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Postdoctoral research report

Impacts of Climate Change on Arid Regions

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Declaration and Approval

I hereby confirm this work is original and supported by my own experimental results.

Name and descriptions	**Signed**	**Date**
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Preface

The present research has analyzed many aspects, which has covered the main scope of climate change issue in several fields such as variation of glaciers mass-balance, hydrological cycle, drought pattern, vegetation cover, land use change, and food security. During the collaboration from 01/2017 to 12/2018, I wrote nine articles, seven were published in 2017, one was published in 2018 and another one is submitted to Climate Research Journal (under review). In addition, I am a co-author in a paper but did not mention in this report.

This report consists of nine chapters; each chapter is one article. Several methodologies have been followed to accomplish the research objectives. I have discussed the impact of global warming on the mass balance of the glacier in the Northern Hemisphere in ten glacier stations, which were distributed in three continents including eight countries, such as China, Svalbard, Sweden, Norway, Iceland, Greenland, Canada, and United State. The period of glacier mass balance analysis was from 1979 to 2016.

Also, I have investigated the impacts of temperature rise trend on glacier-mass balance, snow density, snowmelt, snow depth, and runoff by using observations of nine glacier stations that covered most of China over the period of 1979-2013. The materials used in this research such as Arcgis software v 10.2, SPSS software v 17 and Matlab. Additionally, I used the observation data of glacier (19 glacier stations); precipitation and temperature (66 stations).

The meteorological drought indices (SPI and SPEI) were used to monitor the drought cycle in China, Sudan, and South Sudan. Normalized Difference Vegetation Index (NDVI) was utilized to monitor the vegetation cover change in China and Sudan. The analysis land use/cover change and food security in Sudan are also my among my current research contributions.

I wish these contributions would be more useful for the future researches, and also useful for decision-makers.

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Abstract

This report is divided into nine sections. In section one (Chapter 1) the impacts of temperature trends on glacier-mass balance, snowmelt and runoff were investigated. The impacts of temperature trend on glacier-mass balance, snowmelt and runoff were assessed by using observations of ten glacier stations which distributed in three continents including eight countries such as China, Svalbard, Sweden, Norway, Iceland, Greenland, Canada and United State, the period of study is during 1979-2016. The analysis showed an increasing trend of temperature on all of the selected stations. Here, we present that an average of ten stations, the temperature ℃ was increasing at the rate of 0.54/10a. The increasing trend of temperature showed a negative relationship with annual glacier-mass balance on most of the stations and caused a decrease in annual glacier mass-balance. Results of Pearson's correlation analysis showed a highly significant negative correlation between temperature with glacier mass-balance (correlation coefficient CC = -0.618 at 0.01 significance level). There was a significant positive correlation between temperature and snowmelt (CC = 0.753 at 0.01 significance level), also there was a significant positive correlation between temperature with runoff (CC = 0.89 at 0.01 significance level). The increasing trend of temperature caused an increasing trend in both annual snowmelt and runoff anomaly % at the rate of 16.44/10a and 16.49/10a, respectively. There was a declining trend in glacier mass-balance at a rate of -0.17/10a. We concluded that the annual snowmelt and annual runoff are significantly sensitive to temperature in the ten stations of the study area. This contribution has provided information will be useful for further understanding of glacier mass-balance variation research and water resource management.

In chapter two, the research to investigate the impact of temperature trend on glacier-mass balance, snow density, snowmelt, snow depth and runoff by using observations of nine glacier stations that covered most of China during 1979-2013. Trend analysis showed an increasing trend of temperature on all of the selected stations. On average, temperature ℃ was increasing at the rate of 0.46/10a. The increasing trend of temperature showed a negative relationship with annual glacier-mass balance on most of the stations and caused a decrease in annual balance. Results of Pearson's correlation analysis showed a highly significant negative correlation between temperature and snow density (correlation coefficient (CC = -0.661 at 0.01 significance level). There was a significant positive correlation between temperature and snowmelt (CC = 0.532 at 0.01 significance level). There was a significant negative correlation between temperature and snow depth (correlation coefficient (CC = -0.342 at 0.05 significance level). Moreover, there was a significant positive correlation between temperature and runoff (CC = 0.586 at 0.01 significance level). An increasing trend of temperature caused an increasing trend of annual snowmelt and runoff anomaly % at the rate of 24.82/10a and 9.87/10a, respectively. On the other hand, a declining trend in annual snow density and snow depth anomaly % was found at a rate of -5.32/10a and -1.93/10a, respectively. We concluded that the snow density, snowmelt and runoff are significantly sensitive to temperature in China. This contribution has provided information for further understanding of glacier variation and its influencing factors.

In chapter three, the research to investigate the drought cycles in two countries (Sudan and South Sudan) by using characteristics of Standardized Precipitation Index (SPI) during 1961-2013 to provide valuable information for better adaptation and mitigation of consequences of drought to create a strategically good planning. This study compared the effectiveness of SPI on a long-term scale of (1, 3, 12, 24, 36 and 48 months lead time) drought conditions. The SPI 12-month showed high frequency of droughts in 1966 - 1968, 1974, 1984 - 1985, 1991 - 1992, 2000 - 2003, 2005 - 2006 and 2010. A high frequency of an annual-SPI mild drought was found in: Portsudan, Dongala, Shendi, Khartoum, Alfashir, Geneina, Malakal, Juba and Wau; moderate drought in: Portsudan, Halfawadi, Karrima, Abuhamed, Atbara, Gadarif and Edduim; severe drought in: Aroma, Kassala, Wadmedani, Edduim, Elobeid, Zalingei and Geneina; and extreme drought in: Gadarif, Singa, Abunama, Edduim, Elobeid, Alfashir and Zalingei. The increasing trend of drought, which was associated with the decreasing

tendency of precipitation, would reduce the natural vegetation and crop covers as well as livestock production. In fact, this research has revealed that ongoing droughts caused by a decrease in precipitation would eventually reduce the natural vegetation cover, croplands, and livestock production.

In chapter four, the research to investigate the impacts of climate variations on land use policies, food security and vegetation cover in Gadarif State (eastern Sudan) from 1961 to 2013. Analysis of precipitation and temperature time series revealed that the annual precipitation was decreasing while the temperature was increased in the study area. Precipitation was decreasing at a rate of −50.3 mm/10a, while the temperature was increasing at a rate of 0.02°C/10a. The result of both SPEI and SPI showed that the Gadarif State has been changed to a high frequency of drought during 1961-2013. Sorghum yield showed a significant positive relationship with precipitation during July and October (CC = 0.364 and 0.321, respectively), moreover, a significant positive relationship between Sesame yield and precipitation was observed during July (CC = 0.335). A significant negative relationship between Sorghum yield and mean temperature was observed during the rainy season (July to October) with CC = -0.278. The yield productivity of Sorghum and Sesame had decreased significantly (from more than 800 kg/ha in the 1960s to less than 200 kg/ha in 2000s for Sorghum, while 500 kg/ha in 1960s to 100 kg/ha in 2000s for Sesame). The Mechanized Rain-fed Agriculture (MRA) area of Sorghum and Sesame in the Gadarif State had been increased from 1,058,241 ha in 1961to 2,799,655 ha in 2013. Thus, we ultimately suggest that in the Gadarif State, policymakers must strive for an increase in yield per unit area by using sufficient fertilizers along with the gradual increment in tendencies of grain production through expansion of the cultivated area.

In chapter five, the Qinghai Province, situated in the northwest of China, is experiencing continuous warming. This ongoing warming has a direct connection to vegetation cover, with significant societal and economic impacts in this region. In the present study, we investigate the correlation between climate change and vegetation cover in Qinghai Province. The analysis shows that in the Qinghai Province, the order of NDVI is highest in summer followed by autumn, spring and winter. By calculating the average annual and seasonal-NDVI values, it is deduced that the main type of vegetation cover in the Qinghai Province has an upward trend at the rate of 0.013/10a, 0.016/10a, 0.035/10a and 0.058/10a for annual, winter, spring and summer, respectively. While a downward trend at a rate of 0.056/10a is present in autumn-NDVI. At the 0.01% significance level, a significant positive relationship of winter-NDVI with mean winter precipitation and temperature is revealed. Mean NDVI of spring and autumn show a significant positive relationship with respective seasonal mean precipitation. However, a significant difference is present between mean summer-NDVI and mean summer precipitation. Furthermore, mean NDVI of summer and autumn has a significant negative relationship with respective seasonal mean temperature.

In chapter six, the research to investigate the land cover changes in Sudan in the period of 2001-2013 by using the MODIS data and to identify the climate factors influencing the land cover. SPSS software was used to investigate the correlation of climate factor with vegetation cover, also Arcgis software was used to analyze the NDVI data. The results indicate that the monthly average timescale, NDVI value curve distribution in the year, July to October as the centre to both sides of decreasing vegetation cover in the year. In the spatial distribution of mean NDVI in Sudan, a high value was found in the southern part. On the other hand, a low value of vegetation cover was found in the northern part. NDVI spaces mean presenting features values: autumn follows by summer then winter. By calculation of average annual and seasonal-NDVI values, it was deduced that the main vegetation cover type was increasing in winter and summer seasons at the rates of 0.014/10a and 0.008/10a, respectively. While winter-NDVI was decreasing the rate of 0.001/10a and 0.026/10a in autumn and on the annual scale, respectively. Annual NDVI showed a significant degradation (area = 12705.7 km^2, 0.5 % of total area) in the middle and eastern parts and significant improvement (area = 22485.4 km^2, 0.9 % of the total area) in the southern part of the country due to the increase in precipitation and decrease in temperature. Mean summer and autumn-NDVI showed a significant difference 0.01 % significance level with mean summer and autumn precipitation (correlation coefficients = 0.955 and 0.953, respectively). While there was a significant negative relationship between mean summer and autumn-NDVI with mean summer and autumn temperature at 0.01% significance level (correlation coefficients = -0.270 and -0.820, respectively).

In chapter seven, the research to investigate the drought pattern in Qinghai Province for the period between 1961and 2013. Utilizing the monthly precipitation data of 32 stations and adopting the Standardized Precipitation Index (SPI), we explore the possible drought events in Qinghai Province over the past 53 years. We find a high frequency of drought in the Qinghai Province (based on 12-month SPI index) in 1962, 1966-1967, 1970, 1973, 1986, 1992-1993, 1996 and 2001-2004. We demonstrate that some areas in the eastern Qinghai (including Mangya, Lenghu, Xiaozaohuo, Dachaidan, Ge'ermu, Wudaoliang, Nuomuhong and Tuoyuohe) are changing from humid to drought climate. On the other hand, most of the eastern part of Qinghai Province is changing to a humid environment. We demonstrate that the drought is persistently occurring in Qinghai Province with prolonged periods. The degree order of seasonal-SPI drought index in Qinghai Province is maximum in summer followed by autumn, spring and winter. Findings of this study have significant implications for setting up adaptation and mitigation strategies related to forest and natural resources.

In chapter eight, the recent climatic changes are posing a great threat to natural resources and biodiversity worldwide and the threat is particularly eminent in Sub-Saharan Africa, urging for better adaptation interventions. In turn, in this study, we explored the drought pattern in Sudan and South Sudan for the period between 1961 and 2013. Consistent with several recent studies those characterized drought patterns; we used the Standardized Precipitation-Evapotranspiration Index (SPEI) of drought to explore possible drought events in two countries Sudan and South Sudan over the last 53 years. In Sudan, the temperature is increasing, while precipitation is dramatically decreasing. In south Sudan, we saw an opposite scenario where temperature is generally has a declining trend and precipitation is increasing. In addition, the recurrence last drought periods for the most times was moderate except the fact that in 1984, 1991, and 2000 most of Sudan and South Sudan has witnessed extreme and severe drought periods. There is a wide seasonal and spatial variability in drought intensity, as some areas became drier in summer and wetter in autumn and winter. Overall, we provide evidence that the drought is persistently occurring in Sudan with a prolonged period. This information is of high value for setting up adaptation and mitigation strategies related to forest and natural resources.

In chapter nine, the research has made to investigate and monitor the Impact of Land Use and Land Cover (LULC) changes in the eastern part of Sudan (Gadarif state) by using multi-temporal Landsat data for the years 1986, 1994 and 2013. LULC grades in the classification scheme are; Forest, Mechanized Rain-fed Agriculture (MRA), Irrigated land, Rangeland, Settlement and Water. Individual classifications based on a maximum likelihood of algorithm are employed. The results showed that a significant extensive change of LULC patterns has occurred during the previous years within the study area. The major trends were drastic conversions of natural vegetation into large-scale MRA, which increased from 1058241.2 ha in 1981 to 2459264.7 ha in 2013. This resulted in a progressive loss and degradation of Rangeland areas in Gadarif state; Rangeland was decreased from 4342154.2 ha in 1986 to 3473940 ha in 2013. Forest area and Rangeland are reduced due to of expansion in modern mechanized farming because of increasing human population to satisfy an increasing demand for food.

CHAPTER ONE

Impact of global warming on glacier mass-balance variation in different regions during 1979-2016

1.1 Introduction

Approximately 12% of the Earth's surface is covered with ice (Pachauri et al. 2007). During the quiescent phase, the ice is stagnant or flowing at a velocity lower than required to maintain the glacier size. Snow and ice accumulation in the upper area and ice melting in the lower area of the glacier gradually contribute to a steeper surface profile that is considered fundamental to re-turn the glacier surface to the pre-surge state and subsequently enables a new surge (Ingólfsson et al. 2016). It has been reported that since 1850, most glaciers in the world have been shrinking due to climate warming (Bolch et al. 2012), and the shrinkage has continued over the last two decades (IPCC 2012).

The climate with the physical properties of ice determines the extent and behaviour of glaciers, a statement that underpins the rationale for the examination of former and contemporary glacier behaviour, leading to an examination of past and present glacier behaviour within a climatic context (Paterson 1994). The evidence of a warming of the climate system is widely accepted in the scientific community, and since the 1950s, many of the observed changes are unprecedented over decades to centuries (IPCC 2012). The seasonal melt a happen around 15-20 July through the whole 21st century and coincide with the rising temperature. Therefore, the glacier melt is projected to increase with related to rise of temperature (Lang et al. 2015). Increasing temperatures have resulted in the loss of more than half of the glaciers in Asia since 1900 (Ravazzani et al. 2015).

Global increases in surface temperature have direct and indirect implications for the hydrological cycle. Anthropogenic changes in radioactive forcing affect precipitation, evaporation, and sensible heat transfer at the Earth's surface (IPCC 2012). In fact, Climate warming has impacted in most mountain glaciers, including glaciers in the Tianshan Mountains, which are in a state of rapid terminus retreat (Wang et al. 2015; Wang et al. 2013). Under global warming, glaciers are experiencing the heavy amount of glacier ablation around the world, which caused the sea-level rise and mountain (Jevrejeva et al. 2008).

Much remains unknown about the system's history before the mid-nineteenth century and the hydrological characteristics and processes of both glaciers (Häusler et al. 2016). The Pacific coastal sector of West Antarctica and the Antarctic Peninsula, in particular, are undergoing mass loss of ice, surface warming (Pedro et al. 2016; Thomas et al. 2015; Rignot et al. 2014). Studies of past mountain glacier fluctuations in many locations, such as Norway and the European Alps, have been used extensively to examine past climate changes (Dahl and Nesje 1992).

Therefore, the problem statement and justifications for this research are that the glaciers retreat will eventually lead to the loss of frozen water resource. The glacier meltwater has described playing a crucial role in irrigation during the hot and dry seasons (Sorg et al. 2014).

Snowmelt from mountain snowpacks provided an important source of freshwater for human consumption and agriculture in many regions worldwide (Christensen et al. 2004). More than one-sixth of the world's population depends on glaciers or seasonal snow for their available water, and these supplies are at significant risk because of climate warming (Barnett et al. 2005). Recent worldwide observations showed that local glaciers and ice caps (GICs) are responsible for 25% of the total global mean sea level rise (1993-2010), equivalent to 0.86 mm yr^{-1} (Church et al. 2013).

In addition to loss water from melting glaciers, the sea level can be raised, only Greenland Ice sheet that is a huge storehouse of water on Earth, and has the potential to raise the global sea level by approximately 7 m if completely melted (Houghton et al. 2001). The widespread mountain glaciers conserve huge freshwater and thus their changes have vital impacts on regional water resource and economic society besides sea level (IPCC 2012).

The fresh water is vital to the functioning of all terrestrial ecosystems both flora and the fauna that make up those ecosystems. The global hydrological cycle, renewable water resources amount to 42,000 km^3/year, the total water needs still represent only a small share of about 9 per cent of internal renewable water resources but this average masks (Food and Agriculture Organization 2001). While this proportion is likely to increase as the global human population increases in the next thirty years and the demand for water (Expósito and Berbel 2017).

The objectives of this study are as follows: (i) to explore the spatial and temporal patterns of climate variability impacts such as temperature on glacier mass-balance, snowmelt and runoff. To this end, analyses of correlation of temperature with glacier mass-balance, snowmelt and runoff; (ii) to analyse the glacier mass balance variations; (iii) to identify knowledge gaps, which need to be addressed in the future research, in addition to those indicated in previous publications. Because, IPCC (2012), showed that the global mean temperature has increased by 0.85 ℃, over the period of 1880 to 2012 and this increase in temperature is likely due to anthropogenic activities that have increased the concentrations of greenhouse gases to unprecedented levels.

Meanwhile, Marzeion et al. (2012) and Gardner et al. (2013) both showed the global warming increasing, almost the glaciers worldwide have continued to shrink as revealed by the time series of measured changes in glacier length, area, volume and mass. In addition, Lukas (2012) provided recession during the summer (ablation season) is greater than advance during the winter (accumulation season) over consecutive years. Also, Oerlemans (2005) reported that the glaciers respond sensitively to climate change, they have shown that the retreat was in response to a relatively small during an increase in global mean temperature. For all those reasons, the knowledge of the glacier mass balance is crucial both for climatic sensitivity studies and for understanding the hydrological behaviour (Wang et al. 2012; Li et al. 2010), Haeberli et al. 2008, Bolch 2007).

1.2 Materials and Methods

1.2.1 Data collection

We used the past local glacier mass-balance data which was obtained from world glacier monitoring service WGMS, http://wgms.ch/data_databaseversions. In addition, the data of snowmelt and runoff were obtained from European Centre for Medium-Range Weather Forecasts (ECMWF), http://apps.ecmwf.int/datasets/data/interim-mdfa/levtype%3Dsfc.

This research intended to provide insight into the amplitude and rate of natural changes, which were occurred due to anthropogenic influences on climate that have an impact on glacier mass-balance variation. EXCEL and SPSS (V.17) software were used to statistical analyses, such as the Pearson's correlation analyse has used to investigate the relationship between temperature, glacier mass-balance, snowmelt and runoff. This research has followed the methods of the previous study of Yagoub et al. (2018), glacier mass-balance variation in China during the past half-century.

In this paper, the formulation of per cent anomaly % reflects the direct result of simple principle which reflects the period of the snow properties such as snow density, snowmelt, snow depth and runoff. For calculations of anomaly % the formula is given below:

$$Anomaly\,\% = \frac{x-\bar{x}}{\bar{x}} \times 100 \quad (1)$$

Where, is the snow property of specific period, is average of snow property of the specific period. The advantage of anomaly per cent is that it has a simple and clear meaning.

1.2.2 Study area

In this study, we extend the study area to cover different regions; we have selected ten glacier stations, which covered different countries such as China, Svalbard, Sweden, Norway, Iceland, Greenland, Canada and United State. The WGMS IDs of these stations are 853, 291, 332, 317, 3088, 1629, 39, 0, 3690 and 205, respectively the names are URUMQI GLACIER NO. 1, MIDTRE LOVENBREEN, STORGLACIAEREN, AALFOTBREEN, HOFSJOKULL E, MITTIVAKKAT, DEVON ICE CAP NW, WHITE, MELVILLE SOUTH ICE CAP and SOUTH CASCADE (Fig. 1-1 and Table 1-1).

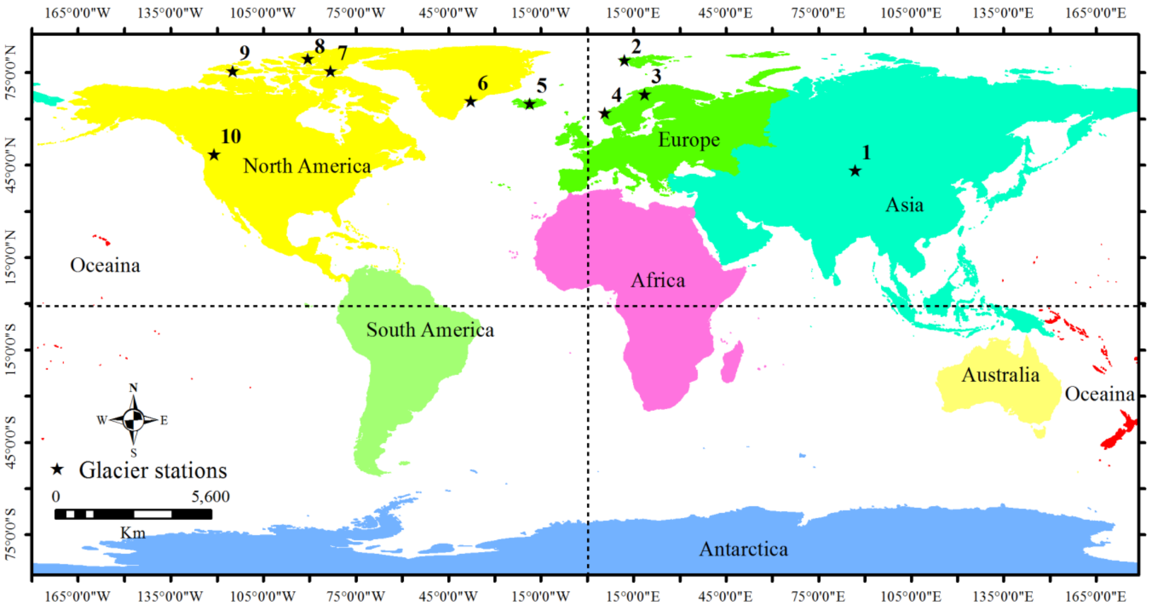


Fig.1-1. Distribution of the ten glacier stations of the study area

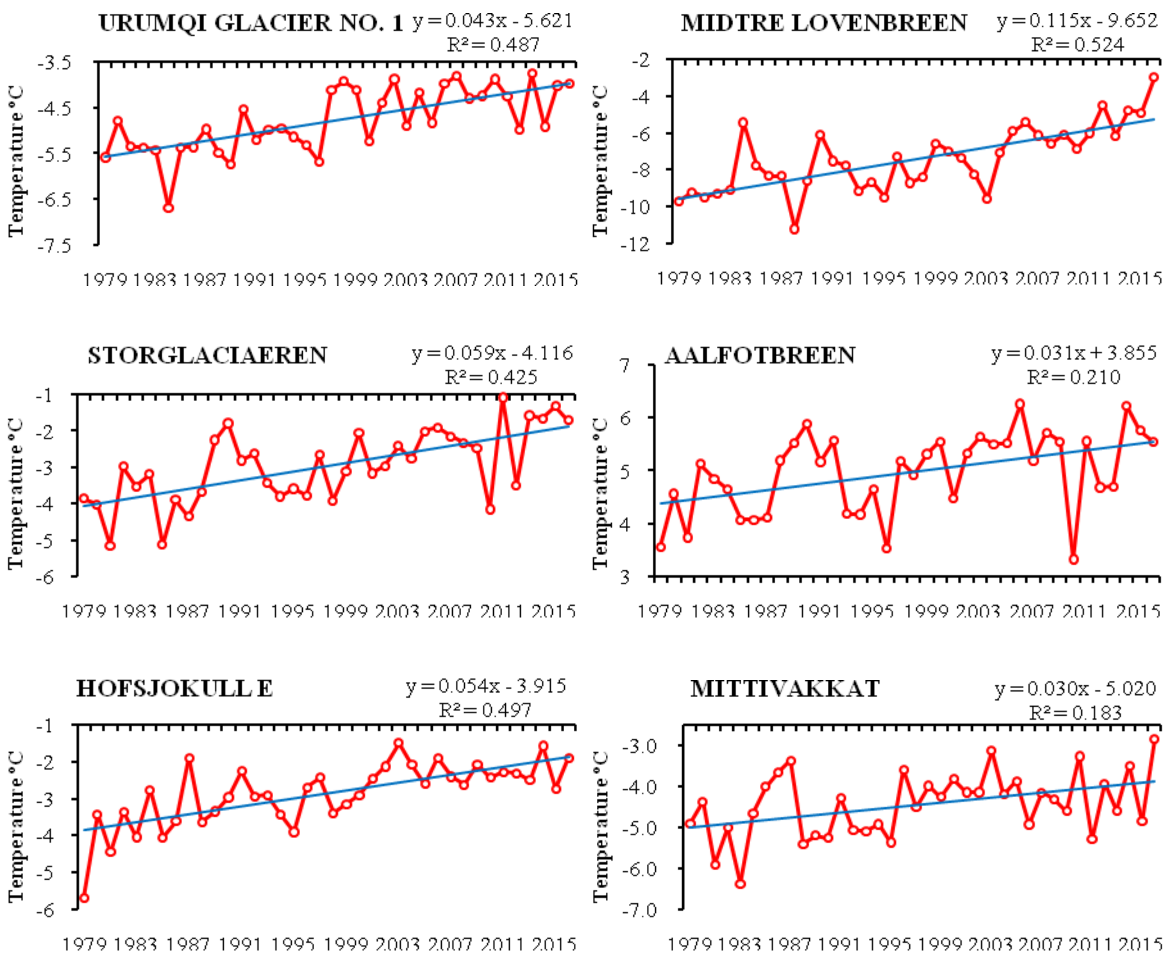
Table 1.1 Distribution of the ten glacier stations of study area including continent, country, name, WGMS_ID, latitude and longitude

No.	Continent	Country	Name	WGMS_ID	Lat.	Long.
1	Asia	China	URUMQI GLACIER NO. 1	853	43.12	86.81
2	Europe	Svalbard	MIDTRE LOVENBREEN	291	78.88	12.05
3	Europe	Sweden	STORGLACIAEREN	332	67.90	18.57
4	Europe	Norway	AALFOTBREEN	317	61.75	5.65
5	Europe	Iceland	HOFSJOKULL E	3088	64.80	-18.58
6	North America	Greenland	MITTIVAKKAT	1629	65.70	-37.80
7	North America	Canada	DEVON ICE CAP NW	39	75.42	-83.25
8	North America	Canada	WHITE	0	79.45	-90.70
9	North America	Canada	MELVILLE SOUTH ICE CAP	3690	75.40	-115.0
10	North America	United State	SOUTH CASCADE	205	48.35	-121.1

1.3 Results

1.3.1 Analysis of climate factors

In fact, the understanding of the relationship between climate factors with glacier mass-balance in past decades is very important for the prediction of future trends. A significantly increasing trend of temperature ℃ covered all the ten stations are shown in Fig. 1-2. The warming rate of temperature during 1979-2016 mainly was 0.43/10a, 1.15/10a, 0.59/10a, 0.31/10a, 0.54/10a, 0.3/10a, 0.6/10a, 0.4/10a, 0.77/10a and 0.33/10a, respectively, in the URUMQI GLACIER NO. 1, MIDTRE LOVENBREEN, STORGLACIAEREN, AALFOTBREEN, HOFSJOKULL E, MITTIVAKKAT, DEVON ICE CAP NW, WHITE, MELVILLE SOUTH ICE CAP and SOUTH CASCADE. The surface temperatures on mountain glaciers have direct reflections of heat budget on the glacier surface, which controls the degree of ablation. An understanding of surface temperatures is therefore crucial in simulating the evolution of mountain glaciers and in understanding a glacier's response to climate change (Wu et al. 2015). The annual and seasonal climatic trends resulted in shrinkage of a glacier in the Tianshan over the last century, especially in the recent decades, thus, has to cause a serious impact on the hydrological regime of this area(Wang et al 2013).



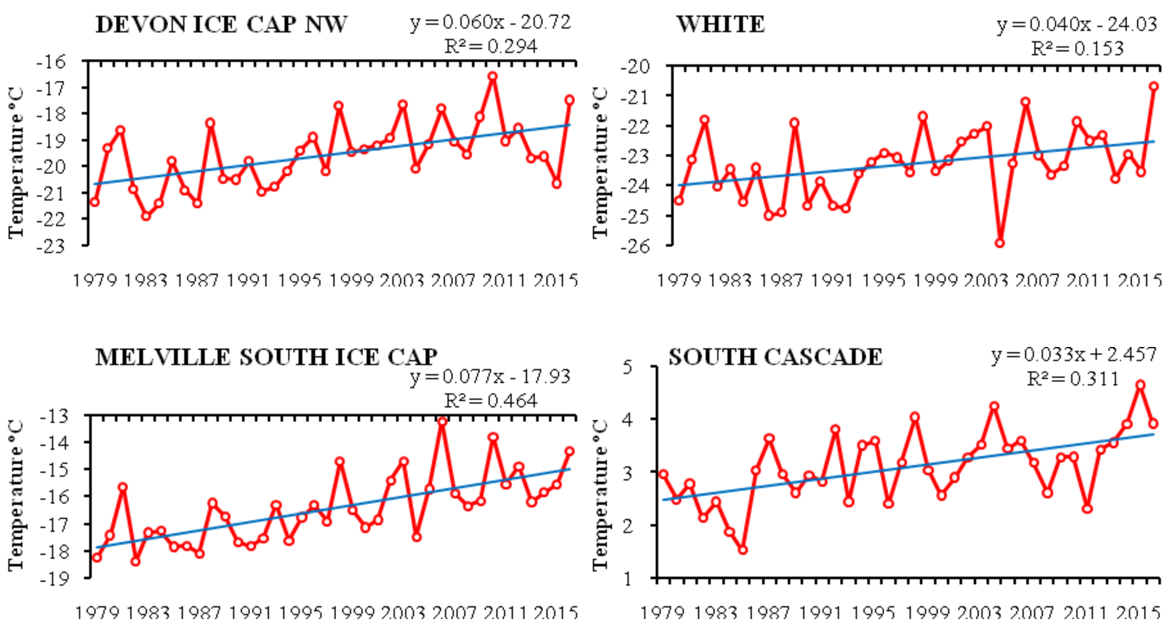


Fig. 1-2. Changes in annual temperature ℃ of the ten meteorological stations during 1979-2016

1.3.2 The annual glacier mass-balance

As shown in Fig. 1-3, a high decreasing rate of annual glacier-mass balance (m w.e.) in all ten stations occurred in URUMQI GLACIER NO. 1, MIDTRE LOVENBREEN, STORGLACIAEREN, AALFOTBREEN, HOFSJOKULL E, MITTIVAKKAT, DEVON ICE CAP NW, WHITE, MELVILLE SOUTH ICE CAP and SOUTH CASCADE, respectively with the rates of -0.17/10a, -0.03/10a, -0.12/10a, -0.39/10a, -0.29/10a, -0.48/10a, -0.11/10a, -0.14/10a, -0.21/10a and -0.01/10a.

Wang et al. (2014), reported that the ice volume in Urumqi Glacier No. 1 has decreased during 1981-2006, which caused glacier thinning. Thus, these changes were responses to the regional climatic warming, which showed a dramatic temperature ℃ increase rate 0.6/10a during these 25 years. Benjamin et al. (2016), showed that the Icelandic glaciers are sensitive to climate variability on short-term time scales owing to their North Atlantic maritime setting, and have been undergoing ice-marginal retreat since the mid-1990s. In addition, previous Studies (Hannesdottir et al. 2015; Mernild et al. 2014; Bradwell et al. 2013) have stated that the temperate glaciers of Iceland are particularly sensitive to climatic fluctuations on an annual to decadal scale, and have exhibited rapid rates of ice-marginal retreat and mass loss during the past decade.

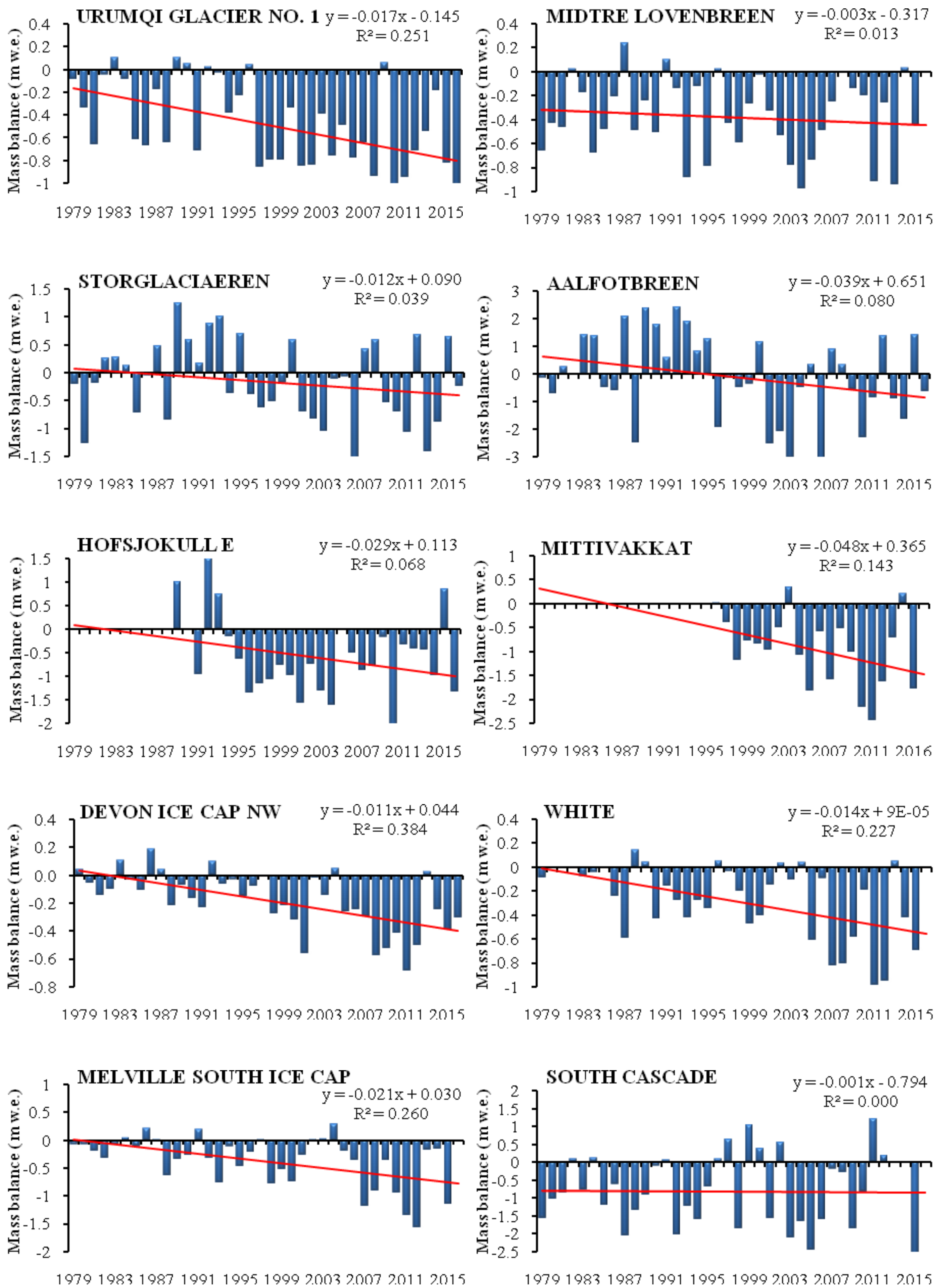


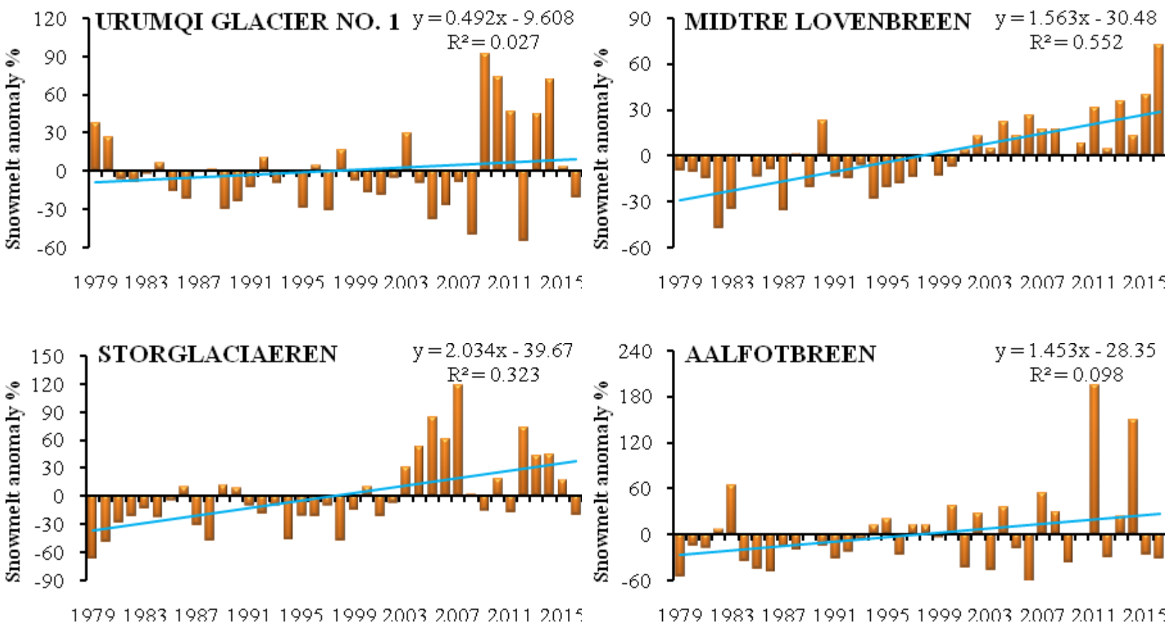
Fig. 1-3. The annual glacier-mass balance (m w.e.) of the ten stations during 1979-2016

1.3.3 The snowmelt

In late April or May, the melt stage begins as snow temperature increases with increasing solar input, and the diurnal temperature range in the snow cover increases. Melt onset occurs in May or June when liquid water begins to accumulate near the top of the snow cover and among the interstices of the snow grains within the snow volume (Barber et al. 1994), with continued warming, the snow water volume increases to the point where the gravity bonds break and the water drains freely to the base of the snow cover (Barber et al. 1995).

As shown in Fig. 1-4, a high increasing rate of annual snowmelt anomaly % in all ten stations occurred in URUMQI GLACIER NO. 1, MIDTRE LOVENBREEN, STORGLACIAEREN, AALFOTBREEN, HOFSJOKULL E, MITTIVAKKAT, DEVON ICE CAP NW, WHITE, MELVILLE SOUTH ICE CAP and SOUTH CASCADE, respectively with the rates of 4.92/10a, 15.63/10a, 20.34/10a, 14.53/10a, 10.43/10a, 33.33/10a, 12.27/10a, 16.33/10a, 21.14/10a and 15.48/10a.

In Central Asia, the water from glacier melts provides an estimated 20-40 % of total runoff during summers, both as a seasonal contribution and from glacier imbalance, up to 70-80 % in extremely hot and dry periods (Kääb et al. 2015). However, the sensitivity of glaciers and ice caps in Greenland to prolonged warm periods is less well constrained and geological records documenting the long-term glacial history are needed to put recent observations the lakes received meltwater from the initial deglaciation, the meltwater input ceased as the glaciers most likely disappeared (Nicolaj et al. 2017).



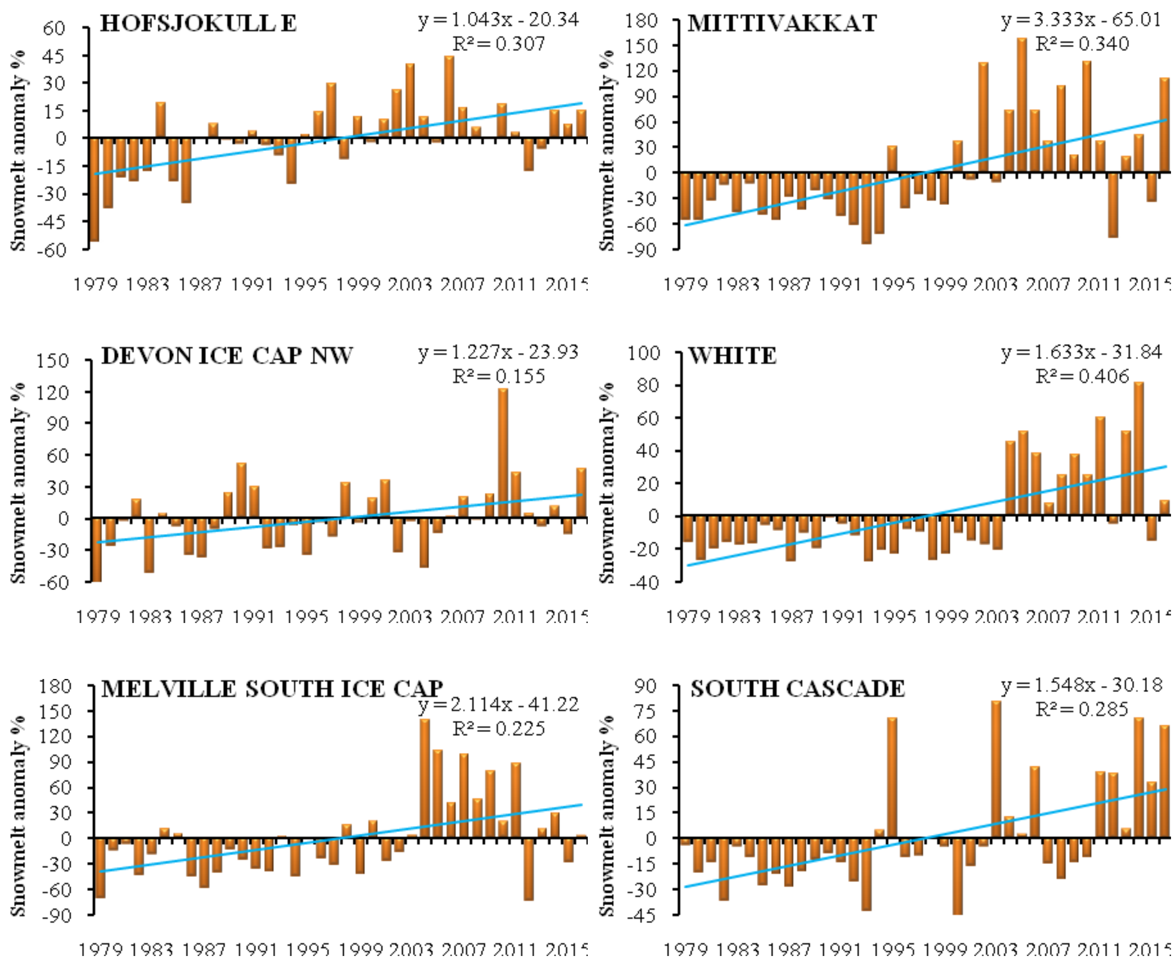


Fig. 1-4. The annual snowmelt anomaly % of the ten stations during 1979-2016

1.3.4 The runoff

As shown in Fig. 1-5, a high increasing rate of annual runoff anomaly % in all ten stations occurred in URUMQI GLACIER NO. 1, MIDTRE LOVENBREEN, STORGLACIAEREN, AALFOTBREEN, HOFSJOKULL E, MITTIVAKKAT, DEVON ICE CAP NW, WHITE, MELVILLE SOUTH ICE CAP and SOUTH CASCADE, respectively with the rates of 15.82/10a, 10.24/10a, 10.59/10a, 6.26/10a, 7.21/10a, 42.05/10a, 17.91/10a, 23/10a and 11.56/10a. The runoff has increased significantly since the 1980s, flowing out from the Tianshan Mountains.

The glacial retreat has a major impact on water resources in arid regions (Li et al. 2011). There is a significant positive correlation existing between air temperature and river fluxes in both catchments, especially in the glacial catchment in the Urumqi River in the eastern Tianshan (Li et al. 2012). The increase in temperature has a great influence on the seasonal distribution of runoff and this led to a decrease in glacier area, thus the most spectacular feature is the continual water level was rise (Hongbo et al. 2014). The glacial lakes in the central Himalaya expanded rapidly by 17.11% from 1990 to 2010 (Nie et al. 2014).

