the analysis period. The results reveal that TWSA and groundwater storage anomalies are highly variable in both space and time from one region to the next.

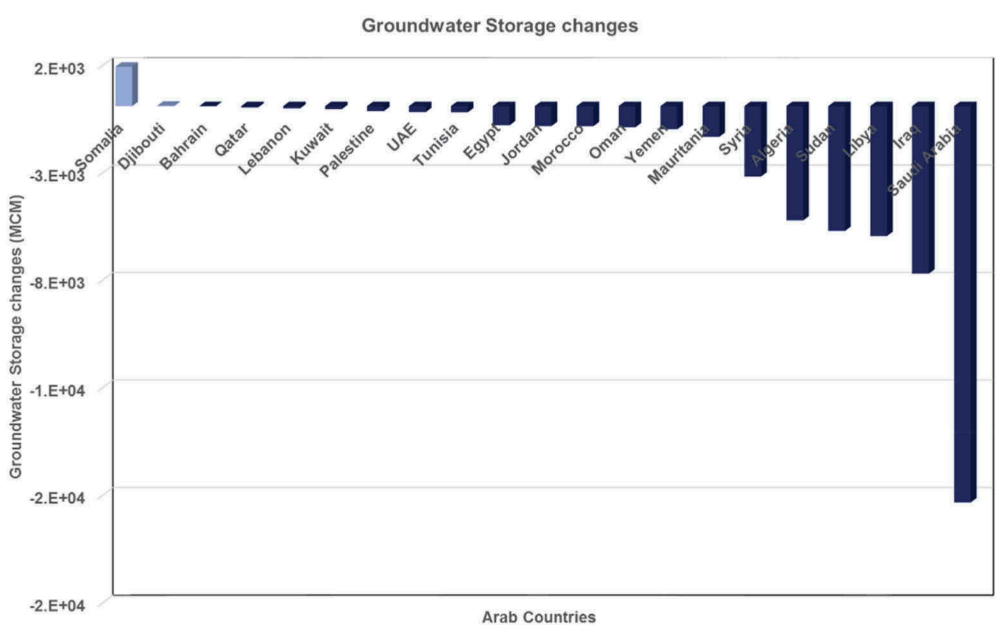

Figure 12. Groundwater storage changes (MCM) estimated from October 2002 to September 2015 for all Arab countries, showing a decrease in the water storage in all countries except Somalia and Djibouti.