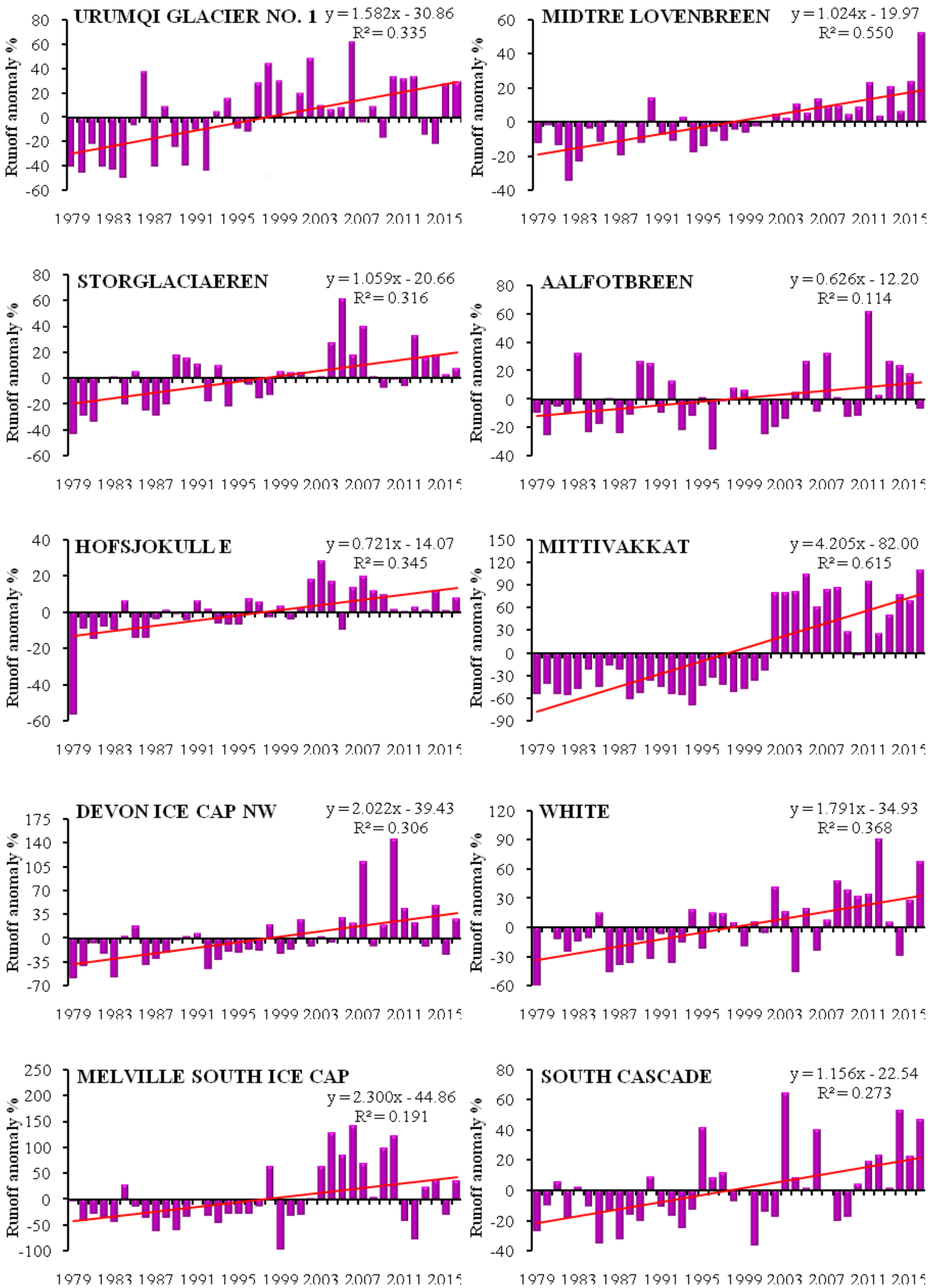


Fig. 1-5. The annual runoff anomaly % of the nine stations during 1979-2016

1.4 Discussions

As shown in Table 1-2, URUMQI GLACIER NO. 1 station showed there is a correlation coefficient between annual temperature with annual glacier mass-balance negative relationship (CC = -0.617**) and positive relationship between annual temperature with annual runoff (CC = 0.581**). The correlation coefficients of annual temperature with annual snowmelt and annual runoff in the MIDTRE LOVENBREEN station, respectively are significantly positive relationship (CC = 0.700** and 0.705**), also there is a significantly positive correlation of annual temperature with annual snowmelt and annual runoff in STORGLACIAEREN station, respectively (CC = 0.466** and 0.525**).

The AALFOTBREEN station showed a significantly positive correlation of annual temperature with annual runoff (CC = 0.475**). The HOFSJOKULL E station showed a significant positive correlation between annual temperature with annual snowmelt and annual runoff, respectively (CC = 0.755** and 0.848**), also there is a significantly positive correlation between annual temperature with annual snowmelt and annual runoff in MITTIVAKKAT station, respectively (CC = 0.351* and 0.408*). The DEVON ICE CAP NW station showed a significant negative correlation between annual temperature with annual glacier mass-balance (CC = -0.567**), while a positive correlation of annual temperature with annual snowmelt and annual runoff, respectively (CC = 0.582** and 0.628**). The both WHITE and MELVILLE SOUTH ICE CAP stations showed a significant positive correlation between annual temperature with annual runoff, respectively (CC = 0.521** and 0.495**).

The SOUTH CASCADE station showed a significant negative correlation between annual temperature with annual glacier mass-balance (CC = -0.518**) and a significantly positive correlation between annual temperature with annual snowmelt and annual runoff, respectively, (CC = 0.527** and 0.479**). David et al. (2012), showed the melt-percentage series from the Devon Island and Agassiz (Ellesmere Island) ice caps are well correlated with the Devon net mass balance and show a large increase in melt since the middle 1990s. Accelerating melt rates since the late 20th century finds echoes in Greenland (Mote 2007) and in Svalbard glaciers (Kohler et al. 2007), indicating a general trend across the Arctic. The warming may be driven by increased pole-ward heat advection in response to rising global temperatures (Quinn et al. 2008). Accelerating ice loss during recent years has made the Greenland Ice Sheet one of the largest single contributors to global sea level rise, accounting for 0.5 of the total 3.2 mm yr-^{1}.

This loss is predicted to continue and will most likely increase in the future as a consequence of global warming (Nicolaj et al. 2017).

Table 1-2. The correlation coefficient between temperature with glacier mass-balance, snowmelt and runoff in the ten stations during 1979-2016.

No	Name	Glacier mass-balance		Snowmelt		Runoff	
		Sig.	P value	Sig.	P value	Sig	P value
1	URUMQI GLACIER NO. 1	-0.617**	0.00	0.15	0.37	0.581**	0.00
2	MIDTRE LOVENBREEN	0.06	0.73	0.700**	0.00	0.705**	0.00
3	STORGLACIAEREN	0.00	1.00	0.466**	0.00	0.525**	0.00
4	AALFOTBREEN	-0.02	0.90	0.29	0.08	0.475**	0.00
5	HOFSJOKULL E	-0.35	0.07	0.755**	0.00	0.848**	0.00
6	MITTIVAKKAT	0.35	0.13	0.351*	0.03	0.408*	0.02
7	DEVON ICE CAP NW	-0.567**	0.00	0.582**	0.00	0.628**	0.00
8	WHITE	0.04	0.80	0.07	0.66	0.521**	0.00
9	MELVILLE SOUTH ICE CAP	-0.219	0.193	0.32	0.05	0.495**	0.00
10	SOUTH CASCADE	-0.518**	0.00	0.527**	0.00	0.479**	0.00

Note: * means at a significance level of 0.05; ** means at a significance level of 0.01.

Fig. 1-6 showed that the average temperature ℃ of the ten stations during 1979-2016 has a high increasing trend at the rate of 0.54/10a. There is a decreasing trend of annual glacier mass-balance (m w.e.) rate of -0.17/10a. In addition, there is an increasing trend of annual snowmelt and annual runoff anomaly % at the rate of 16.44/10a and 16.49/10a, respectively.

In the previous section, we described the correlation coefficient of the mean temperature of the ten stations during 1979-2016 has a highly significant negative relationship with mass-balance (CC = -0.618** at 0.01 level). In addition, there is a high positive relationship between temperature with snowmelt and runoff, respectively (CC = 0.753** and 0.890** at 0.01 level) see Table 1-3. The contribution of glacier melting to sea level rise increased from (0.50 ±0.18) mm per year in 1961-2004 to (0.77 ±0.22) mm per year in 1991-2004 due to climate warming Accelerating melt rates since the late 20th century finds echoes in Greenland (IPCC 2013 and 2007)).

Recent observations indicate that the climate-induced changes are indeed underway in the High Arctic, such as including warming of the troposphere (Santer et al. 2005) resulted in a decrease in snow cover area (Comiso 2006). Here, we introduced represent relationships between all parameters have clearly shown in Fig. 1-7 in horizontal and vertical axis during 1979-2016.

Table 1-3. The correlation coefficient of the mean of the ten stations, first between temperature with glacier mass-balance, snowmelt and runoff. Second between glacier mass-balance with snowmelt and runoff and final between snowmelt with runoff, the correlation coefficient during 1979-2016

	Glacier mass-balance		Snowmelt		Runoff	
	Sig.	P value	Sig.	P value	Sig.	P value
Temperature	-0.618**	0.00	0.753**	0.00	0.890**	0.00
Glacier mass-balance			-0.532**	0.00	-0.647**	0.00
Snowmelt					0.882**	0.00

Note: * means at a significance level of 0.05; ** means at a significance level of 0.01.

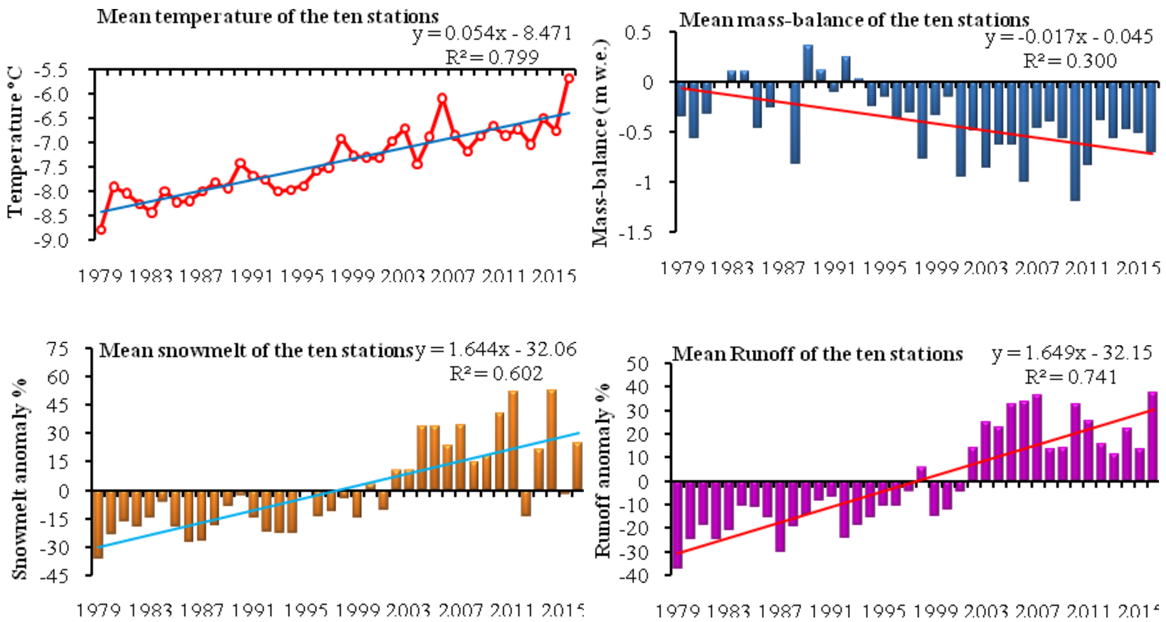


Fig. 1-6. Cumulative changes of mean temperature, mass-balance, snowmelt and runoff during 1979-2016

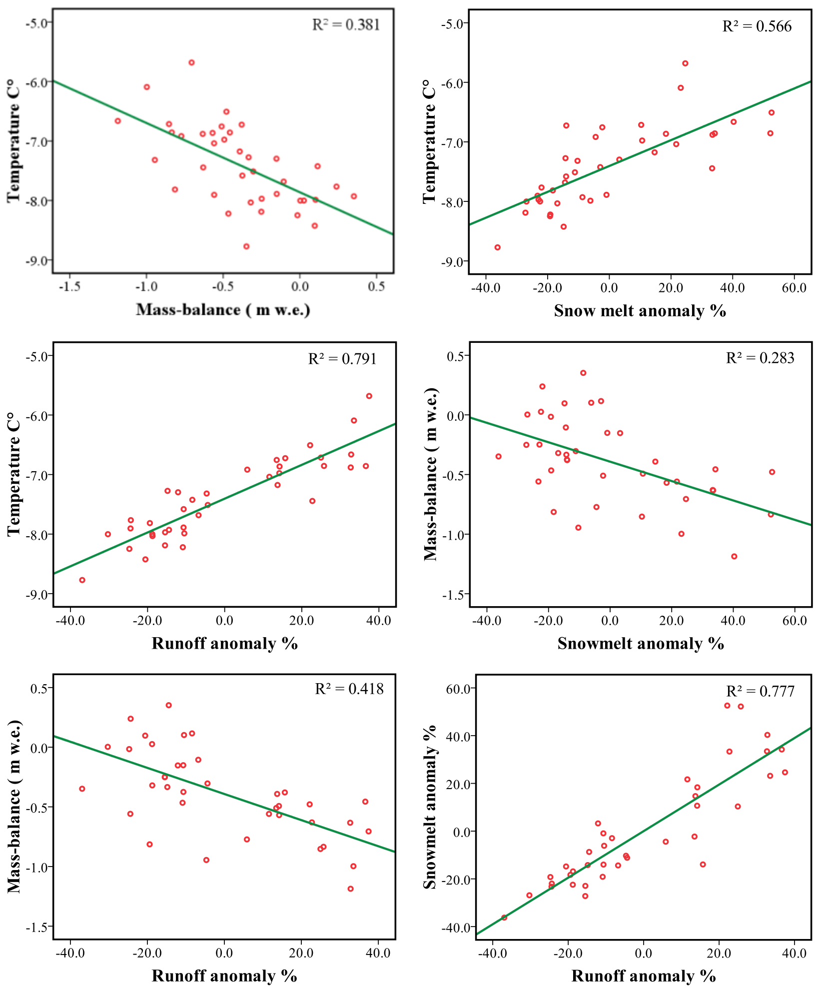


Fig. 1-7. Comparison of the relationships between the parameters of mean the ten stations that have shown in horizontal and vertical axis during 1979-2016.

1.5 Conclusion

Our analysis of a 38-year in this paper is provided with a unique opportunity is tested the sensitivity of the glacier mass-balance, snowmelt and runoff to a temperature in a ten glacier stations from different regions. Accordingly, this research provided a brief overview of major glacier mass-balance change, snowmelt and runoff. In addition, we provided baseline knowledge to analyse data and research on climate and glacier issues to reduce the negative impacts on melt and runoff, which have serious implications for human societies due to depending on fresh water from cryospheric sources.

The survey results in this research showed that the significant increase in temperature has a high relationship with melting glacier and runoff in all ten stations. In fact, the study area showed a retreat of glacier mass-balance with an increase in snowmelt and runoff. Both changes have high significant correlations with temperature increase. In suggestions, we call to better preparedness and strategies to create good plans that can adapt to climatic and cryospheric variables. Thus, an adaptation to negative impacts of climate change on glaciers is foremost a challenge that has to be tackled at the local or regional scale.

CHAPTER TWO

Glacier Mass-Balance Variation in China during the Past Half Century

2.1 Introduction

Global climate models predict that the Arctic will experience greater than global average temperature and precipitation increases in response to the build-up of greenhouse gases (ACIA, 2005). The largest glacierized region outside the Arctic and Antarctic is Himalayan. Glacier changes in this region are spatially heterogeneous and not well known. Himalayan glaciers are a focus of public and scientific debate.

Prevailing uncertainties are of major concerns because some projections of their future have serious implications for water resources. Most Himalayan glaciers are losing mass at rates similar to glaciers elsewhere (Bolch et al., 2012). Global climate change is driving the behaviour of mountain glaciers worldwide (Marzeion et al., 2014). Based on the observed global air and ocean temperatures, it can be said that the rate of temperature increase is higher at higher altitudes (Immerzeel, 2008).

The seasonal melt maxima happen around 15-20 July through the whole 21st century and coincide with the rising temperature. In the second half of the century, the temperature and, therefore, the melts are projected to increase more after their seasonal maximum than at the beginning of summer. The melt asymmetry is also partly explained by changing snowfall that is projected to increase before June but to significantly decrease in late summer (Lang et al., 2015). Climate warming has impacted most mountain glaciers, including glaciers in the Tianshan Mountains, which are in a state of rapid terminus retreat (Wang et al., 2013, 2014). Increasing temperatures have resulted in the loss of more than half of the glaciers in Asia since 1900 (Ravazzaniet al., 2015). In addition, any decrease in glacier melt runoff often also leads to economic losses and associated negative social consequences (Vergara et al., 2007). Adverse impacts associated with a decrease of snow and ice and the related changes in melt runoff can affect societies seriously (Beniston et al., 2011).

The climate with the physical properties of ice determines the extent and behaviour of glaciers, a statement that underpins the rationale for the examination of former and contemporary glacier behaviour, leading to an examination of past and present glacier behaviour within a climatic context (Paterson, 1994). The problem statement and justifications of this research are that the glaciers retreat will eventually lead to loss of frozen water resource, glacier areas have a wide range of practical applications in water resource, and they support the sustainable development of the arid and semi-arid environment systems in west China. Glacier runoff is the main contributor to water supplies for agriculture in western China. In these regions, glacier meltwater has been described to play a crucial role for irrigation during the hot and dry seasons (Sorg et al., 2014). Glaciers in the west of China have been retreating over the past 56 years. Glacier melting causes negative mass balance with strong impacts on the quantity and seasonal distribution of runoff in western China. Monitoring the long-term behaviour of surge-type glaciers and the detailed study of individual surges is essential for improving our knowledge of the physical mechanisms behind surging (Kamb et al., 1985). Water resources provided by alpine glaciers are an important pillar for people in the arid regions of western China (Min et al., 2017).

The hypotheses of this research are that climate change is the main factor causing glacier variations. The summer temperature and precipitation were basic factors to determine the ablation and accumulation of glaciers. The glaciers were been affected by the increasing temperature in the long timescale. On the other hand, precipitation is only obvious for short-term and small-scale of glaciers. According to Häusleret al. (2016) much remains unknown about the system's history before the mid-nineteenth century and the hydrological characteristics and processes of both glaciers.

The main objectives of this study, to explore and analyze the spatial and temporal patterns of climate variability impacts such as temperature on glacier annual balance, snow density, snowmelt, snow depth and snowmelt runoff. To this end, analyses of correlation of climatic factors and their correlations with glacier mass balance; analyses of glacier mass balance variations; an estimation of temperature and glacier mass correlations; to identify knowledge gaps that should be addressed in future research in addition to those indicated in previous publications.

2.2 Material and methods

2.2.1 Data collection

Monthly temperature and precipitation records of climatic stations are derived from the China Meteorological Data Service Center http://data.cma.gov.cn. The glacier annual balance was obtained from world glacier monitoring service WGMS http://wgms.ch/data_databaseversions/. In addition, the data of snow density, snowmelt, snow depth and runoff were obtained from http://apps.ecmwf.int/datasets/data/interim-mdfa/levtype%3Dsfc European Centre for Medium-Range Weather Forecasts (ECMWF) for the period of 1979-2013.

2.2.2 Anomaly per cent

In this paper, the formulation of per cent anomaly (%) reflects the direct result of a simple principle which reflects the period of snow properties such as snow density, snowmelt, snow depth and runoff. The count formula is given below:

$$Anomaly\,\% = \frac{x-\bar{x}}{\bar{x}} \times 100 \qquad (1)$$

Where, x is the snow property of specific period, $\bar{x}$ is average of snow property of the specific period. The advantage of anomaly per cent is that it has a simple and clear meaning.

2.2.3 Study area

For the present analysis, we have selected the western part of China, because most of the glaciers in China are situated in the western parts of the country. In this study, glaciers located in the west of China are divided into nine stations according to their locations (their WGMS IDs are 849, 853, 856, 1510, 3694, 3955, 3978, 3987 and 3991 (Table 2-1 and Fig. 2-1). This study area has a complex and diverse climate type, variegations of temperature and precipitation, dry climate, uneven distribution of water resources and serious water shortages in the northwest part of the China, harsh natural conditions and high frequency of drought.

Table 2-1 The study area with name, WGMS: ID, general name, special location, latitude and longitude

Name	WGMS: ID	GEN LOCATION	Lat	Long
Hailuogou	849	HENGDUAN SHAN	29.58	101.93
Urumqi Glacier No. 1	853	TIAN SHAN	43.00	87.00
Qiyi	856	QILIAN SHAN	39.24	97.76
Xiao Dongkzmadi	1510	TIBETAN PLATEAU	33.17	92.13
Kangwure	3694	HIMALAYA	28.45	85.75

Meikuang	3955	KUNLUN MT. E	35.67	94.18
Gurenhekou	3978	TIBETAN PLATEAU	30.18	90.47
Parlung N0. 94	3987	SOUTHEAST TIBETAN PLATEAU	29.39	96.98
Naimona Nyi	3991	HIMALAYA W	30.45	81.33

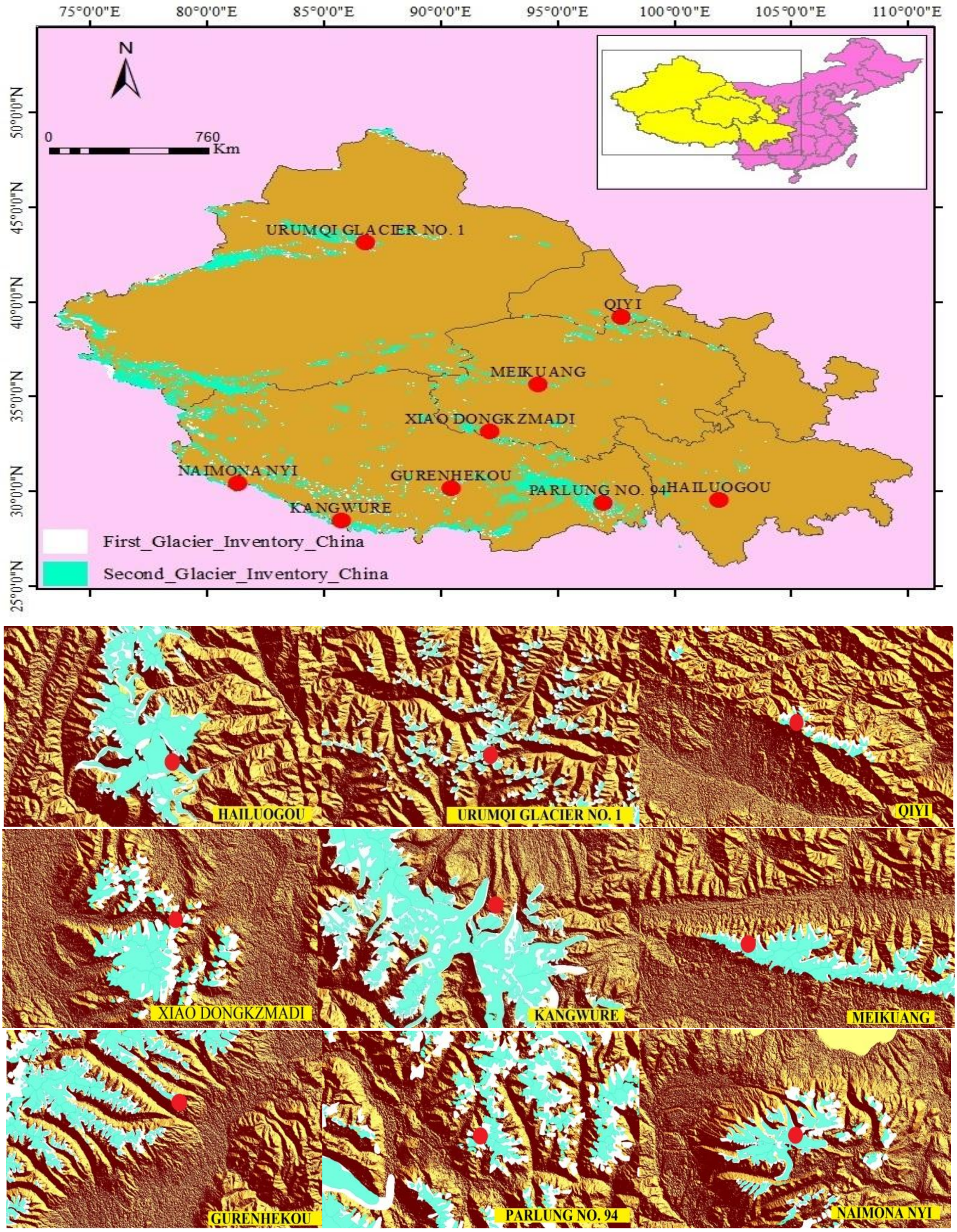


Fig. 2-1 Location of the study area including nine glacier stations with a distribution of first and second glacier inventory

2.3 Results

2.3.1 Analysis of climate factors

In fact, the understanding of the relationship between climate factors with glacier mass-balance in past decades is very important for the prediction of future trends. A significantly increasing trend of temperature ℃ covered all the nine stations (Fig. 2-2). The warming rate of 1979-2013 mainly was 0.32/10a, 0.47/10a, 0.49/10a, 0.58/10a, 0.46/10a, 0.57/10a, 0.47/10a, 0.26/10a and 0.56/10a, respectively, in the HAILUOGOU, URUMQI GLACIER NO. 1, QIYI, XIAO DONGKZMADI, KANGWURE, MEIKUANG, GURENHEKOU, PARLUNG NO. 94 and NAIMONA NYI.

The surface temperatures on mountain glaciers have direct reflections of heat budget on the glacier surface, which controls the degree of ablation. An understanding of surface temperatures is therefore crucial in simulating the evolution of mountain glaciers and in understanding a glacier's response to climate change (Wu et al., 2015). Recently, Shi et al. (2014) reported that the average temperature has increased at the rate of 0.3℃/10a (1961-2010) on the 533 selected meteorological stations around China. Global mean temperature has increased by 0.85℃, over the period of 1880 to 2012 and this increase in temperature is likely due to anthropogenic activities that have increased the concentrations of greenhouse gases to unprecedented levels (IPCC, 2013).

As shown in Fig. 2-3, a great discrepancy existed in precipitation with increase or decrease rate. There is a significant increase in URUMQI GLACIER NO. 1, QIYI, XIAO DONGKZMADI, KANGWURE, MEIKUANG, GURENHEKOU and PARLUNG NO. 94. A declining trend in precipitation was found only in the HAILUOGOU and NAIMONA NYI. Bhogendra et al. (2014) reported an increasing trend in winter and spring temperature and decreasing trends of precipitation, a significant negative trend in snow cover area during these seasons identified in Himalaya. The observed increase in summer temperatures and the related glacier down wasting has led to a noticeable decrease of frozen water resources in Central Asia, with possible future impacts on the economy of all downstream countries in the region (Petrakov et al., 2016). The annual and seasonal climatic trends resulted in shrinkage of glaciers in the Chinese Tianshan over the last century, especially in the recent decades, thus causing a serious impact on the hydrological regime of this area (Li et al., 2010; Wang et al., 2013).

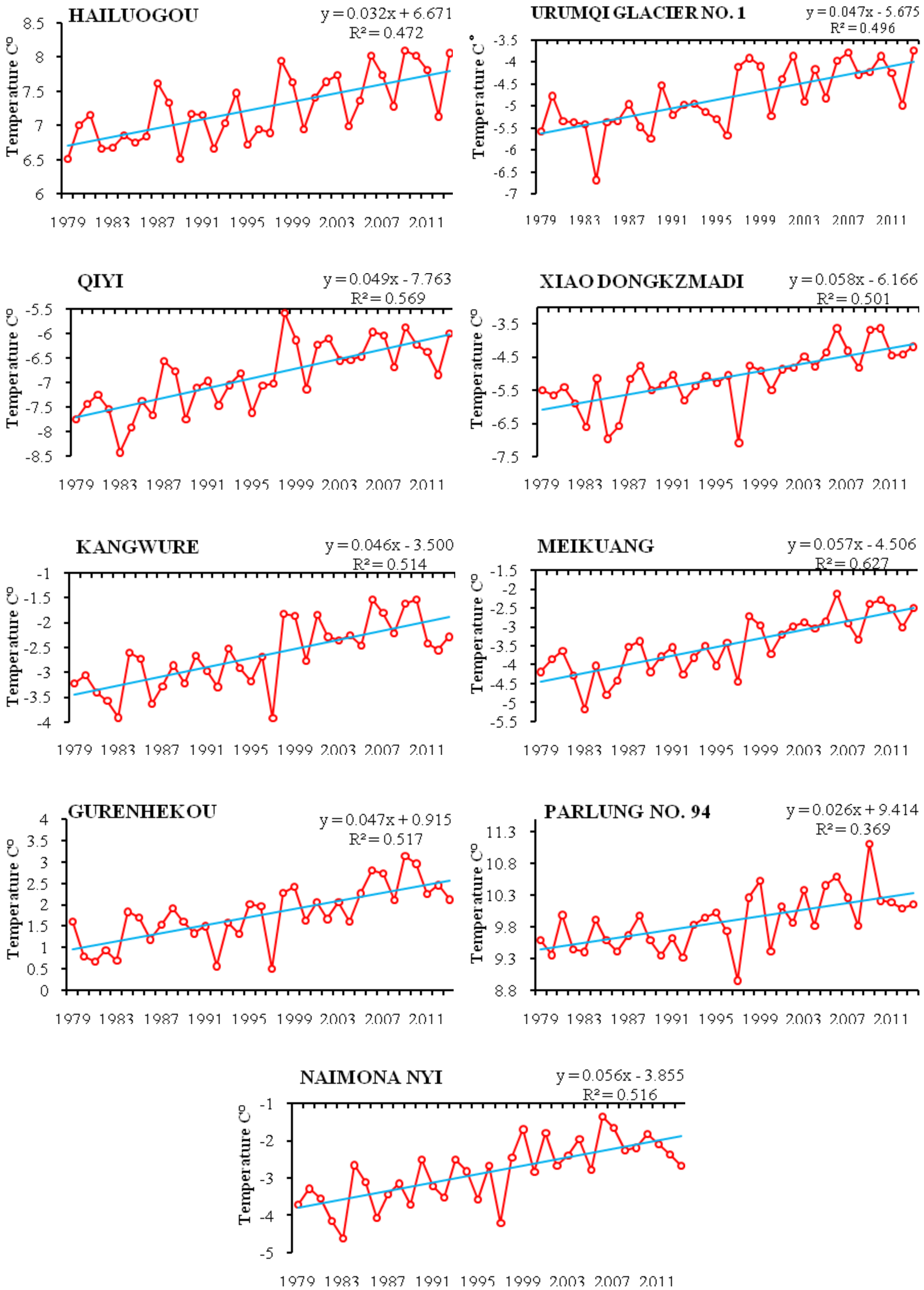


Fig. 2-2 Changes in annual temperature ℃ of the nine meteorological stations during 1979-2013

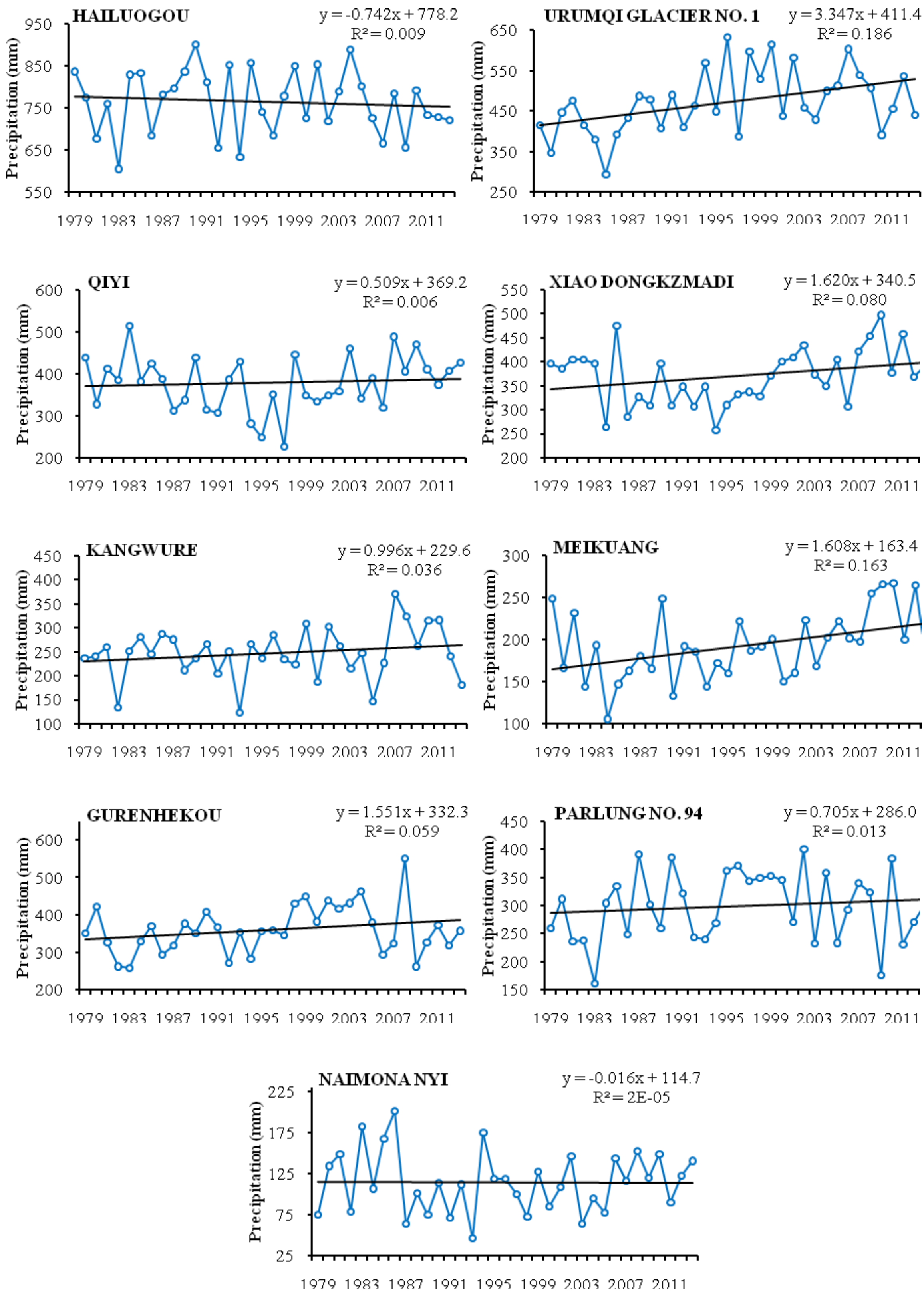


Fig. 2-3　Changes in annual precipitation (mm) of the nine meteorological stations during 1979-2013

2.3.2 The glacier annual balance

As shown in Fig. 2-4, a high decreasing rate of annual glacier-mass balance (m. w.e.) occurred in HAILUOGOU, URUMQI GLACIER NO. 1, QIYI, XIAO DONGKZMADI, KANGWURE, MEIKUANG, GURENHEKOU, PARLUNG NO. 94 and NAIMONA NYI, with the rates of -1.186/10a, -0.18/10a, -0.21/10a, -0.31/10a, -0.14/10a, -0.25/10a, -1.41/10a, -0.35/10a and -0.03/10a, respectively. There is a general trend of glacial retreat and mass defect worldwide during the past several decades (Zemp et al., 2015; Pratap et al., 2016).

The glacier retreat since the Little Ice Age, i.e. during the period of 15th-19th centuries in China (Su and Shi, 2002). Understanding the glacier mass balance is necessary to explain the rate of shrinkage and to infer the impact of climate change. Which was lower than that for glaciers globally -0.013 m w.e. per year). It indicated that the rate of glacial melting (mass loss) in China was higher than that in glaciers worldwide (Che et al., 2017). In fact, glaciers in the Himalaya have experienced a decline since the end of the Little Ice Age (Dobhal et al., 2004), also at an increased declining rate during the past few decades (Bolch et al., 2008).

There has been a great deal of attention given to understanding the increasing temperature and decreasing snow accumulation in the Himalayas due to observed and projected warming (Adam et al., 2009). Rapid shrinkage and dramatic volume loss of the glaciers in the eastern Tianshan Mountains have resulted in water shortages in the surrounding arid regions of China (Wang et al., 2016). The Kangwure Glacier has experienced a significant mass deficit since the 1970s, with 34.2 % of area loss, 48.2 % of ice volume loss and 7.5 m of average thickness decrease.

The investigating in Kangwure Glacier during the recent few decades, found that the length, area, volume and average thickness of this glacier have decreased by 9 %, 34.2 %, 48.2 % and 7.5 m, respectively (MA et al., 2010). Glaciers in the Tibetan Plateau have been retreating during the past few decades resulting from global warming (Shangguan et al., 2008). During 1970-2007, overall annual temperatures increased gradually in the north to south of the West Nyainqentanglha Range, respectively, resulting in the areas of the two glaciers reduced over the last nearly four decades. The rate of temperature increase in the north is higher than that in the south (Yuet al., 2013). Since the 1990s, the URUMQI GLACIER NO. 1 and XIAO

DONGKZMADI stations showed a highly significant decrease in annual mass balance.

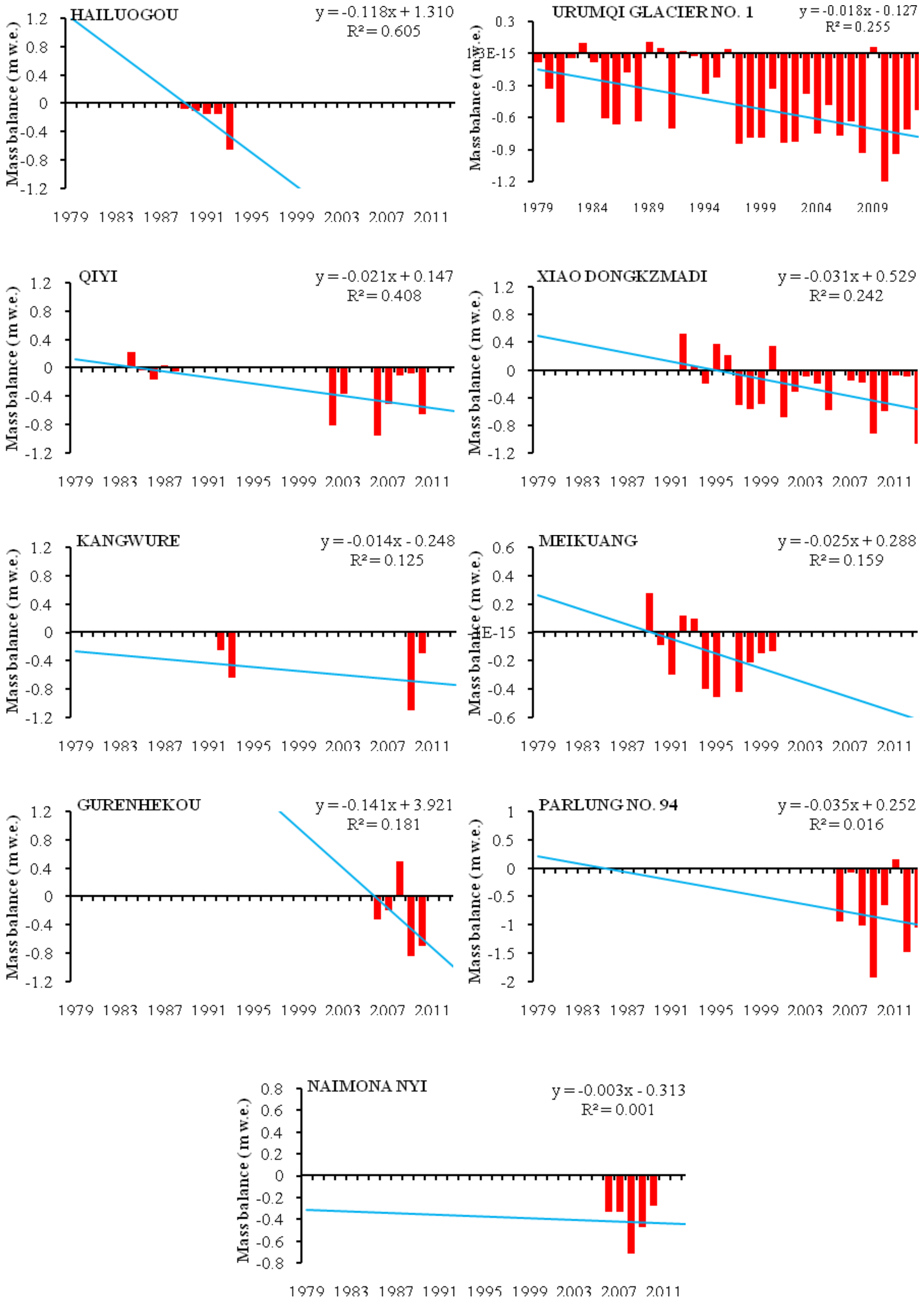
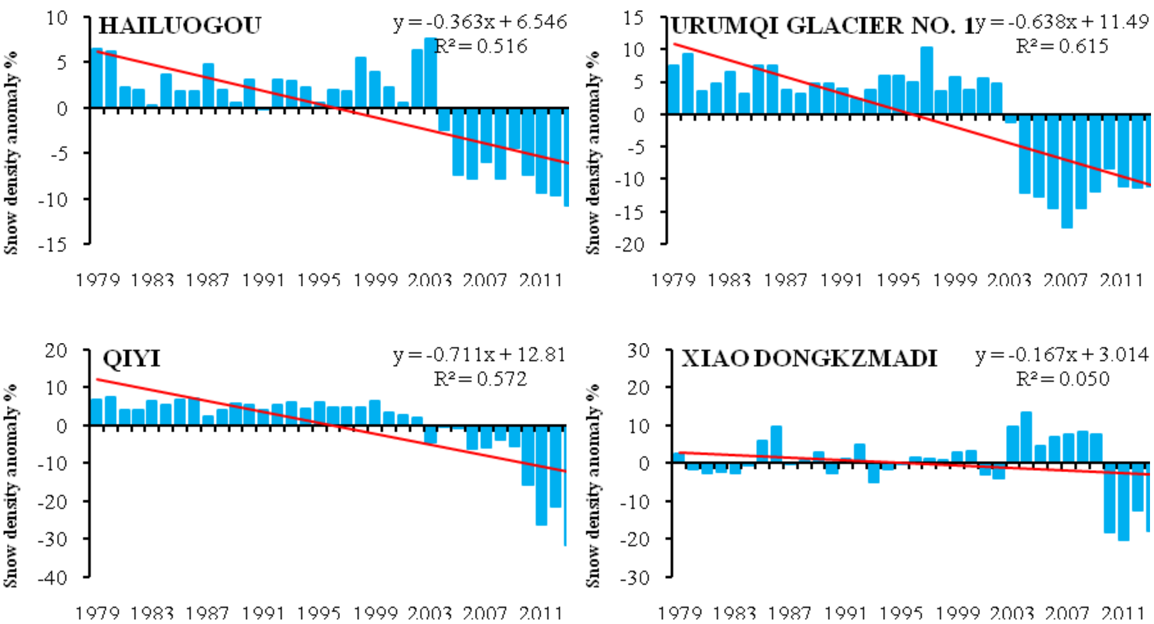


Fig. 2-4 The annual glacier-mass balance (m w.e.) of the nine stations during 1979-2013

2.3.3 The snow density

There are many discrepancies in annual snow density anomaly % is shown in Fig. 2-5. The decline rate of annual snow density anomaly % was -3.63/10a, -6.38/10a, -7.11/10, -1.67/10a, -5.65/10a, -5.92/10a, -3.94/10a, -8.01/10a and 5.58/10a, respectively in HAILUOGOU, URUMQI GLACIER NO. 1, QIYI, XIAO DONGKZMADI, KANGWURE, MEIKUANG, GURENHEKOU, PARLUNG NO. 94 and NAIMONA NYI. The glacier in QIYI station has seriously shrinking over the past 37 (during 1972-2009) years. The glacier terminal retreated about 6 %, the area reduced about 13.1%, the volume reduced about 35.3 %, and glacier shrinkage is mainly in the form of thinning.

Glacier average thickness reduced from 36.8 m in 1972, to 27.4 m in 2009. Meteorological data around the study area shows that this region in recent decades has undergone differential warming which is the main reason for rapid glacier shrinkage (Liu et al 2013). The glacier sensitivity tests indicate that in the Payuwang Valley in western Nyaiqentanggulha Shan, the glaciers responded to centennial-scale shifts in climate. The tributary glaciers coalesce into the main valley and expand rapidly there (Xu and Glasser, 2015).



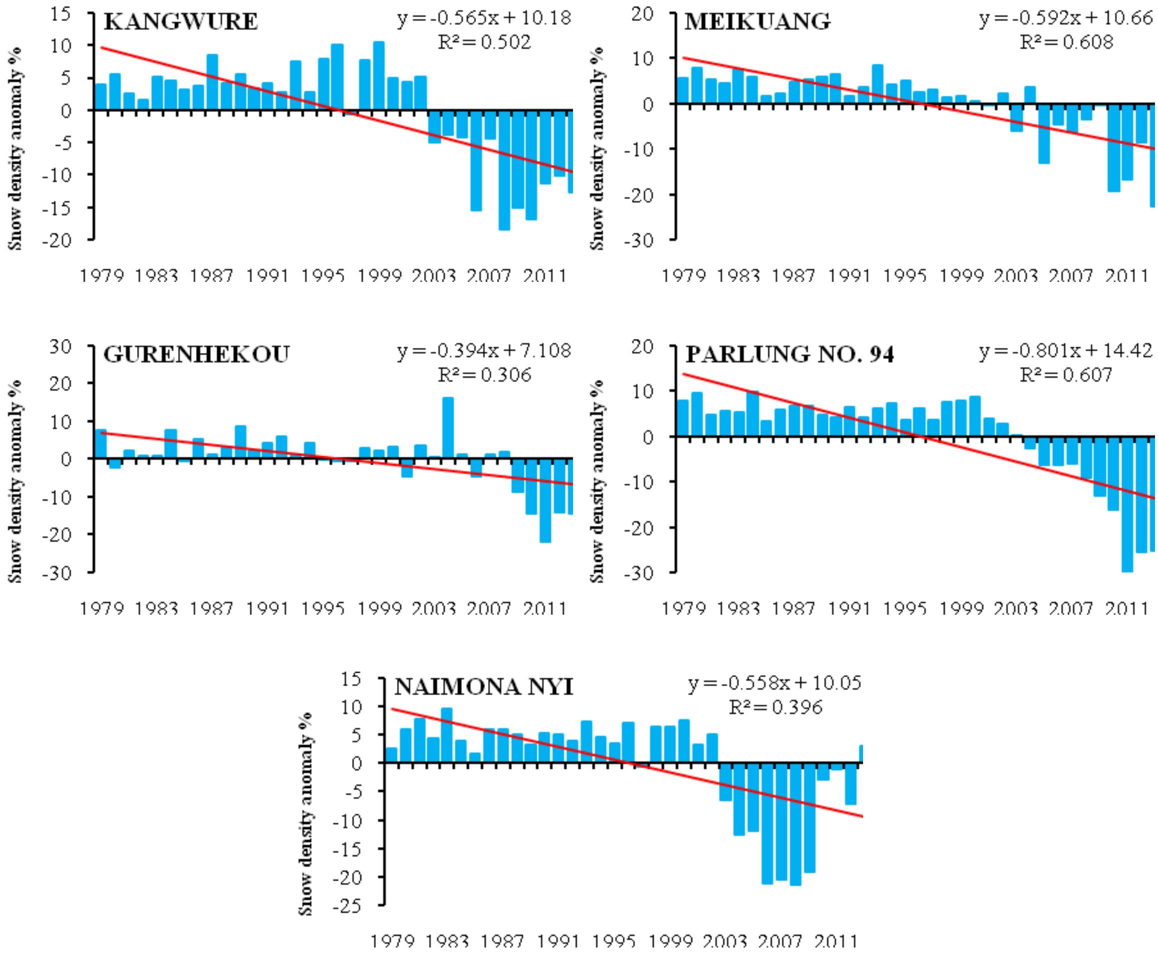
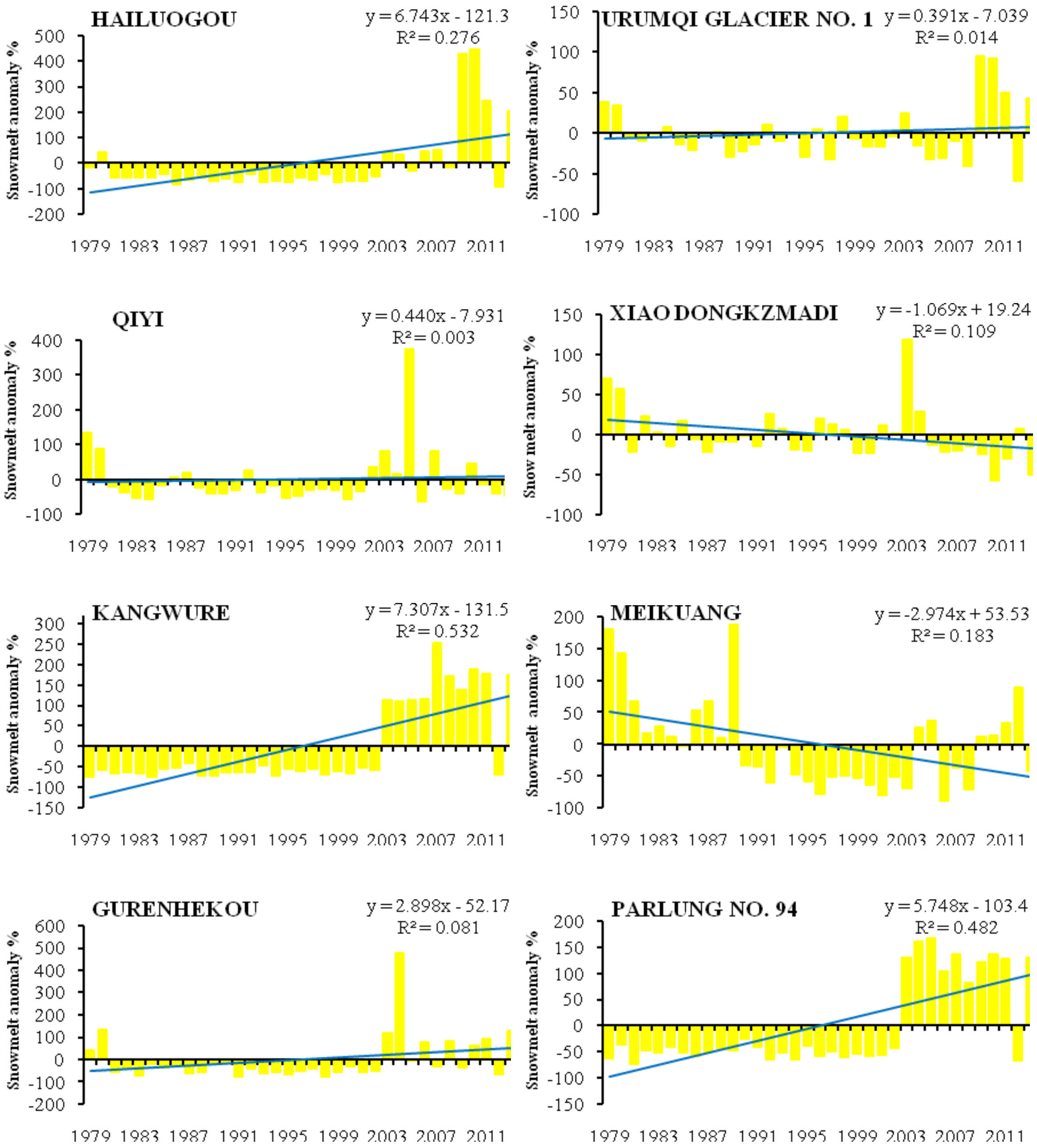


Fig. 2-5 The annual snow density anomaly % of the nine stations during 1979-2013

2.3.4 The snowmelt

As shown in Fig. 2-6, a high increasing rate of annual snowmelt anomaly % occurred in HAILUOGOU, URUMQI GLACIER NO. 1, QIYI, KANGWURE, GURENHEKOU, PARLUNG NO. 94 and NAIMONA NYI, with the rates of 67.43/10a, 3.91/10a, 4.4/10a, 73.07/10a, 28.98/10a, 57.48/10a and 16.2/10a, respectively. Since 1974, the Kangwure Glacier has retreated 303 m. The area changed from 2.98 km^2 to the present 1.96 km^2, with a loss of 34.2 % of the area.

The ice volume reduced from 0.0998 km^3 to 0.0517 km^3, a decrease of 48.2 % in the past 3 decades. The calculation also shows that the glacier average thickness was reduced by 7.5 m. These give a direct impression of the detailed glacier change in the Kangwure Glacier (MA et al., 2010). Nyainqentanglha mountain glacier surface elevations were decreased by 8.39 ±0.45 m during 2003-2009. Over the same period, at least 1.01 km^3 of glacial meltwater flowed into the Nam Co Lake, assuming a glacial runoff coefficient of 0.6. The mean glacier mass-balance value was -0.4 m w.e. indicating that glacier meltwater in the catchment contributes to lake level rise. The contribution rate of glacial meltwater to the lake volume rise was 20.75 % (Hongbo et al., 2014). In Central Asia, the meltwater from glaciers provides an estimated 20-40 % of total runoff during summers, both as a seasonal contribution and from glacier imbalance, up to 70-80 % in extremely hot and dry periods (Kääb et al., 2015).



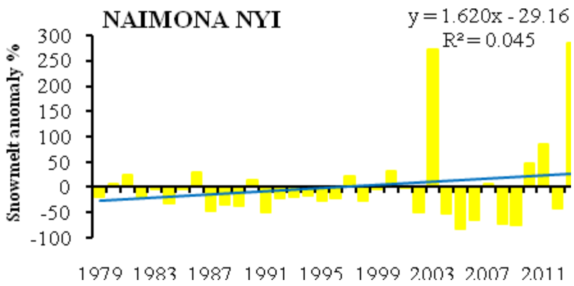
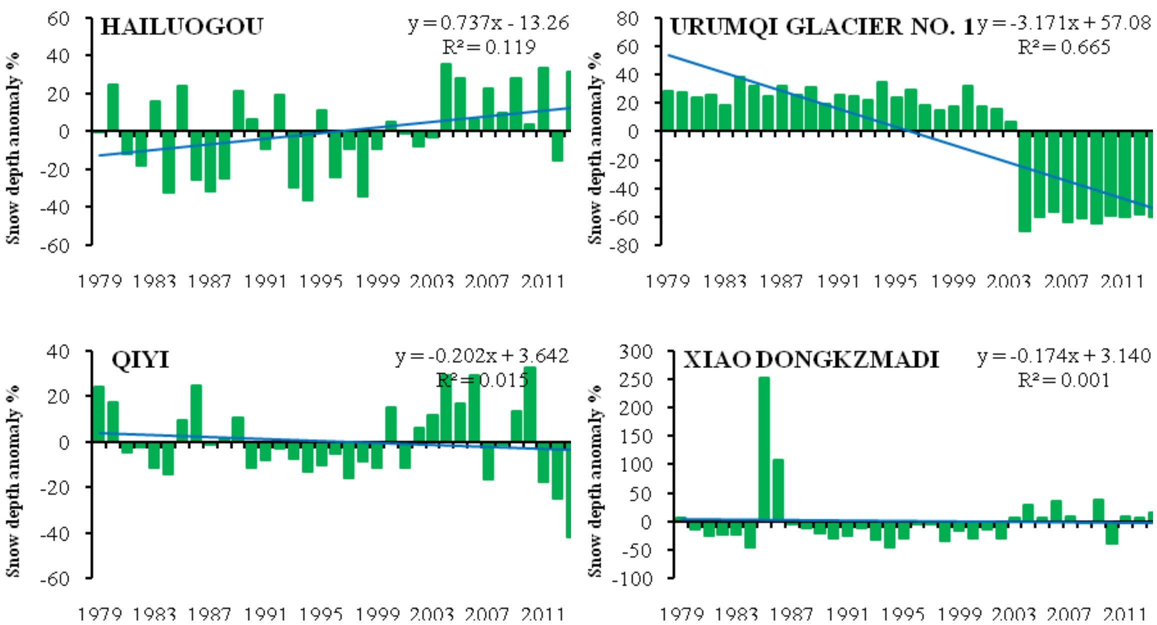


Fig. 2-6　The annual snowmelt anomaly % of the nine stations during 1979-2013

2.3.5 The snow depth

The decreasing rate of annual snow depth anomaly % was -31.71/10a, -2.02/10a, -1.74/10a, -17.56/10a, -4.93/10a, -4.93/10a, respectively in URUMQI GLACIER NO. 1, QIYI, XIAO DONGKZMADI, KANGWURE, PARLUNG NO. 94 and NAIMONA NYI as shown in Fig. 2-7. In Tianshan, the glaciers have responded differently according to their annual mass balances, lengths, areas, equilibrium line altitudes that are responses to an increase in both temperature and precipitation. URUMQI GLACIER NO. 1 branches can indicate climate changes at the Urumqi River head region, especially the temperature variation (Xu et al., 2011).During 1958-2007, the QIYI station showed a significant negative correlation exists between temperature with mass balance, area, length and thickness are respectively -0.59, -0.65, -0.63, and -0.65 (Jing et al., 2012).



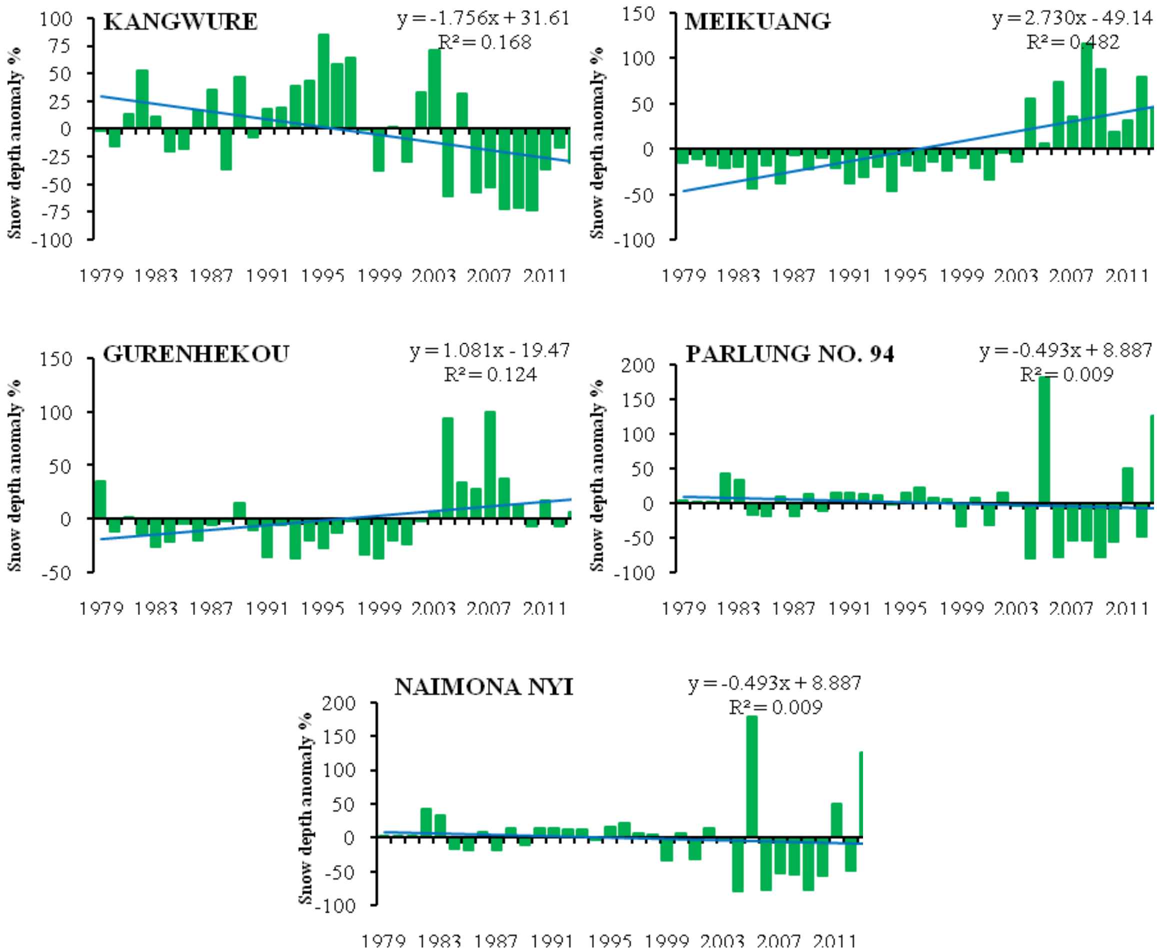
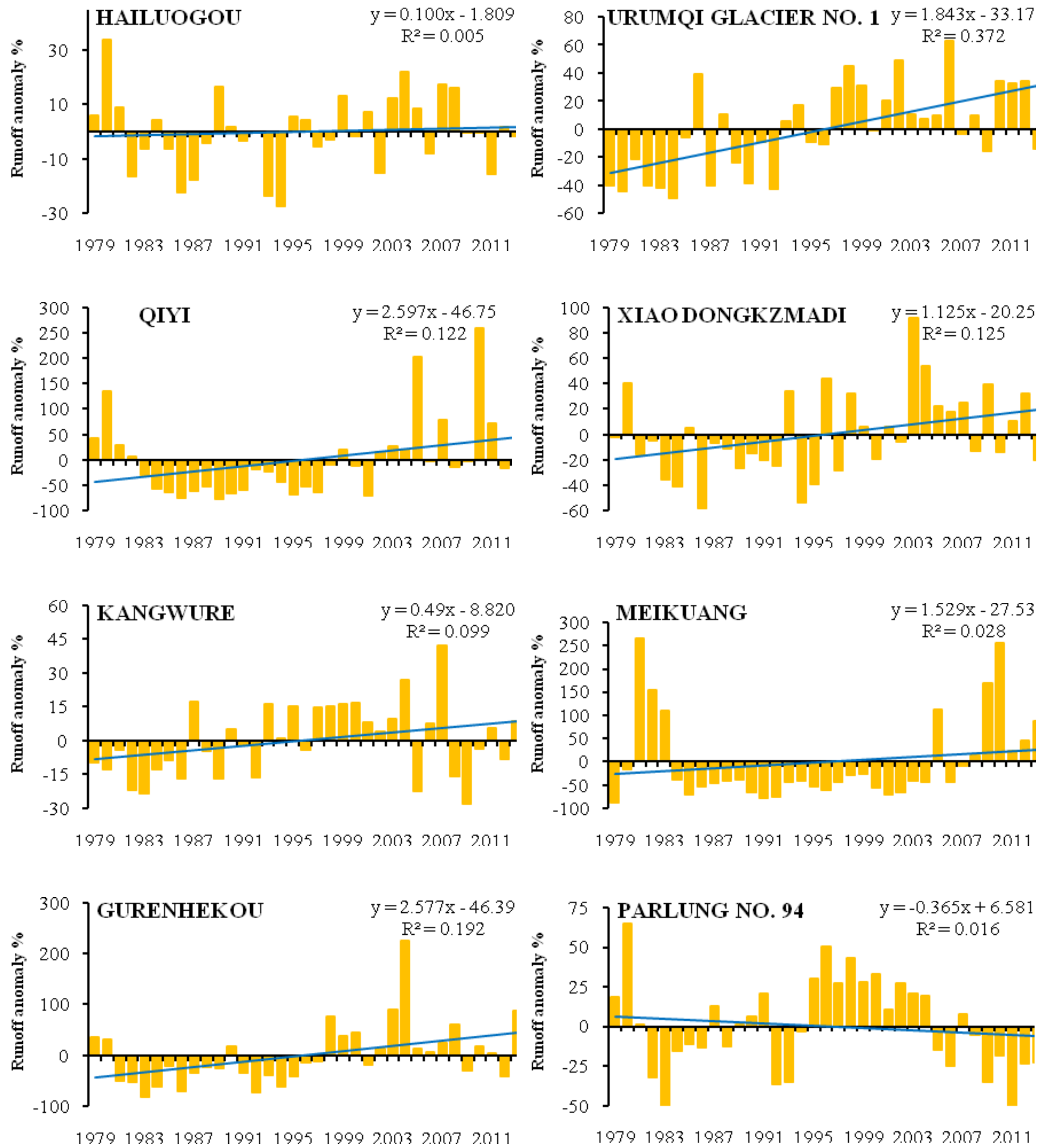


Fig. 2-7 The annual snow depth anomaly % of the nine stations during 1979-2013

2.3.6 The runoff

As shown in Fig. 2-8, a high increasing rate of annual runoff anomaly % occurred in HAILUOGOU, URUMQI GLACIER NO. 1, QIYI, XIAO DONGKZMADI, KANGWURE, MEIKUANG and GURENHEKOU at the rates of 1/10a, 18.43/10a, 25.97/10a, 11.25/10a, 4.9/10a, 15.29/10a and 25.77/10a, respectively. The runoff has increased significantly since the 1980s, flowing out from the Tianshan Mountains. The glacial retreat has a major impact on water resources in arid regions (Li et al., 2011). There is a significant positive correlation existing between air temperature and river fluxes in both catchments, especially in the glacial catchment in the Urumqi River in the eastern Tianshan (Li et al 2012). In Tianshan, as estimated by Min et al. (2017), the increase of runoff occurred mainly in the ablation season (from May to October). Increased runoff is concentrated mainly in June, July, and August. Within this period, radiation is sufficient and increased precipitation on the glacier leads to melt, which leads to an increased runoff in the watershed. The increase in air temperature and precipitation has a great influence on the seasonal distribution of runoff. Nam Co Lake in the Nyainqentanglha mountain glacier has increased from 1998.78 ±5.4 to 2023.8 ±3.4 km^2; the glacier-covered area has decreased from 832.34 to 821.0 km^2 and the drainage basin area has decreased from 201.1 ±4.2 to 196.1 ±2.3 km^2. However, the most spectacular feature is the continual water level rise from 2003 to 2009 without an obvious associated increase in precipitation (Hongbo et al., 2014). The glacial lakes in the central Himalaya expanded rapidly by 17.11% from 1990 to 2010 (Nie et al., 2013).



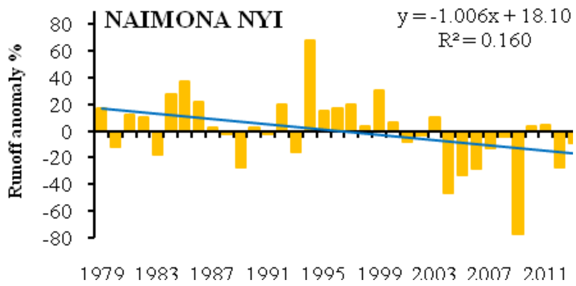


Fig. 2-8 The annual runoff anomaly % of the nine stations during 1979-2013

2.4 Discussions

As shown in Table 2-2, Hailuogou station showed there is a correlation coefficient between annual temperature with annual density negative relationship (CC = -0.398*) and positive relationship between annual temperature with annual snowmelt (CC = 0.608**). The correlation coefficients of annual temperature with annual mass balance, snow density and snow depth at the URUMQI GLACIER NO. 1 station, respectively are significantly negative relationship (CC = -0.589**, -0.512** and -0.630**), also there is a significantly positive correlation of annual temperature with Runoff (CC = 0.556**). The QIYI station showed a significantly negative correlation of annual temperature with annual balance and annual snow density (CC = -0.665* and -0.501**, respectively).

The XIAO DONGKZMADI station showed a significant negative correlation between annual temperature with annual balance (CC = -0.657**), also there is a significantly positive correlation of annual temperature with Runoff (CC 0.423*). The KANGWURE station showed a significant negative correlation between annual temperature with annual snow density and snow depth (CC = -0.486** and -0.642**, respectively), while a positive correlation of annual temperature with annual snowmelt (CC = 0.598**). The MEIKUANG station showed a significant negative correlation of annual temperature with annual snow density (CC = -0.673**). The GURENHEKOU station showed a significant negative correlation of annual temperature with annual balance and annual snow density (CC = -0.987** and -0.454**, respectively).

The PARLUNG NO. 94 station showed a significant negative correlation between annual temperature with annual snow density (CC = -0.468**), while there is a significant positive correlation between annual temperature with annual snowmelt (CC = 0.568**). The

NAIMONA NYI station showed a significant negative correlation of annual temperature with annual snow density and annual snow depth (CC = -0.546** and -0.387*, respectively).

Table 2-2 The correlation coefficient between temperature with snow density, snowmelt, snow depth and runoff in the nine stations during 1979-2013.

	Station name	Mass balance		Snow density		Snowmelt		Snow depth		Runoff	
		Sig.	P	Sig.	P	Sig.	P	Sig.	P	Sig.	P
1	Hailuogou	-0.30	0.63	-0.398*	0.02	0.608**	0.00	0.05	0.76	-0.08	0.63
2	Urumqi Glacier No. 1	-0.589**	0.00	-0.512**	0.00	0.21	0.23	-0.630**	0.00	0.556**	0.00
3	Qiyi	-0.665*	0.02	-0.501**	0.00	0.10	0.55	-0.05	0.80	0.33	0.05
4	Xiao Dongkzmadi	-0.657**	0.00	-0.21	0.22	-0.30	0.08	-0.29	0.09	0.423*	0.01
5	Kangwure	-0.47	0.53	-0.486**	0.00	0.598**	0.00	-0.642**	0.00	0.32	0.06
6	Meikuang	-0.13	0.68	-0.673**	0.00	-0.275	0.11	0.23	0.00	0.25	0.15
7	Gurenhekou	-0.987**	0.00	-0.454**	0.01	0.09	0.59	0.27	0.11	0.30	0.08
8	Parlung N0. 94	-0.44	0.28	-0.468**	0.00	0.568**	0.00	-0.16	0.36	-0.16	0.36
9	Naimona Nyi	0.77	0.12	-0.546**	0.00	0.03	0.84	-0.387*	0.02	-0.26	0.13

Note: * means at a significance level of 0.05; ** means at a significance level of 0.01.

The average temperature of the nine stations during 1979-2013 showed a highly increasing trend at the rate of 0.46 C ?10a, which has resulted in an increasing trend of annual snowmelt and runoff anomaly at the rate of 24.82 %/10a and 9.87 %/10a, respectively. On the other hand, there was a declining trend in annual snow density and snow depth anomaly at the rate of -5.32 %/10a and -1.93 %/10a, respectively (Fig. 2-9).

Wang et al., (2014) reported that the ice volume in Urumqi Glacier No. 1 was decreased during 1981-2006, which caused glacier thinning. Thus, these changes were responses to the regional climatic warming, which showed a dramatic increase of 0.6 C ?10a during the 25 years (1979-2013).

In fact, under global warming, glaciers are experiencing the heavy amount of glacier ablation around the world, which caused the sea-level rise and mountain (Jevrejeva et al., 2008). The results in Table 2-3 showed that the correlation coefficient of the mean temperature of the nine stations during 1979-2013 has a highly significant negative relationship with snow density (CC = -0.661** at 0.01 level). There is a high positive relationship between temperature with snowmelt (CC = 0.532** at 0.01 level), in addition, a positive relationship between temperature and runoff has a correlation coefficient of 0.586** at 0.01 level. In addition, representative relationships between all parameters have clearly shown in Fig. 2-10 in horizontal and vertical axis during 1979-2013.

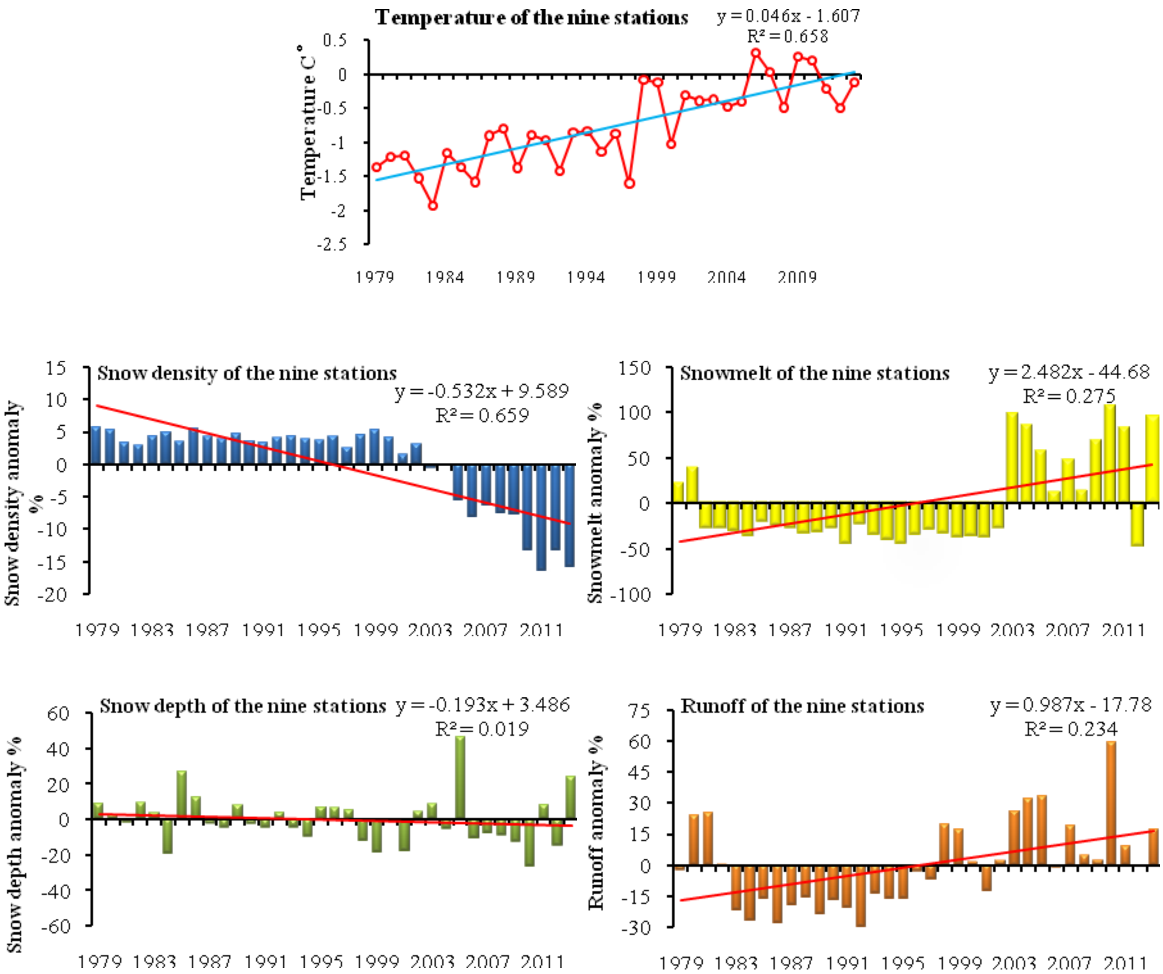


Fig. 2-9 Cumulative changes of mean temperature, snow density, snowmelt, snow depth and runoff during 1979-201

Table 2-3 The correlation coefficient of the mean of the nine stations, firstly between temperature and snow density, snowmelt, snow depth and runoff. Secondly, between snow density and snowmelt, snow depth and runoff, thirdly between snowmelt and snow depth and runoff, finally snow depth with runoff, the correlation coefficient during 1979-2013.

	Snow density		Snowmelt		Snow depth		Runoff	
	Sig. value	P value	Sig. value	P value	Sig. value	P value	Sig. value	P value
Temperature	-0.661**	0.00	0.532**	0.00	-0.342*	0.04	0.586**	0.00
Snow density			-0.662**	0.00	0.02	0.92	-0.491**	0.00
Snowmelt					0.17	0.34	0.712**	0.00
Snow depth							-0.03	0.86

Note: * means at significance level of 0.05; ** means at significance level of 0.01.

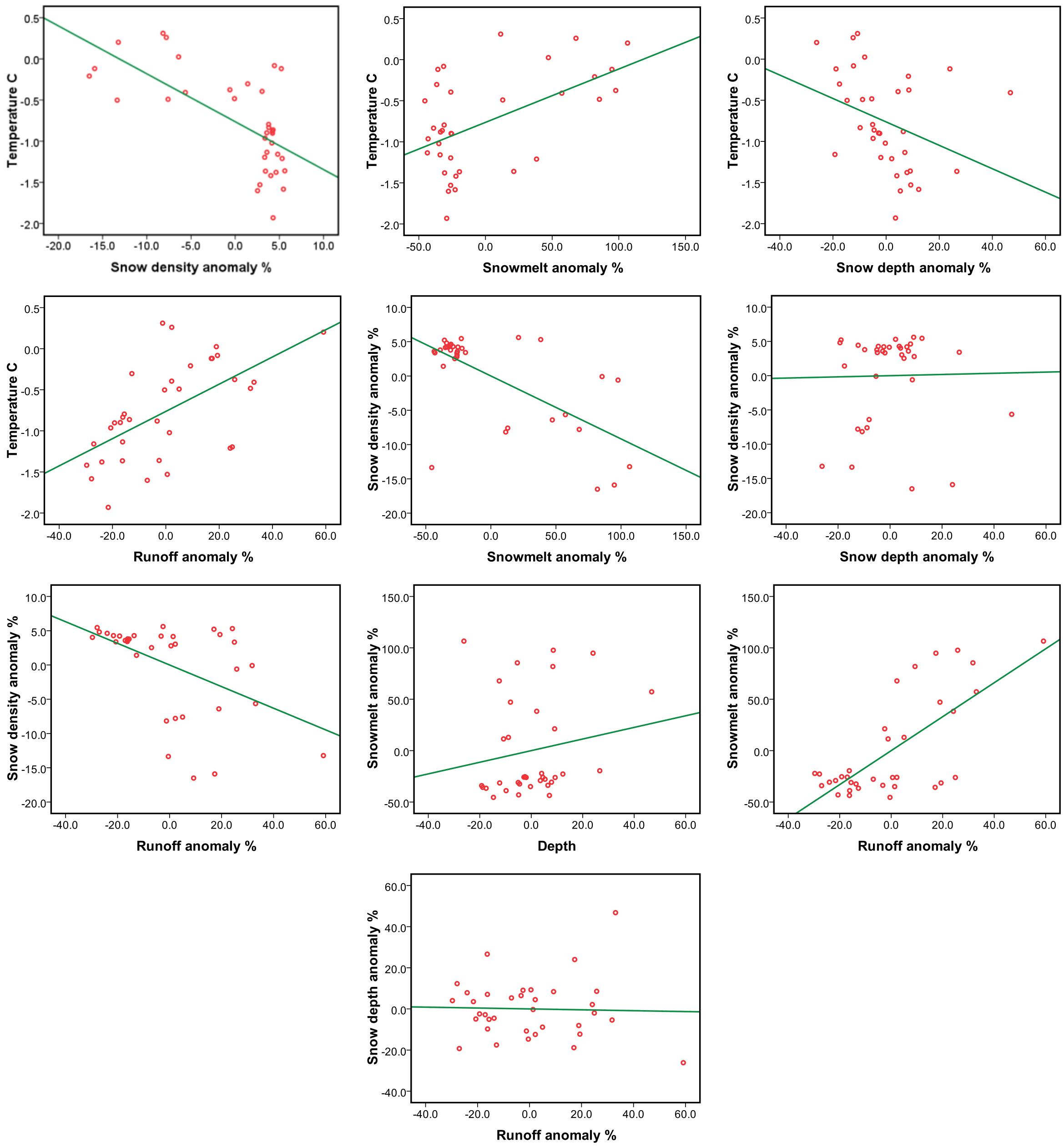


Fig. 2-10 The relationships between the parameters of mean the nine stations that have shown in horizontal and vertical axis during 1979-2013.

2.5 Conclusion

The present study confirms continuous glacier mass loss and accelerated glacier area shrinkage during the period 1979-2013 on nine glacier stations in China. Accordingly, this research provided a brief overview of major glacier balance change, snow density, snowmelt and runoff. Moreover, this study provides baseline knowledge to analyze data and research on a climate change adaptation perspective to reduce the negative impacts on melt and runoff, which have serious implications for human societies due to depending on fresh water from cryospheric sources.

The survey results showed that a significant increase in temperature during the past half-century has a high relationship with melting glacier in China. In fact, the study area showed a retreat of snow density and snow depth, on the other hand, the increase in snowmelt and runoff. Both changes have highly significant correlations with temperature increase. In suggestions, we call to better preparedness and strategies to create good plans that can adapt with climatic and cryospheric variables.

Thus, an adaptation to negative impacts of climate change on glaciers is foremost a challenge that has to be tackled at the local or regional scale and within the societal context of the target region.

CHAPTER THREE

Detection of Drought Cycles Pattern in Two Countries (Sudan and South Sudan) by Using Standardized Precipitation Index SPI

3.1 Introduction

Climate change is one of the biggest threats to nature and humans in the 21st century. It is well reported that an increase in the use of fossil fuel will accelerate global warming and eventually will lead to the extinction of civilizations with the passage of time (Lonngren and Bai 2008). Generally, variations in regional ecosystems are the consequences of both climate change and local anthropogenic activities, but it is almost impossible to directly differentiate between these two factors (Wessels 2007).

Particularly in arid and semi-arid areas, increased anthropogenic activities can easily lead to the degradation of certain ecosystems, even causing serious ecological and economic losses (Harris 2010). Due to the ongoing global warming and intensified anthropogenic activities over the last century (Consortium 2013 and Raupach et al. 2013), the socioeconomic drivers have started to overwhelm the great forces of nature for some selected processes regionally or even on the global scale (Erb 2006). Several meteorological and socioeconomic implications of this situation have been discussed (Peter 1983).

In semi-arid Sudan, water availability is the primary constraint upon human habitation and activity. Large areas of central Sudan have an inadequate supply of water to meet even the basic daily requirements of human and livestock (El Sammani 1978). Mawdsley et al. (1994) defined the drought by using two types of drought indicators: (a) environmental indicators, which measure the direct effect of the hydrological cycle, precipitation, temperature, evapotranspiration, river flow, etc., and (b) water resources indicators, which measure the severity in terms of the impact on water supply, e.g. water supply for domestic, agricultural, industrial, fisheries and recreational purposes.

Although “drought indices can only reflect drought conditions based on hydro-meteorological variables and unable to quantify the economic losses” (Mishra and Singh 2010) indices for monitoring climate variability and drought impacts are useful tools for designing drought response plans, assessing the need for domestic and international aid decision to affected populations and declaring drought emergency (Quiring 2009). The drought index is the basis for arid climate research, and to measure the extent of the drought key (Piara et al. 2014). Palmer (1965) proposed a new drought index, considering a number of elements including precipitation, temperature, soil moisture, evapotranspiration. Standardized precipitation index (SPI) is the most widely used drought index. The calculation of SPI is simple and multiple time scales can be used anywhere.

Meteorological drought results from the reduction of precipitation, while agricultural drought is related to a shortage of available water for plant growth. Hydrological drought refers to a deficiency of surface and subsurface water supply. Finally, socioeconomic drought is associated with insufficient supply to meet the demand of some economic good with the above three types of drought (McKee et al. 1993). Meteorological drought occurs more frequently and commonly than other three kinds of droughts, meanwhile, it normally triggers other types of drought, including agricultural, hydrological and socioeconomic drought (WMO 2006).

The Sahara Desert has described as encroaching southwards at an increasing rate. This desertification phenomenon is considered as mainly human-induced. Sudan is one of the driest but also the most variable countries in Africa in terms of precipitation. Extreme years (either good or bad) are more common than average years (Zakieldeen 2007).

The devastating Sahelian desiccation over the last generation of the 20th century Hulme (2001) has motivated many scientists to identify the changes in drought conditions in Sudan, perhaps due to the diversified vegetation and climatic features of the country. Several studies show that Sudan is suffering from degradation of its land resources through overgrazing, range fires, deforestation, inappropriate agricultural practices and the highly variable precipitation and recurrent droughts (Ayoub 1998).

The objective of this research is to show the drought pattern in two countries (Sudan and South Sudan) during 1961-2013 by using characteristics of Standardized Precipitation Index (SPI). The usefulness of results is to provide valuable information for better adaptation and mitigation of consequences of drought to create a strategically good planning.

3.2 Material and Methods

3.2.1 Study Area

Sudan and South Sudan are located in the northeastern part of Africa (Fig. 3-1), combined cover area is 2501010 km2, extending from the latitude of 2° 40' - 22° 30' N and from longitude 21° 50 ' - 38° 50' E, altitude 40 - 870 m. Literature indicates that drought has become more frequent in recent decades. Early to mid-1970s, mid-1980s; early 1990s and early 2000s were reported as common drought years and were among the 10 driest years in the central region of Sudan (Elagib 2009).

Table 3-1 showed the geographical location, altitude and annual precipitation of meteorological stations in Sudan and South Sudan. Most of the observed precipitation occurs during the rainy season from March to October. Humidity level is very high in a rainy season. The Nile River traverses through the length of South Sudan and Sudan. The Nile River basin contributes most of Sudan’s available surface water, transporting over 93 billion cubic meters (bcm) of water per year on average, though only a one-fifth of this may be used in accordance with a 1959 water use treaty with Egypt (NAPA 2007).

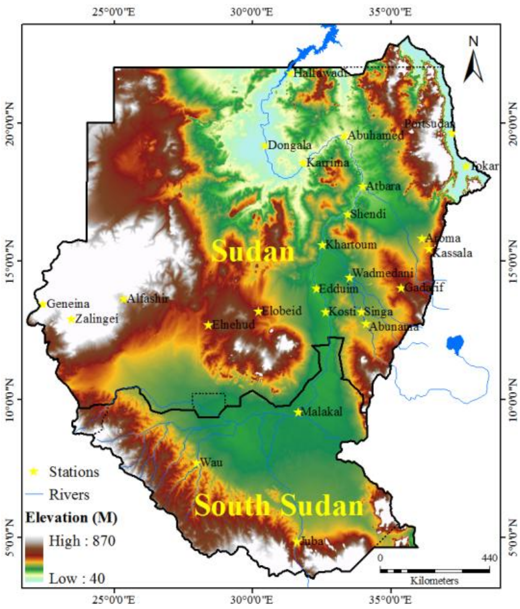


Fig. 3-1 The distribution of meteorological stations in Sudan and South Sudan

3.2.2 Standard Precipitation Index SPI

The SPI was developed by McKee et al. (1993), it is a meteorological drought index and is based solely on precipitation data. Two main advantages arise from the use of the SPI index.

First, as the index is based only on precipitation data so its evaluation is relatively easy (Cacciamani et al. 2007). Second, the index makes it possible to describe drought on multiple time scales (Tsakiris and Vangelis 2004).

Details about the SPI index computation can be found in several papers including (Khalili et al. 2011). SPI index is a simple calculation based on the concept that precipitation deficits over varying periods or time scale influence groundwater, reservoir storage, soil moisture, snowpack, and streamflow. Computations for flexible multiple time scales provides early warning of drought and help to assess drought severity. Several datasets could be used for drought monitoring.

However, there are few technical requirements, a data set should be suitable for an operational monitoring and forecasting chain employing the SPI index. Firstly, it should be long enough (at least 30 yr), as recommended by McKee et al. (1993). SPI index calculation can be calculated on 1, 3, 12, 24, 36 and 48 months equal time scales.

Table 3-1 The Longitude and latitude, altitude and annual precipitation of meteorological stations in Sudan and South Sudan

	Stations	Longitude	Latitude	Altitude (m)	Precipitation (mm)
1	Abuhamed	33°44´	19°51´	313	12.5
2	Abunama	34°06´	12°65´	434	632.0
3	Alfashir	25°31´	13°58´	738	170.5
4	Aroma	35°94´	15°77´	445	234.8
5	Atbara	33°75´	17°64´	385	42.9
6	Dongola	30°63´	19°20´	249	7.0
7	Edduim	32°19´	13°89´	385	230.5
8	Elnehud	28°44´	12°65´	573	438.8
9	Elobeid	30°31´	13°27´	610	357.3
10	Gadarif	35°31´	14°21´	571	521.0
11	Geneina	22°50´	13°27´	845	748.1
12	Halfawadi	31°25´	21°08´	320	3.8
13	Juba	31°56´	4°84´	598	735.1
14	Karrima	31°88´	18°58´	242	13.5
15	Kassala	36°25´	15°46´	490	341.0
16	Khartoum	32°50´	15°46´	383	133.3
17	Kosti	32°81´	12°96´	362	362.7
18	Malakal	31°56´	9°84´	392	719.8
19	Portsudan	37°19´	19°83´	41	35.6
20	Shendi	33°44´	16°70´	378	62.0
21	Singa	34°06´	12°96´	426	536.7
22	Tokar	37°81´	18°89´	256	171.8
23	Wadmedani	33°44´	14°52´	407	216.9
24	Wau	28°13´	7°65´	440	912.7
25	Zalingei	23°44´	12°96´	862	549.3

Table 3-2 Classification criteria of SPI index in Sudan and South Sudan

	Drought category	SPI
1	No drought	< -0.5
2	Mild drought	-0.5 ～-1.0
3	Moderate drought	-1.0 ～-1.5
4	Severe drought	-1.5 ～ -2.0
5	Extreme drought	> -2

3.2.3 Mann-Kendall M-K Test

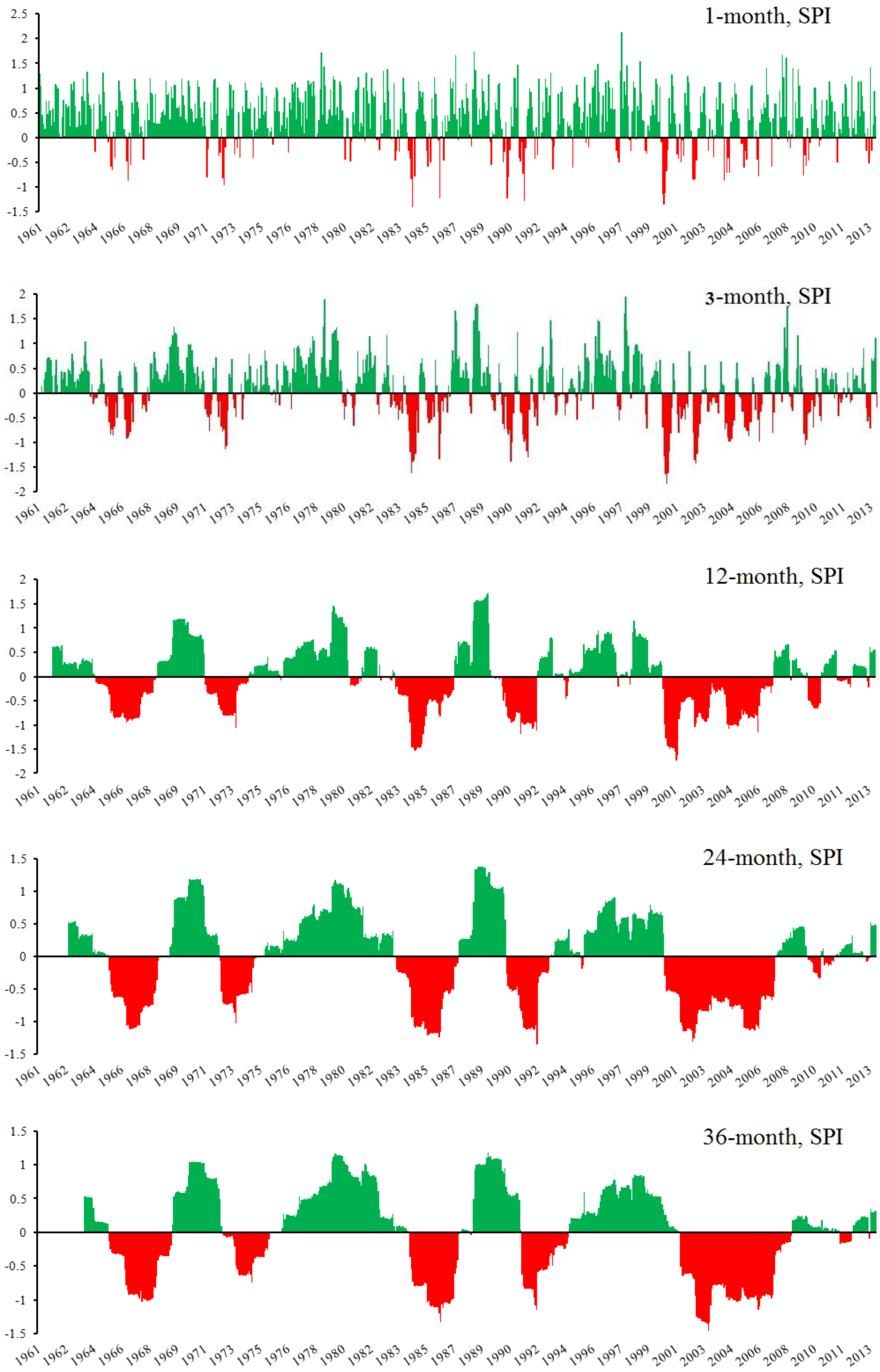
Testing the significance of observed trends in hydrologic and climatic time series has received a great deal of attention recently. Mann-Kendall test, developed by Mann (1945) and Kendall (1975) is used for trend analysis. The rank-based M-K test is the most widely used nonparametric test for trend detection. This test can be applied to a time series data without considering the probability distribution.

Distribution-free tests have the advantage that their power and significance are not affected by the actual distribution of the data. This is in contrast to parametric trend tests, such as the regression coefficient test, which assume that the data follow the normal distribution, and so their power can be greatly reduced in the case of skewed data (Hamed 2009).