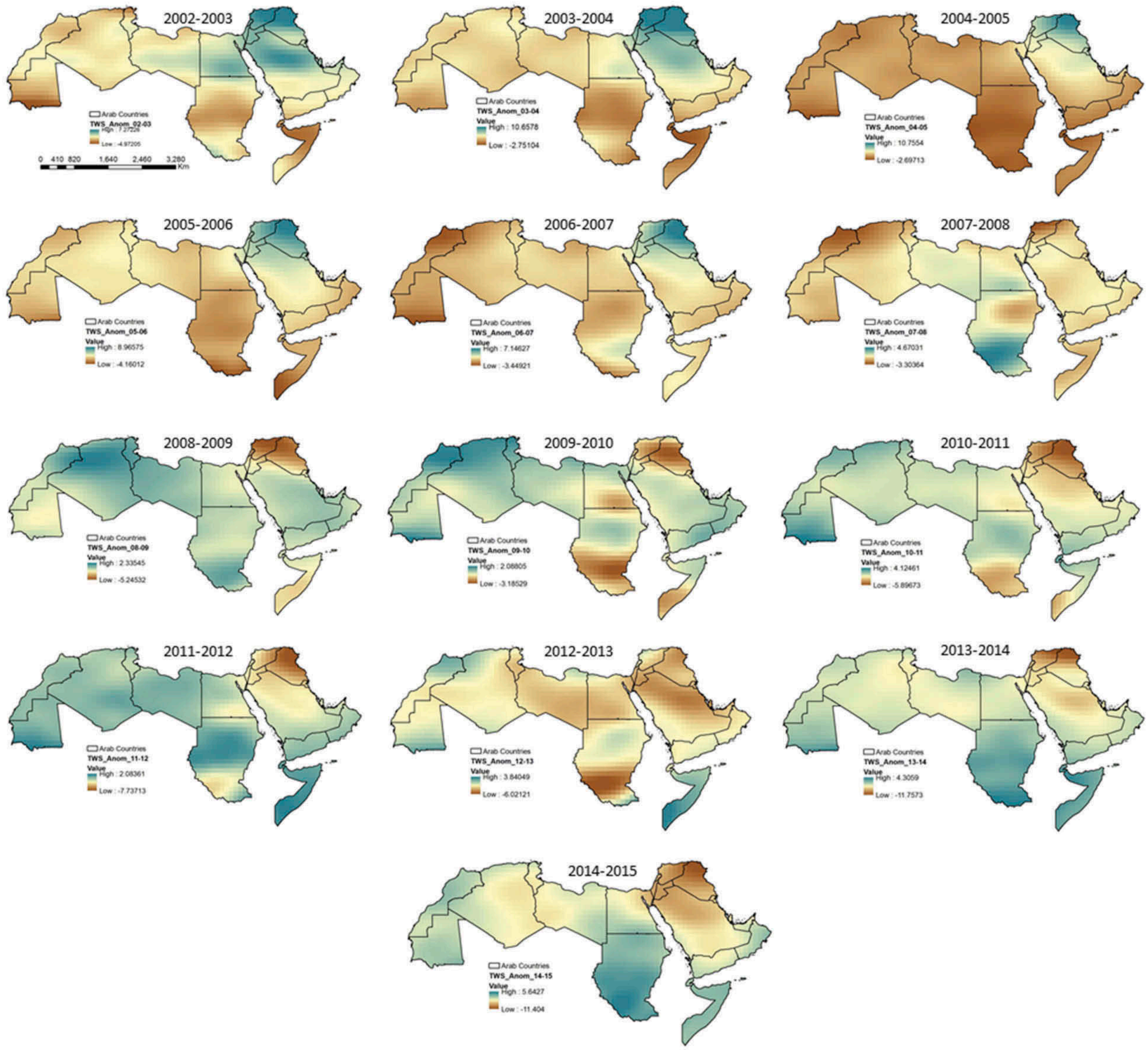

Figure 13. Spatial variability of GRACE TWSA in Arab countries, showing the spatial changes between countries and a high variability from October 2002 to September 2015.

Conclusions

The Arab region lies mainly in arid to semi-arid zones and renewable water resources are exceptionally low compared to other regions in the world. In this study, tools such as global data sets were utilized to analyze the spatial and temporal variability of water resource components, including rainfall, NDVI, ET, total water storage, and groundwater. The trend analysis by using Mann–Kendal and Sen's Slope methods was conducted temporally and spatially considering the whole region, and countries and sub-regions. The precipitation over the Arab region was found to be very variable and exhibited two trends: declining from 2003–2008 and increasing from 2009–2015. Based on the trend analysis, the Arab countries, North Africa, and Gulf countries are showing a declining trend of rainfall, but the west Asia countries is exhibiting an increasing trend.

NDVI exhibited an increasing general trend over the Arab region and all sub-regions due to the increase of agriculture activities from population growth and development. Statistical significance trend for NDVI was found about 90% and 95% in many countries over the region. Based on Sen's Slope, most of the countries are showing an increasing trend of NDVI. There is no significance statistical trend of ET over the region and sub-regions, but generally, the ET is declining in all the regions except North Africa is increasing. Satellite-based data were used successfully to evaluate the water resources availability and variability in the Arab region. GRACE data and GLDAS data were used to estimate the TWSA and groundwater storage anomalies for all countries, which are highly variable across both space and time. An interesting finding was observed from these analysis that the year of 2008 is a remarkable year as the rainfall was declining, NDVI was remarkably increasing, and ET was increasing, therefore, the total water storage over the area showed that 2008 is a remarkable declining year over the region.

Most of the countries suffer from a dramatic decline in the TWS, except Sudan and Somalia. Saudi Arabia, Iraq, Algeria, Libya, Egypt,