3.3 Result and Discussions

3.3.1 Standard Precipitation Index SPI

As already described in the detail comparative studies of many scholars on a variety of meteorological drought indices, exploration of each index area is not a simple adaptation of the linear trend of each index. As reported by Elagib and Elhaj (2011), the high drought in Sudan and South Sudan was observed in 1973, 1981, 1984, 1990, 1991, 2000, 2001, 2002, 2005, 2006, 2007 and 2008. Fig. 3-2 showed that the SPI 12-month had a high frequency of drought in 1966 - 1968, 1974, 1984 - 1985, 1991 - 1992, 2000 - 2003, 2005 - 2006 and 2010. SPI 24-month showed a high frequency of drought in 1966 - 1968, 1974, 1984 - 1986, 1992 and 2000 - 2008. SPI 36-month showed a high frequency of drought in 1967 - 1968, 1974, 1984 - 1987, 1992 and 2000 - 2007. SPI 48-month showed a high frequency of drought in 1967 - 1968, 1985 - 1986 and 2001 - 2007.


1-month, SPI
2.5
2
1.5
1
0.5
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-0.5
-1
-1.5
3-month, SPI
2
1.5
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0.5
0
-0.5
-1
-1.5
-2
12-month, SPI
2
1.5
1
0.5
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-1
-1.5
-2
24-month, SPI
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36-month, SPI
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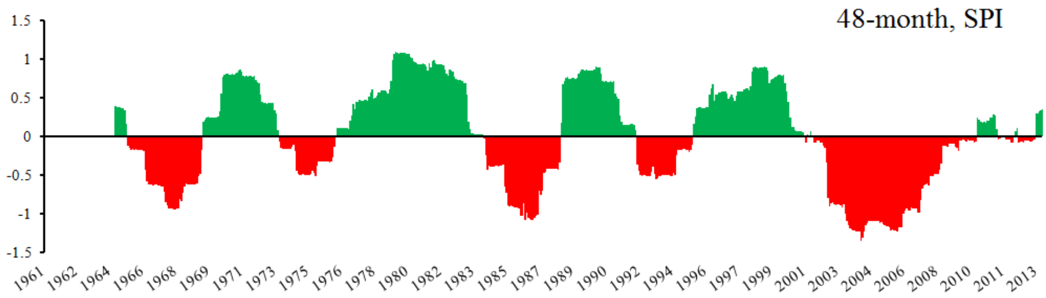


Fig. 3-2 SPI values in Sudan and South Sudan during 1961 - 2013

3.3.2 Mann-Kendall M-KTest

Table 3-3 showed that the winter-SPI drought trend had a significant trend in Aroma (P = 0.00), Gadarif (P = 0.00), Kassala (P = 0.01) and in Abuhamed (P = 0.05). Summer-SPI drought trend was significant at P = 0.00 in Zalingei, Atbara, Edduim, Elobeid, Khartoum, Shendi, and Alfashir; at P = 0.01 in Abuhamed, Aroma, Dongola, Elnehud, Kosti, and Wadmedani; at P = 0.00 in Karrima, Gadarif and Geneina; at P = 0.04 in Kassala; and at P = 0.05 in Halfawadi. Autumn-SPI drought trend was significant at P = 0.00 in Kassala and Aroma; at P = 0.01 in Shendi and Wadmedani; and at P = 0.02 in Atbara.

Winter-SPI humid trend was significant at the 0.05 confidence level in Juba, Wau, Malakal, and Portsudan. Summer-SPI humid trend was significant at the 0.05 confidence level in Juba and Wau. Autumn-SPI humid trend was significant at the 0.05 confidence level in Juba, Malakal, and Wau. Juba, Malakal, and Wau are locating in South of Sudan.

Table 3-3 Drought index of M-K test for seasonal-SPI drought index in Sudan and South Sudan during 1961 - 2013

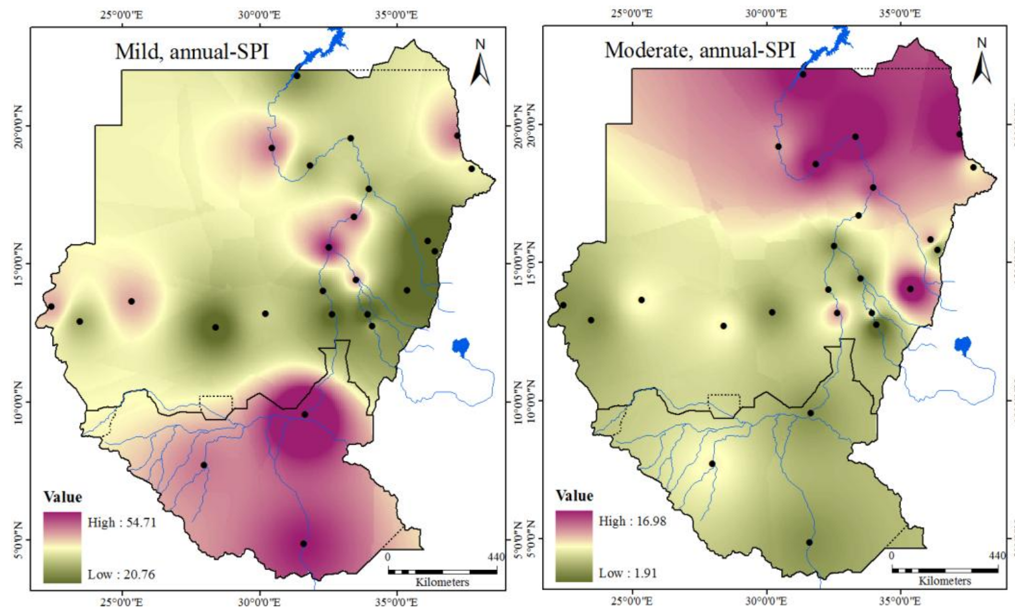
	Station	Winter		summer		autumn	
		Z value	P value	Z value	P value	Z value	P value
1	Abuhamed	***-1.50***	0.05	***-2.40***	0.01	-0.71	0.24
2	Abunama	-0.72	0.24	-0.94	0.17	-1.20	0.12
3	Alfashir	-0.21	0.42	***-2.70***	0.00	1.70	0.10
4	Aroma	***-3.60***	0.00	***-2.26***	0.01	***-3.54***	0.00
5	Atbara	***-1.87***	0.03	***-3.52***	0.00	***-2.00***	0.02
6	Dongola	0.30	0.49	***-2.43***	0.01	-0.21	0.42
7	Edduim	-0.48	0.31	***-3.20***	0.00	-0.90	0.18
8	Elnehud	0.60	0.27	***-2.21***	0.01	-0.88	0.19
9	Elobeid	0.03	0.49	***-2.72***	0.00	-1.00	0.16
10	Gadarif	***-3.07***	0.00	***-2.14***	0.02	***-2.72***	1.00
11	Geneina	-1.06	0.14	***-2.00***	0.02	-0.15	0.44
12	Halfawadi	***-1.67***	0.05	***-1.64***	0.05	-0.07	0.48
13	Juba	4.78	0.00	4.23	0.00	3.12	0.00
14	Karrima	-1.02	0.15	***-2.00***	0.02	-0.08	0.53
15	Kassala	-2.54	0.01	***-1.80***	0.04	***-4.18***	0.00
16	Khartoum	-0.65	0.26	***-2.76***	0.00	-1.30	0.10
17	Kosti	-1.30	0.09	***-2.54***	0.01	***-0.28***	0.39

18	Malakal	4.40	0.00	1.57	0.06	3.08	0.00
19	Portsudan	2.10	0.02	-0.28	0.39	-1.42	0.08
20	Shendi	-0.66	0.26	***-2.85***	0.00	***-2.21***	0.01
21	Singa	-1.53	0.06	-1.23	0.11	-1.47	0.07
22	Tokar	0.42	0.34	-1.12	0.13	0.75	0.23
23	Wadmedani	-1.24	0.11	***-2.55***	0.01	***-2.26***	0.01
24	Wau	4.23	0.00	1.91	0.03	2.01	0.02
25	Zalingei	-0.52	0.30	***-3.38***	0.00	0.22	0.41

Note: The bold and italic values are drought, underline values are humidity both with P value ≥ 0.05

3.3.3 Spatial Variation of Drought Frequency

Fig. 3-3 showed the frequency distribution of four annual-SPI drought categories in Sudan and South Sudan during 1961-2013. The high frequency of an annual-SPI mild drought was found in Portsudan, Dongala, Shendi, Khartoum, Alfashir, Geneina, Malakal, Juba and Wau; moderate drought in Portsudan, Halfawadi, Karrima, Abuhamed, Atbara, Gadarif and Edduim; severe drought in Aroma, Kassala, Wadmedani, Edduim, Elobeid, Zalingei and Geneina; extreme drought in Gadarif, Singa, Abunama, Edduim, Elobeid, Alfashir and Zalingei.



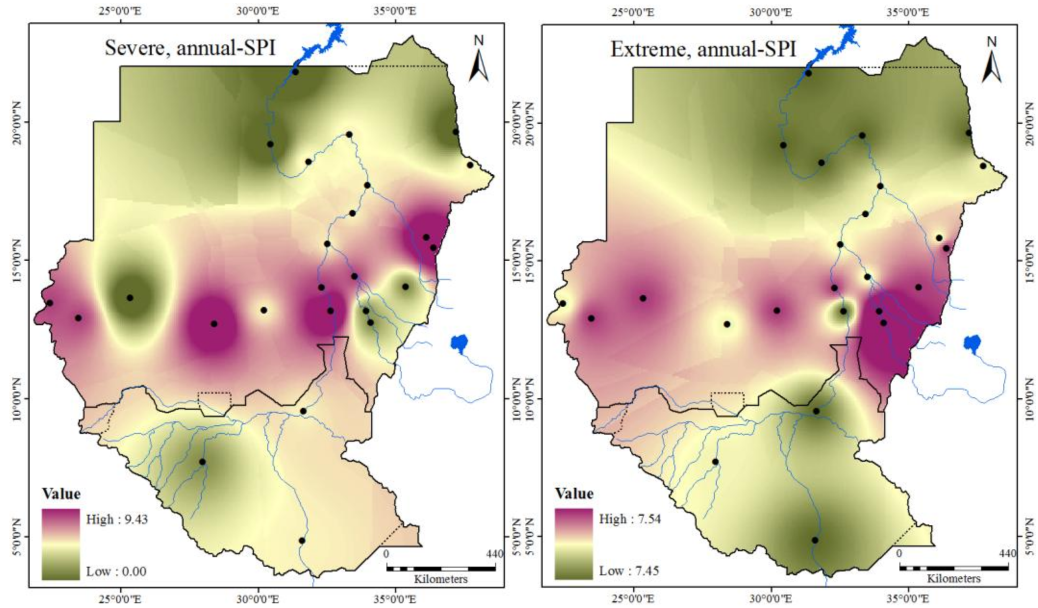
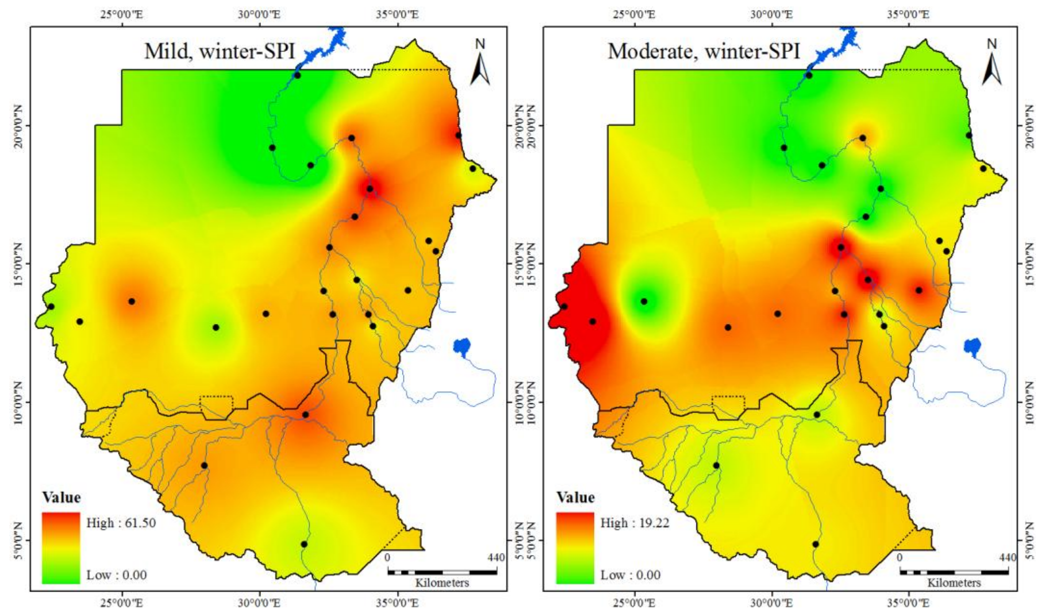


Fig. 3-3 The frequency distribution of an annual-SPI of a four drought categories in Sudan and South Sudan during 1961 - 2013

Fig. 3-4 showed the frequency distribution of four winter-SPI drought categories in Sudan during 1961-2013. The high frequency of a winter-SPI mild drought was found in Portsudan, Abuhamed, Atbara, Alfashir, and Malakal; moderate drought in Gadarif, Khartoum, Wadmedani, Kosti, Zalingei and Geneina; severe drought in Edduim, Elnehud and Juba; extreme drought in Tokar, Kassala, Singa, Abuhamed and Wau.



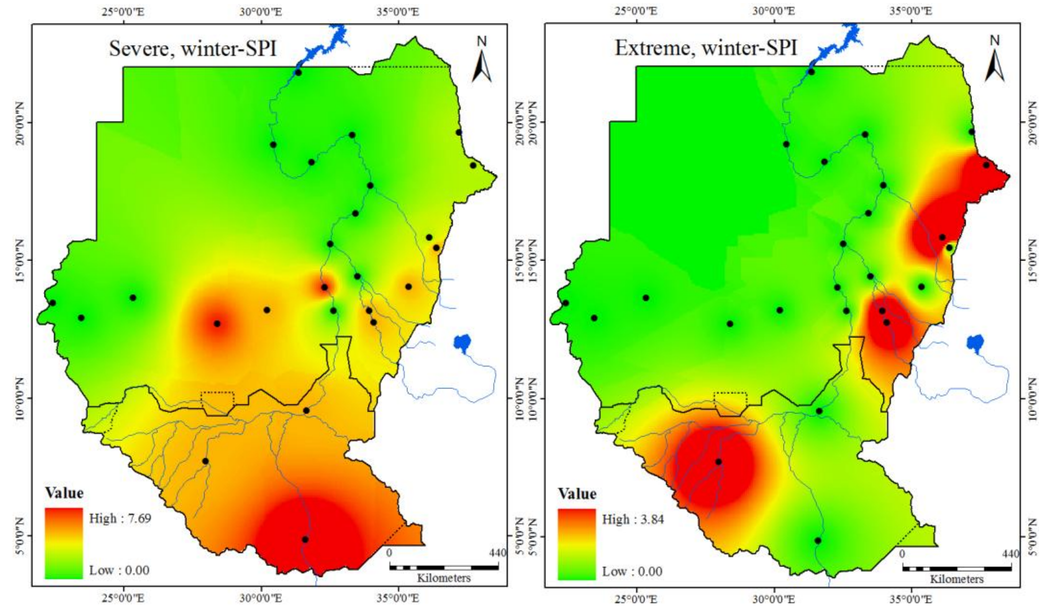
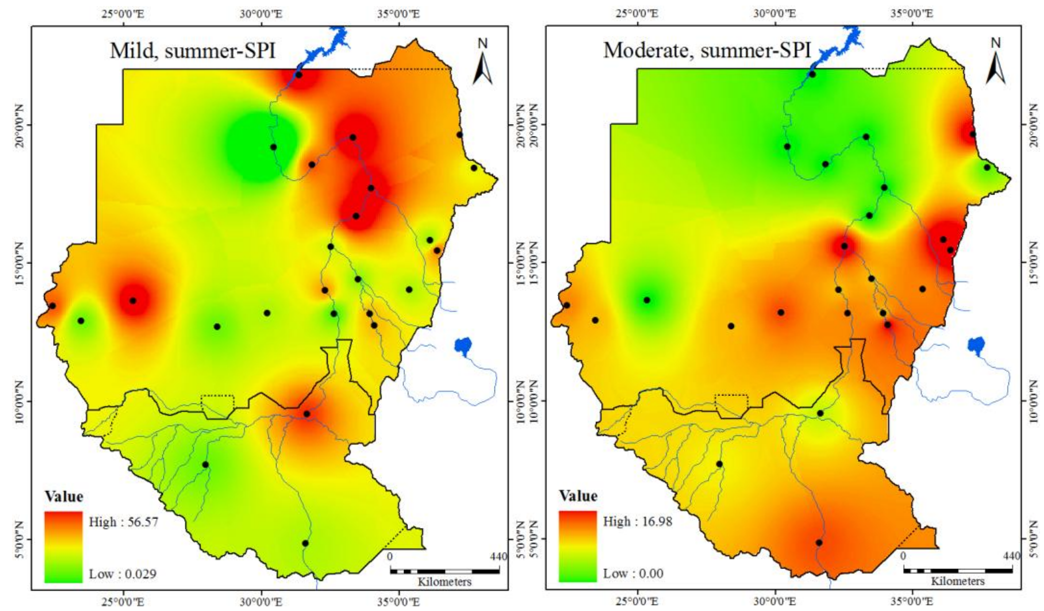


Fig. 3-4 The frequency distribution of a winter-SPI of a four drought categories in Sudan and South Sudan during 1961 - 2013

Fig. 3-5 showed the frequency distribution of four summer-SPI drought categories in Sudan during 1961-2013. The high frequency of summer-SPI mild drought was found in Halfawadi, Karrima, Abuhamed, Atbara, Shendi, Alfashir, Geneina and Malakal; moderate drought in Portsudan, aroma, Kassala, Khartoum, Abunama, Geneina and Juba; severe drought in Tokar, Gadarif, Wadmedani, Edduim, Elobeid, Elnehud, Zalingei, Juba and Wau; extreme drought in Tokar, Aroma, Singa, Abunama, Kosti, Elobeid, Elnehud, Geneina, Malakal and Wau.



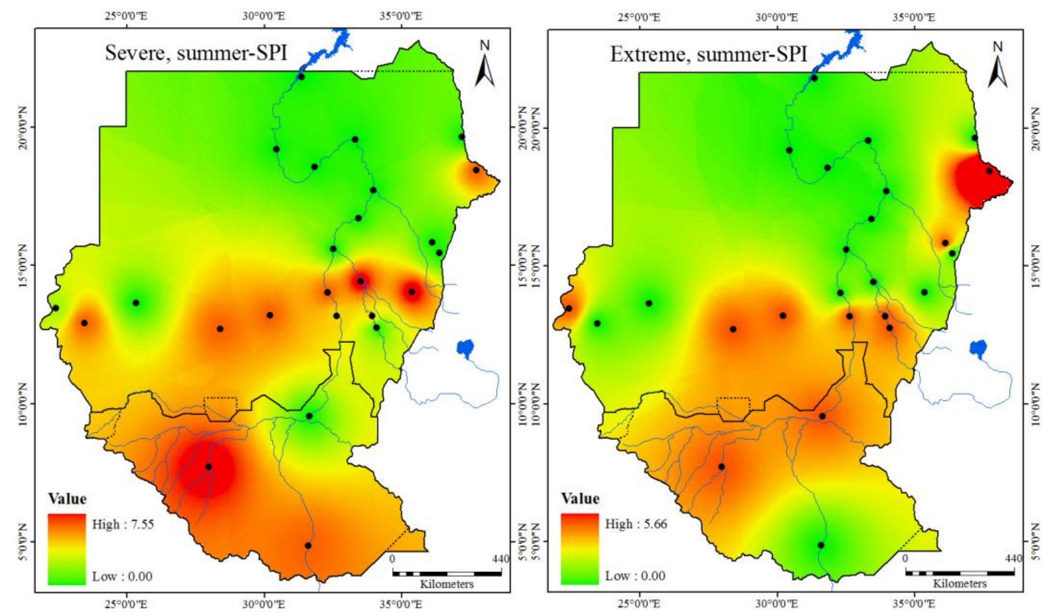
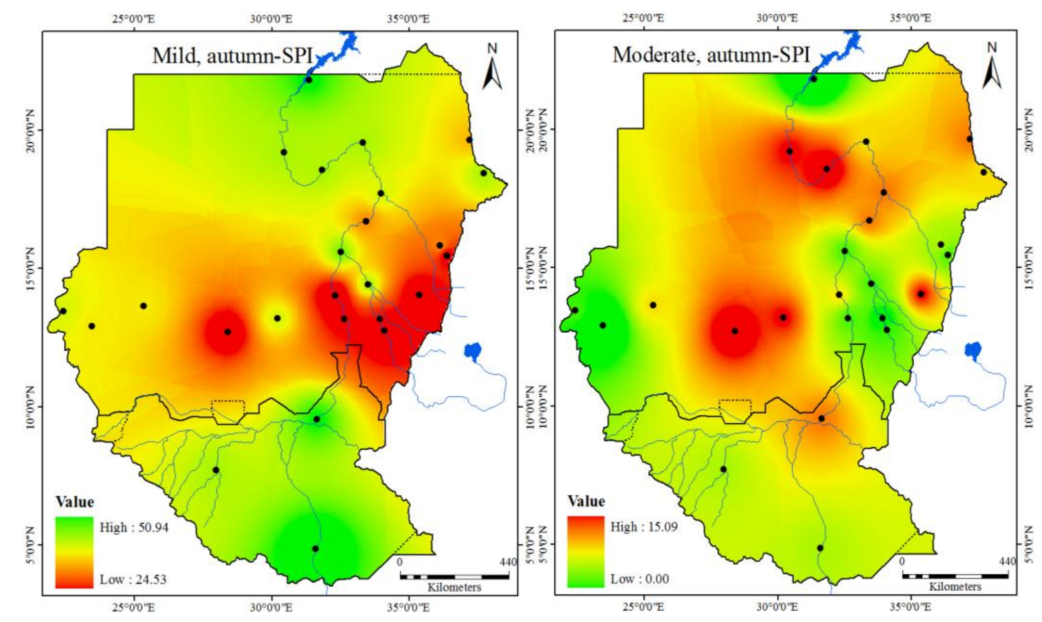


Fig. 3-5 The frequency distribution of a summer-SPI of a four drought categories in Sudan and South Sudan during 1961 - 2013



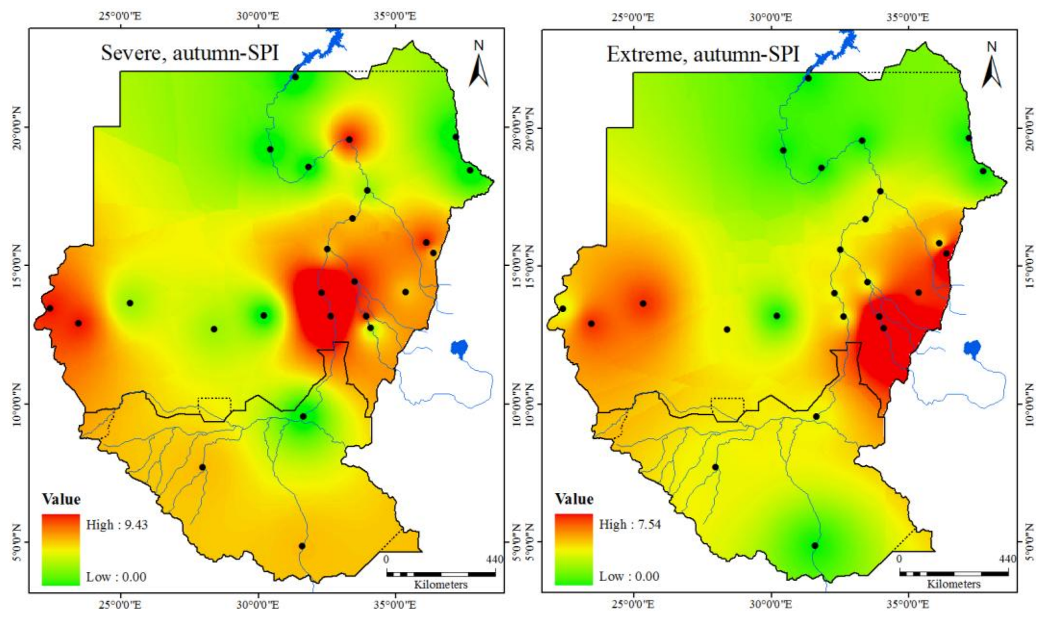


Fig. 3-6 The frequency distribution of an autumn-SPI of a four drought categories in Sudan and South

3.3.4 Drought Trends and Mutation Detection

Fig. 3-7 showed the location of the areas which were changed from humid to drought in northeast and middle of Sudan including Halfawadi, Dongola, Karrima, Abuhamed, Atbara, Shendi, Portsudan, Tokar, Aroma, Kassala, Gadarif, Wadmedani, Edduim, Elobeid, and Elnehud. The UF curve on 0.05 level of significance lines in 1998 - 2010 showed that the drought trend is very significant, UF and UB lines intersect in 1995 which is the beginning of mutation of the droughts. The annual-SPI UF curve showed a significant trend in the 2000s, 1989 is the beginning of mutation detection of drought.

3.3.5 Actual Comparison SPI Drought Index in the Highest Drought Years

Fig. 3-8 showed the monitoring of SPI drought index in 1984, 1991 and 2000, the actual comparison of SPI index in the highest drought years to monitor the degree of droughts in Sudan and South Sudan. 1984-SPI showed extreme drought in Geneina, Zalingei, and Alfashir; severe drought in Elnehud, Elobeid, Edduim, Gadarif, Abuhamed, Dongola, and Juba; moderate drought in Malakal, Kosti, Wadmedani, Khartoum, Aroma, Abuhamed, and Dongola; mild drought in Wau, Kassala, Tokar, and Halfawadi.

However, 1991-SPI showed the extreme drought in Singa, Abuhamed, Gadarif, and Kassala; severe drought in Malakal, Elobeid, Elnehud, Edduim, Wadmedani, and Aroma; moderate drought in Wau, Geneina, Zalingei, and Khartoum; mild drought in Juba, Alfashir, Shendi, Atbara, Karrima and Dongola. 2000-SPI showed the extreme drought in Zalingei, Alfashir, Elnehud, Elobeid, Edduim, Khartoum, Shendi, and Kassala; severe drought in Kosti and Atbara; Moderate drought in Gadarif, Karrima, and Abuhamed; Mild drought in Juba, Malakal, Singa, Dongola, and Halfa.

3.3.6 Influences of Drought in Sudan

Climate changes, successive droughts, population pressure and chronic food shortages are the major threats in the North Kordofan state. Drought problems in Sudan will increase if the above trends continue. The drought in North and Western Sudan, North Kordofan and Darfur, Kassala State and some parts of the rain-fed areas in central Sudan are influencing agriculture, livestock, water resources and health (NAPA 2007). Sudan suffered a severe famine in the mid-1980s.

Examination of the mean annual precipitation for some of the most severely affected regions in Sudan revealed that most severe famines of the past two decades (1984-85, 1973-74, 1965-66) were associated with the worst multiple-year droughts (Patrik et al. 1991). The livestock prices decrease during drought periods, indicating disposal of assets on a large and widespread scale. There has been a drought in some of the main grain producing areas, such as Gadarif, and in some more impoverished parts of the country. In other places, there has been a disastrous dry spell mid production season, and in parts of the west and east, water is becoming very scarce. Pasture across northern Sudan is reported to be very poor (Margarel et al 1990).

There are many ongoing national policy processes that have parallel aims to climate change adaptation. Water harvesting techniques have been implemented for nine areas in several states (North Darfur, Nile, North Kordofan, and West Kordofan). These projects have increased community access to reliable water, increasing their capacity to cope with the impacts of reduced precipitation, increased temperature and drought, all of which have been integrated into the NAPA consultation process. At the state level, many environment councils have been established.

By virtue of the broad NAPA consultation process conducted in Sudan, many of these councils have recently begun to formally propose potential adaptation measures in their sectoral policy discussion. This has been a very clear outcome, particularly with respect to food security, water, and public health sectors (NAPA 2007).

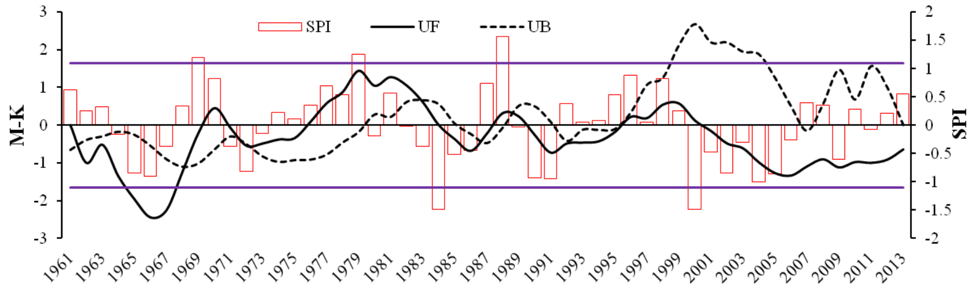


Fig. 3-7 Interannual variations and Mann-Kendall test of SPI drought index in Sudan and South Sudan during 1961 - 2013

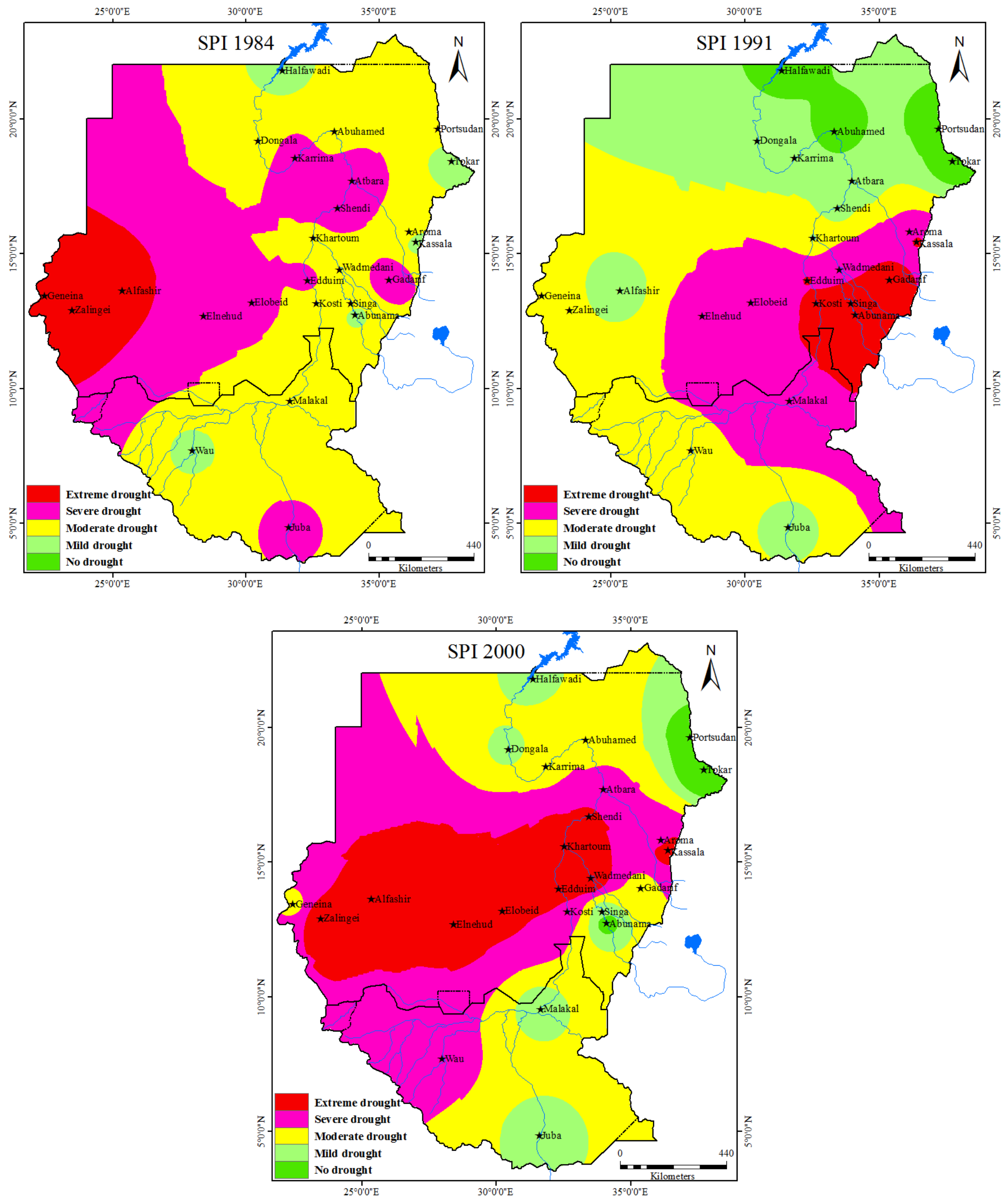


Fig. 3-8 Monitoring results of SPI drought index in Sudan and South Sudan in 1984, 1991 and 2000

3.4 Conclusions

This study revealed that a decrease in precipitation caused droughts which consequently would reduce the natural vegetation cover, croplands and livestock production. Drought indices designed to provide a concise overall picture of droughts are often derived from massive amounts of hydro-climatic data and are used for making decisions on water resources management and water allocations for mitigating the impact of droughts.

In recent years, the study area is influenced by intense climate warming and a decrease of precipitation, drought occurs frequently over arid areas. Most drought studies focus on quantifying drought on the regional or global scales, but this generalization can obscure localized effects.

This study recommends diversifying livelihood options in order to cope with the variations in local weather as well as adopting a number of steps to change the wrong agricultural practices. Understanding of community perceptions and their sharing in designing policies and projects for effective adaptation strategies can allow coping with the impacts of climate change.

Adapting and mitigating the drought periods: improving livelihoods, agroecosystem resilience, agricultural productivity and the provision of environmental services. Also essential to note that a range of fundamental natural resources, including land, water, air, biological diversity including forests, grasslands, etc., provide the indispensable base for an agricultural production system and sustenance of agricultural ecosystems.

Make many works to improve food security conditions, food security monitoring, and early warning systems, to macroeconomic policy, relief management and institutional strengthening both at the national and sub-national level, long-term food security planning and save the strategic reserves of food security.

CHAPTER FOUR

Investigation of Climate and Land Use Policy Change Impacts on Food Security in Eastern Sudan, Gadarif State

4.1 Introduction

Climate change is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is as well as natural climate variability observed over comparable times (UNFCCC 1992). Global mean temperature has increased by 0.85˚C, over the period 1880 to 2012 and this increase in temperature is likely due to human activities that have increased the concentrations of greenhouse gases to unprecedented levels (IPCC 2013). In Africa, Sudan is one of the driest countries. It also has most variable rainfall in the continent. Extreme years "either good or bad" are more common than average years (Zakieldeen 2007).

In Sudan, the drought cycles have resulted in a severe negative social and economic impacts, including human and livestock fatalities and resettlement of about three million people near the Nile River. Decreasing of the palatable forbs led to appearing the invader grasses, which are unpalatable to livestock. The share of agriculture in GDP % of Sudan has a decreasing trend between 1965 and 2013. Furthermore, the share of agriculture in GDP % of Sudan is a decline in many years which is correlated with low precipitation and high temperature (Yagoub 2016).

The share of agriculture in GDP of Sudan was significantly decreased from 42% in 2000 to 29% in 2014 (World Bank 2014). Gadarif State underwent a highly significant increase of maximum temperature during summer, winter and autumn (Magboul et al. 2015). The vegetation cover was cleared changing of land use cultivation of crops, as the forest lands are usually characterized by high fertile and suitable for growing crops, which becomes as an appetizer for farmers to clear trees. The expansion of mechanized rain-fed schemes, illicit cutting for charcoal and firewood, traditional rain-fed agriculture and overgrazing were causes of deterioration that affected ecological equilibrium and biodiversity (Idreas and Abdo Desougi 2015).

Land mismanagement, due to Mechanized Rain-fed Agriculture (MRA), led to soil deterioration and change in soil physical properties. Consequently, crop yield, socioeconomic and environmental settings were adversely influenced (Adam et al. 2015). The MRA in Gadarif State is the most important area in the country since it contributes significantly to the total food production for the majority of inhabitants (Lotfie 2013). Loss of soil fertility and rainfall variability is among such factors. Crops yields are declined level of significance, which indicates a significant decline in soil fertility (Ayoub 1999). Previously, Fahmi et al. (2017) reported some measures for improvement of rain-fed agriculture in central Sudan, according to the priority should be given to measures that will increase the soil fertility; and further investigate the impact of meteorological drivers on crop production in Sudan (Meri and Stuart 2017). As recommended by (Yagoub 2016), a creating more livelihood options to adapt to the local weather with an understanding of local community and their sharing planning policies for effective adaptation strategies with the impacts of climate change in Sudan. As reported by UNDP/UNSO (1997), the rain-fed agriculture is depended on a large extent on smallholder; subsistence agriculture is a source of livelihood of the most population in sub-Saharan Africa. A 38% of the population in sub-Saharan Africa lives in drought-prone drylands.

The objectives of this research were to investigate influences of climate change on food security and vegetation cover, a number of specific objectives were formulated to assess climate change in Gadarif State considering the period of 1961 to 2013 in the light of the status.

4.2 Material and Methods

4.2.1 Study Area

Gadarif State is located in latitudes 12˚48' and 15˚50' N and longitudes 33˚40' and 36˚47'E, covers an area of about 6225794.91 ha (Fig. 4-1). The estimated population of Gadarif State is 1,348,378 people (Modawi et al 2015). The state is a semi-arid climatic condition with an aridity index ranging from 0.2 to 0.4 (Elhag 2006). The average mean annual temperature of Gadarif State is 30˚C. Gadarif State receives the highest temperature in April and May.

4.2.2 Data Collection and Analysis

Monthly and annual precipitation and temperature data of Gadarif State were collected from the Sudan Meteorological Authority. Fig. 4-2(a)-(e) showed the annual precipitation and temperature, in addition, monthly precipitation and temperature of the rainy season (July to October) during 1961-2013. This study consisted of two types of data. The primary data involves climatic data for the years 1961-2013.

Vegetation and crop yield in eastern Sudan rain-fed agriculture would highly depend on the state of the climate, particularly precipitation variables (Larsson 1996). In 2009, Sorghum productivity was a decline of 42% of the normal yield; also, the annual precipitation amount was 87% of the normal (Sulieman and Elagib 2012). Also, we calculated the Standard Precipitation Evapotranspiration Index (SPEI) and Standard Precipitation Index (SPI) at scale of 1-, 12-, 24-, 36- and 48-month scale to investigate the drought categories according to Yagoub (2016) and Yagoub et al. (2017a), no drought > -0.5; mild drought -0.5 to -1.0; moderate drought -1.0 to -1.5; severe drought -1.5 to -2.0; extreme drought < -2.

4.2.3 Food Security

Food security data of Gadarif State from 1961 to 2013 was the crop yield of Sorghum (*Sorghum bicolor*) and Sesame (*Sesamum indicum*). Moreover, research documents, national and international relevant projects documents, related official records and annual reports were used as supporting data.

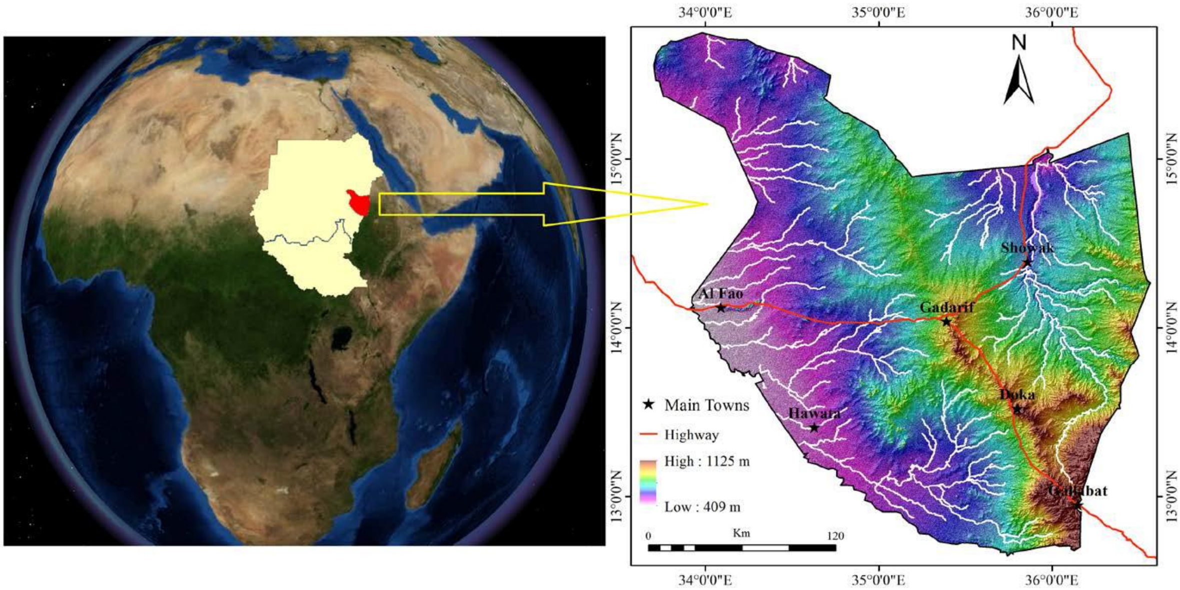
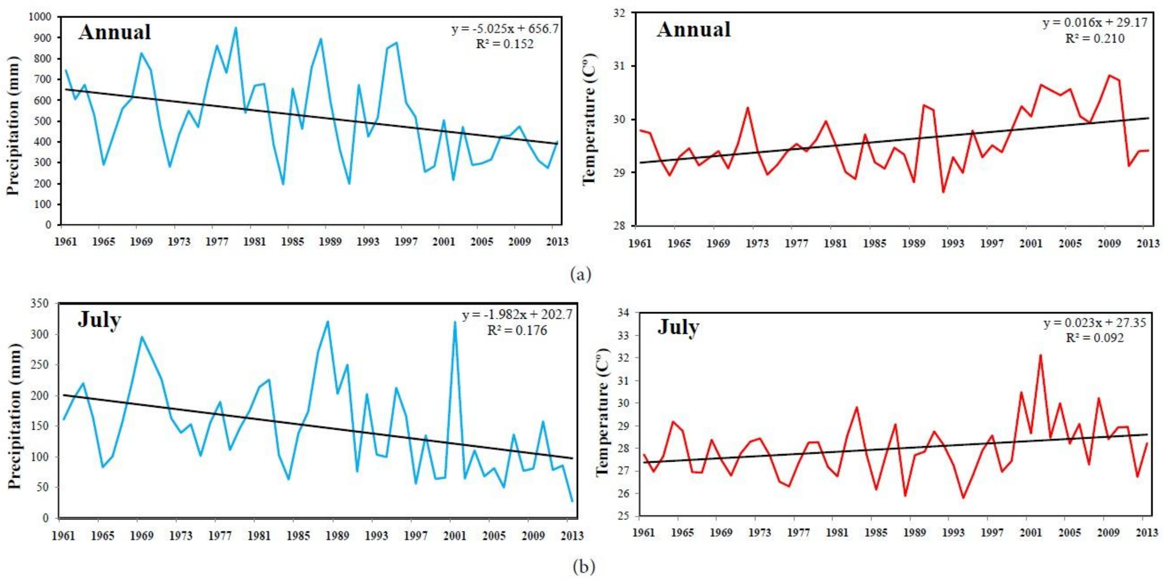


Fig. 4-1 Study area Gadarif State



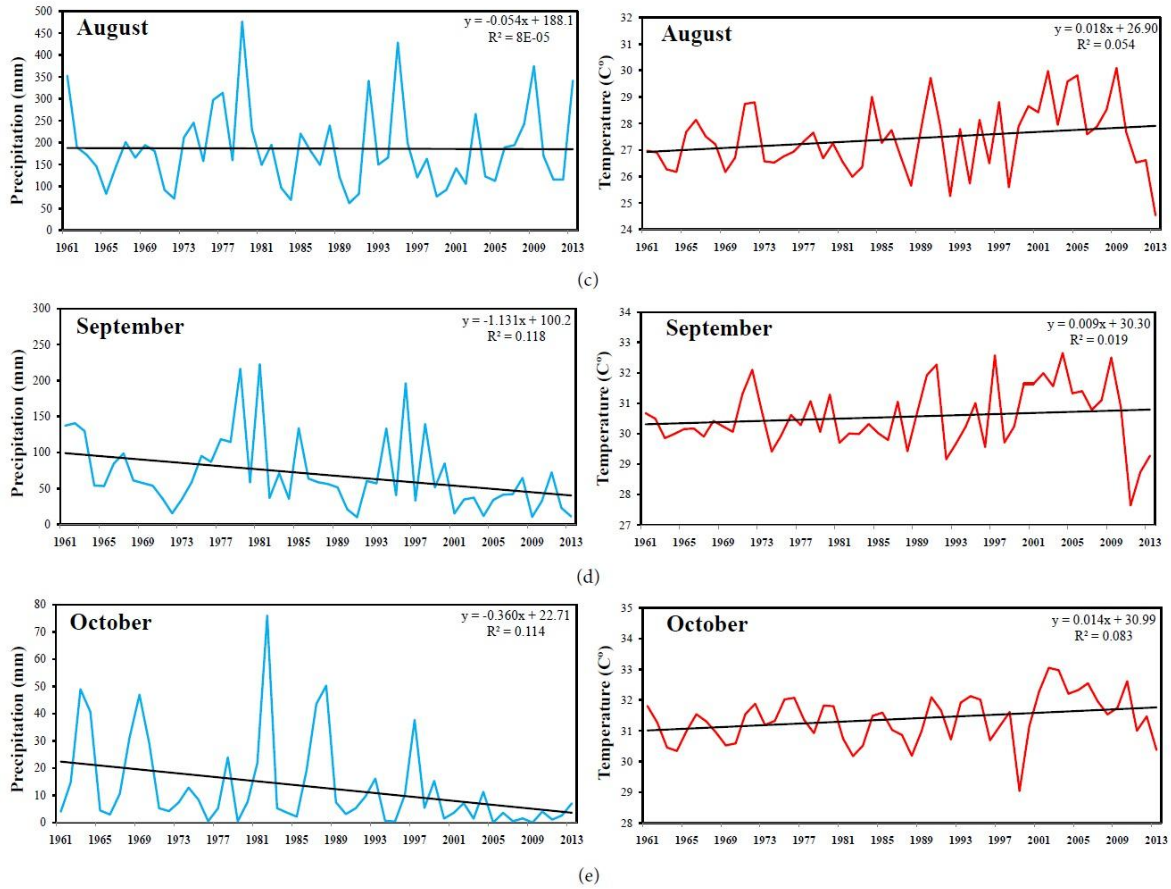


Fig. 4-2 The mean annual precipitation and temperature. In addition, monthly precipitation and temperature of July to October in Gadarif State during 1961-2013

4.3 Result and Discussion

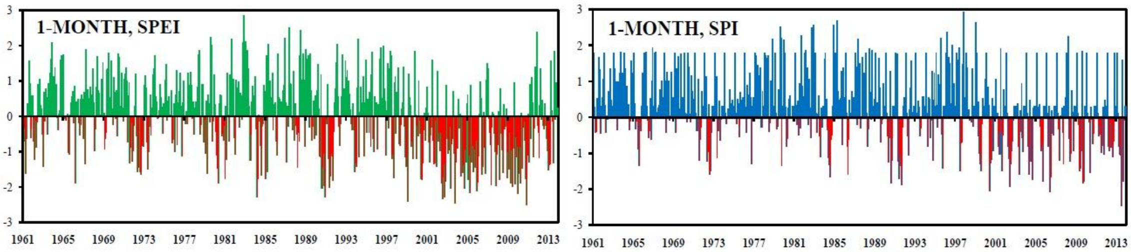
4.3.1 Climate Data and Drought Indices Analyses

Fig. 4-2(a)-(e) showed the variations of annual and monthly precipitation and temperature anomaly in Gadarif State for the 53 years. Annual precipitation and temperature anomalies showed great fluctuations all over the Gadarif State. By alternating the fluctuations of positive and negative anomalies, the most negative precipitation anomalies periods have been recorded, for example, in 1965, 1973, 1983, 1984, 1990, 1991, 1999, 2000 and 2002 (Fig. 4-2(a)).