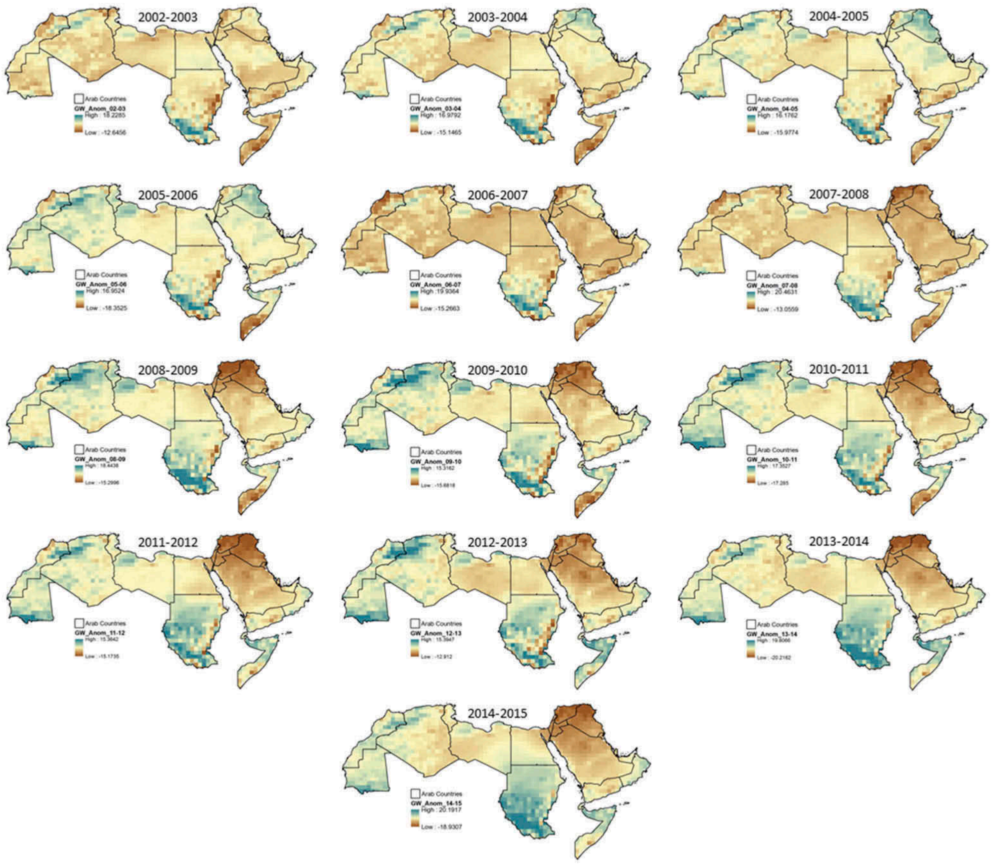

Figure 14. Spatial variability of groundwater storage anomalies TWSA of Arab countries, showing the spatial changes between countries and a high variability from October 2002 to September 2015.

Syria, and Jordan show an extreme shortage of water resources. Somalia and Sudan show an increase in average TWSA; this might be due to receiving very high amounts of precipitation. The most vital contribution of this study shows that water scarcity in the Arab region is increasing over time with a significant high spatiotemporal variability. This urges the policy- and decision-makers in these countries to consider supply and demand management strategies for the future. The present study could provide a spatiotemporal analysis for the water resources availability in all Arab countries; this could be the way forward for more sustainable water management in the future. Consequently, such implications and results will be a guide for all stakeholders, including government, society, and the private sector, to manage their water availability. The logical extension of this study is to deeply focus on each country separately and consider a longer analysis period along with climate change scenarios.

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Appendix A.