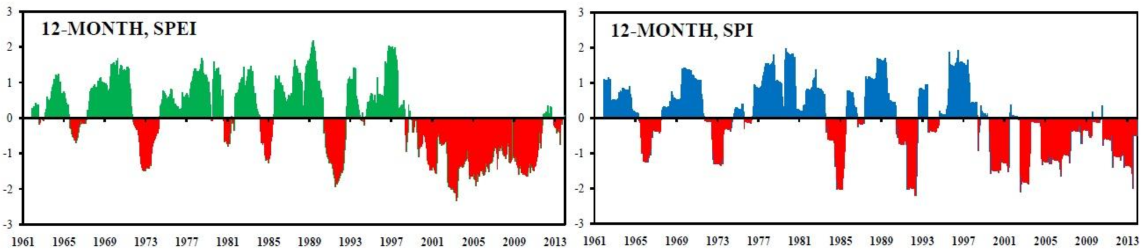
Wet years were also noticed for example, in 1969, 1970, 1977, 1979, 1987, 1988, 1992, 1995 and 1996. Likewise, temperature showed fluctuations with a generally increasing trend in 1972, 1980, 1984, 1990, 1991, 2007 and 2008. The analysis of precipitation and temperature data for the Gadarif State showed that there was a steep decreasing trend in annual precipitation and increasing trend in temperature.

The precipitation was decreasing at the rate of -50.3 mm/10a, while the temperature was increasing at the rate of 0.02˚C/10a. The monthly precipitation showed a declining trend rate of -19.8 mm/10a, -0.5 mm/10a, -11.3 mm/10a and -3.6 mm/10a for July, August, September and October, respectively, while temperature showed an increasing trend at a rate of 0.02˚C/10a, 0.02˚C/10a, 0.01˚C/10a and 0.01˚C/10a for July, August, September and October, respectively. Elagib and Elhaj (2011) found an increasing trend in mean, maximum and minimum temperature over the whole Sudan in line with a significant decline of precipitation over the northern half of Sudan.

As reported by Sulieman and Elagib (2012), Gadarif State had observed a significant climate warming, increased precipitation variability and seasonality and intensified aridity conditions from 1941 to 2009. Fig. 4-3 showed that the SPEI and SPI drought indices have a temporal frequency can enabling the detection of persistent dry and humid period’s pattern. The SPEI index at 12-month showed that a high frequency of drought in 1972- 1973, 1984, 1991-1992 and 2000-2011, while SPI 12-month shows a high frequency of drought in 1966, 1972-1973, 1984, 1986, 1991-1992 and 1999-2013. In addition, both SPEI and SPI showed that the Gadarif State from 1999 to 2011 has been changed to a high frequency of drought. As reported by Elagib and Elhaj (2011), Gadarif State showed an extreme drought in 984 and 1990; severe drought in 1991 and 2005; moderate drought in 2000, 2001, 2002, 2007 and 2008; mild drought in 2006. In addition, Yagoub (2016) and Yagoub et al. (2017a) showed that the climate of Gadarif State has a big changing from humid to extreme drought in a period of 1961-2013.



(a)



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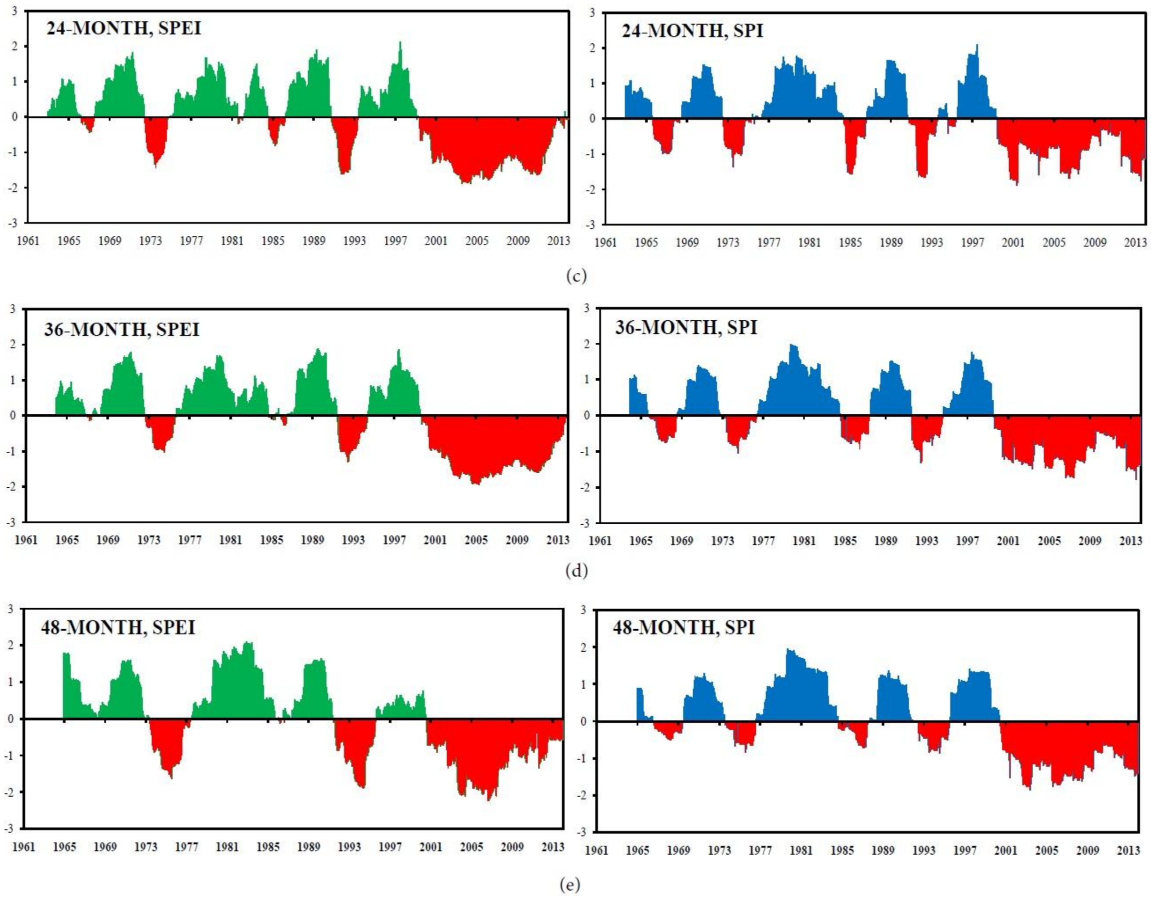


Fig. 4-3 Distribution of SPEI and SPI values at 1-, 12-, 24-, 36- and 48-month timescale in Gadarif State during 1961-2013

4.3.2 Food Security Analysis

Fig. 4-4 showed that the MRA area of two main grain crops (Sorghum and Sesame) in Gadarif State had increased from 1,058,241 ha to 2,799,655 ha from 1961 to 2013. The increased scale of MRA in the Gadarif State was started in 1945 when the Colonial British Government decided to cultivate the cracking clays of Central Sudan in order to satisfy the food demands of army units in East Africa (SKAP 1992). In the 1960s, massive land areas in Sudan were cleared for crop cultivations. Consequently, at the end of the 1970s to the early 1980s, most of the lands were changed to MRA (Craig 1991).

Projected climate change impacts and growing socioeconomic pressures on agriculture highlighted the intensification of desertification of arable areas. Moreover, the humid agro-climatic zones are likely to shift southward, rendering areas of the north increasingly unsuitable for agriculture (NAPA 2007). The expansion of agricultural lands due to the favourable government farming policy is among the main reasons behind the land use changes in East Africa (Reid et al. 2004). Fig. 4-5(a and b) captured that the yield productivity of Sorghum and Sesame. It was observed that the yields of both crops (Sorghum and Sesame) were decreased significantly from more than 800 kg/ha and 500 kg/ha in the 1960s to less than 200 kg/ha and 100 kg/ha in 2000 s, respectively. Sustainability of agricultural practices in rain-fed areas is a big challenge for the production of food in Gadarif State as well as other areas of Sudan. Precipitation is the main irrigation source for crops cultivated in the rainy season (July to October).

Table 4-1 showed that the correlation coefficients of Sorghum and Sesame yield with precipitation and temperature in Gadarif State during 1961-2013. The results explored that there was a significant positive relationship between Sorghum yield and precipitation of July and October; respective correlation coefficients were 0.364 and 0.321. A significant negative correlation of Sorghum yield with the mean temperature was found during July to October (CC = -0.278). There was a significant positive relationship between Sesame yield and precipitation of July (CC = 0.335).

In Africa, in addition to the greatest problem of high annual variability of precipitation, the seasonal precipitation also varies drastically as well (UNDP/UNSO 1997). Therefore, the climate change in addition to intensified extreme events could influence the crop yield seriously (Sivakumar and Hansen 2007). The variations of temperature, precipitation and atmospheric CO_2 concentration can affect significantly in crop yield (Downing 1996). Land use patterns had changed significantly in Gadarif State from 1986 to 2013. The natural vegetation was changed drastically (from 1,538,597 ha in 1986 to 2,459,264 ha in 2013) to MRA. That leads to extensive loss and degradation of rangeland areas in Gadarif State. Rangeland areas in the state were decreased from 4,342,154 ha in 1986 to 3,473,940 ha in 2013. Forest area and rangeland were reduced due to the expansion of modern mechanized farming to satisfy increased demand for food due to the increased human population (Yagoub et al. 2017b).

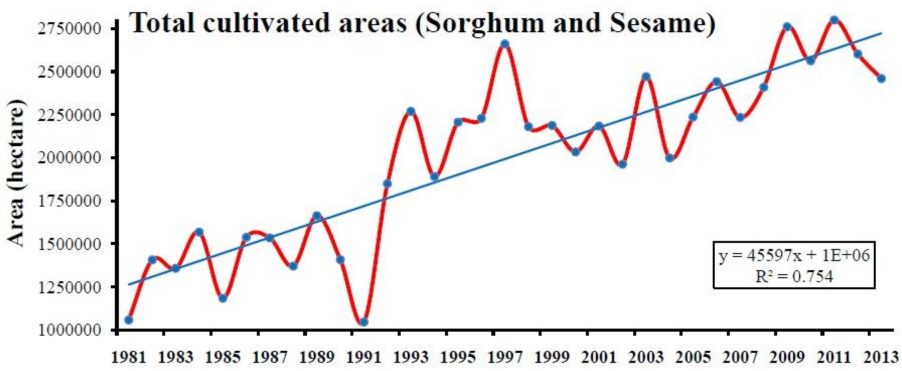


Fig. 4-4 Total areas of MRA during the period 1981-2013

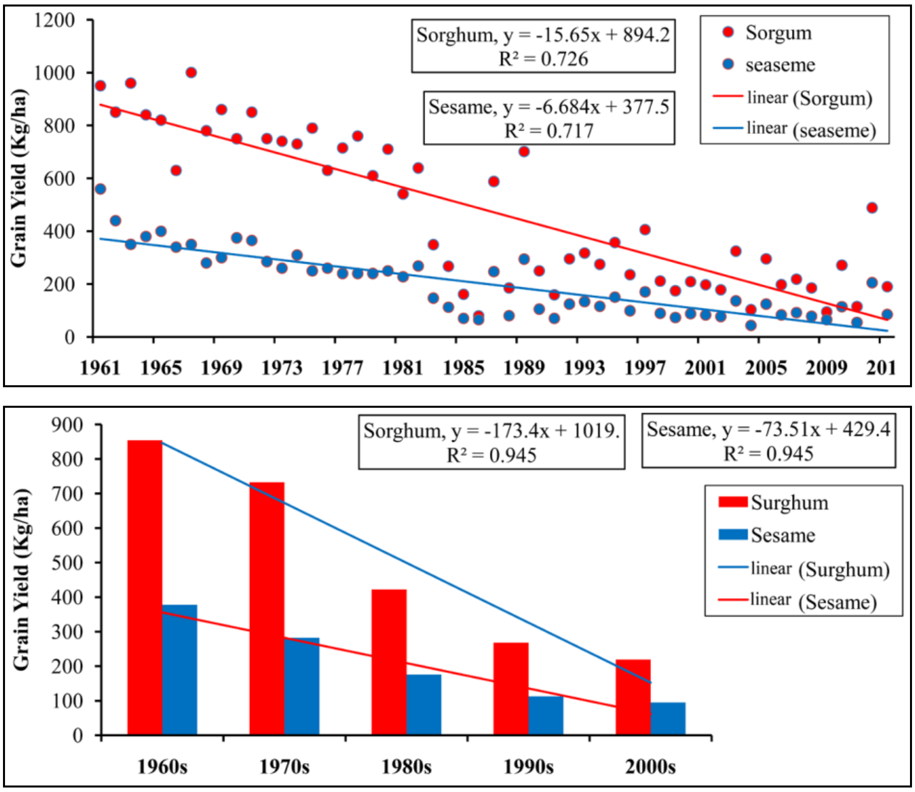


Fig. 4-5(a and b) Yield production of the main two grain types of food security in Gadarif State, which they depend on rainy season during 1961-2013

Table 4-1. Correlation coefficients of sorghum and sesame yield production with precipitation and temperature by using SPSS software in Gadarif State during 1961-2013

	Month	Precipitation	Temperature
Sorghum	Jul	.364**	-0.248
	Aug	.058	-0.25
	Sep	.251	-0.133
	Oct	.321*	0.131
	Jul to Oct	.329*	-.278*
Sesame	Jul	.335*	-0.233
	Aug	.069	-0.233
	Sep	.254	-0.132
	Oct	.053	-0.192
	Jul to Oct	.318*	-0.260

Drastic decrease of natural vegetation areas resulted in progressive loss and degradation of grazing area in most of the Gadarif State (Sulieman and Elagib 2012). The dynamic rate of vegetation cover, deterioration and decline were terribly speedy over the few decades. In Gadarif State, large tracts of the forests and rangeland were converted to cultivation lands, which made these resources unable to satisfy fodder need for grazing and food security.

The overall forest area was reduced because of expansion in modern mechanized farming because of increasing human population. The local community of Gadarif State started illegal cutting of wood to satisfy the local needs of charcoal and other domestic uses, also to boost their income. The nomads do not have any alternative for animal feeding except lopping the trees during the dry season and feeding on young regeneration throughout the rainy season. Current information on the status of vegetation cover and changes in its composition and structure area is restricted, whereas the speed of climatic variations has serious effects on the planning of the management processes in forest reserves. Adversely, the grazing livestock causes notable damage to the refurbishment of the forest. Adam et al. (2015) stated that the conflicts of the farmer-herder for land use caused a major challenge for rural societies as well as Sudan's local authorities. According to Sulieman and Elagib (2012), the extension of cultivated areas resulted in the drastic decrease in the natural vegetation lands. Ayoub (1999) reported that the Sudan Government's new agricultural policies are focusing more on MRA ventures to increase the grain production through expansion of the cultivated area only, not through increased per unit yield.

4.4 Conclusions

In this study, we have combined the results of the impacts of variations in climate and land use policies on food security from 1961 to 2013 to provide a baseline for policymakers in Gadarif State, eastern Sudan. We conclude that the policymakers must consider an increase in yield per unit area and utilization of different varieties of fertilizer in addition to the enhancement of grain production through expansion of the cultivated area. We recommend the establishment of strong coordination among the concerned sectors such as Forest National Corporation, Mechanized Rain-fed Agriculture, Rangeland management, Wildlife management and Research Institutes to arrive for land use management. Based on the findings of this study, it is recommended that additional investigations on crops suitable for Gadarif State during drought season should also be carried out for more accurate information, which can be used for crop modelling of appropriate agricultural and water management during a drought cycle. Further studies on drought prediction using future climate scenarios in Gadarif State by utilizing methods presented in this study may be considered for in-depth analysis. Nowadays, climate change has become the major determinant to the environment worldwide and most of the environmental changes are associated with the climatic anomalies. To best of our knowledge, a few of studies have so far been conducted to address this global problem. Agricultural activities in Gadarif State are directly affecting the proportion of forest resources because of change in agricultural ends up, in the unfair exploitation of the forests. Throughout the last four decades, progressive changes within the environment occurred due to the conversion of forest and grassland into cultivated land.

CHAPTER FIVE

Correlation between Climate Factors and Vegetation Cover in Qinghai Province, China

5.1 Introduction

Global mean temperature has increased by 0.85 ℃ over the period of 1880 to 2012 and this increase in temperature is likely due to anthropogenic activities that have increased the concentrations of greenhouse gases to unprecedented levels (IPCC 2013). Over the last 50 years, the Qinghai Province of China is experiencing continuous warming which is approximately three times more than the global warming rate. The increasing trend in temperature is one of the main reasons for climate change which consequently lead to droughts and negative effects on vegetation cover due to the increase in evapotranspiration in the region (Piao et al. 2011).

A plausible warmer world with longer and more severe droughts could lead to rapid collapse of tropical forest communities converting them from a net carbon sink to a large carbon source with cascading ecosystem effects affecting global climate-vegetation feedbacks (Lewis 2006). Due to the monsoon climate interacted with the complicated geographical landscapes; high-frequency severe droughts are the most devastating natural disasters in China. According to statistics, the drought affected and damaged areas have greatly increased in the past 50 years (Wang et al. 2012). In the 2000s, extreme droughts occurred frequently in China, for example, the winter-spring drought in southwest China during 2009-2010 (Lu et al. 2011; Zhao et al. 2013) and the spring-summer drought over the middle and lower reaches of Yangtze River in 2011 (Lu et al. 2013).

The drought has especially affected the agricultural areas in northern China (Wang et al. 2011). The regional geological, geomorphologic and ecological systems are complex and diverse. These natural factors and climate change are intertwined, making regional economic and social developments extremely challenging. The regional economic community has demonstrated a high degree of sensitivity to these changes. The literature shows that there has been a significant warming trend in Northwest China since 1951 (Yu et al. 2005; Wang et al. 2007). Thus, droughts are difficult to pinpoint in time and space since it is very complex to identify the moment when a drought starts and ends, and also to quantify its duration, magnitude and spatial extent (Burton et al. 1978; Wilhite 2000).

China is on the top in the world in paddy rice, wheat and fresh vegetable production. In total, China ranks no. 1 in the world in the production of 45 agricultural commodities (FAO 2005).

Series of geological disasters and environmental problems of agricultural biological disasters in the Qinghai Province will consequently influence the societal and economic conditions (Yang and Liu 2012). Global climate change and anthropogenic activities are the main driving forces of terrestrial ecosystems (Haberl 1997).

The reduced soil moisture content due to drought led to adirect impact on agricultural production, resulting in poor plant growth, or even wither and significantly reduced crop yield. The crop root uptake water and salts from the soil, on the other hand, leaf exhaust large amounts of water through transpiration to maintain its normal physiological process (Zhang and Shan 1997). Sedges are insensitive to the short-term changes in environmental conditions, while forbs may decrease at the expense of grass biomass (Yan et al. 2014).

The quantitative evaluation of direct economic loss of the grassland and livestock due to drought and snow disaster comes true. The evaluation model is in line with grass pasture growth law and livestock production characteristics. The evaluation in accord with the actual loss of animal husbandry. Therefore, the evaluation can be used in the grassland animal husbandry assessment (Yan et al. 2013).

China has about 328 million people involved in agricultural labour, and a vast majority of them are small and marginal farmers (operating 0.4 ha on average). Further, the vast majorities of farmers depend on rain-fed crops and are, therefore, particularly vulnerable to the vagaries of the climate (World Bank 2007). The government of China (GoC) recognizes the importance of revitalizing the agricultural insurance industry to meet the needs of farmers throughout China in a better way (World Bank 2007). The Department of Crop Production and the Ministry of Agriculture in China have initiated schemes having significant contributions in anti-disaster and disaster relief. The agricultural sectors have strengthened monitoring and early warning of disasters (China Agriculture Yearbook 2012).

5.2 Material and methods

5.2.1 Study area

Fig. 5-1 shows the geographical location and topography of Qinghai Province. This province has a large variety of ecosystems, from the sub-tropical rainforest in the south-east to the alpine deserts in the north-west. Among all types of land cover vegetation, alpine grassland is the dominant ecosystem, combined cover an area of 715823.8 km^2, extending from the latitude of 31 °40' - 39 °30' N and longitude of 89 °25 ' - 103 °04' E and altitude 1721-8500 m. The total irrigated area in Qinghai Province, as reports in China Agriculture Yearbook (2014) is 259.3 (10^3 ha) out of which 182.4 (10^3 ha) is effective irrigated area, 31.2 (10^3 ha) is woodland area, 6.8 (10^3 ha) orchard area, 38.9 (10^3 ha) is pasture land and 155 (10^3 ha) is actual effective irrigated area, respectively.

The major economic indices are a number of enterprises, employment in the year (person), business income (10^3 RMB) and Tax payment (10^3 RMB): 20, 2966, 1273 and 1035, respectively.

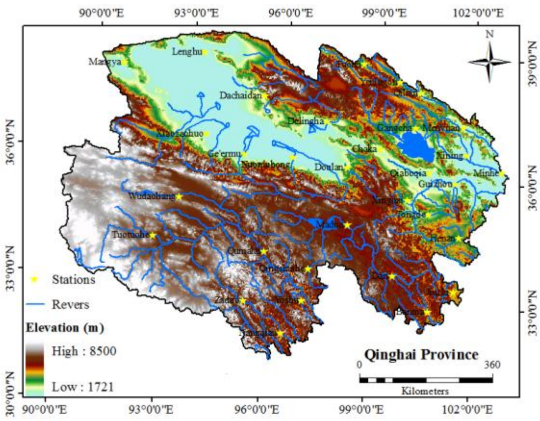


Fig. 5-1 Distribution of meteorological stations and grid points of climate data in the study area

5.2.2 Normalized Difference Vegetation Index NDVI

In this research, we utilize the MODIS data of 16-day temporal and 250 m spatial resolution (MOD13Q1, collection 5), for a period of 2001-2013. This data was obtained from NASA website (ftp://ladsweb.nascom.nasa.gov/allData/5/MOD13Q1). This data maintains by the NASA in Land Processes Distributed Active Archive Center (LP DAAC) at the USGS/Earth Resources Observation and Science (EROS) Centre. A vegetation index is an indicator that describes the greenness, relative density and health of vegetation for each picture element (pixel). Although there are several vegetation indices, NDVI is one of the most widely used vegetation indexes and its range varies from 1.0 to -1.0.

5.2.3 Linear trend (slope)

Analysis of linear regression trend was carried out using Arcgis v 10.2 Software, which can simulate trends in each grid (Stow et al. 2007). Arcgis can be used to reflect different periods of vegetation cover characteristics. In this study, the relative slope, in Formula (1), was used to indicate the relative NDVI change in every pixel point.

$$\theta_{slope} = \frac{n \times \sum_{i=1}^{n} i \times NDVI_i - \sum_{i=1}^{n} i \sum_{i=1}^{n} NDVI_i}{n \times \sum_{i=1}^{n} i^2 - \left(\sum_{i=1}^{n} i \right)^2} \qquad (1)$$

Where i is the annual number; n is monitoring period (the cumulative number of years); NDVI as NDVI mean value of the i year; slope is each pixel NDVI trends of the slope, if slope > 0, indicating that the pixel NDVI value in n years is increasing, otherwise it is reducing. This study will change into a significant increase, a slight increase, essentially the same, slightly reduced and a significant reduction, and the statistics of the study area in 2001 - 2013 vegetation changes and the percentage of each class area.

5.2.4 Correlation

Correlation between geographical elements, it is possible to explain the closeness of the relationship between geographic features, and closely related to the degree of mutual determination between geographical elements, mainly through the correlation coefficient calculation and testing to complete. In this research, the study of NDVI and average annual temperature and annual precipitation by-pixel spatial correlation, the correlation coefficient used to reflect the sequence of climatic factors and NDVI degree of correlation, the correlation coefficient value in (-1 and 1) of between. Formula:

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}} \qquad (2)$$

Where: n is the number of time series, x and y are two elements of the correlation, and represent the average of the two elements of the sample values, and finally delineated thresholds based on the number of data, the results of the correlation level of significant.

5.3 Result and discussions

Fig. 5-2 shows the vegetation on the monthly average time scale in the Qinghai Province, the NDVI value distribution show that May to August are the centre to both sides of vegetation cover in a year, which corresponds to the average monthly vegetation NDVI values: 0.12, 0.12, 0.13, 0.15, 0.26, 0.35., 0.36, 0.28, 0.15, 0.12, 0.12 and 0.12 for January to December, respectively. Overall, the rainy season (April to September) has higher vegetation covers.

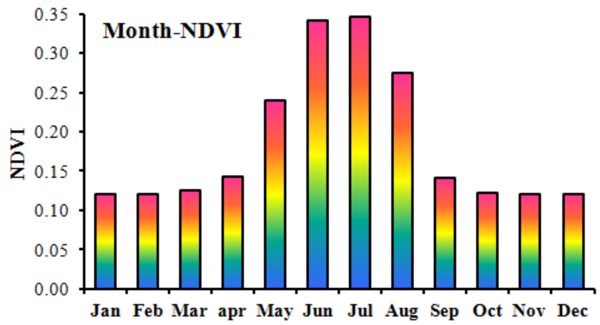


Fig. 5-2 The distribution of the mean monthly-NDVI in Qinghai Province over the period of 2001-2013.

5.3.1 Spatial distribution of vegetation

Spatial distribution of mean NDVI in Qinghai Province is shown in Fig. 5-3 which clearly exhibits the mean annual and seasonal-NDVI, a high value is in the eastern and southern part of the Qinghai Province. The vegetation cover is high in the eastern and southern part due to humid climate zone. The vegetation cover is widely distributed in woodland, grasslands and cropland. The north-west part has a low vegetation cover value due to the location in the desert area, which is covered by rock and sands with low precipitation.

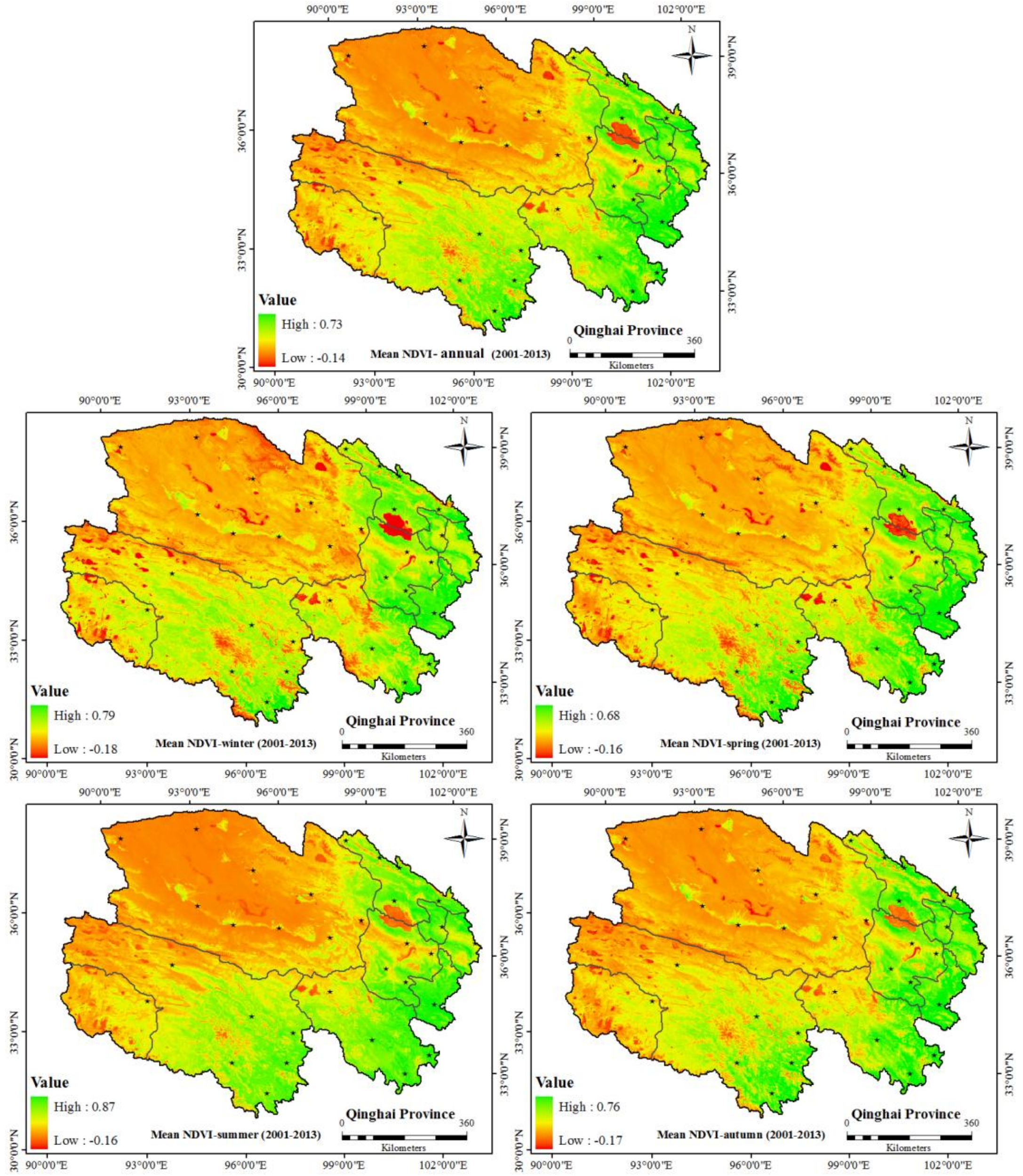
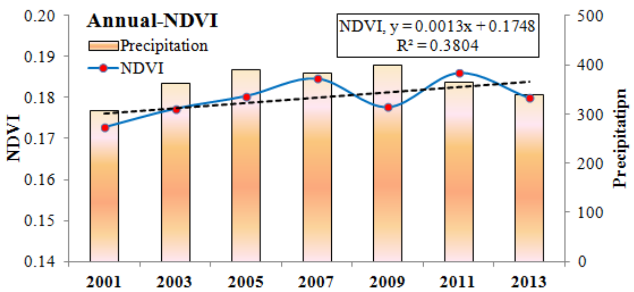


Fig. 5-3 Spatial distribution of mean annual and seasonal-NDVI in Qinghai over the period of 2001-2013

Fig. 5-4 shows the calculation of NDVI; each season of the Qinghai Province is ranked based on NDVI. The summer season has the highest NDVI followed by autumn, spring and winter. Analysis of average annual and seasonal-NDVI shows that the main vegetation cover type in the Qinghai Province has an upward trend at the rate of 0.013/10a, 0.016/10a, 0.035/10a and 0.058/10a for annual, winter, spring and summer, respectively. While an autumn-NDVI has a downward trend at a rate of 0.056/10a.

The plain and other highland mountain areas have different values due to seasonal differences in the degree of green crops and woodland, grassland due to seasonal changes in climate factors. Yan L. et al (2013) analyzed and investigated the data of pasture, precipitation and disaster monitoring in 20 grassland ecological monitoring sites in Qinghai Province from 2003 to 2011. They found that, at 0.001 % significance level, grassland herbage yield and precipitation have a close relationship. A good correlation was found between the forage yield at the end of August and the precipitation from May to August.

Table 5-3 shows that there is a significant positive relationship between mean annual-NDVI and mean annual precipitation at the 0.01 % significance level, correlation coefficients 698 with P value 0.00. However, a decline in 2009-NDVI was found due to the increase in precipitation in that particular year, as reported on the website of China Statistical Information Network: http://www.tjcn.org/help/3574.html. In 2009, the prices of agricultural production materials decline to 2.2% compared with the previous year. Producer Price Index (PPI) declined to 8.7 %. Yan L. et al (2013) reported that the snow disasters in December 2008 in Doulan (middle part of Qinghai Province) caused the death of livestock which was 0.11 % of the total Loss (18455x10 ^{3}RMB).



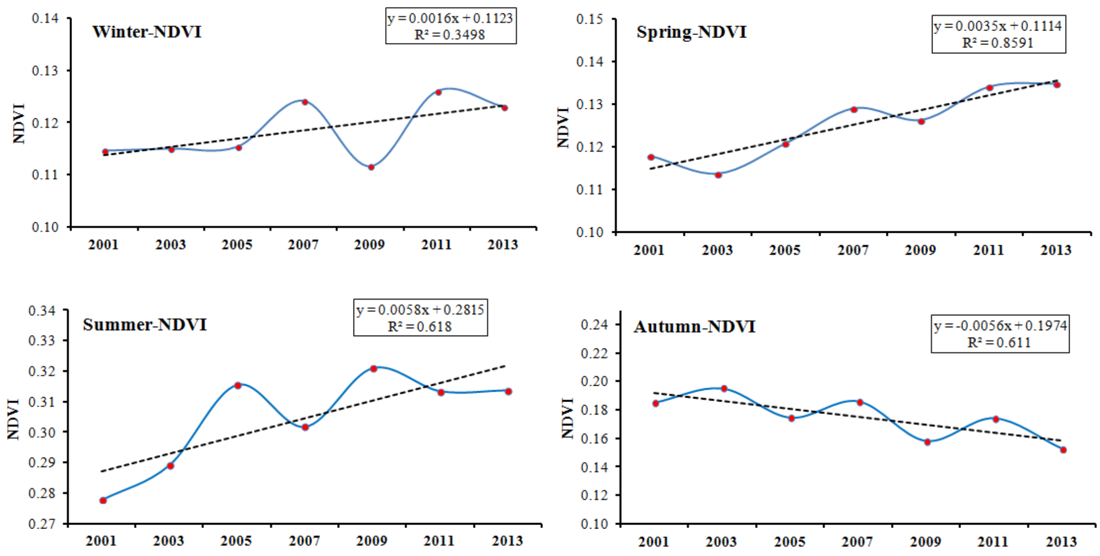


Fig. 5-4 Trend of different vegetation types, annual and seasonal-NDVI change in Qinghai Province over the period of 2001-2013

5.3.2 Spatial variation of vegetation cover

5.3.2.1 Annual

Based on the calculation of principle *θslope* value, the spatial variation was reclassified into seven categories from low to high value: significant degradation, moderate degradation, mild degradation, no change, mild improvement, moderate improvement and significant improvement. Fig. 5-5 and Table 5-1 show that there is general improvement of vegetation in the southeast, the eastern and middle part of Qinghai Province, while south-west is in under degradation.

The order of spatial variation of vegetation cover is: significant degradation (an area of 5604.8 km ^{2}accounts 0.8 % of the total area, moderate degradation (an area of 8547.8 km ^{2}accounts 1.2 % of the total area), mild degradation (an area of 17924.1 km ^{2}accounts 2.5 % of the total area), no change (an area of 613070.8 km ^{2} accounts 85.6 % of the total area), mild improvement (an area of 36475.3 km ^{2} accounts 5.1 % of the total area), moderate improvement (an area of 22429.3 km ^{2} accounts 3.1 % of the total area) and significant improvement (an area of 11771.6 km ^{2}accounts 1.6% of the total area).

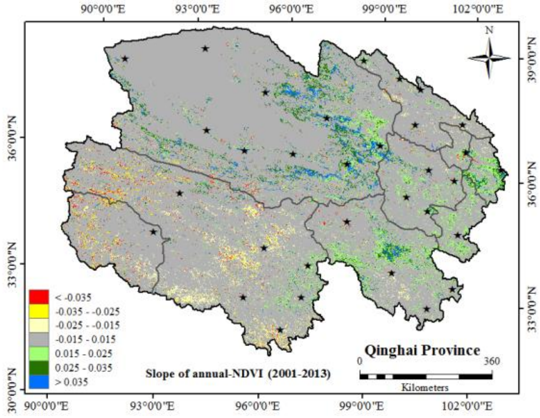


Fig. 5-5 Temporal change characteristic of mean annual-NDVI based on the linear trend in Qinghai Province over the period of 2001-2013

Table 5-1 Statistical result of trend of mean annual-NDVI change simulated in Qinghai Province over the period of2001-2013

	Category	θSlope range	Mean NDVI	
			Area Km ²	%
1	Significant degradation	θ<-0.035	5604.8	0.8
2	Moderate degradation	-0.035<θ>-0.025	8547.8	1.2
3	Mild degradation	-0.025<θ>-0.015	17924.1	2.5
4	No change	-0.015<θ>0.015	613070.8	85.6
5	Mild improvement	0.015<θ>0.025	36475.3	5.1
6	Moderate improvement	0.025<θ>0.035	22429.3	3.1
7	Significant improvement	θ>0.03	11771.6	1.6
	Total		715823.8	100

5.3.2.2 Seasonal

Using linear regression analysis, mean seasonal vegetation cover in Qinghai Province period was calculated from 2001-2013, spatial reclassification was divided into seven categories: significant degradation, moderate degradation, mild degradation, no change, mild improvement, moderate improvement and significant improvement and then the vegetation was analyzed. Fig. 5-6 and Table 5-2 show the spatial variation of significant degradation in the Qinghai Province mean seasonal-NDVI (2.6, 1.7, 0.7and 19.2 % of the total area in winter, spring, summer and autumn, respectively).

The higher change of degradation in autumn-NDVI is locating in the southern part of northeastern Qinghai Province. While, a significant improvement was found depicted as 4.2%, 6.8%, 11.3% and 1.3% of the total area in winter, spring, summer and autumn, respectively. The order of improvement is spring > summer > winter > autumn. No change was found in 79.6%, 74.4%, 61.1% and 58.4 % of the total area in winter, spring, summer and autumn, respectively. Baoxiong et al. (2014) reported that the 2001 - 2011 was the period of remarkable human intervention on the alpine grassland ecosystem (fencing degrading grassland and reducing livestock number), therefore, it played a much more important role in the grassland restoration. This implies that the obvious decline in the number of livestock animals and large-scale building the fences over the Qinghai-Tibet Plateau alpine grassland in recent years relieved the grazing pressure of the rangeland.

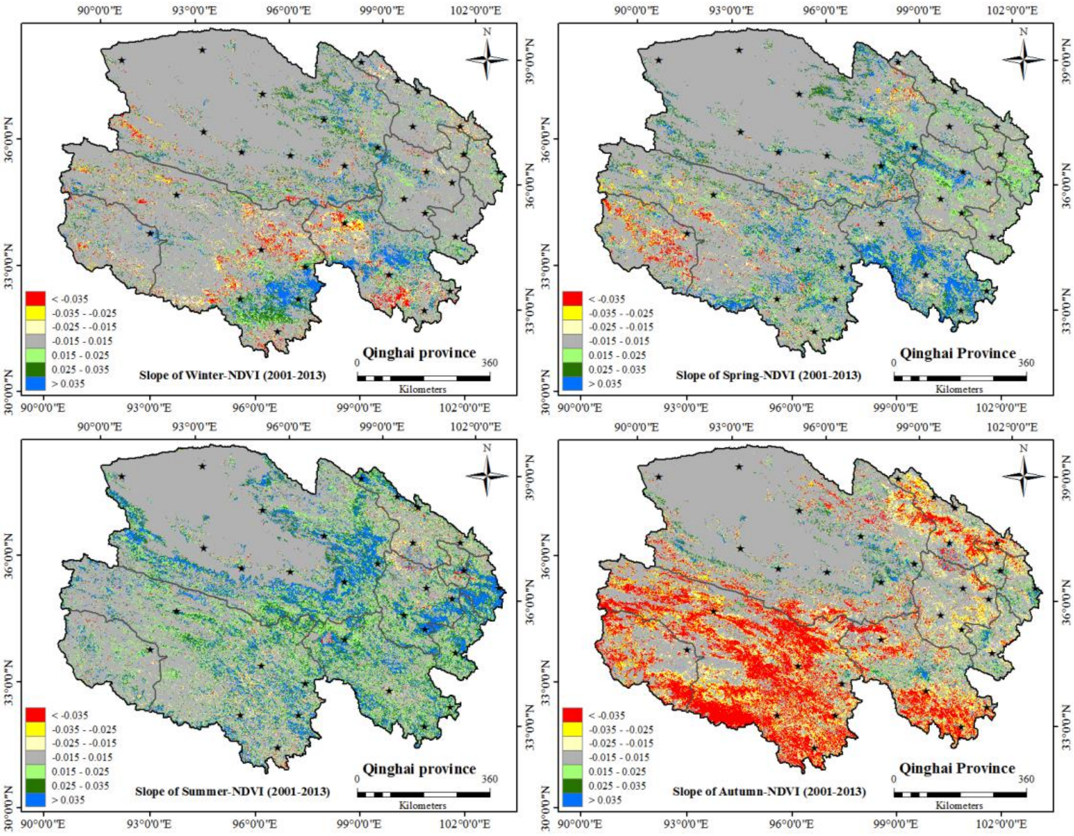


Fig. 5-6 Spatial-temporal change characteristic of mean seasonal-NDVI based on the Slope in Qinghai Province over the period of 2001-2013

Table 5-2 Statistical result of trend of mean seasonal-NDVI change simulated in Qinghai Province over the period of 2001-2013

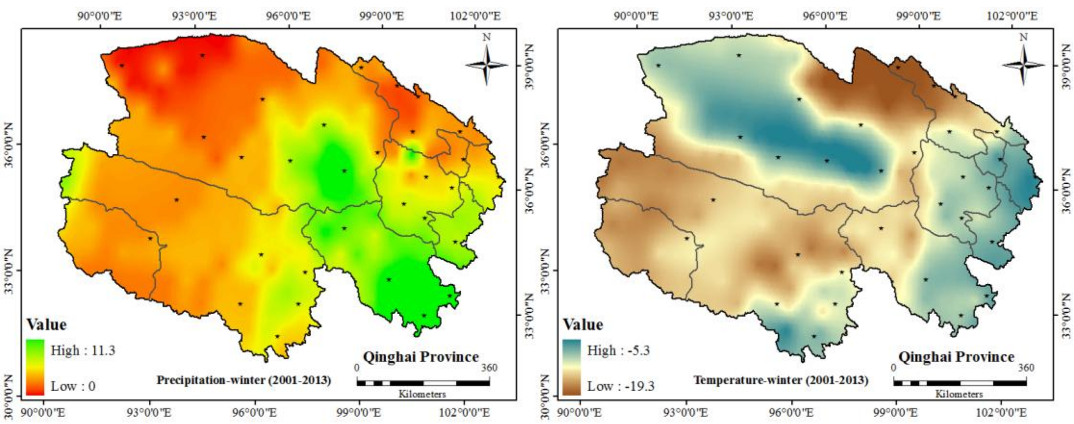
	Category	θSlope range	Winter		Spring		Summer		Autumn	
			Area Km ²	%	Area Km ²	%	Area Km ²	%	Area Km ²	%
1	Significant degradation	θ<-0.035	18647.1	2.6	12351.3	1.7	4870.7	0.7	137223.7	19.2
2	Moderate degradation	-0.035<θ>-0.025	13575.9	1.9	12441.0	1.7	5259.1	0.7	58084.6	8.1
3	Mild degradation	-0.025<θ>-0.015	18026.6	2.5	12211.4	1.7	11956.7	1.7	62151.4	8.7
4	No change	-0.015<θ>0.015	569743.6	79.6	532533.3	74.4	437078.4	61.1	417940.4	58.4
5	Mild improvement	0.015<θ>0.025	31739.4	4.4	53193.6	7.4	102224.4	14.3	16939.9	2.4
6	Moderate improvement	0.025<θ>0.035	33787.9	4.7	44542.9	6.2	73276.1	10.2	13880.8	1.9
7	Significant improvement	θ>0.03	30303.3	4.2	48550.3	6.8	81158.4	11.3	9602.9	1.3
	Total		715823.8	100	715823.8	100	715823.8	100	715823.8	100

5.3.3 Relationship between vegetation cover and climate factors

Programming in SPSS was used to calculate the correlation coefficients between NDVI and spatial variation of climate factors in Qinghai Province over the period of 2001-2013. Seasonal precipitation and temperature at each site were used to draw the trends of a spatial distribution of precipitation and temperature by using interpolation in Arcgis. Fig. 5-7 shows the presence of significant differences in seasonal precipitation and temperature trends in recent 13 years. Spatial characteristics of seasonal temperature show a variation of a mainly significant increasing trend of warming in whole Qinghai Province, while spatial characteristics of precipitation show a decreasing trend in most of the parts of Qinghai Province.

Table 5-3 shows a significant positive relationship between mean winter-NDVI and mean winter precipitation at the 0.01 % significance level, correlation coefficient 0.256with P value 0.00; also, there is a significant positive relationship between mean winter-NDVI and mean winter temperature at the 0.01 % significance level, correlation coefficients 0.190 with P value 0.00. There is a significant positive relationship between mean spring-NDVI and mean spring precipitation at the 0.01% significance level, correlation coefficients 0.630 with P value 0.00, while there is no significant difference between mean spring-NDVI and mean spring temperature.

A significant difference is found between mean summer-NDVI and mean summer precipitation at 0.01 % significance level, correlation coefficients 0.638with P value 0.00, while there is a significant negative relationship between mean summer-NDVI and mean summer temperature at 0.01, correlation coefficients -0.216 with P value 0.00. There is a significant positive relationship between mean autumn-NDVI with mean autumn precipitation at the 0.01 % significance level, correlation coefficients 0.734 with P value 0.00, while there is no significant difference between mean autumn-NDVI and mean autumn temperature.



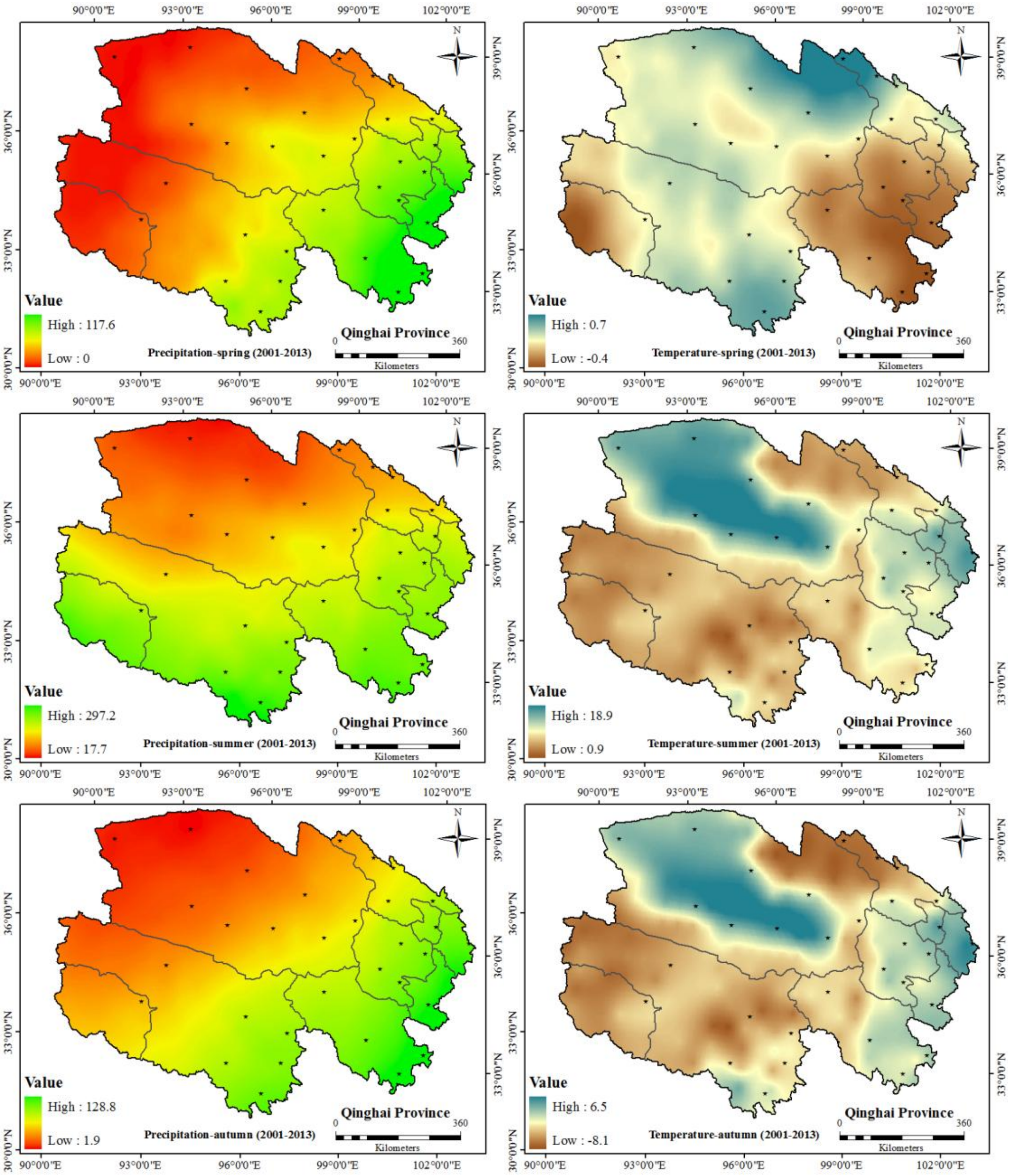


Fig. 5-7 Spatial and temporal distribution of the mean seasonal trend of temperature and precipitation for the past 13 years (2001-2013) in Qinghai Province.

Table 5-3 Correlation coefficients of NDVI with climate data and three drought indices, correlation of three drought indices with climate data and three droughts and correlation of SPEI and SPI with elevation using SPSS software in Qinghai Province over the period of 2001-2013

	Correlation	Pearson correlation	P value, Sig. (2-tailed)
1	Winter-NDVI with precipitation	.256**	0.000
2	Winter-NDVI with temperature	.190**	0.000
3	Spring-NDVI with precipitation	.630**	0.000
4	Spring-NDVI with temperature	0.066	0.268
5	Summer-NDVI with precipitation	.638**	0.000
6	Summer-NDVI with temperature	-.216**	0.000
7	Autumn-NDVI with precipitation	.734**	0.000
8	Autumn-NDVI with temperature	0.080	0.177
9	Mean-NDVI with precipitation	.698**	0.000
10	Mean-NDVI with temperature	-0.002	0.975

**Correlation is significant at the 0.01 level (2-tailed)
*Correlation is significant at the 0.05 level (2-tailed)

5.3.4 Correlation of NDVI with climate factors

In order to analyze the relationship between high and low vegetation cover and climatic factors in Qinghai Province, we utilize the mean annual precipitation and temperature of 288 sites in recent 13 years. Using correlation analysis method, grid-related calculations were obtained in Arcgis v 10.2 Software, as shown in Fig. 5-8. Table 5-3 shows the presence of a significant positive relationship between the mean annual-NDVI and mean annual precipitation at the 0.01% significance level, correlation coefficients 0.698 with P value 0.00, while there is no significant difference between the mean annual-NDVI with mean temperature.

To test the correlation between the vegetation cover and annual precipitation and temperature, it is divided into eight grades according to the principle of division of significance test different threshold point. Table 5-4 shows the statistics of the correlation coefficient between mean annual-NDVI and climate data factor in Qinghai Province over the period of 2001 - 2013. The correlation coefficient between mean annual-NDVI and precipitation is significant negative in 0.3 % of total area, high negative in 0.5 % of total area, moderate negative in 3.9 % of total area and low negative in 44.8% of the total area. While low positive correlation, moderate positive correlation, highly correlated and significant positive correlation is: 46.0%, 3.8%, 0.5% and 0.2% of the total area, respectively.

The correlation coefficient between mean annual-NDVI and temperature is significant negative correlation, high negative correlation, moderate negative correlation and low negative correlation: 0.4%, 0.7%, 6.3% and 61.8% of the total area, respectively. While low positive correlation, moderate positive correlation, highly correlated and significant positive correlation is: 28.8%, 1.7%, 0.2% and 0.1% of the total area, respectively.

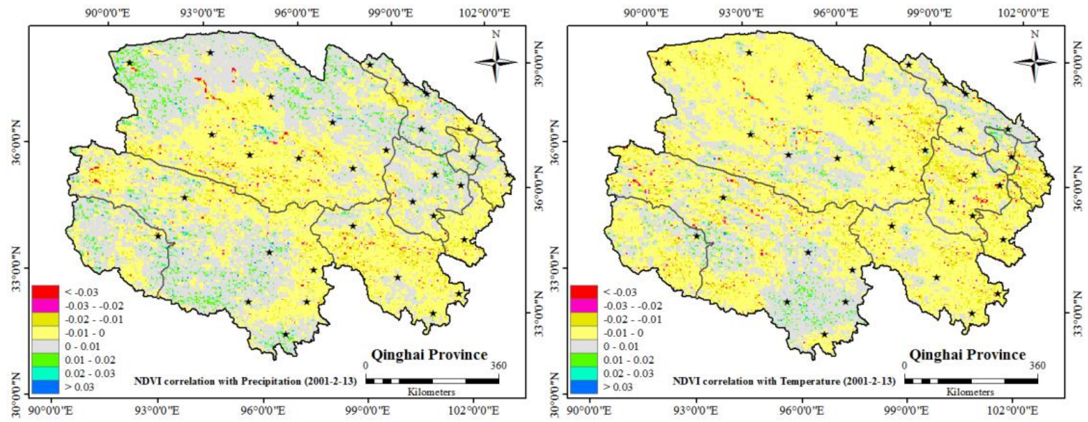


Fig. 5-8 Correlation between mean annual-NDVI and climate factors in Qinghai Province over the period of 2001-2013.

Table 5-4 The statistics of the correlation coefficient between mean annual-NDVI and climate data factor in Qinghai Province over the period of 2001-2013.

	Category	Correlation range	Precipitation		Temperature	
			Area Km ²	Area %	Area Km ²	Area %
1	A significant negative correlation	<-0.03	2352.9	0.3	2966.6	0.4
2	High negative correlation	-0.03～-0.02	3686.4	0.5	5330.9	0.7
3	Moderate negative correlation	-0.02～-0.01	27984.7	3.9	44883.1	6.3
4	Low negative correlation	-0.01～0.00	320608.6	44.8	442360.1	61.8
5	Low positive correlation	0.00～0.01	329231.6	46.0	205962.7	28.8
6	Moderate positive correlation	0.01～0.02	26946.0	3.8	12180.3	1.7
7	Highly correlated	0.02～0.03	3391.5	0.5	1422.4	0.2
8	A significant positive correlation	>0.03	1622.0	0.2	717.6	0.1
	Total		715823.8	100.0	715823.8	100.0

5.4 Conclusions

Findings of this study show that when drought occurs due to a decrease in precipitation, it can reduce the natural vegetation and crop covers as well as livestock production and consequently influence the economy. In recent years, Qinghai Province was affected by intensified climate warming and a decrease of precipitation, arid zone showed a frequent trend in recent years, affecting the region more widely.

The economic losses caused by drought are also growing rapidly in the region; therefore, need to take comprehensive measures, a common response of whole society, a principle of the whole society to participate fully in the role of the government and drought relief headquarters. Qinghai Province has a growing agricultural sector and a keen desire to seek policy options that will increase incomes for the many lower-income households involved in agriculture and other related economic activities.

This study recommends additional investigations to discover the crops suitable in the Qinghai Province during drought conditions, which can be used for crop modelling for appropriate agricultural and water management during drought. Further studies on drought prediction under future climate scenarios in Qinghai Province using methods presented in this study will be part of the future direction of this study.

The influences of drought in Qinghai Province, such as the shortage of food led to humanitarian disaster including the risk of death, injury and diseases during the famines. A succession of dry years resulted in severe social and economic impacts. The reduced moisture content of soil led to a direct effect on agricultural production, resulting in poor plant growth, or even wither and significantly reduced crop yield.

Grassland is decline and decreasing the palatable forbs led to appearing the invader grasses which is unpalatable to livestock and affecting by derogates from livestock by the death, emergency slaughter, direct economic losses and affected in livestock herders. For example Adaptation activities need to be implemented in an integrated way and take a long-term view, rather than involving short-term, stand-alone projects. Institutions working on environmental issues should be better coordinated.

CHAPTER SIX

Investigation of Vegetation Cover Change in Sudan by Using Modis Data

6.1 Introduction

The drought was commenced in 1968 and persisted very strongly throughout the 1970s and 1980-1981 continued into 1982, which was the third driest year of the period 1968-1982, and also appears to have received substantially less rainfall than the drought years of the 1940s (Peter J1983).   Sudan is the least developed country in Africa, as one of the most vulnerable continents to climate change and climate variability. This situation is aggravated by the interaction of multiple stresses occurring at various levels, such as endemic poverty; institutional weaknesses; limited access to capital, including markets, infrastructure and technology, ecosystem degradation, complex disasters and conflicts. These, in turn, have weakened people's adaptive capacity, increasing their vulnerability to projected climate change.

In recent times, human activities have caused, and are continuing to cause, great changes to the composition of the atmosphere. The major concern of both scientific and public communities is the enhanced greenhouse effect caused by anthropogenic activities. In 1977, 57 million people in drylands were suffering the direct effects of land that had degraded to the extent where it no longer produced enough food to sustain them. By 1984, their number had risen to 135 million (UNEP 1992).

The Sahara desert has been described as encroaching southwards at an increasing rate. This desertification phenomenon has been considered to be mainly human-induced. Sudan is one of the driest but also the most variable countries in Africa in terms of rainfall. Extreme years (either good or bad) are more common than average years (Zakieldeen 2007). Rural water supply in semi-arid Sudan is closely dependent upon annual rainfall. In semi-arid Sudan, water availability is the primary constraint upon human habitation and activity. Large areas of central Sudan are characterized by an inadequate supply of water to meet even the basic daily requirements of man and livestock El Sammani, M., (1978).

During the last decade, the African regions and countries have been the subject of a number of assessments and interpretations of temperature trends. Over eastern Africa, nighttime warming and daytime cooling in the northern part of the region and cooling during both times of the day in the Mozambique Channel region were evident (King'uyu et al. 2000). The devastating Sahelian desiccation over the last generation of the 20th century has motivated many scientists to identify the changes in drought conditions in Sudan Eldredge et al. (1988)

and Walsh et al. (1988), perhaps due to the diversified vegetation and climatic features of the country.

Several studies showed that Sudan is suffering from degradation of its land resources through overgrazing, range fires, deforestation, inappropriate agricultural practices and the highly variable rainfall and recurrent droughts (Ayoub 1998). As reported by Yagoub et al. (2017a) that the recurrence last drought periods in Sudan for the most times was moderate except the fact that in 1984, 1991, and 2000 most of Sudan and South Sudan has witnessed extreme and severe drought periods. There is a wide seasonal and spatial variability in drought intensity, as some areas became drier in summer and wetter in autumn and winter.

The objectives of this research are to investigate the land cover change in Sudan in the periods of 2001-2013 by using the MODIS data, in addition, to investigate the climate factors affecting the land cover as recommended by Yagoub et al. (2015), for further research on the use of remote sensing in monitoring LULC changes in Sudan. Particularly these studies not only improve our understanding about LULC changes and its implications in management and conservation efforts.

Yagoub et al. (2017b) investigated Impact of Land Use and Land Cover (LULC) changes in the eastern part of Sudan by using multi-temporal Landsat data, showed that a significant extensive change of natural vegetation patterns has occurred during 1987 - 2013. All records of monthly precipitation and temperature on a spatial resolution of 0.5*0.5 degree grids containing 845 stations were downloaded from Climatic Research Unit, https://crudata.uea.ac.uk/cru/data/hrg/cru_ts_3.22/cruts.1406251334.v3.22/.

Arcgis was used for analyzing and mapping the vegetation cover. SPSS software was used to investigate the correlation of climate factor with vegetation cover.

6.2 Material and Methods

6.2.1 Study area

Fig. 6-1 showed the Sudan, which is located in the northeastern part of Africa, the area of Sudan is 2501010 km²; extending from a latitude of 2°40' - 22°30' N and from longitude 21° 50' - 38°50' E, altitude varies between 40 and 870 m. According to UNESCO (1977) during the hot summer, the maximum temperature exceeds 40℃. As many other Sahelian African countries, Sudan is a drought-prone area. Findings indicate that drought has become more recurrent in recent decades, of which those of the early to mid-1970s, mid-1980s; early 1990s and early 2000s can be noted as common drought years and were among the driest 10 years in the central region of Sudan (Elagib 2009).

Sudan expanded its agricultural production mainly through an increase in rain-fed cropland, 42 percent under large-scale mechanized agriculture and the remainder under small-scale traditional cultivation, and kept its per capita total crop area at about 0.49 hectares which is quite high by regional and global standards (Ministry of Environment and Tourism 1996).

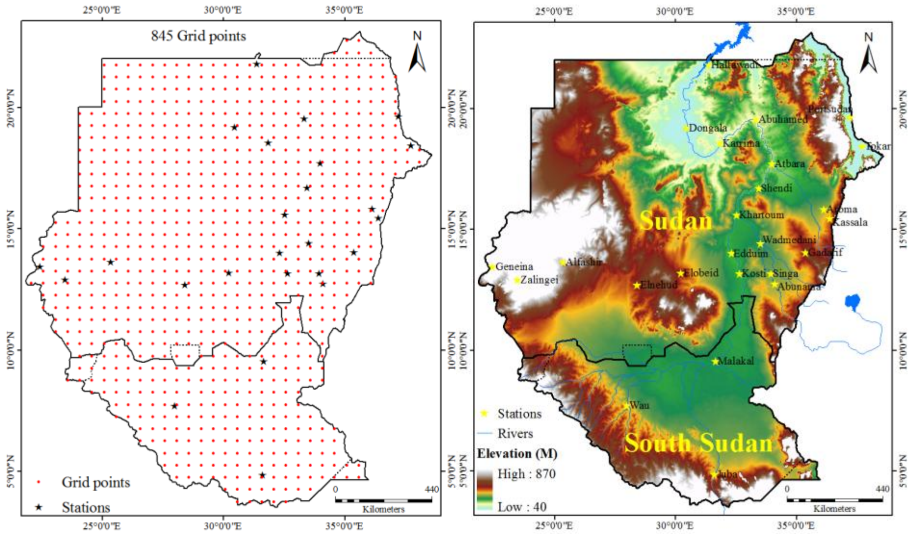


Fig. 6-1 The distribution of meteorological stations and grid points of climate data in study areas

6.2.2 Normalized Difference Vegetation Index NDVI

The MODIS data has a 16-day temporal and 250 m spatial resolution (MOD13Q1, collection 5). MODIS data for the period of 2001 - 2013 is obtained from:

ftp://ladsweb.nascom.nasa.gov/. This data is maintained the NASA in Land Processes Distributed Active Archive Center (LP DAAC) at the USGS/Earth Resources Observation and Science (EROS) Centre. Original MODIS_NDVI is scene in (h20v06, 07 and 08, and h21v06, 07 and 08) for Sudan. The website:

http://phenology.cr.usgs.gov/ndvi_foundation.php is used to download the NDVI value. A vegetation index is an indicator that describes the greenness, the relative density and health of vegetation for each picture element (pixel) in a satellite image. Although there are several vegetation indices, one of the most widely used is the Normalized Difference Vegetation Index (NDVI), NDVI values range from 1.0 to -1.0.

6.2.3 Linear trend (slope)

Linear regression trend analysis by using Arcgis software can simulate trends in each grid (Stow et al. 2007), and can reflect different periods of vegetation cover spatial trends characteristics. Formula:

$$\theta_{slope} = \frac{n \times \sum_{i=1}^{n} i \times NDVI_i - \sum_{i=1}^{n} i \sum_{i=1}^{n} NDVI_i}{n \times \sum_{i=1}^{n} i^2 - \left(\sum_{i=1}^{n} i \right)^2}$$

(1)

Where i is the annual number; n is monitoring period (the cumulative number of years); NDVI as NDVI mean value of the i year; slope is each pixel NDVI trends of the slope, if slope > 0, indicating that the pixel NDVI value in n years is increasing, otherwise it is reducing. This study will change into a significant increase, a slight increase, essentially the same, slightly reduced and a significant reduction, and the statistics of the study area in 2001 - 2013 vegetation changes and the percentage of each class area.

6.2.4 Correlation

Correlation between geographical elements, it is possible to explain the closeness of the relationship between geographic features, and closely related to the degree of mutual determination between geographical elements, mainly through the correlation coefficient calculation and testing to complete. In this research, the study of NDVI and average annual temperature and annual precipitation by-pixel spatial correlation, the correlation coefficient used to reflect the sequence of climatic factors and NDVI degree of correlation, the correlation coefficient value in (-1 and 1) of between. Formula:

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}} \qquad (2)$$

Where: n is the number of time series, x and y are two elements of the correlation, and represent the average of the two elements of the sample values, and finally delineated thresholds based on the number of data, the results of the correlation level of significant.

6.3 Result and discussions

Sudan has complex and diverse climate types, uneven distribution of water resources and serious water shortages in the northern part, harsh natural conditions and a high frequency of drought. Drought is one of the most important natural disasters in Sudan. Drought disasters in Sudan agricultural production especially for relatively large impact not only affect the stability and security of food production, in addition, is one of the main factors restricting the development of the economy in Sudan.

6.3.1 Vegetation cover of monthly time scale

Fig. 6-**2** showed the vegetation variation in Sudan, on a monthly average timescale, NDVI value showed a peak curve distribution in the year. July to October as the center to both sides of decreasing vegetation cover in descending order of the year, which corresponds to the average monthly vegetation NDVI values were: 0.2, 0.19, 0.19, 0.2, 0.21, 0.26, 0.32, 0.36, 0.36, 0.32, 0.26 and 0.22 for the months from January to December, respectively. Overall the growing season (July to October) higher overall vegetation cover in autumn.

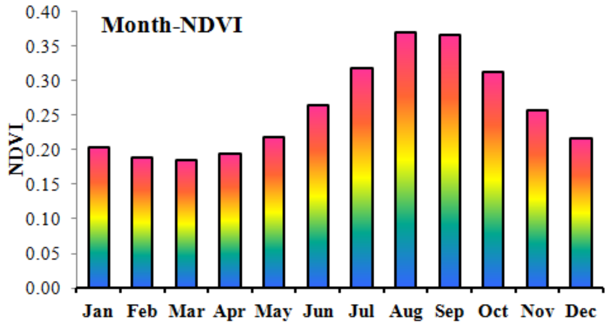


Fig. 6-2 The distribution of the mean monthly-NDVI in Sudan during 2001 - 2013

6.3.2 Spatial distribution of vegetation cover

The spatial distribution of mean NDVI in Sudan, Fig. 6-3 showed that the mean annual and seasonal-NDVI, as a whole, have high values in the southern part. The vegetation cover is high in the south of Sudan due to humid climate zone near the equator line; the vegetation cover is widely distributed in woodland, grasslands and crops, vegetation in forests, and grasslands with a high NDVI value. The Northern part has a low value of vegetation cover; NDVI is negative in areas covered by sand, rock and desert due to locating in the biggest desert in the world.

Fig. 6-4 showed the calculation of NDVI; know each season of Sudan in space presenting features values: autumn follows by summer then winter. The NDVI has different value due to seasonal differences in the degree of green crops and woodland, grassland due to seasonal changes in climate factors. By calculating the average annual and seasonal-NDVI value, it was found that the main vegetation cover type has an upward trend at a rate of 0.014/10a and 0.008/10a, for winter and summer, respectively. While winter-NDVI has a downward, trend at a rate of 0.001/10a and 0.026/10a for annual and autumn, respectively.

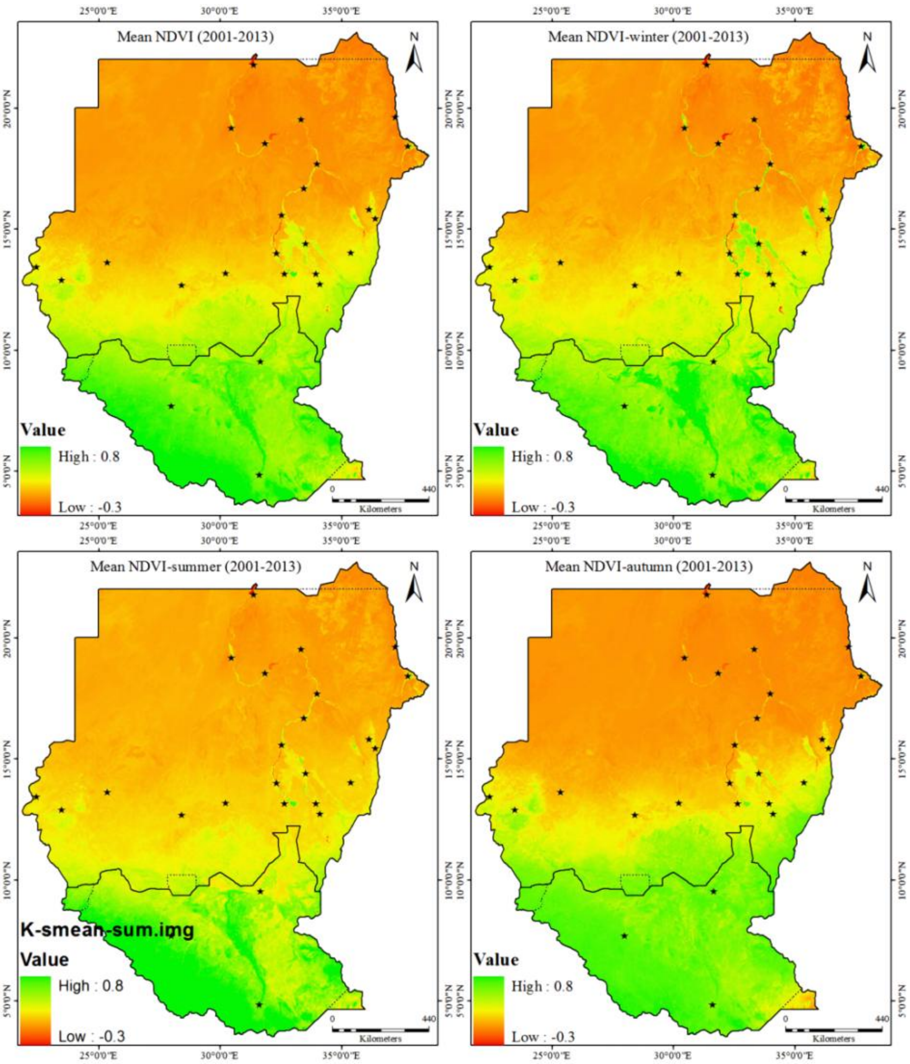


Fig. 6-3 Spatial distribution of mean annual and seasonal-NDVI in Sudan during 2001 - 2013

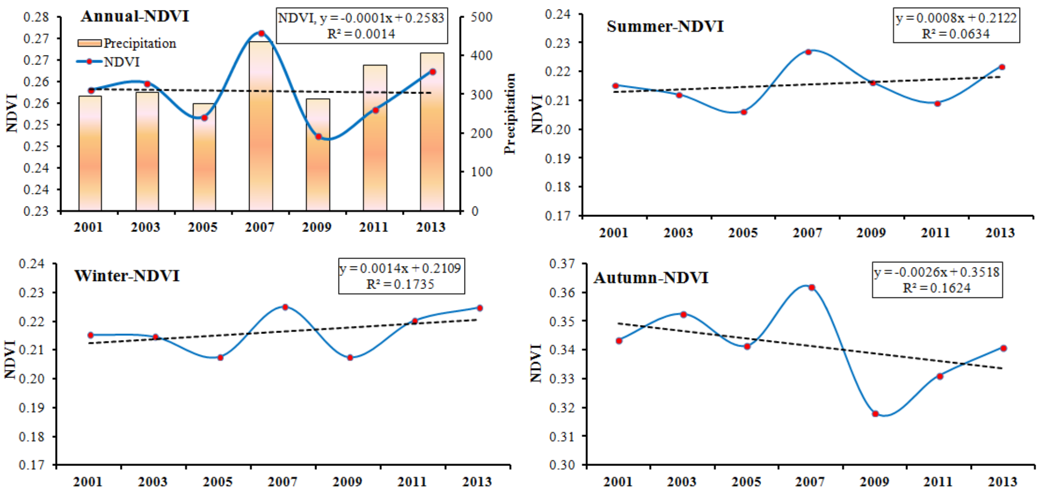


Fig. 6-4 Trend of different vegetation types annual and seasonal-NDVI change in Sudan 2001 - 2013

6.3.3 Spatial variation of vegetation cover

6.3.3.1 Annual

Based on principle *θslope* (calculated by linear regression) value (between -1 and 1) of mean annual-NDVI in Sudan during 2001 - 2013, the land was reclassified from low to high values into seven categories: significant degradation, moderate degradation, mild degradation, no change, mild improvement, moderate improvement and significant improvement.

Fig. 6-5 and Table 6-1 showed the spatial variation of vegetation cover: significant degradation area is 12705.7 km^2 (accounts 0.5 % of the total area) and most of this area is located in the middle and eastern part; moderate degradation area is 28343.4 km^2 (accounts 1.1 % of the total area); mild degradation area is 94550.6 km^2 (accounts 3.8 % of the total area); no change area is 2118701.5 km^2 (accounts 84.7 % of the total area); mild improvement area is 150225.9 km^2 (accounts 6.0% of the total area); moderate improvement area is 73997.4 km^2 (accounts 3.0% of the total area) and significant improvement area is 22485.4 km^2 (accounts 0.9 % of the total area).

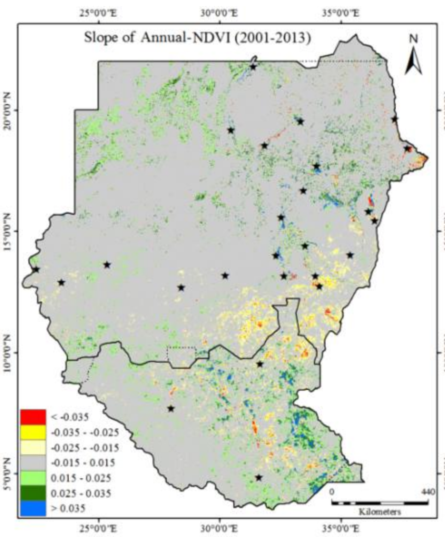


Fig. 6-5 Spatial-temporal change characteristic of mean annual-NDVI based on the slope in Sudan during 2001 - 2013

Table 6-1 Statistical result of trend of mean annual-NDVI change simulated in Sudan during 2001 - 2013

	Category	θSlope range	Mean NDVI	
			Area Km ²	% of total area
1	Significant degradation	θ<-0.035	12705.7	0.5
2	Moderate degradation	-0.035<θ>-0.025	28343.4	1.1
3	Mild degradation	-0.025<θ>-0.015	94550.6	3.8
4	No change	-0.015<θ>0.015	2118701.5	84.7
5	Mild improvement	0.015<θ>0.025	150225.9	6.0
6	Moderate improvement	0.025<θ>0.035	73997.4	3.0
7	Significant improvement	θ>0.03	22485.4	0.9
	Total		2501010	100

6.3.3.2 Seasonal

The mean vegetation cover in Sudan during 2001 - 2013 is calculated by using linear regression analysis. Before the seasonal analysis of vegetation, the reclassified NDVI was further divided into seven categories (from low to high values): significant degradation, moderate degradation, mild degradation, no change, mild improvement, moderate improvement and significant improvement. Fig. 6-6 and Table 6-2 showed that Sudan mean seasonal-NDVI.

The spatial variation of significant degradation is 0.9, 0.9, and 5.1 % of the total area in winter, summer and autumn, respectively. The high change of degradation in autumn is locating in the middle-eastern part of Sudan due to the decrease in precipitation and an increase in temperature. While, the significant improvement is 2.2, 3.3 and 2.0 % of the total area in winter, summer and autumn, respectively. The high improvement is locating in the southern part of Sudan due to the increase in precipitation and a decrease in temperature. No change is 80.8, 80.5 and 71.3 % of the total area in winter, summer and autumn, respectively.

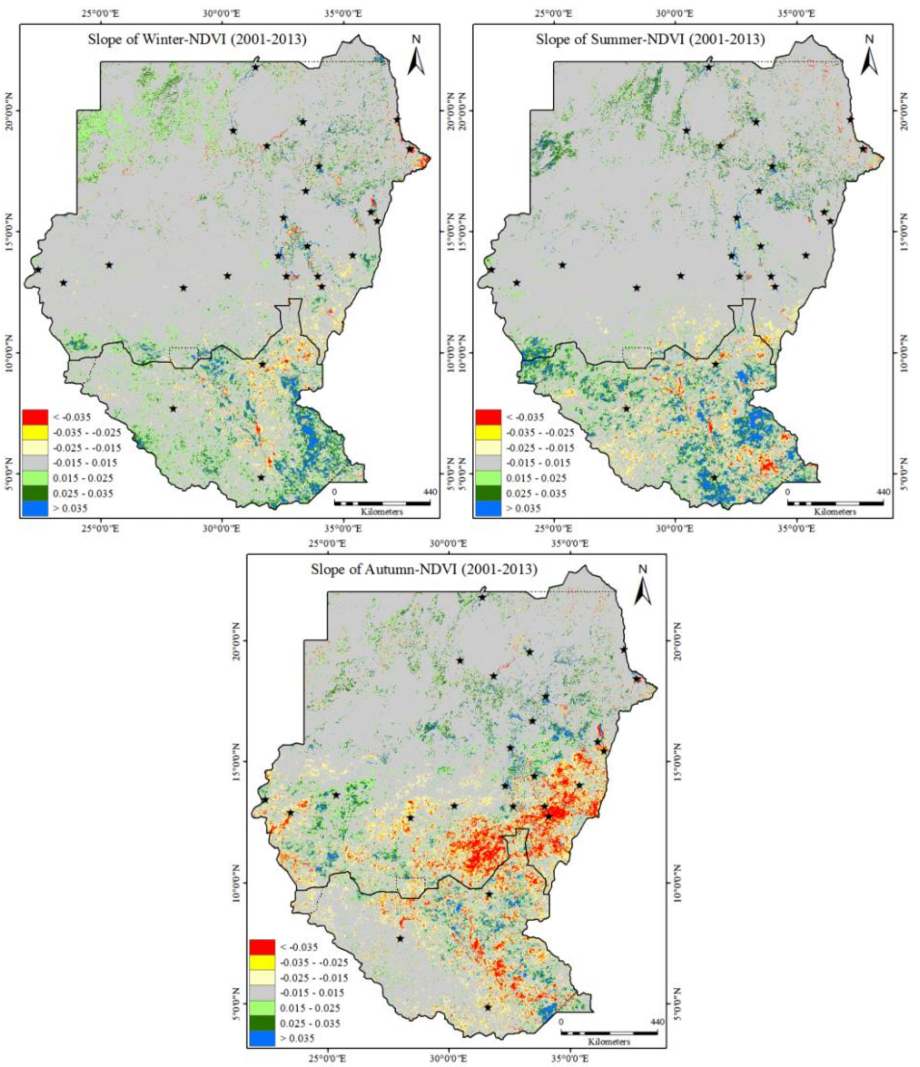


Fig. 6-6 Spatial-temporal change characteristic of mean seasonal-NDVI based on the Slope in Sudan during 2001 - 2013

Table 6-2 Statistical result of trend of mean seasonal-NDVI change simulated in Sudan during 2001 - 2013

	Category	θSlope range	Winter		Summer		Autumn	
			Area Km ²	%	Area Km ²	%	Area Km ²	%
1	Significant degradation	θ<-0.035	21307.1	0.9	23439.6	0.9	128506.4	5.1
2	Moderate degradation	-0.035<θ>-0.025	24978.6	1.0	34998.9	1.4	112684.1	4.5
3	Mild degradation	-0.025<θ>-0.015	58275.7	2.3	72830.1	2.9	192501.9	7.7
4	No change	-0.015<θ>0.015	2020584.8	80.8	2014143.7	80.5	1782067.7	71.3
5	Mild improvement	0.015<θ>0.025	210813.6	8.4	144869.6	5.8	134926.4	5.4
6	Moderate improvement	0.025<θ>0.035	110011.8	4.4	128752.2	5.1	100675.8	4.0
7	Significant improvement	θ>0.03	55038.6	2.2	81975.8	3.3	49647.8	2.0
	Total		2501010	100	2501010	100	2501010	100

6.3.4 Relationship between vegetation cover and climate factors

The correlation coefficients between NDVI and spatial variation of climate factors in Sudan during 2001 - 2013 are calculated by using SPSS software. The spatial distributions of trends in the precipitation and temperature are estimated by interpolating seasonal precipitation and temperature data. Fig. 6-7 showed the presence of significant differences in seasonal precipitation and temperature trends. Spatial characteristics of seasonal temperature showed the variation in all northern parts of Sudan, mainly warming as the main feature has a significant increasing trend, while seasonal precipitation showed decreasing trend in most of the northern parts of Sudan.

Precipitation has a high increasing trend in the southern part of Sudan. Table 6-3 showed that there is a significant positive relationship between mean winter-NDVI and mean winter precipitation at the 0.01% significance level (correlation coefficients 0.735** with p-value 0.00), while there is a significant positive relationship between winter-NDVI and mean winter temperature at the 0.01% significance level (correlation coefficients 0.739** with P value 0.00).

Mean summer-NDVI showed a highly significant difference with mean summer precipitation at 0.01% significance level (correlation coefficients 0.955** with P value 0.00), while there is a significant negative relationship between mean summer-NDVI and mean summer temperature at 0.01% significance level (correlation coefficients -0.270** with P value 0.00). There is a highly significant positive relationship between mean autumn-NDVI with mean autumn precipitation at the 0.01% significance level (correlation coefficients .953** with p-value 0.00), while there is a highly significant difference between autumn-NDVI and mean autumn temperature (correlation coefficients -.820** with P value 0.00).

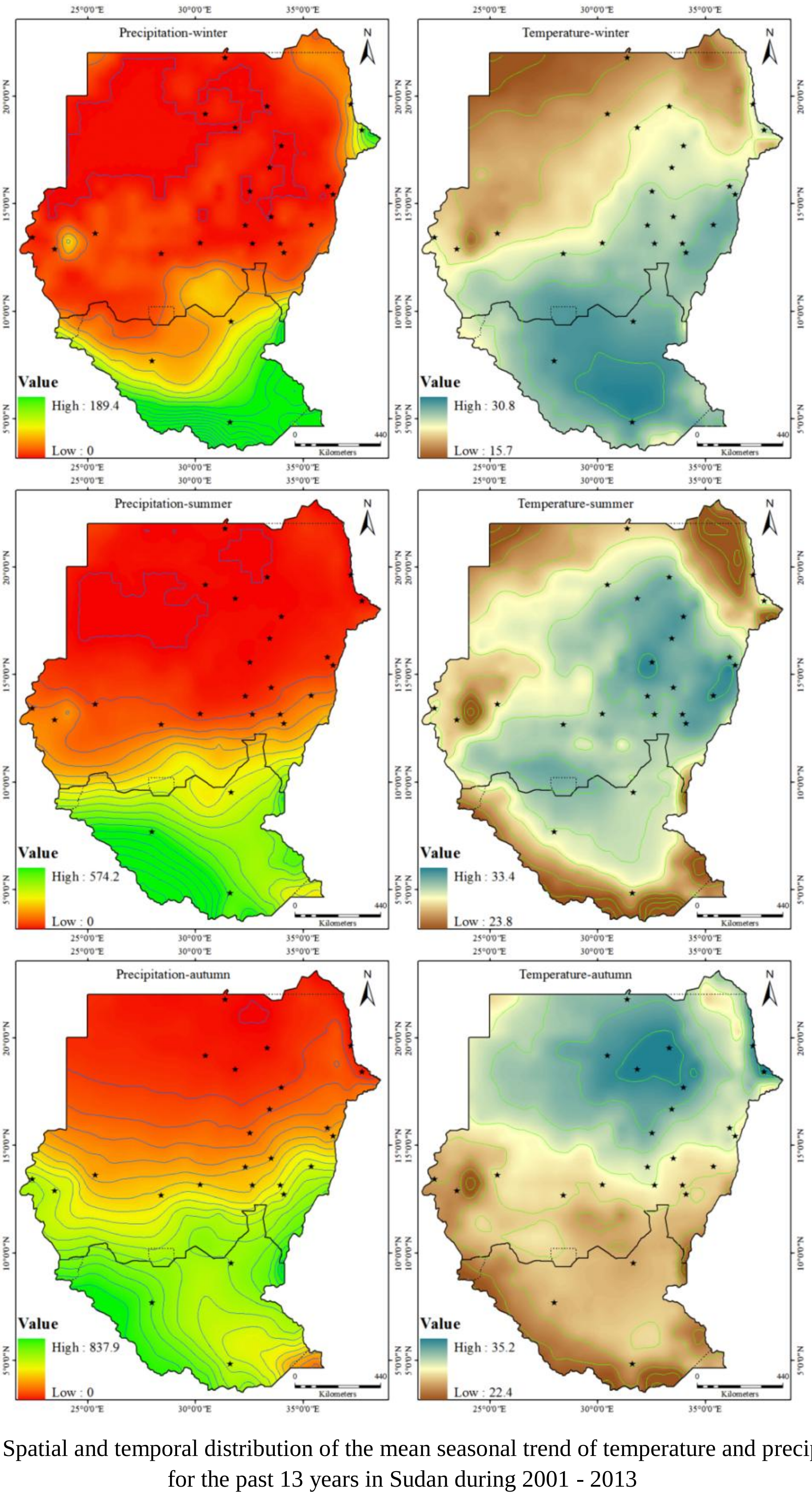


Fig. 6-7 Spatial and temporal distribution of the mean seasonal trend of temperature and precipitation for the past 13 years in Sudan during 2001 - 2013

Table 6-3 Correlation coefficients of NDVI with climate data using SPSS software in Sudan during 2001 - 2013

	Correlation	Pearson correlation	P value, Sig. (2-tailed)
1	Winter-NDVI with precipitation	.735**	0.000
2	Winter-NDVI with temperature	.739**	0.000
3	Summer-NDVI with precipitation	.955**	0.000
4	Summer-NDVI with temperature	-.270**	0.000
5	Autumn-NDVI with precipitation	.953**	0.000
6	Autumn-NDVI with temperature	-.820**	0.000
7	Mean-NDVI with precipitation	.963**	0.000
8	Mean-NDVI with temperature	.079*	0.020

**Correlation is significant at the 0.01 level (2-tailed)
*Correlation is significant at the 0.05 level (2-tailed)

6.3.5 Correlation of NDVI with climate factors

In order to find the relationship between high and low vegetation cover and climatic factors in Sudan, we use the mean annual precipitation and temperature data of 845 sites in recent 13 years. Using the correlation method, grid related calculations are made in Arcgis, as shown in Fig. 6-8. Table 6-3 showed that there is a highly significant positive relationship between mean annual-NDVI and mean annual precipitation at the 0.01 % significance level (correlation coefficient 0.963** with p-value 0.00), there is a significant positive relationship between the mean annual-NDVI and mean annual temperature at the 0.05% significance level (correlation coefficient 0.079* with P value 0.02).

To test the relationship of vegetation cover with annual precipitation and temperature, it is dividing into eight grades according to the principle of division of significance test at different threshold points. Table 6-4 showed the statistics of the correlation coefficient between mean annual-NDVI and climate data factor in Sudan during 2001 - 2013. The correlation coefficient between mean annual-NDVI and precipitation is a significant negative correlation, high negative correlation, moderate negative correlation and low negative correlation: 0.1, 0.1, 0.8, and 18.8 % of the total area, respectively. While low positive correlation, moderate positive correlation, high positive correlation and a significant positive correlation is: 69.3, 9.6, 0.9 and 0.4 % of the total area, respectively.

The correlation coefficients between mean annual-NDVI and temperature are significantly negative, high negative, moderate negative and low negative: 0.2, 0.6, 4.8 and 48.1 % of the total area, respectively. While low positive correlation, moderate positive correlation, highly positive correlation and significant positive correlation are: 44.1, 1.8, 0.2 and 0.2 % of the total area, respectively.

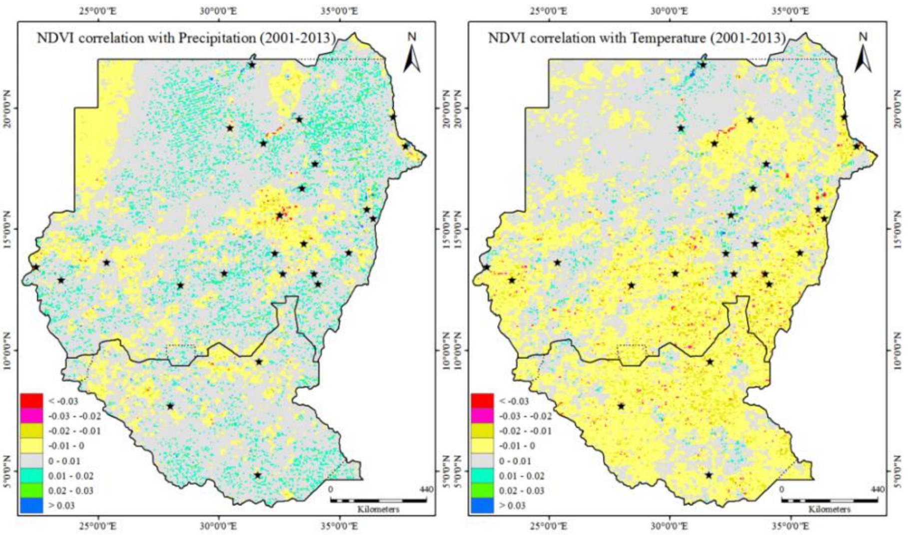


Fig. 6-8 Correlation between mean annual-NDVI and climate factors in Sudan during 2001 - 2013

Table 6-4 The statistics of correlation coefficient between mean annual-NDVI and climate data factors in Sudan during 2001 - 2013

	Category	Correlation range	Precipitation		Temperature	
			Area Km^2	%	Area Km^2	%
1	A significant negative correlation	<-0.03	1724.7	0.1	6092.4	0.2
2	High negative correlation	-0.03～-0.02	2811.9	0.1	13776.8	0.6
3	Moderate negative correlation	-0.02～-0.01	20583.4	0.8	119858.2	4.8
4	Low negative correlation	-0.01～0.00	469668.1	18.8	1203204.6	48.1
5	Low positive correlation	0.00～0.01	1733614.2	69.3	1102266.6	44.1
6	Moderate positive correlation	0.01～0.02	240514.2	9.6	45983.9	1.8
7	Highly correlated	0.02～0.03	22945.4	0.9	6061.8	0.2
8	A significant positive correlation	>0.03	9148.2	0.4	3765.7	0.2
	Total		2501010	100	2501010	100

6.4 Conclusion

Sudan is typical of other least developed countries in Africa in being highly vulnerable to climate change and climate variability. Most drought studies focus on quantifying drought at the regional or global scale. Grassland is decline and decreasing the palatable forbs led to appearing the invader grasses which is unpalatable to livestock and affecting by derogates from livestock by the death, emergency slaughter, direct economic losses and affected in livestock herders. This research showed successfully contribution of MODIS NDVI 250 m for vegetation cover detection distribution in Sudan. Climate factors have high effects on land cover. In spatial scale distribution of mean NDVI in Sudan, it is deduced that a high value of vegetation cover is in the southern part and a low value of that in the northern part. Precipitation and temperature are the main factors which influence the change of vegetation cover and the impact is not the same in different areas. The changes of vegetation cover were primarily influenced by temperature followed by precipitation. This information is of high value for setting up adaptation and mitigation strategies related to forest and natural resources.