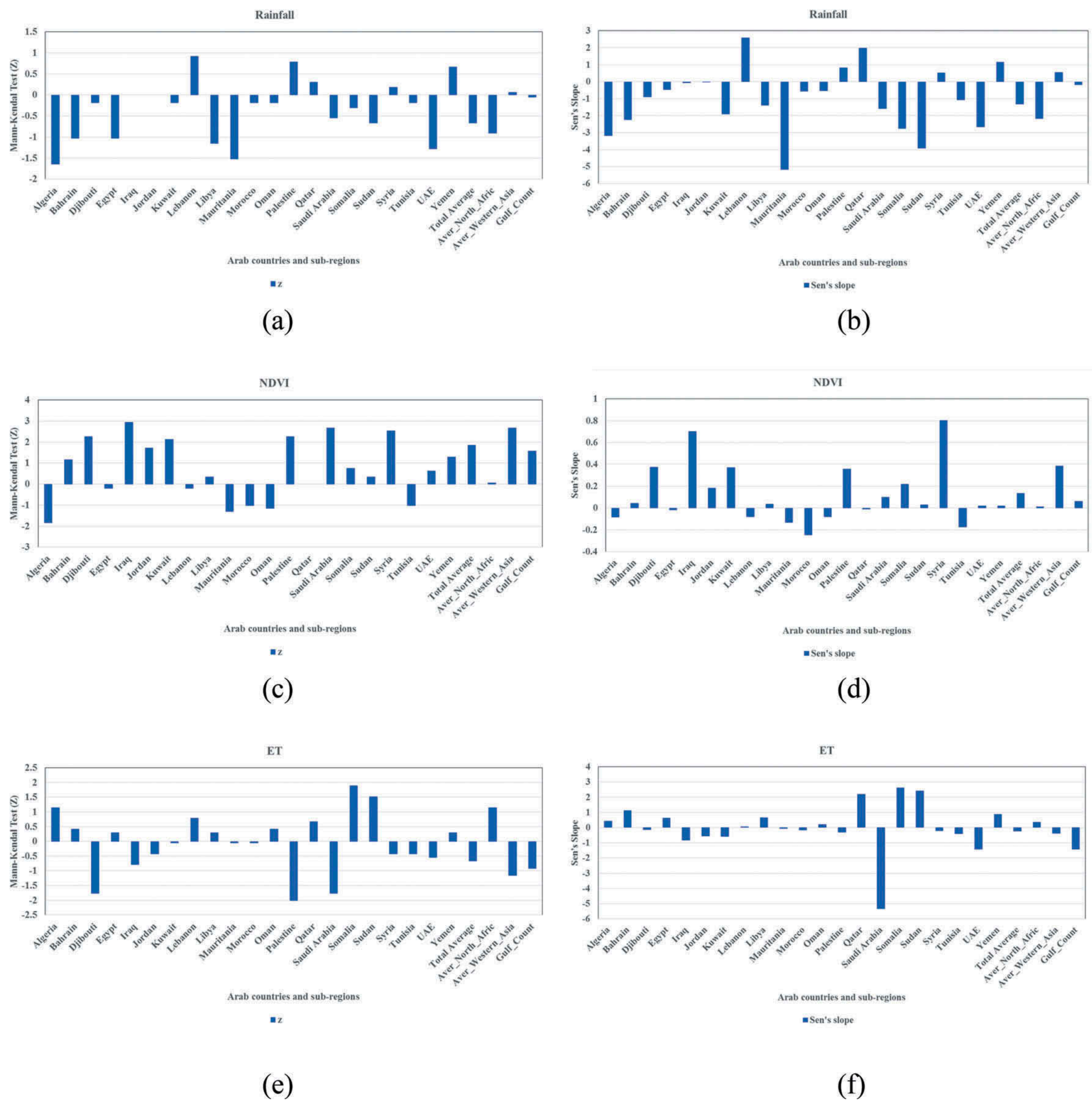

Figure A1. Trend Analysis of Mann-Kendal test and Sen's slope for the rainfall data (a, b), NDVI (c, d), and ET (e, f).

Table A1. Mann-Kendall trend test, Pettitt's test, and Sen's slope for the rainfall data over the Arab region.

		Mann-Kendall trend test			Pettitt's test		Sen's slope	
	Country	z	p-value	S	Change points		Sen's slope	Significance level
1	Algeria	-1.647	0.100	-28.000	4		-3.192	90%
2	Bahrain	-1.037	0.300	-18.000	5		-2.250	
3	Djibouti	-0.183	0.855	-4.000	9		-0.911	
4	Egypt	-1.037	0.300	-18.000	7		-0.469	
5	Iraq	0.000	1.000	0.000	5		-0.080	
6	Jordan	0.000	1.000	0.000	5		0.000	
7	Kuwait	-0.183	0.855	-4.000	5		-1.918	
8	Lebanon	0.915	0.360	16.000	4		2.602	
9	Libya	-1.159	0.246	-20.000	6		-1.388	
10	Mauritania	-1.525	0.127	-26.000	8		-5.181	
11	Morocco	-0.183	0.855	-4.000	4		-0.572	
12	Oman	-0.183	0.855	-4.000	11		-0.537	
13	Palestine	0.793	0.428	14.000	4	9	0.831	
14	Qatar	0.305	0.760	6.000	8	9	1.990	
15	Saudi Arabia	-0.549	0.583	-10.000	5		-1.589	
16	Somalia	-0.305	0.760	-6.000	4	5	-2.752	
17	Sudan	-0.671	0.502	-12.000	5	6	-3.917	
18	Syria	0.183	0.855	4.000	5		0.534	
19	Tunisia	-0.183	0.855	-4.000	5		-1.092	
20	UAE	-1.281	0.200	-22.000	11		-2.669	
21	Yemen	0.671	0.502	12.000	3		1.159	
22	Total Average	-0.671	0.502	-12.000	5		-1.321	
23	Aver_North_Afric	-0.915	0.360	-16.000	5		-2.175	
24	Aver_Western_Asia	0.061	0.951	2.000	5		0.547	
25	Gulf_Count	-0.061	0.951	-2.000	5		-0.184	

Table A2. Mann-Kendall trend test, Pettitt's test, and Sen's slope for the NDVI data over the Arab region.