CHAPTER SEVEN

MONITORING OF DROUGHT IN QINGHAI PROVINCE BY USING STANDARDIZED PRECIPITATION INDEX (SPI)

7.1 Introduction

The drought can be defined on the basis of two indicators: (a) environmental indicators (b) water resources indicators (Mawdsley et al. 1994). The drought index is the basis for arid climate research and to measure the extent of the drought in a region (Piara, 2014). Both global climate change and anthropogenic activities are the main driving forces of terrestrial ecosystems (Field 2001). With the increase in climate warming and intensified anthropogenic activities over the last century (Raupach et al. 2013), socio-economic drivers are beginning to overwhelm the great forces of nature for some selected processes regionally or even on the global scale (Erb et al. 2009).

Drought is among the major meteorological and environmental problems facing humanity (Zhang et al. 2012). Causes and concepts of climate change divided the theories that explain climate change phenomenon into three categories: extraterrestrial, terrestrial, and oceanic and atmospheric changes (Mustafa 2007). Due to the monsoon climate interacted with the complicated geographical landscapes, severe droughts of high frequency are among the most devastating natural disasters in China. According to statistics, the drought-affected areas and drought-damaged areas have greatly increased in the past 50 years (Wang et al. 2012).

The drought has especially affected the agricultural areas over northern China (Wang et al. 2011). Drought indices are continuous functions of rainfall and/or temperature, river discharge or other measurable hydro-meteorological variables, commonly used to quantify the definition of drought (Thornthwaite 1948). Effective Drought Index (EDI-Byun) and the Reconnaissance Drought Index RDI (Tsakiris et al. 2007) and Standardized precipitation index (SPI) are commonly used for drought analysis. Among them, SPI is more widely used the index because of simple calculation and having multiple time scales (Mckee et al. 1993).

The world's arid areas are mainly distributed in most parts of Asia, most of Australia, most of Africa, western North America and western South America. Among them China drought is particularly prominent, involving a very wide range, mainly in the north-west and northeast regions. And in China, Qinghai Province, located in the dry arid areas of north-west China, is prominent because of more frequent and severe droughts.

7.2 Material and methods

7.2.1 Study area

Qinghai Province has a large variety of ecosystem types, from sub-tropical rain forest in a southeast to alpine desert in the north-west. Among all types of land cover vegetation, alpine grassland is the dominant ecosystem, combined cover an area of 715823.8 km2, extending from latitude of 31°40' - 39°30' N and longitude of 89°25 ' - 103°04' E and altitude 1721 - 8500 m (Fig. 7-1). In addition, Table 7-1 shows the longitude and latitude, altitude and annual precipitation of meteorological stations in Qinghai Province.

7.2.2 Standard Precipitation Index SPI

Monthly precipitation records of all available stations in the Qinghai Province were obtained from China meteorological data service (http://data.cma.gov.cn) for the period of 53 years (1961 to 2013). The SPI index was developed by McKee *et al*. (1993). Details about the SPI index computation can be found in several papers including McKee et al. (1993, 1995), Guttman, (1999) and Khalili et al. (2011). SPI is a simple calculation based on the concept that precipitation deficits over varying periods or time scales. SPI index values based on long-term precipitation may change up to 24 months are not reliable (McKee et al. 1993). The index calculation is simple, consider only the precipitation factor, and having multiple time scales, typically have 1, 3, 12, 24, 36 and 48 months equal time scales. Table 7-2 shows the threshold values of drought for the normal standardized of SPI.

7.3 Result and discussions

7.3.1 Variation of the annual precipitation

Fig. 7-2 shows the variations of precipitation anomaly in Qinghai Province over the period of 53 years (1961-2013). We find obvious fluctuations in positive and negative anomalies. The annual distribution of precipitation anomalies is negative in 1962, 1991, 1992, and 200-2002. The annual precipitation negative anomaly corresponding years are mainly dry drought disaster years in Qinghai Province. A continuous series of positive precipitation anomalies is revealed during 2003 - 2013.

Table 7-1 The Longitude and latitude, altitude and annual precipitation of meteorological stations in Qinghai Province

	Stations	Longitude	Latitude	Altitude (m)	Precipitation (mm)
1	Mangya	38°15´	90°51´	2945	49.2
2	Lenghu	38°45´	93°20´	2770	17.0
3	Tuolei	38°48´	98°25´	3367	297.1
4	Yeniugou	38°25´	99°35´	8320	416.3
5	Qilian	38°11´	100°15´	2787	406.5
6	Xiaozaohuo	36°48´	93°41´	2767	28.9
7	Dachaidan	37°51´	95°22´	3173	89.1
8	Delingha	37°22´	97°22´	2981	180.7
9	Gangcha	37°20´	100°08´	8301	382.2
10	Menyuan	37°23´	101°37´	7850	519.1
11	Ge'ermu	36°25´	94°54´	2808	43.0
12	Nuomuhong	36°26´	96°25´	2790	46.5
13	Doulan	36°18´	98°06´	3191	202.9
14	Chaka	36°47´	99°05´	3088	211.3
15	Qiaboqia	36°16´	100°37´	2835	318.3
16	Xining	36°43´	101°45´	2295	387.3
17	Guizhou	36°02´	101°26´	2237	255.5
18	Minhe	36°19´	102°51´	1814	345.2
19	Wudaoliang	35°13´	93°05´	4612	289.6
20	Xinghai	35°35´	99°59´	3323	365.3
21	Tongde	35°16	100°39´	3289	428.6
22	Tuotuohe	34°13´	92°26´	4533	291.6
23	Zaduo	32°54´	95°18´	4066	535.0
24	Qumalai	34°08´	95°47´	4175	420.9
25	Yushu	33°01´	97°01´	3681	486.2
26	Maduo	34°55´	98°13´	4272	321.5
27	Qingshuihe	33°48´	97°08´	4415	517.0
28	Dari	33°45´	99°39´	3968	554.2
29	Henan	34°44´	101°36´	8500	585.7
30	Jiuzhi	33°26´	101°29´	3629	744.0
31	Nangqian	32°12´	96°29´	3644	538.3
32	Banma	32°56´	100°45´	8530	659.0

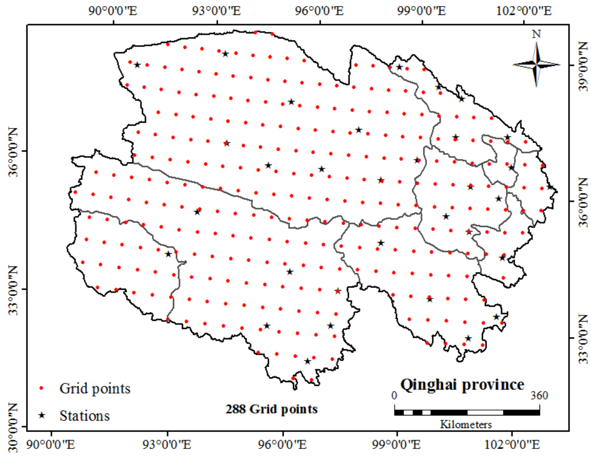


Fig. 7-1 The distribution of meteorological stations in Qinghai Province

Table 7-2 Classification criteria of SPI drought index in Qinghai Province

	Drought category	SPI
1	No drought	< -0.5
2	Mild drought	-0.5 ～-1.0
3	Moderate drought	-1.0 ～-1.5
4	Severe drought	-1.5 ～ -2.0
5	Extreme drought	> -2

Note: Refer to Khalili et al. (2011) and Wang Q. et al. (2015)

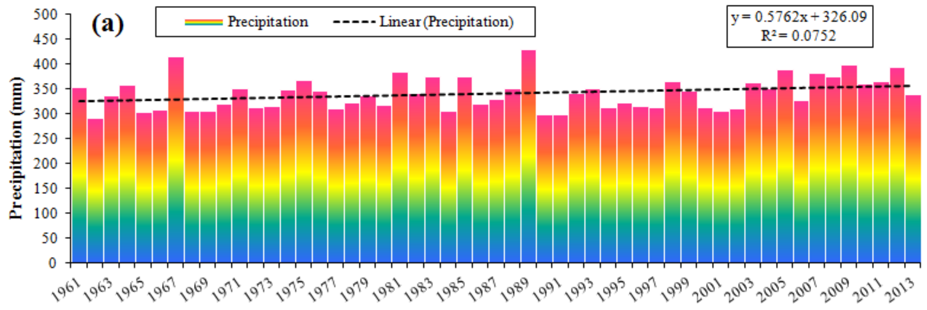
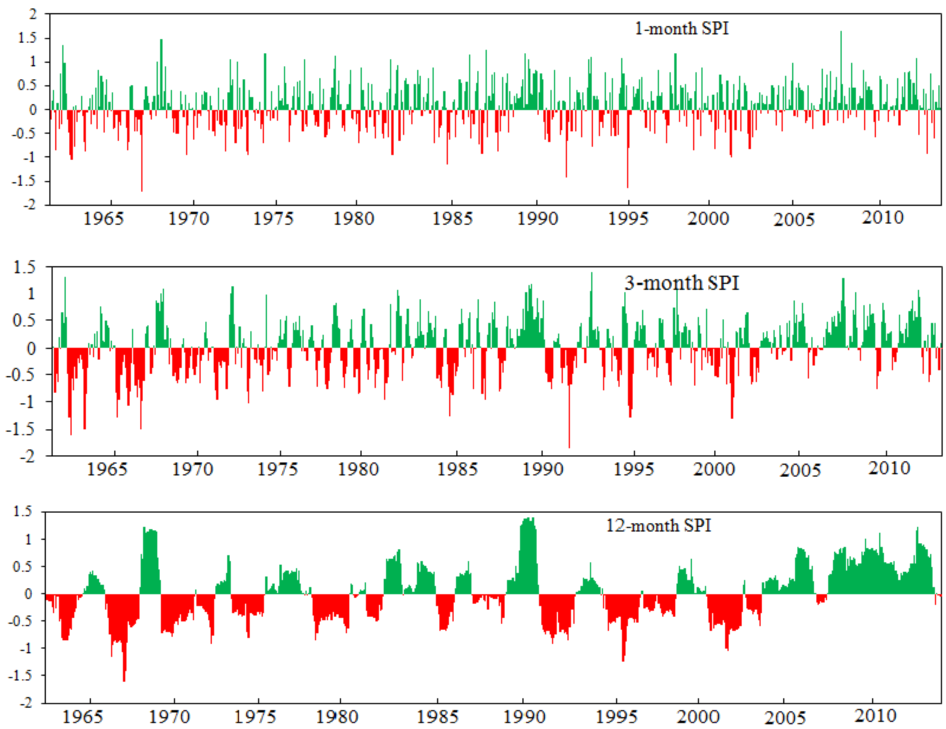


Fig. 7-2 Mean annual precipitation and temperature

Fig. 7-3 shows the SPI values in the Qinghai Province. SPI is calculated at timescales of 1, 3, 12, 24, 36 and 48-month over the period of 1961 to 2013. Because of shorter temporal scale, a greater frequency of SPI index series is obtained. SPI 12- month shows a high frequency of drought in: 1962, 1966-1967, 1970, 1973, 1986, 1992-1993, 1996 and 2001-2004. 24-month shows the high frequency of drought in 1963-1964, 1966-1967, 1970, 1973, 1979-1981, 1992-1993, 1995-1997 and 2002-2004. A 36-month shows a high frequency of drought in 1965-1966, 1969-1971, 1979-1981, 1993, 1996-1998 and 2003-2004. 48-month shows a high frequency of drought in 1964-1966, 1970, 1980, 996-1998, 2002-2004. The last eight years (from 2006 to 2013) shows no drought condition based on SPI values.



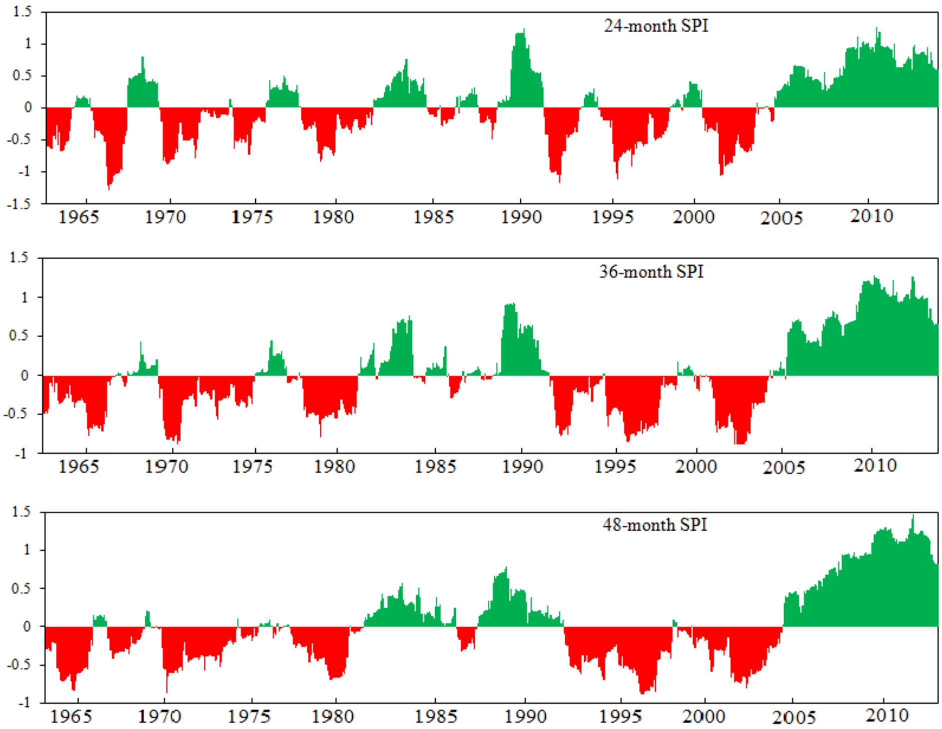


Fig 7-3 SPEI and SPI values on 1, 3, 12, 24, 36 and 48-month time scale in Qinghai Province during1961 - 2013

7.3.2 Drought frequency spatial variation

Fig. 7-4 shows the frequency distribution of seasonal and annual-SPI of a total drought category in Qinghai Province during 1961-2013. The high frequency of annual-SPI drought is obtained in Lenghu, Qilian, Delingha, Chaka, Doulan, Qiaboqia, Tongde and Qingshuihe. The high frequency of annual-SPI of mild drought in: Lenghu, Wudaoliang, Delingha, Doulan, Chaka and Qiaboqia; moderate drought in: Dachaidan, Nuomuhong, Zaduo, Dari, Tongde, Guizhou and Henan; severe drought in: Xiaozaohuo, Delingha, Yushu, Xinghai, Gangcha and Xining; and extreme drought in: Xiaozaohuo, Tongde, Qumalai, Yushu, Nangqian, Maduo, Dari and Banma.

7.3.3 Drought trends and mutation detection

Fig. 7-5 shows the trends of annual SPI in Qinghai Province. The annual-SPI forward curve (UF curve) shows that the drought trend was not significant in the 1960s to the 1990s in Qinghai Province which alternating wet and dry cycles; after the 1990s, drought aggravated north-west of Qinghai Province.

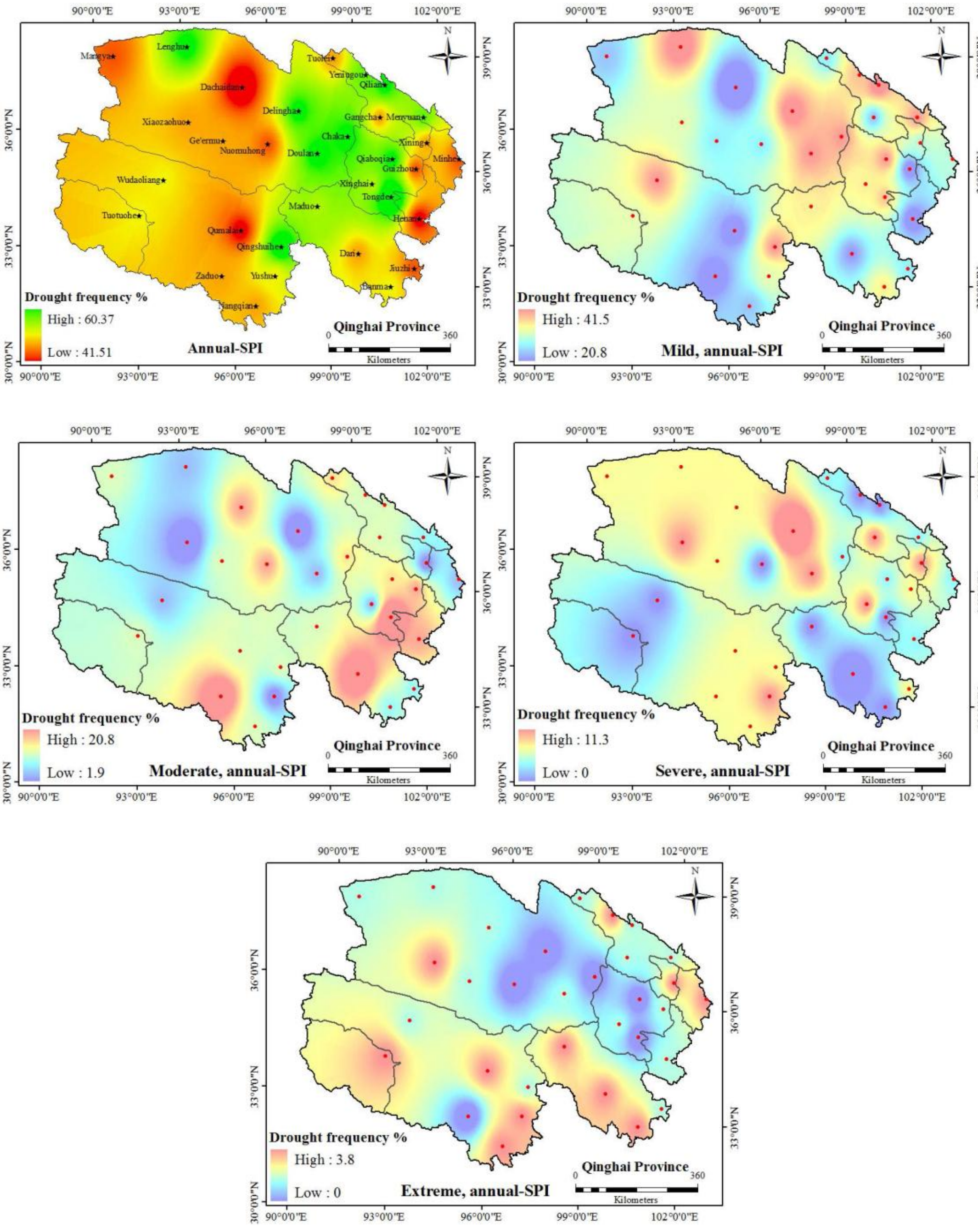


Fig. 7-4 The frequency distribution of seasonal and annual- SPI of a total drought category in Qinghai Province during 1961-2013

The UF curve is 0.05 % significant level line. The annual-SPI UF curve shows that nearly Qinghai Province in 2000s drought trend is not significant, 2004 is the beginning of mutation detection of the humid.

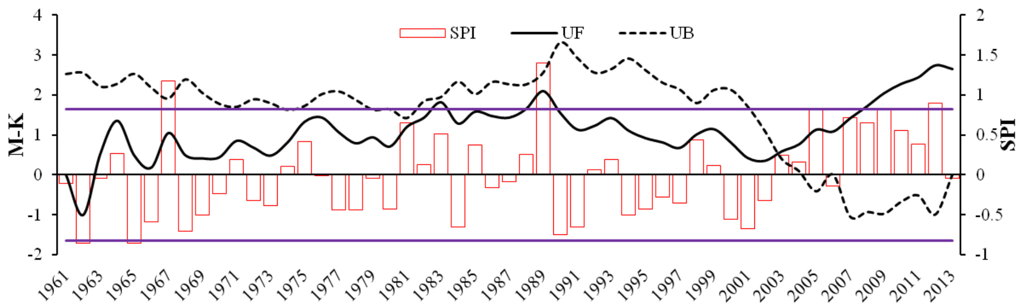
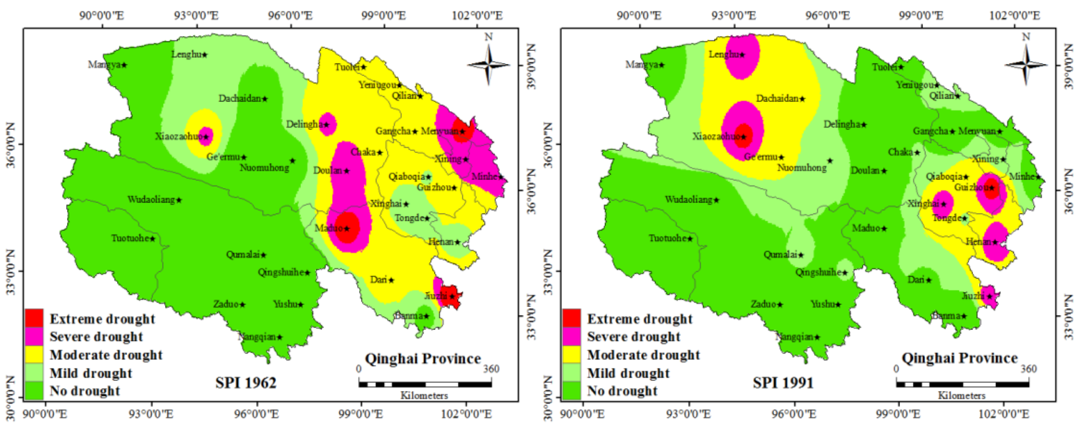


Fig. 7-5 Interannual variation and Mann-Kendall test of SPI drought index in Qinghai Province during 1961-2013

The actual comparison of SPI drought index in high drought periods Fig. 7-6 shows the monitoring of SPI drought index in 1962, 1991 and 2001, the actual comparison of SPI index in highest drought periods to monitor the degree of drought in Qinghai Province. The 1962-SPI shows the extreme drought in Maduo, Menyuan and Jiuzhi; severe drought in Xiaozaohuo, Delingha, Minhe and Xining; moderate drought in Tuolei, Yeniugou, Qilian, Gangcha, Chaka, Guizhou and Dari; and mild drought in Xining, Tongde and Henan.

There is no drought look same as 1962-SPEI in most of the middle, southwest and south part. The 1991-SPI drought index shows the extreme drought in Xiaozaohuo, Guizhou; severe drought in Lenghu, Xinghai, Henan and Jiuzhi; Moderate drought in Dachaidan, Ge’ermu and Qiaboqia; and mild drought in Chaka and Xining. The 2001-SPI index shows that the extreme drought in Mangya; severe drought in Xiaozaohuo, Qingshuihe, Banma and Gangcha; Moderate drought in Dachaidan and Minhe; Mild drought in Lenghu, Zaduo, Ge’ermu, Nuomuhong, Maduo, Dari and Henan.



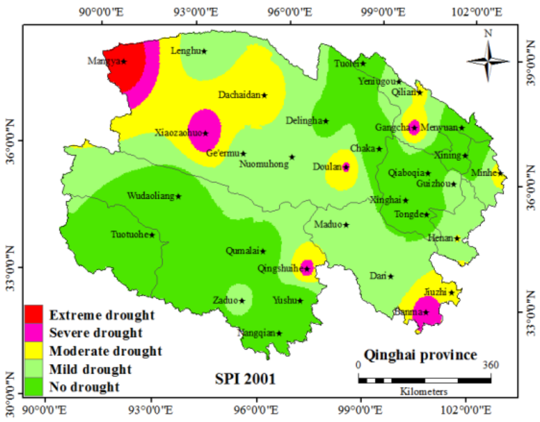


Fig. 7-6 Monitoring results of SPI drought index in Qinghai Province of 1962, 1991 and 2001

7.4 Conclusion

Drought indices, designed to provide a concise overall picture of droughts, are often derived from massive amounts of hydroclimatic data and are used for making decisions for water resources management and water allocations for mitigating the impact of droughts. In recent years, Qinghai Province is observing intensified climate warming and a decrease of precipitation. Frequent trends in an arid zone are affecting the region more widely, the economic losses caused by drought is also growing.

These situations highlight the need to take comprehensive measures. This study is focusing in Qinghai Province, using inputs and outputs of SPI index to characterize drought type, severity, and duration, which can assist in identifying appropriate adaptation strategies to minimize the impacts of drought to the agriculture and water sector. This work has a unique contribution for achieving a drought index, which can identify meteorological drought by simply overlaying the maps of the drought index.

The use of quantitative SPI for drought management reduces the subjective preferences of decision makers. The SPI is good for the assessment of drought of grassland, wildlife life-threatening and indirect economic losses of grassland ecosystems far beyond the direct economic loss. This study recommended adapting and mitigating the drought periods: improving livelihoods, agro-ecosystem resilience, agricultural productivity and the provision of environmental services. In addition, we recommended more additional investigations on crops suitable for the Qinghai Province during drought should be carried out for more accurate information, which can be used for crop modelling of appropriate agricultural and water management during drought. Further studies on drought prediction using future climate scenarios in Qinghai Province, using methods presented in this study, will be part of the future direction of this study.

CHAPTER EIGHT

DETECTION OF DROUGHT PATTERN IN SUDAN USING STANDARDIZED PRECIPITATION EVAPOTRANSPIRATION INDEX (SPEI)

8.1 Introduction

Drought is considered a major environmental problem facing humanity, as about one-third of the world's countries located in arid and semi-arid areas including Sub-Saharan Africa (Zhang et al. 2012). Recent climate change reports have classified Sub-Saharan Africa as one of the most susceptible, sensitive and vulnerable regions of the world to the impacts of drought events as more severe and longer drought periods have been observed since the1970s in these areas (IPCC 2007). A plausible warmer world with longer and harsher droughts could lead to a rapid collapse in tropical forest communities converting them from a net carbon sink into a large carbon source with cascading effects on global climate-vegetation feedbacks (Lewis 2006).

The recent findings of the Intergovernmental Panel on Climate Change (IPCC) (e.g. IPCC 2007 and 2013), showed that climate change is already having clear impacts on natural resources and subsequently affecting livelihoods of millions of people around the world. Not only these current noticeable heat waves and destructive drought events but also similar climatic change-related crises have been predicted to continue increasing in frequency and severity over the next few decades and specifically in arid zones. Perhaps such an increase in frequency of drought in these fragile arid ecosystems such as sub-Saharan Africa, for example, will have severe consequences on natural forest and biodiversity (Siddig 2014).

Examples of these ecological consequences on arid-lands forests may include; failure of trees natural regeneration, species-range shift, changes in community structure and composition, reduction in species abundance, reduction in forest products as well as a spread of fires and diseases. Sudan is one of the driest but also the most variable countries in Africa in terms of rainfall. Extreme years (either good or bad) are more common than average years (Zakieldeen 2007). While the drought of 1968 was very severe and persisted throughout the early 1970s, the second wave was limited to the year 1982 only, but harsher and was considered the third driest year in the period of 1940-1982. Also, the year 1982 appears to have received substantially less rainfall than the drought years of the 1940s. Despite these drought impacts in Sudan, the knowledge on measuring the occurrence, frequency, and severity is limited. Furthermore, there is limited information about future scenarios and their possible impacts on natural resources at the country scale.

This obviously makes the need for more in-depth studies and analysis to understand how crucial is this phenomenon. For instance, questions like how severe the drought can get every year and where (i.e. in which part of the country) is of deep concern. In addition, what does the recurrence interval of the drought and what are the determinants of this is a very important question as well as how long each drought period takes (i.e. how many years).

Fortunately, drought indices provide reasonable answers to many of these questions. According to the definition of drought by Mawdsley et al. (1994), there are two types of drought indicators: (a) environmental indicators, which measure the direct effect on the hydrological cycle, including among others, rainfall, temperature, evapotranspiration, river flow, etc., and (b) water resources indicators, which measure the severity in terms of the impact on the use of water, e.g. water supply for domestic or agricultural use, fisheries or recreation. Although these both types of drought indicators are useful tools and easy to construct based on historical hydro-meteorological data, however, they can only reflect drought conditions (e.g. intensity) with no ability to quantify the economic losses or destruction level (Mishra and Singh 2010). Drought indices are very important tools for environmental research and management in arid zones. Their values not only for measuring the spatiotemporal extent of drought events but also are useful tools for guiding decision making to declare a drought state of emergency, for example, and designing drought-mitigation plans (Quiring 2009; Piara 2014).

Moreover, environmental indices in general including drought indices are a significant communication tool between environmental scientists and public. Intuitively, these indices enable scientists to describe and quantify the state and trend of the environment to ordinary people in a simple and understandable number. Among the earliest efforts and developments in drought indices, Thornthwaite (1948) has proposed a simple drought index which based on the value of precipitation in a certain point of time minus evapotranspiration at the same period. Although Thornthwaite’s index was very simple but had provided an important foundation for later research by other drought scientists. Almost two decades later Palmer (1965) proposed a new drought index i.e. the Palmer Drought Severity Index In addition to precipitation and evapotranspiration values, PDSI consider temperature and soil moisture information.

Despite decades since the emergence of these drought indices, PDSI has been recognized as a milestone in the history of drought indices and now being widely used in the United States and around the world. The Standardized Precipitation-Evapotranspiration Index (SPEI) is the most recent and famous drought index, proposed by Vicente-Serrano et al. (2010). The

SPEI is based on precipitation and potential evapotranspiration (PET), and it combines the sensitivity of PDSI to changes in evaporative demand with the multiscalar nature of the SPEI. Details of the method used to calculate the SPEI can be found in Vicente-Serrano et al. (2010) and Beguería et al. (2014). SPEI applied the Thornthwaite procedure (Thornthwaite 1948) to estimate the PET, which has the advantage of requiring limited data of monthly mean temperature. The drought intensity grading based on the SPEI's values is presented below in Table 8-1 and readers are referred to Liu et al. (2013) and Wang et al. (2015) for the full description of SPEI grading.

Table 8-1 Classification of drought intensity based on SPEI drought index

	Drought category	SPEI
1	No drought	< -0.5
2	Mild drought	-0.5 ～-1.0
3	Moderate drought	-1.0 ～-1.5
4	Severe drought	-1.5 ～ -2.0
5	Extreme drought	> -2

During the last decade, temperature trends in some African regions have been the subject of a number of assessments and monitoring projects. Findings showed that eastern Africa has dominated cool daytime and warm nighttime but no warm time was found in the Mozambique Channel region (King'uyu et al. 2000).

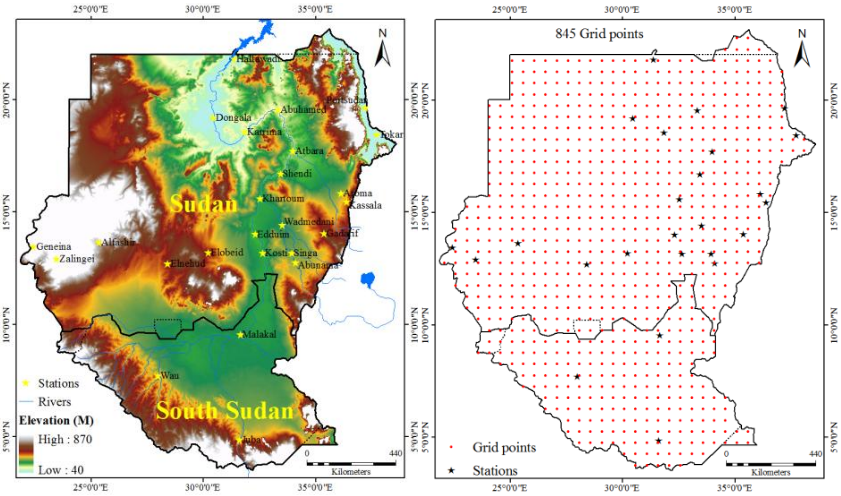
The devastating Sahelian desiccation over the last fifty years of the 20th century has motivated many scientists to monitor the changes in drought conditions in Sudan (Eldredge et al. 1988; Hulme, 1990; Hulme, 2001). Several studies showed that Sudan is suffering from land degradation as a result of highly variable rainfall and recurrent droughts (Ayoub 1998). While South Sudan is generally cooler and wetter, Sudan has a dry and harsher climate due to the dominant variable precipitation and temperature as well as high frequency of drought periods. Apparently, drought is one of the most important natural disasters in Sudan not only for its substantial influences agricultural production, food security, livestock, but also it causes significant disturbances to the forest ecosystems. Recent observations showed that Sahara desert is encroaching southwards at alarming rate due to vegetation cover degradation in semi-arid zones as a result of the drought.

Additionally, drought can lead to an increase in natural resources related to conflicts and civil wars, expand shifting cultivation areas, and insecurity in land tenure (Sivakumar et al. 2007). Of course, these are reasonable causes of concern to environmental scientists in both countries to address these issues by knowing more about drought patterns and consequences. Although there were several attempts to study drought in Sudan and South Sudan, still there is an absence of recent analysis of drought pattern and trends. In the current study, based on precipitation and temperature data from 25 weather stations from both countries over the period 1961 - 2013, we aim to; (a) explore the spatial and temporal variation pattern in precipitation and temperature, (b) and detect the occurrence of drought periods and their geographic extent based on SPEI.

8.2 Material and methods

8.2.1 Study area

This study focused on Sudan and South Sudan, which are located in the northeastern to a central part of Africa (Fig. 8-1). Both countries together cover an area of 2501010 km extending from a latitude of 2°40' 21°50 ' - 38°50' E. While Sudan is drier as its northern half is entirely desert forming the southeast borders for Sahara desert, South Sudan is wetter and greener given its location near equator line. In the mountainous areas of western Sudan, the winter is considered mild with mean temperature slightly less than 20 ℃. Excluding South Sudan, there is a wide range of difference in temperature between the monthly minimum and maximum temperature. During the hot summer, the maximum temperature exceeds 40 ℃.



* Source of DEM data: (http://srtm.csi.cgiar.org/), resolution = 90 m × 90m

Fig. 8-1 The distribution of meteorological stations and grid points of climate data in two study areas

As many other Sahelian African countries, Sudan is a drought-prone area (Elagib 2009). Despite these harsh conditions, Sudan is one of the wealthiest countries in Africa for its natural resources. With less than 4% of the continent's population, it has 7% of the continent's cropland, 13% of its pasture land, and 10% of its livestock population (WRI/UNEP/WB/UNDP 1996). Table 8-2 shows the longitude and latitude, altitude and annual precipitation of meteorological stations used in this study.

Table 8-2 The Longitude and latitude, altitude and annual precipitation of meteorological stations in Sudan

	Stations	Longitude	Latitude	Altitude (m)	Precipitation (mm)
1	Abuhamed	33 °44 ´	19 °51 ´	313	12.5
2	Abunama	34 °06 ´	12 °65 ´	434	632.0
3	Alfashir	25 °31 ´	13 °58 ´	738	170.5
4	Aroma	35 °94 ´	15 °77 ´	445	234.8
5	Atbara	33 °75 ´	17 °64 ´	385	42.9
6	Dongola	30 °63 ´	19 °20 ´	249	7.0
7	Edduim	32 °19 ´	13 °89 ´	385	230.5
8	Elnehud	28 °44 ´	12 °65 ´	573	438.8
9	Elobeid	30 °31 ´	13 °27 ´	610	357.3
10	Gadarif	35 °31 ´	14 °21 ´	571	521.0
11	Geneina	22 °50 ´	13 °27 ´	845	748.1
12	Halfawadi	31 °25 ´	21 °08 ´	320	3.8
13	Juba	31 °56 ´	4 °84 ´	598	735.1
14	Karrima	31 °88 ´	18 °58 ´	242	13.5
15	Kassala	36 °25 ´	15 °46 ´	490	341.0
16	Khartoum	32 °50 ´	15 °46 ´	383	133.3
17	Kosti	32 °81 ´	12 °96 ´	362	362.7
18	Malakal	31 °56 ´	9 °84 ´	392	719.8
19	Portsudan	37 °19 ´	19 °83 ´	41	35.6
20	Shendi	33 °44 ´	16 °70 ´	378	62.0
21	Singa	34 °06 ´	12 °96 ´	426	536.7
22	Tokar	37 °81 ´	18 °89 ´	256	171.8
23	Wadmedani	33 °44 ´	14 °52 ´	407	216.9
24	Wau	28 °13 ´	7 °65 ´	440	912.7
25	Zalingei	23 °44 ´	12 °96 ´	862	549.3

8.2.2 SPEI

The SPEI development requires information about monthly temperature and precipitation records for all the area within the study focus. We gathered the monthly temperature and precipitation data from Sudan Meteorological authority for 25 weather stations across Sudan and South Sudan for the period of 1961-2013 (Fig. 8-1).

8.2.3 Mann-Kendall test M-K

We applied the Mann-Kendall test, developed by Mann, (1945) and Kendall, (1975) in order to detect the significant trends in SPEI time series. The rank-based Mann-Kendall (M-K) test is the most widely used nonparametric method for trend detection. We particularly used this method due to sensitivity and nature of meteorological data to alternative parametric tests those assume specific probability distribution. Temperature and precipitation data that we used to construct SPEI have no exception and are likely to be not normally distributed and usually having outliers.

8.3 Result and discussion

8.3.1 Pattern of temperature and annual precipitation

Precipitation anomaly shows great fluctuations all over Sudan and South Sudan. Alternating positive and negative anomalies fluctuations, the most negative anomalies periods have been recorded, for example, in 1966, 1972, 1984, 1991 and 2000 (Fig. 8-2a). On the other hand, wet years are also noticed, for example, in 1969, 1979, 1988 and 2011. Likewise precipitation and temperature have shown fluctuations around the average with a generally increasing trend (Fig. 8-2a - bottom).

On the basis of analysis of precipitation and temperature data for the twenty-two stations of Sudan, a steep decreasing trend in annual precipitation and increasing trend in temperature were found (Fig. 8-2b, respectively). Oppositely, and from a similar subset analysis for the three stations of South Sudan only, we found that there are rapidly increasing trend in precipitation (Fig. 8-2c).

8.3.2 Drought pattern based on SPEI

SPEI provided useful information about drought patterns i.e. occurrence, intensity and extent throughout the study area during the 53-year window. While our SPEI results were calculated at time scales of 1, 4, 12, 24, 36, and 48-month, here we only present a result for 12-month time step which showed the occurrence of a highest number of drought periods (i.e. drought frequency). As in Fig. 8-3, SPEI 12-month shows high number drought occurrences (i.e. periods) that were happened in 1973 - 1975, 1981, 1991 - 1992, 2000 - 2001, 2003 - 2006 and 2008- 2011. Also, we noted that the 2000s witnessed three drought periods with a recurrence interval of 2.5 years on average.

According to the drought intensity classes, there are four categories include mild, moderate, severe and extreme drought. SPEI index showed that mild drought is the most dominant drought level in Sudan on the annual as well as the seasonal basis. Table 8-3 shows the percentages of different drought intensities that detected in Sudan and South Sudan annually and across seasons. Also, SPEI trend analysis by Mann-Kendall (M-K) test showed significant increasing trend in the seasonal drought patterns in towns such as Wadmedani, Tokar, Portsudan, Kassala, Gadarif, Dongala, Aroma and Abuhamed (P = 0.00), while significant (i.e. P = 0.00) decreasing trends in all three stations of South Sudan (i.e. became more humid). Table 8-4 presents the results of the seasonal drought trends as computed by M-K test.

8.3.3 Correlation of the SPEI drought index with precipitation and temperature

SPEI calculated from Juba station's data presenting South Sudan and from Elobied, Geneina, Kasala and Wadi-Halfa stations for Sudan were correlated with the same stations precipitation and temperature data. While precipitation in Juba showed a weak and negative correlation with SPEI, but there was a clear significant negative association between temperature and SPEI (Table 8-5). For Sudan's stations, SPEI for Kassala and Wadi-Halfa showed a strong correlation with both precipitation and temperature, but drought in Elobied and Geneina indicated no significant correlation with precipitation, although they were highly correlated with temperature.

Table 8-5 shows the association between drought index and precipitation and temperature in five towns in Sudan and South Sudan.

8.3.4 Spatial distribution of drought intensity

Drought appears to occur in many locations in the study area with different levels of intensities. In general, Portsudan, Karrima, Abuhamed, Atbara, Elobeid, Malakal and Wau showed high level of drought, whereas towns like Kosti, Singa, Abunama, Kassala, Gadaref exhibited low levels of drought (Fig. 8-4). More details about the seasonal variability in drought intensity can be found in Fig. 8-4.

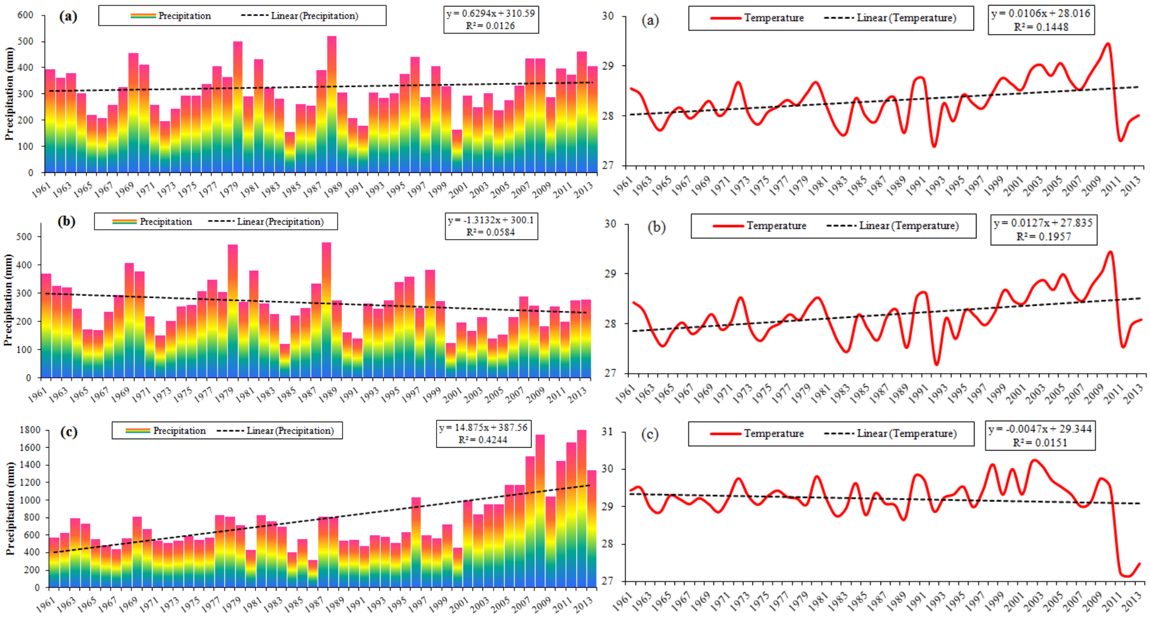


Fig. 8-2 (a-c) Mean annual precipitation and temperature trend in Sudan and South Sudan from 1961 to 2013. (a) Results for all 25 stations of the study area (i.e. both Sudan and South Sudan). (b) Results from only twenty-two station of Sudan. (c) Results from only three station of South Sudan

Table 8-3. Percentage of SPEI summer and autumn seasons in Sudan and South Sudan

Drought category		SPEI %			
		winter	summer	autumn	annual
1	No drought	52.69	51.85	51.25	52.00
2	Mild drought	27.15	25.51	29.13	25.51
3	Moderate drought	10.69	13.89	10.19	11.85
4	Severe drought	06.00	05.89	06.79	08.60
5	Extreme drought	03.46	02.87	02.64	02.04
	Total drought	47.31	48.15	48.75	48.00

Table 8-4 Results of SPEI-seasonal trend analysis in Sudan and South Sudan during 1961 SPEI-drought intensities occurred in the whole year as well as winter, South Sudan during 1961 - 2013

	Stations	winter		summer		autumn	
		Z value	P value	Z value	P value	Z value	P value
1	Abuhamed	***-3.27***	0.00	***-2.83***	0.00	***-2.83***	0.00
2	Abunama	***-2.39***	0.01	-0.91	0.18	-1.56	0.06
3	Alfashir	-1.37	0.09	-1.50	0.07	-0.8	0.21
4	Aroma	***-2.68***	0.00	-1.43	0.08	***-3.00***	0.00
5	Atbara	***-2.70***	0.00	***-2.88***	0.00	***-2.22***	0.01
6	Dongola	***-2.94***	0.00	-1.20	0.11	***-2.66***	0.00
7	Edduim	***-2.39***	0.01	***-2.12***	0.02	***-2.06***	0.02
8	Elnehud	-0.73	0.23	***-2.14***	0.02	***-1.6***	0.05
9	Elobeid	***-1.93***	0.03	***-2.54***	0.01	-1.42	0.08
10	Gadarif	***-2.96***	0.00	***-1.94***	0.03	***-2.74***	0.00
11	Geneina	***-1.35***	0.09	***-2.17***	0.01	-0.68	0.25
12	Halfawadi	***-2.45***	0.01	-0.39	0.35	***-1.94***	0.03
13	Juba	3.57	0.00	1.93	0.10	2.34	1.00
14	Karrima	***-2.60***	0.00	-1.27	0.10	***-1.96***	0.03
15	Kassala	***-2.71***	0.00	-1.30	0.10	***-4.40***	0.00
16	Khartoum	***-2.56***	0.01	-1.48	0.07	***-1.85***	0.03
17	Kosti	***-1.71***	0.04	-1.52	0.06	-1.02	0.15
18	Malakal	1.20	0.10	-0.33	0.37	2.92	0.00
19	Portsudan	***-2.63***	0.00	-1.60	0.05	***-3.70***	0.00
20	Shendi	***-2.50***	0.01	***-2.19***	0.01	***-2.22***	0.01
21	Singa	***-2.32***	0.01	***-1.20***	0.11	***-1.63***	0.05
22	Tokar	***-1.90***	0.03	***-3.86***	0.00	***-4.47***	0.00
23	Wadmedani	***-2.19***	0.01	***-1.70***	0.05	***-2.85***	0.00
24	Wau	2.52	0.01	0.370	0.23	1.43	0.92
25	Zalingei	-0.29	0.38	-2.16	0.02	***-0.43***	0.33

Note: The bold and italic values are indicating drought, while the underlined values are indicating trends towards humid conditions (both with P value < 0.05)

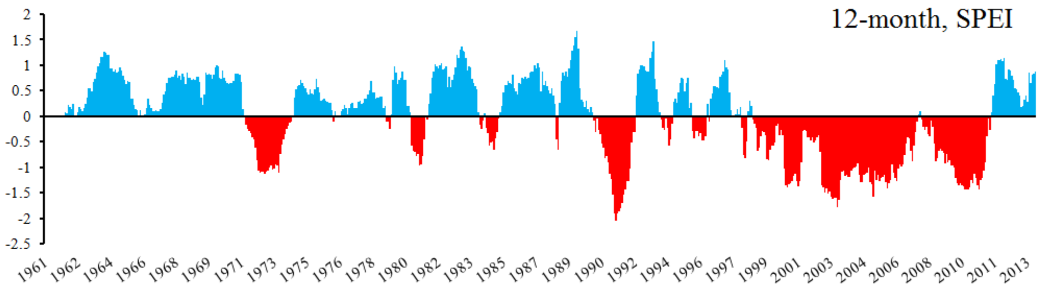


Fig. 8-3 SPEI drought index values in Sudan and South Sudan during 1961- 2013, based on the 12-month time scale

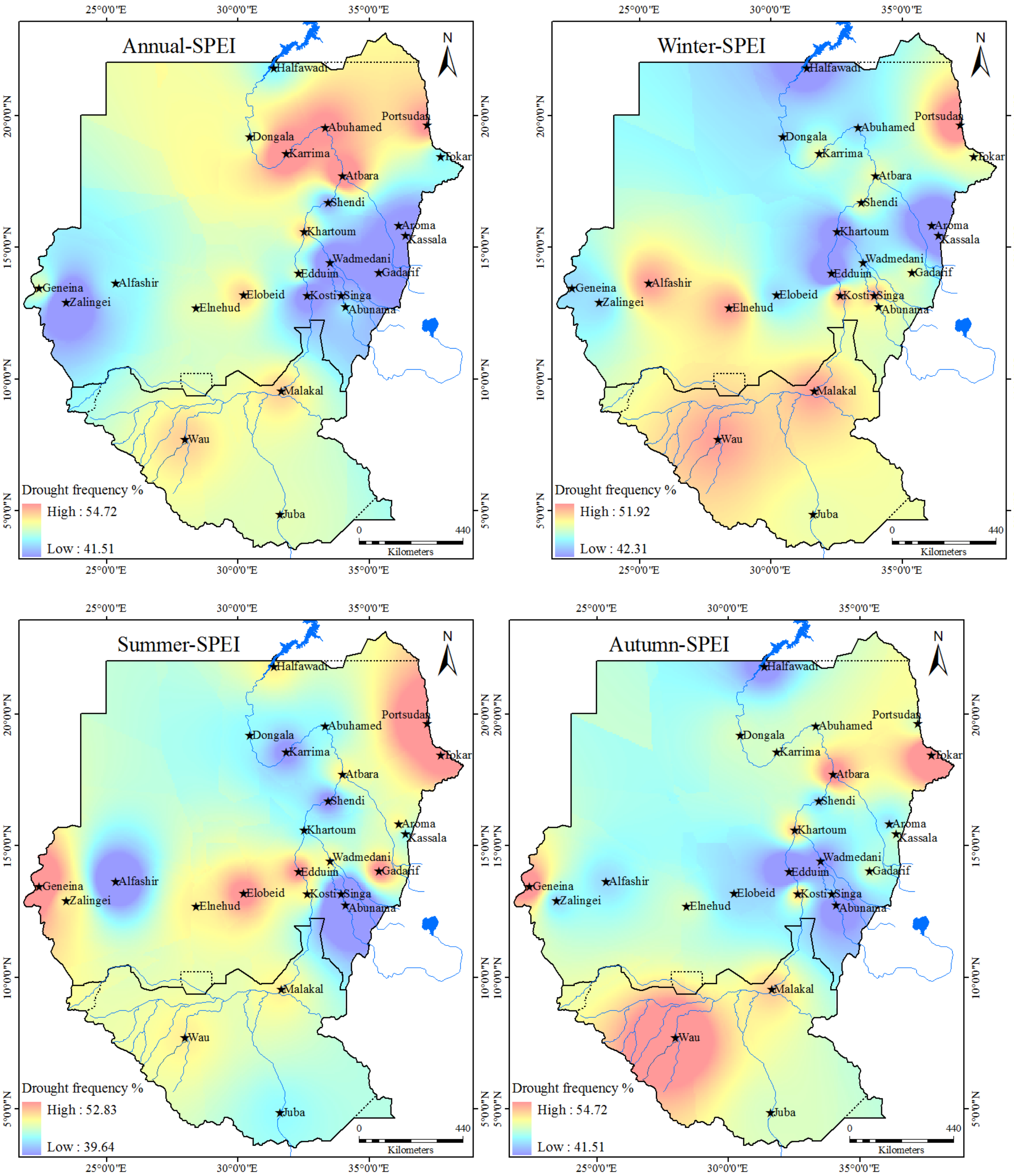


Fig. 8-4 The distribution of an annual and seasonal SPEI drought index of total drought intensity in Sudan and South Sudan during 1961- 2013

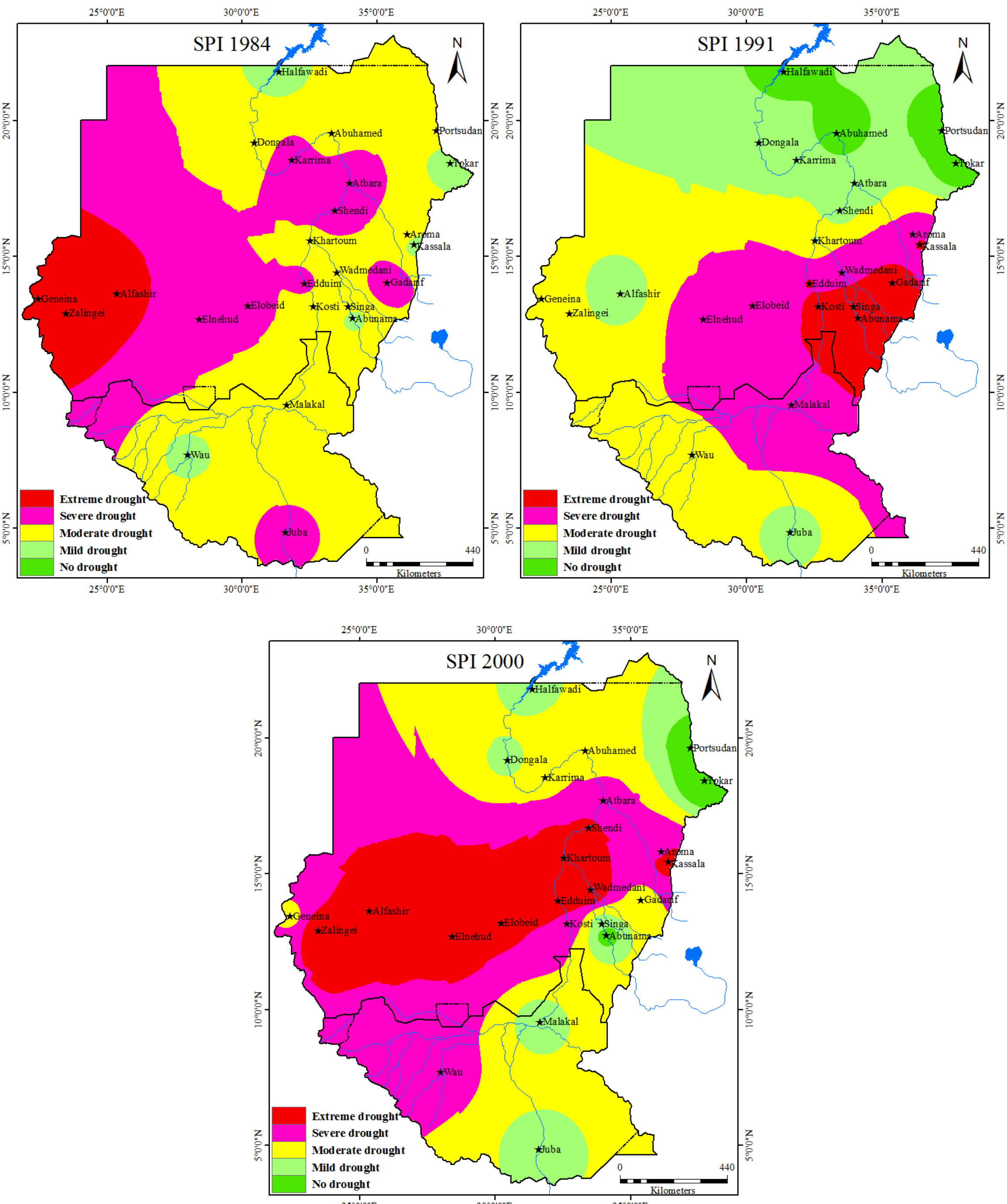


Fig. 8-5 changes in drought intensity in Sudan in the top-three highest drought periods (1984, 1991 and 2000)

Table 8-5 Correlation between SPEI drought index and precipitation five weather stations in Sudan and South Sudan

	SPEI with Precipitation		SPEI with Temperature	
	Pearson correlation	P value, Sig.	Pearson correlation	P value, Sig.
Elobeid	0.265	0.055	-.646**	0.000
Geneina	0.077	0.583	-0.580**	0.000
Juba	-0.191	0.170	-.638**	0.000
Kassala	.529**	0.000	-.856**	0.000
Halfawadi	.343*	0.012	-.925**	0.000

**Correlation is significant at the 0.01 level (2-tailed)

*Correlation is significant at the 0.05 level (2-tailed)

8.3.5 A comparison of intensity in the top-three driest periods

Finally, according to SPEI drought index, we presented a comparison of the intensity and distribution of drought in Sudan for the top three drought periods observed during the study window in Sudan and South Sudan (Fig. 8-5). These noticeable years with highest drought intensity were 1984, 1991 and 2000. For the year 1984, SPEI indicated that the majority of Sudan witnessed a mild to moderate drought except Geneina and Zalingei have an extreme drought. For the same year, South Sudan was dominated by severe drought in Juba and Malakal, but Wau with mild drought (Fig. 8-5).

The year 1991 marked the harshest drought as much of Sudan has witnessed severe drought except western Darfur and red sea coast regions where conditions were moderate (Fig. 8-5). In 1991, South Sudan, in general, was wet except Malakal, which was characterized by extreme drought conditions (Fig. 8-5). Finally, the year 2000 indicated that there were extreme drought events in the western region of Sudan and most parts of South Sudan except Malakal. All other parts of the country showed mild to moderate effects of drought at that year (Fig. 8-5).

8.4 Conclusion

The increasingly-intensified desertification and recent climatic change have stimulated detailed studies of precipitation and temperature records in many areas of the world including Sudan and South Sudan. In this study, we showed that temperature is increasing and precipitation is substantially decreasing in Sudan, though South Sudan is getting cooler and wetter.

Moreover, drought has increased dramatically in the last two decades consistent with the increased temperature and reduced precipitation that we just observed. Not only these conclusions, but also we argue that these conditions may dramaticcally degrade natural vegetation cover, crops production, and livestock production consistent with the currently observed losses in many areas of Sudan.

Most drought studies focus on quantifying drought and its impacts at the regional or global scale, but this generalization can obscure localized effects. Therefore, this study has focused on the country scale to characterize drought occurrence, severity, and duration in a relatively small scale. Indeed these findings can inform policy making and adaptation strategies. We believe that our findings may be of great value to sectors such as agriculture, forestry, animal and livestock, and water resources in their efforts to minimize the impacts of drought.

For example, our study confirmed that losses in agricultural production occurred in Sudan in 1984, 1991 and 2000 those were the years of heist drought intensity. Based on our analysis and increased frequency of drought, we also suggest that livelihood sector should adopt drought-adaptation options in grazing and animal movement and seasonality in order to mitigate any losses due to anticipated drought years. This particularly will be helpful if it happens in concert with local nomadic communities' involvement in designing policies and projects for effective adaptation strategies.

SPEI drought index has proven to be an excellent tool to get information about the history of drought spread and intensity in a cost-effective way. With reliance only on temperature and precipitation data that readily available nowadays, we suggest that all natural resources sectors (e.g. grassland, wildlife, and forestry) must develop this index for monitoring the drought patterns and its potential impacts on arid-land ecosystems and habitats in regular and long-term periods.

CHAPTER NINE

Assessing the Impacts of Land Use Changes on Vegetation Cover in Eastern Sudan

9.1 Introduction

Climate Change is a global threat to natural resources and livelihoods of human societies, compounded by the increase in anthropogenic activities. It was calculated that the increase of fossil fuel use will increase global warming and lead to the extinction of civilizations over the coming centuries (Lonngren and Bai 2008). The findings of the Intergovernmental Panel on Climate Change (IPCC). IPCC (2007) reported that climate change is already having strong impacts on human societies and the natural world, and is expected to do so for decades to come.

More severe and longer droughts have been observed since the 1970s over tropical and subtropical areas, as such, drying trend has been linked to higher temperatures and increased evaporation. A plausible warmer world with longer and more severe droughts could lead to rapid collapse of tropical forest communities converting them from a net carbon sink into a large carbon source with cascading ecosystem effects affecting global climate-vegetation feedbacks (Lewis 2006).

Sudan is one of the driest but also the most variable countries in Africa in terms of rainfall. Extreme years (either good or bad) are more common than average years (Zakieldeen 2007). Recently, UNFCCC (1992) defined that the climate changes as a change of climate elements that is attributed directly or indirectly to human activities (e.g. industrialization) which consequently alter the composition of the global atmosphere. Also, natural climate variability has been observed over a comparable time period. Noticeably, these changes in the climate have already caused many crises in natural ecosystems including Savanna arid lands of Sub-Saharan Africa.

In Gadarif State, Sudan, the Ministry of Agriculture documented that the cultivated areas were substantially increased and the productivity was dramatically decreased over the last few decades due to the effect of elevated temperature and variability and shortages in rainfall. The vegetation cover in these areas has also been affected by such harsh conditions and change in the climate. These effects included certain areas and species vulnerable to these changes, which has led to a decline in their abundance and diversity. Given these agricultural expansions in forest areas and drought occurrences, it became of high priority to assess the rate of changes in vegetation cover over time in these drylands. The findings of these assessments are very essential and useful in planning for conservation and rehabilitation efforts.

Therefore, the main objective of the present study is to evaluate the changes in LULC in Gadarif state during the last three decades using remote sensing techniques. Specific period covered and satellite images used in this study were for the years 1986, 1994 and 2013.

9.2 Data and methods

9.2.1 Study area

Gadarif state, located in eastern Sudan between latitudes 12°48' and 15°50' N and longitudes 33°40' and 36°47' E, covers an area of about 6225794.91 ha, as shown in Fig. 9-1. The state is characterized by semi-arid climatic conditions with an aridity index ranging from 0.2 to 0.4, as reported by Elhag (2006). The vegetation of the study area largely depends on rainfall. According to Harrison and Jackson (1958), Gadarif area lies in the low rainfall woodland savannah belt on clay soil and the vegetation composed of a great diversity of trees, shrubs and grasses. The average temperature of this region varies between a mean minimum of 22 ℃ in winter and a mean maximum of 37 ℃ in summer. The highest temperature in the study area is reported between April and May. Given the availability of temperature and rainfall measurements both temporally and spatially, these data are commonly used to characterize the climatic state of the territory (Conway et al. 2004; Aguilar et al. 2009; Choi et al. 2009; Rehman 2010).

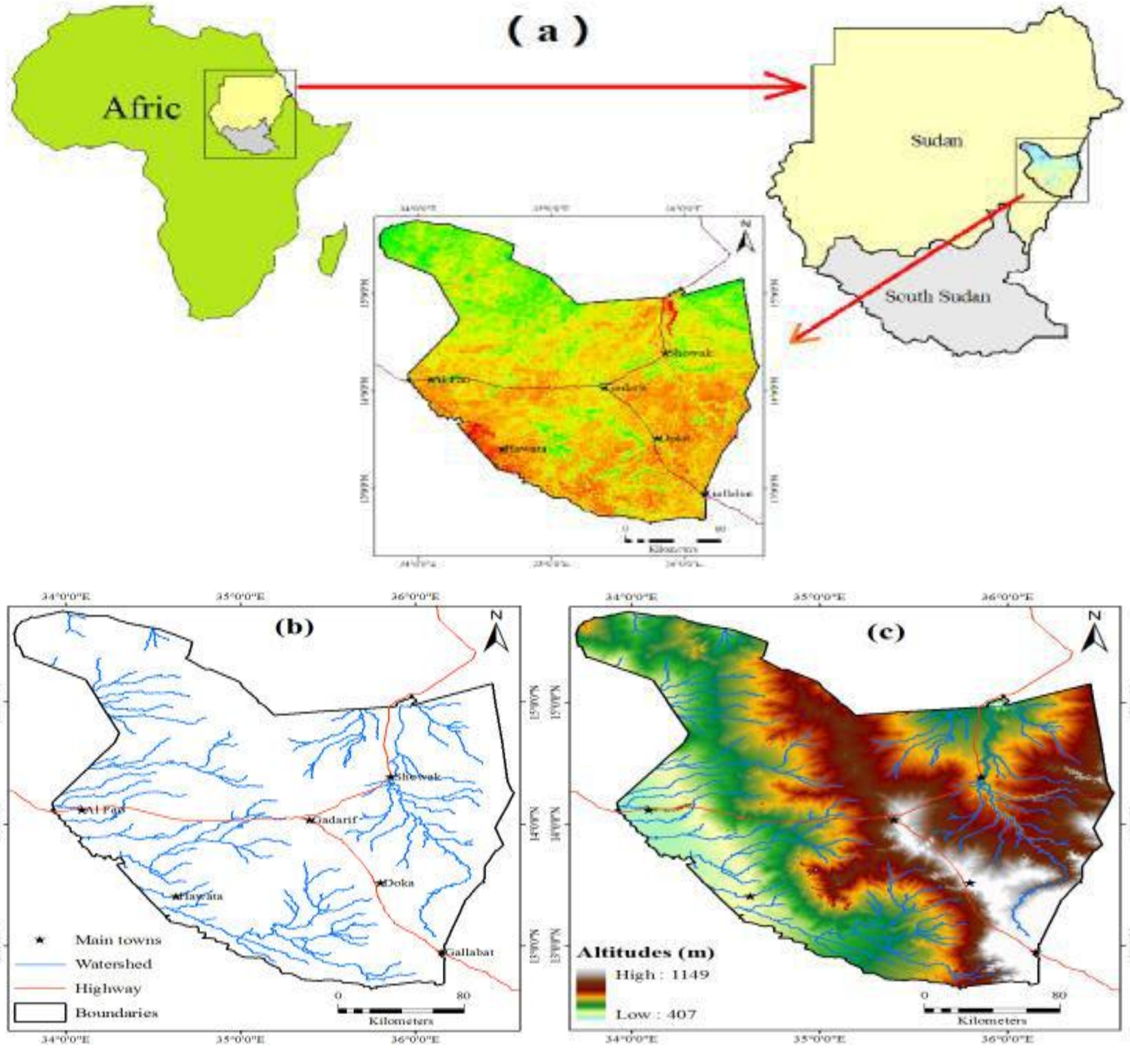


Fig. 9-1 location of the Study area - Gadarif state, Sudan Source of DEM data: http://srtm.csi.cgiar.org resolution of 90 m * 90 m

9.2.2 Satellite images

Thematic Mapper (TM) and Operational Land Imager and Thermal Infrared Sensor (OLI/TIRS) multi-spectral images are the main remote sensing data used in current study. Multi-temporal Landsat imagery for Gadarif state for the years 1986, 1994 and 2013 was used in this study. The technical details of Landsat 4-5 TM and Landsat 8 OLI/TIRS bands have been provided in Table 9-1. For other specification of Landsat satellite; refer to the official portal of Landsat (Landsat Program, NASA web).

The Landsat TM and OLI/TIRS scenes of path and row of Gadarif state were downloaded from USGS web http://earthexplorer.usgs.gov then analyzed including classification to different land use categories. Post classification is a term describing the comparative analysis of spectral classifications for different dates produced independently (Peterson 2004). Despite criticisms focusing on an accumulation of the inherent errors of each individual classification, this is the most appropriate method for comparing multi-source data, as each data layer can be generalized to a common LULC scheme before being compared (Petit 2001). In order to quantify changes of certain LULC type during certain period, we used the following formula:

$$LULCC = \frac{LULC_b - LULC_a}{LULC_a} \times \frac{1}{T} \times 100\% \tag{1}$$

Where LULCC is the rate of change of certain land use and land cover (LULC) type for a certain time period; the subscripts a and b denote the beginning and the end of a time period for LULC change investigation, respectively; and T is the time period. A positive value means that there is an increasing trend for a specific time period for an area of a certain LULC type; otherwise, negative values implies decreasing trend for the area assessed.

Table 9-1 Properties of the data used in the study

Acquisition Date	(Satellite) Sensor	Spectral bands	Ground resolution (m)
1986	Landsat 4-5 TM	3-5	30
1994	Landsat 4-5 TM	3-5	30
2013	Landsat 8 OLI/TIRS	4-6	30

TM= thematic mapper; OLI= Operational Land Imager and TIRS and Thermal Infrared Sensor

In this study the ERDAS IMAGINE 9.2 image and Arcgis 9.3 software's were used for overall image processing. Using the nearest neighbour method, images were resampled into a pixel size of 30 * 30 m. Amulti-date PCC based change detection algorithm is used to determine the LULC changes in four periodic intervals: 1986 to 1994, 1994 to 2013 and 1986 to 2013.

Post-classification comparison (PCC) is a quantitative method that used for independent classification of individual images for these three years for the same geographic location. It is the most commonly used method for LULC change detection mapping (Petit and Lambin 2002; Kamusoko and Aniya 2009). For LULC classification scheme, six-level classes were adopted in Table 9-2. In order to identify and quantify areas of changes, PCC procedure compares corresponding pixels (thematic labels) for each of the two times under consideration (Rutchey and Velcheck 1994; Xiuwan 2002; Jensen 2005; AlFugara et al. 2009).

Table 9-2 Description of LULC classes identified in the study area

LULC classes	Descriptions
Forest	All wooded areas with (75-300 trees/ha). This class includes trees and shrubs.
MRA	Areas currently under crop or land being prepared for raising crops. Agriculture field with no such regular pattern like irrigated land.
Irrigated land	A regular pattern of land, and can be seen very clearly in the image.
Rangeland	This class includes grazing land, area with no vegetation such as bare soil, sand (excluding MRA and Irrigated land), where soil is clearly apparent.
Settlement	Area with man-made structures and activities.
Water	Reservoirs and Rivers.

9.3 Result and discussions

9.3.1 Classification Accuracy Assessment and LULC

Mapping In this study, the image-processing approach is found to be effective in producing compatible LULC data over time, irrespective of the differences in spatial, spectral and radiometric resolution of the satellite data. According to the produced LULC map, Fig. 9-2 shows that the Forest, MRA, Irrigated land, Rangeland, Settlement and water the dominate types of LULC classes for the years 1986, 1994 and 2013. Table 9-3 shows the percentages of LULC classes in the year 1986. Forest, MRA, Irrigated land, Rangeland, Settlement and water have occupied 4, 24.7, 1.2, 69.7, 0.1 and 0.2 per cent of the study area, respectively. In 1994, same types occupied 3.5, 30.4, 1.2, 64.5, 0.2 and 0.3 per cent of the study area, respectively. In 2013 occupied 2.5, 39.5, 1.4, 55.8, 0.6 and 0.3 per cent of the study area, respectively. Noticeably, there is a significant increase in the area of MRA from 24.7 per cent in 1986, to 30.4 in 1994, to 39.5 in 2013. Oppositely, forest area has witnessed a dramatic decline as its area reduced from 4 per cent to 3.5 per cent to 2.5 per cent in the years 1986, 1994 and 2013, respectively. This significant increase in the area of MRA coincidently with shrinking in forest area indicates deforestation and clear-cutting for trees for agricultural expansion, which has been a continuing trend in the study area. In addition to MRA expansions, in fact, many people in Sudan including Gadarif state remove a considerable number of trees for firewood and building materials. Sulieman (2008) reported that agriculture is the main economic activity, followed by livestock raising in the traditional seasonal pattern. Also, as shown in table 9-3, a large decrease in Rangeland 69.7, 64.5 and 55.8 per cent is observed, respectively in 1986, 1994 and 2013 of the study area which it may risks livestock raising in the area. On the other hand, human Settlements are observed in the study area from 0.2, 0.3 and 0.6 per cent during these three periods. Overall, during the period of the study, natural vegetation (i.e.

forests and rangelands) have been significantly cleared and disadvantaged for the MRA and crop supply.

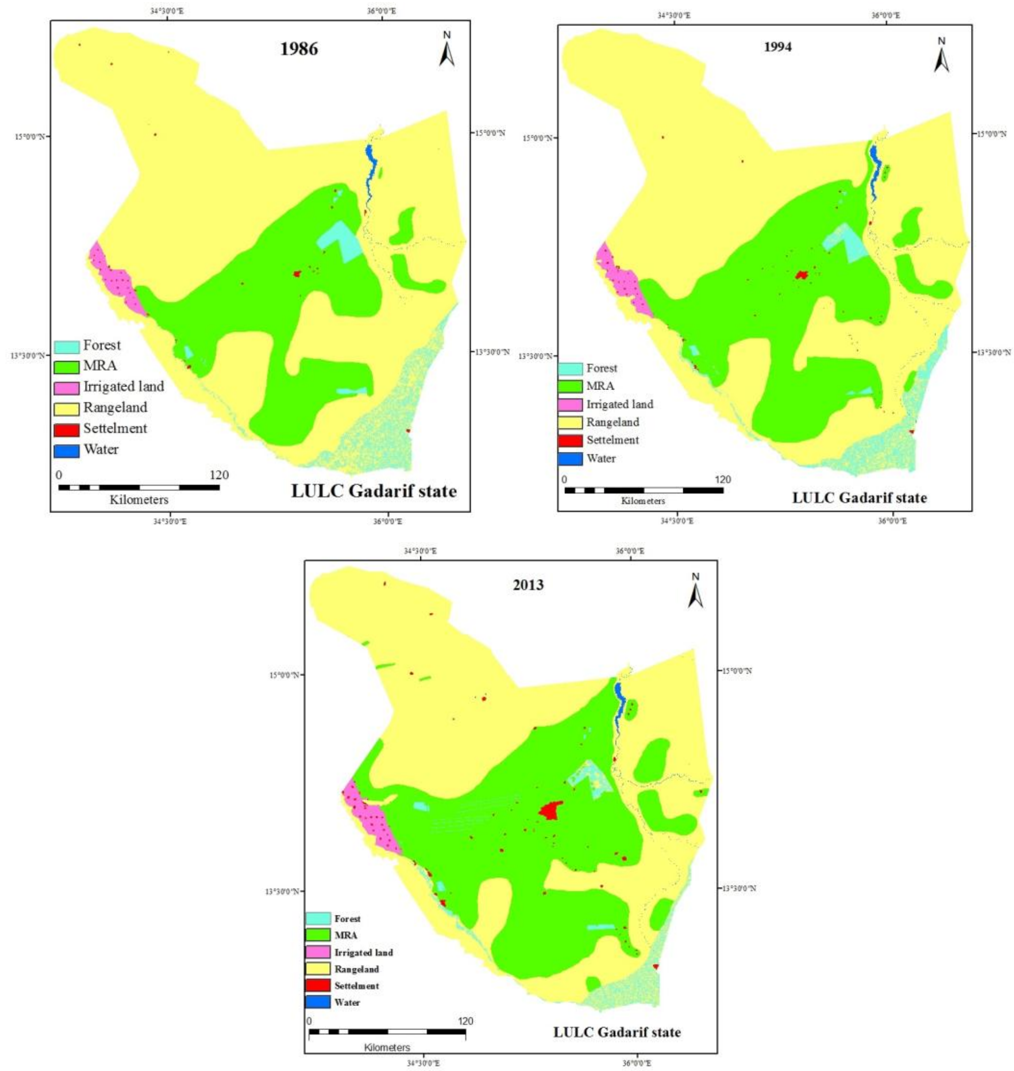


Fig. 9-2 LULC map in 1986, 1994 and 2013

Table 9-3 Areas and percentages of LULC classes for the period 1986 - 2013

	1986		1994		2013	
	Area (hectare)	Area (%)	Area (hectare)	Area (%)	Area (hectare)	Area (%)
Forest	249245	4	215689.2	3.5	154791	2.5
MRA	1538596.6	24.7	1890756.3	30.4	2459264.1	39.5
Irrigated land	72742.4	1.2	74034.7	1.2	84958.4	1.4
Rangeland	4342154.2	69.7	4014748.1	64.5	3473940.0	55.8
Settlement	8657.8	0.1	13317.5	0.2	35518.8	0.6
Water	14398.8	0.2	17249.1	0.3	17322.7	0.3
Total	6225794.91	100	6225794.91	100	6225794.91	100

Table 9-4 Change detection (per cent) of LULC for the period 1984 - 1994

LULC classes	Forest	MRA	Irrigated land	Rangeland	Settlement	Water
Forest	50	6	0	44	0	0
MRA	0	99	0	1	0	0
Irrigated land	0	1	95	3	1	0
Rangeland	2	8	0	90	0	0
Settlement	1	19	11	16	53	0
Water	0	0	0	5	0	95

Data in bold represent unchanged fractions of each class

Table 9-5 Change detection (per cent) of LULC for the period 1994 - 2013

LULC classes	Forest	MRA	Irrigated land	Rangeland	Settlement	Water
Forest	39	10	0	50	0	0
MRA	1	98	0	0	1	0
Irrigated land	0	0	96	1	2	0
Rangeland	1	15	0	84	0	0
Settlement	0	12	3	7	78	0
Water	0	0	8	0	0	91

Data in bold represent unchanged fractions of each class

Table 9-6 Change detection (per cent) of LULC for the period 1986 - 2013

LULC classes	Forest	MRA	Irrigated land	Rangeland	Settlement	Water
Forest	33	13	0	54	0	0
MRA	1	97	0	1	1	0
Irrigated land	0	0	96	1	3	0
Rangeland	1	21	0	77	0	0
Settlement	1	16	8	14	61	0
Water	0	0	0	8	0	92

Data in bold represent unchanged fractions of each class

9.3.2 LULC change analysis

There are several methods exist to study LULC change (Singh 1989; Muchoney and Haack 1994). Using PCC method of Foody (2003), images for the three years were classified separately for change detection in the study area based only on the information contained in each image. With the help of this method, thematic maps of two dates are compared on a pixel-by-pixel basis to extract the change that may have occurred between certain time periods.

There exist four LULC classes in classified maps and every class is represented by one unique code (i.e. pixel value) range from 1 to 4. To detect the change from 1986 to 1994, the LULC 1986 map is multiplied with 10. Then both images for 1986 and 1994 added together. All other pixel values show the change that occurred in the image. The same procedure was adopted to detect the change from 1986 to 1994, 1994 to 2013 and 1986 to 2013. In the study area, LULC classes have changed significantly. Changes are normally quantified per pixel counts, areas or percentages. Different classes are represented as different colures in each image, making it easy to identify not only where changes have taken place but also the class into which the pixels have changed. The change detection statistics for three decades of the study area are presented in Tables 9-(4, 5 and 6). Fig. 9-3 captured the post-classification change analysis for 1986 to 1994, 1994 to 2013 and 1986 to 2013 image classification.

The statistics in Tables 9-(4, 5 and 6) show that the MRA areas have increased significantly, covering approximately 6, 10 and 13 per cent of the Forest for the year 1986 to 1994, 1994 to 2013 and 1986 to 2013, respectively, Yagoub et al. (2015) reported that Trees class in El Rawashda forest, that is that the largest forest in Gadarif state is decreased, while MRA category is increased. Also, MRA areas have increased significantly, covering approximately 8, 15 and 21 of the Rangeland for the year 1986 to 1994, 1994 to 2013 and 1986 to 2013, respectively.

Mohamed (2008) reported that the present natural forest in Sudan is estimated to have declined to approximately 0.8 billion m^2 standing crop, while it was 2.4 billion m^2 in mid-seventies. Since the time when the reservation of natural forests started in 1932, the policy was to concentrate on the management of forests reserves under government control, to organize felling program, protection, conservation, development and management. HCENR (2009) mentioned over-grazing is among the causes of desertification in Sudan. Land degradation is a global problem associated with desertification, loss of biological diversity and deforestation in dry lands, which covers some 47 per cent of the Earth’s surface.

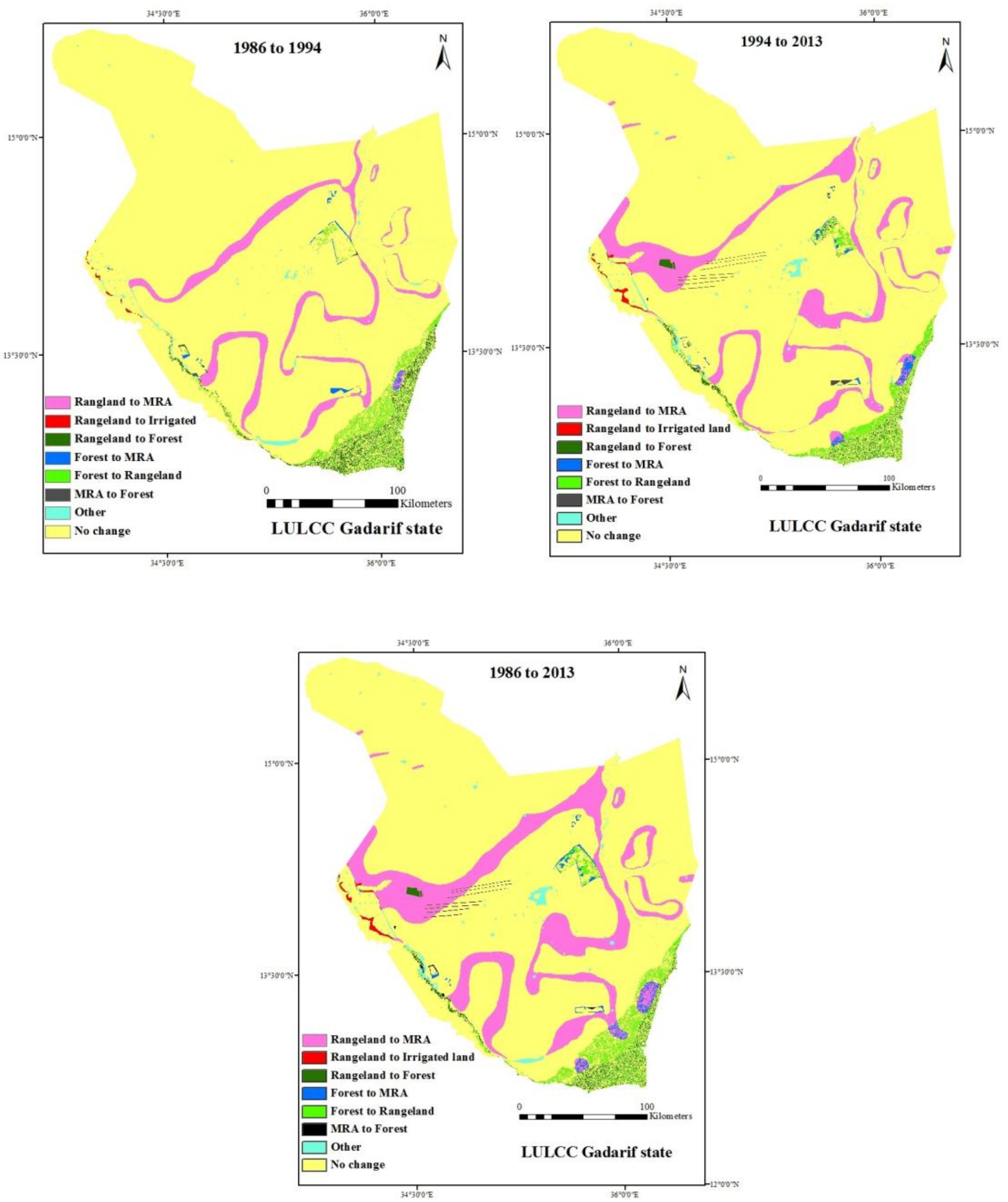


Fig. 9-3 Post classification change analysis for 1984 to 1994, 1994 to 2013 and 1984 to 2013 image classification.

The statistics in Table 9-7 and Fig. 9-3 shows that the percentage of Forest decreased -1.7, -1.5 and -1.4 during the 1986 to 1994, 1994 to 2013 and1986 to 2013, respectively. On the other hand, the MRA has increased 2.9, 1.6 and 2.2 during the 1986 to 1994, 1994 to 2013 and1986 to 2013, respectively. According to Table 9-8 shows the conversion of classes of Forest to MRA is 14172, 22354 and 32393 hectare from 1986 to 1994, 1994 to 2013 and1986 to 2013, respectively. In addition, there is a large conversion from Rangeland to MRA as 358077, 584233 and 928991 ha in a period of 1986 to 1994, 1994 to 2013 and1986 to 2013, respectively.

Table 9-7 LULC change rates (%) for the three study sites

LULC classes	1986 to 1994	1994 to 2013	1986 to 2013
Forest	-1.7	-1.5	-1.4
MRA	2.9	1.6	2.2
Irrigated land	0.2	0.8	0.6
Rangeland	-0.9	-0.7	-0.7
Settlement	6.7	8.8	11.5
Water	2.5	0.0	0.8

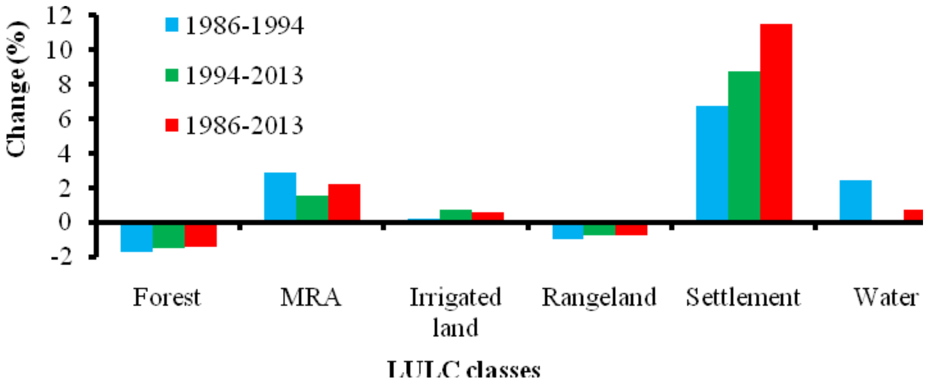


Fig. 9-7 Annual LULC change rates (%) for the three study sites

Table 9-8 Conversion of classes from one class to other one

LULC classes	1986-1994 (hectare)	1994-2013 (hectare)	1986-2013 (hectare)
Forest to Rangeland	110965	108154	135179
Rangeland to Forest	88059	55890	63816
Rangeland to MRA	358077	584233	928991
Forest to MRA	14172	22354	32393
MRA to Settlement	5145	17108	19459
Rangeland to Settlement	2460	5902	8340
Rangeland to Irrigated land	3882	10657	12776
MRA to forest	3877	13940	9817

9.4 Conclusion

Deterioration and decline rate of vegetation cover is terribly occurring throughout the last thirty years. Specifically in Gadarif state, large tracts of the forests and rangeland were converted to cultivation. The overall forest area and Rangeland have reduced because of expansion in modern mechanized farming because of increasing human population to meet the increasing demand for food. In addition, trees feeling by local communities for woods and other livelihoods have contributed to this decline in forest cover.

The nomads usually have no alternatives for animal fodders except lopping trees during the dry season and feeding on young regeneration throughout the rainy season. Apparently, this may have contributed to this forest cover decline as well. Current information on the status of vegetation cover and changes in its area, composition and structure is limited as well as the synergistic impacts from the observed climatic variations in the study area.

During the last four decades, progressive changes within the environment occurred because of forest and grassland conversion into agricultural lands. This study recommends detailed investigations on the most affected trees species and their distribution by such rapid land use changes and clearance. The interactive effects of the anticipated climatic changes in the study area should be an area of priority research. Also, further studies on drought prediction using future climate scenarios in Gadarif state will be useful conservation and rehabilitation plans.

Finally, despite there are legislations requires farmers to cultivate 10% of the agricultural schemes with forest trees, unfortunately, these laws are not effective and majority of the farmers don’t obey it. Therefore, on the light of our findings, we strongly urge governmental agencies to enforce this law and closely monitor its implementation.

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Dedication

Time flies, two years of my life seem merely a blink of eye during my current Postdoctoral study period, but I have learned a lot in different fields. The completion of this fabulous journey would not be possible without the assistance of my family. I dedicate this humble work to my parents, my beloved wife and children.

On the same note, I would like to pay my gratitude to my respected supervisor: "Professor Li Zhong Qin" for his persistent cooperation and guidelines. This would not be possible without his continuous efforts and motivation to improve my work. I am deeply grateful for his valuable suggestions.

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Dr. Yousif Elnour Yagoub Babiker

Curriculum Vitae

PERSONAL DATA

- Name: Yousif Elnour Yagoub Babiker
- Date of Birth: 15/01/1980
- Place of birth: El Kimair Adam, Wadmadani, Sudan
- Gender: Male
- Nationality: Sudanese
- Marital Status: Marriage
- Number of children: Three
- Languages: Arabic, English and Chinese.

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OCCUPATION

- Postdoctoral Fellowship: State Key Laboratory of Cryospheric Sciences/Tian Shan Glaciological Station, Northwest Institute of Eco-Environment and Resources, CAS, 320 Donggang West Road, Lanzhou, 730000. (2017-2018). China.
- Assistant Professor: University of Khartoum, Faculty of Forestry, Department of Conservation and Protection of forest from July 2016 to present. Sudan.
- Lecturer: University of Khartoum, Faculty of Forestry, Department of Conservation and Protection of forest from July 2010 to July 2016. Sudan.
- Teaching Assistant: University of Khartoum, Faculty of Forestry, Department of Conservation and Protection of forest from January 2008 to July 2010. Sudan.
- Extinction Officer: FNC-COR-UNHCR from 20 July 2004 to 15 January 2008. Sudan.

EDUCATIONS

- Postdoctoral Fellowship: State Key Laboratory of Cryospheric Sciences/Tian Shan Glaciological Station, Northwest Institute of Eco-Environment and Resources, CAS, 320 Donggang West Road, Lanzhou, 730000. China. (2017-2018).
- Ph.D: Northwest Normal University, College of Geography and Environmental Science, Lanzhou, China (09/2013-06/2016).
- M.Sc: University of Khartoum - Faculty of Forestry, Khartoum, Sudan (2008-2010).
- B.Sc: University of Khartoum - Faculty of Forestry, Khartoum, Sudan (1999-2003).
- Secondary school: El-Shaheed Mustafa El-Tayeb, Wadmedani, Sudan (1996-1998).
- Intermediate school: El Souriba for boys, Wadmedani, Sudan (1993-1995).
- Primary school: El-Kumair Adam, Wadmedani, Sudan (987-1992).

AWARDS

- University of Khartoum prize for the best academic performance Department of forest management in (2003)
- Faculty of Forestry prize for the second best academic performance in the fifth year (2003)
- University of Khartoum prize for the best academic performance in the third year (2001)
- University of Khartoum prize for the best Publications (400 $ 2018)

SCEITIFIC TRIPS

- Postdoctoral Fellowship: State Key Laboratory of Cryospheric Sciences/Tian Shan Glaciological Station, Northwest Institute of Eco-Environment and Resources, CAS, 320 Donggang West Road, Lanzhou, 730000 (2017-2018), China.
- International Training Workshop on Application of Methane Production Using Common Agricultural waste from July 21, 2014, to August 9, 2014, at School of Life Sciences, Lanzhou University, P.R. China
- Tree Eco-physiology and Carbon Sequestration organized by the Faculty of Forestry, University of Khartoum and Viikki Tropical Recourse Institute (VIITRI) University of Helsinki, under the Finish CIMO North-South-South project during the period 10 - 21 of May 2009. Sudan.
- Scientific visit in 2008 to Hawassa University, Wondo Gent College of Forestry and Natural Rescues, Ethiopia, the aim was to Intensive course on Forest Landscape Restoration in North East Africa organized by the and Viikki Tropical Recourse Institute (VIITRI) University of Helsinki, under the Finish CIMO North-South-South project during the period 16-26 of July 2008. Ethiopia.
- Scientific tours after employment in University of Khartoum with undergraduate students to different forest areas. Sudan

- ➢ Scientific tours through all the University academic years of my study to different forest areas in Sudan as part of the curriculum. Sudan.

EXPERIENCES

- ➢ Teaching and fieldwork assistance at the Faculty of Forestry, University of Khartoum (surveying, enumeration, and working Plans for students of the final year, data collection, data entry and analysis). Demonstration works, for both in laboratories and field for undergraduate students (2008 to present).
- ➢ Computer and internet skills.
- ➢ Drawing and Folkloric Skills.

ACADEMIC PUBLICATION

1. Muhammad Naveed Anjum, Yongjian Ding, Donghui Shangguan, Ijaz Ahmad, Muhammad Wajid Ijaz, Hafiz Umar Farid, Yousif Elnour Yagoub, Muhammad Zaman, Muhammad Adnan. Performance evaluation of latest integrated multi-satellite retrievals for Global Precipitation Measurement (IMERG) over the northern highlands of Pakistan. Atmospheric Research. 205, 134-146, June 2018.
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8. Yousif Elnour Yagoub, Zhongqin Li, Omer Said Musa, Feiteng Wang, Mohammad Naveed Anjum, Zhang Bo and Ji Ding-min. DETECTION OF DROUGHT PATTERN IN SUDAN USING STANDARDIZED PRECIPITATION-EVAPOTRANSPIRATION INDEX (SPEI). International Journal of Recent Advances in Multidisciplinary Research. 4(4): 2546-2554, April 2017.
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