		Mann-Kendall trend test			Pettitt's test		Sen's slope	
	Country	z	p-value	S	Change points		Sen's slope	Significance level
1	Algeria	-1.852	0.064	-2 8.000	5		-0.083	90%
2	Bahrain	1.166	0.244	18.000	7		0.044	
3	Djibouti	2.263	0.024	34.000	7		0.375	95%
4	Egypt	-0.206	0.837	-4.000	10		-0.017	
5	Iraq	2.949	0.003	44.000	5	7	0.702	95%
6	Jordan	1.714	0.086	26.000	5		0.184	90%
7	Kuwait	2.126	0.034	32.000	6		0.371	95%
8	Lebanon	-0.206	0.837	-4.000	5		-0.081	
9	Libya	0.343	0.732	6.000	7		0.036	
10	Mauritania	-1.303	0.193	-20.000	6		-0.134	
11	Morocco	-1.029	0.304	-16.000	8		-0.247	
12	Oman	-1.166	0.244	-18.000	9		-0.081	
13	Palestine	2.263	0.024	34.000	5		0.358	95%
14	Qatar	0.000	1.000	0.000	7		-0.010	
15	Saudi Arabia	2.674	0.007	40.000	7		0.101	95%
16	Somalia	0.754	0.451	12.000	7		0.220	
17	Sudan	0.343	0.732	6.000	7		0.030	
18	Syria	2.537	0.011	38.000	5		0.803	95%
19	Tunisia	-1.029	0.304	-16.000	2		-0.175	
20	UAE	0.617	0.537	10.000	10		0.020	
21	Yemen	1.303	0.193	20.000	2		0.019	
22	Total Average	1.852	0.064	28.000	7		0.135	90%
23	Aver_North_Afric	0.069	0.945	2.000	7		0.011	
24	Aver_Western_Asia	2.674	0.007	40.000	5		0.386	95%
25	Gulf_Count	1.577	0.115	24.000	7		0.063	

Table A3. Mann-Kendall trend test, Pettitt's test, and Sen's slope for the ET data over the Arab region.

		Mann-Kendall trend test			Pettitt's test		Sen's slope	
	Country	z	p-value	S	Change points		Sen's slope	Significance level
1	Algeria	1.159	0.246	20.000	5	4	0.440	
2	Bahrain	0.427	0.669	8.000	11		1.122	
3	Djibouti	-1.769	0.077	-30.000	4		-0.138	90%
4	Egypt	0.305	0.760	6.000	7		0.639	
5	Iraq	-0.793	0.428	-14.000	10		-0.832	
6	Jordan	-0.427	0.669	-8.000	4		-0.551	
7	Kuwait	-0.061	0.951	-2.000	8		-0.583	
8	Lebanon	0.793	0.428	14.000	4	5	0.065	
9	Libya	0.305	0.760	6.000	1	8	0.650	
10	Mauritania	-0.061	0.951	-2.000	11		-0.062	
11	Morocco	-0.061	0.951	-2.000	8		-0.169	
12	Oman	0.427	0.669	8.000	7		0.220	
13	Palestine	-2.013	0.044	-34.000	6		-0.323	95%
14	Qatar	0.671	0.502	12.000	5		2.212	
15	Saudi Arabia	-1.769	0.077	-30.000	9		-5.330	90%
16	Somalia	1.891	0.059	32.000	5		2.632	90%
17	Sudan	1.525	0.127	26.000	5	7	2.425	
18	Syria	-0.427	0.669	-8.000	4		-0.221	
19	Tunisia	-0.427	0.669	-8.000	3	4	-0.424	
20	UAE	-0.549	0.583	-10.000	2		-1.438	
21	Yemen	0.305	0.760	6.000	9		0.895	
22	Total Average	-0.671	0.502	-12.000	3		-0.235	
23	Aver_North_Afric	1.159	0.246	20.000	5		0.354	
24	Aver_Western_Asia	-1.159	0.246	-20.000	4		-0.378	
25	Gulf_Count	-0.915	0.360	-16.000	3		-1.422	