Analysis of Vegetation Health Index (VHI) in drought prone areas of Pakistan and related food security issues

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FINAL APPROVAL

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DEDICATION

We have dedicated our project to my beloved parents and my project supervisor "Syeda Maria Ali" who were the symbol of guidance in our research project, who motivated me to accomplish this project and helped me at every step. Thank you for believing me and for giving me chance to prove and improve myself.

DECLARATION

I hereby declare that the work present in the following thesis is my own effort, except where otherwise acknowledged and that the thesis is my own composition. No part of the thesis has been previously presented for any other degree.

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In the name of Allah the most beneficent and the most merciful

I am grateful to Allah S.W.T our Lord and Cherisher, for guiding me to conceptualize, developed complete my work. Indeed, without His help and will nothing be accomplished. I express my deep gratitude to Prophet Muhammad (SAW), who is ultimate torch bearer and guidance for entire humanity.

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LIST OF ABBREVIATIONS

Acronym	Abbreviation
AZK	Azad Jammu Kashmir
BT	Brightness Temperature
DN	Digital number
EO	Earth Observation
ETM+	Enhanced Thematic Mapper Plus
FAO	Food and Agricultural Organization
GCRI	Global Climate Risk Index
GDP	Gross Domestic Product
GIS	Geographic Information System
GOB	Government of Balochistan
GOP	Government of Pakistan
IFAD	International Fund for Agricultural Development
LSE	Land surface emissivity
LST	Land Surface Temperature
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NIR	Near Infrared
OLI	Operational Land Imager

PV	Proportional Vegetation
SPEI	Standardized Precipitation-Evapotranspiration Index
SWIR	Short wave infrared
TIRS	Thermal Infrared Sensor
TM	Thematic Mapper
TCI	Temperature Condition Index
UNICEF	United Nations International Children's Emergency Fund
USGS	United states geological survey
VCI	Vegetation Condition Index
VIs	Vegetation Indices
VHI	Vegetation Health Index

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ABSTRACT

Drought is one of the most important reluctant temporal process related to climate change that can effect precipitation/rainfall during season or a year, relative humidity of an area and rise in air temperature. The present study was conducted to analyze Vegetation health index (VHI) in drought prone areas of Pakistan especially Sindh and Balochistan and the impact of droughts on food security. For this purpose remote sensing data (Landsat satellite imagery) from USGS is used as main source of data. We used different satellite images from each Landsat series of 5, 7, and 8 to calculate VHI for three different major drought periods in Sindh and Balochistan. The acquisition years of Landsat data range were from 1998-2002, 2004-2005 and 2018-2019 from April to June. In 1998, 1999 and 2004, the maximum NDVI values shows that majority of study areas were consist of rocks, sand, shrubs and grasslands An improvement in the values of NDVI for vegetation covers can be easily seen in 2000, 2001 and 2002 as compared to the NDVI of previous years. Minimum and maximum LST values during 1998-2001 remains same but in 2002 LST increases as compared to previous years which is not anticipated for vegetation health and this study clearly shows that the vegetation health of Sindh and Balochistan is affecting from environmental changes. In 2005 and 2018 majority of areas of Sindh and Balochistan shows lower values of LST that means temperature in 2005 has been increased in majority of areas of study area. From the analysis of VHI area and percentage change detection it is clear that in all types of vegetation covers are affected by the ongoing drought conditions. Years such as 2002, 2004 and 2019 were considered as the worst drought years in history of Sindh and Balochistan. In 2002, Sindh and Balochistan experienced severe to extreme drought conditions as compared to the previous four drought years. In 2002, whole Balochistan province experienced moderate to extreme droughts. This study clearly shows that from 1998 to 2002, the drought conditions in 2001 and 2002 were worse than previous drought years. 143 people and 2.5 million livestock heads perished as a result of the extreme drought in 1999-2000. More than one-and-a-half million people and two million animals were affected by the drought in Balochistan. In Sindh water scarcities and thirst killed at least 127 people across the country's Tharparkar region, which shares borders with India. Nearly 60% of Sindh's population fled to areas with better irrigation systems. While the lack of water during the 2004-2005 drought could have led to famine, no deaths were reported during that time period. Pakistan experienced 40 percent less winter rainfall than typical in 2005.

CHAPTER. 1

INTRODUCTION

1. Introduction

Drought is one of the most important reluctant temporal process related to climate change that can effect precipitation/rainfall during season or a year, relative humidity of an area and rise in air temperature. Natural ecosystems, habitats, agricultural systems, and water sources can all be negatively affected by droughts, making it one of the most costly disasters (Jiao et al., 2016). Droughts have affected more than half of the total world's countries (Masud et al., 2015). Droughts have gotten the world's attention in order to better comprehend the crisis and propose ways to lessen its effects (Ana et al., 2017). Water scarcity is worsened by population increase, urbanization, and energy and industry expansions that do not adhere to water management policies by national and international organizations. Drought-induced water scarcity has been common in many regions, and this is due in part to population growth and industrial development not aligned with water management regulations (Mishra *et al.*, 2010).

All around the world, major droughts have taken place recently. Such as the Chinese Millennium Drought (1994,1997,2002) and the droughts in Tibetan Plateau (1997–2000), the droughts in Indian Subcontinent (2002), the US Texas Drought (2012), the California Drought (2012–2015), the East African Drought (2010), the Balochistan Drought in Pakistan (1998–2002), the worst Papua Drought (1997–1998), and the Australian Millennium Drought (1997–2002) (Ahmed et al. 2016). The Central US, Russia and Central Australia regions were among the states that were exposed to most severe and prolonged droughts during 1951-1970 (Spinoni *et al.* 2014).

Economic, environmental, and human suffering caused by the drought in both develop and developing countries have shown how vulnerable everyone is to this catastrophe. Different factors (e.g., employees' access, money, and improved inclusion) are affected by drought. In a study from Ethiopia, rich families received three times more drought yields than poorer households. Wealthy families changed the way they ate, but under the poorer families they changed the way they ate (Eskinder *et al.*, 2018). Meteorological (less precipitation), agricultural (due to lower soil moisture), socio-economic droughts (water demand, supply) and hydrological droughts (less runoff, groundwater or total storage) are the four main categories into which droughts can be divided. There is a long-term lack of precipitation in all forms of droughts. Droughts affect different parts of the hydrologic cycle in different ways (Wilhite *et al.*, 1985).

1.1. Droughts in Pakistan:

As a result of climate change, Pakistan is considered as one of the most affected and vulnerable countries across the globe. Global Climate Risk Index (GCRI) make ranking of countries that are vulnerable to climate change, and Pakistan has been ranked in the top 10. The biggest dangers are rising temperatures, increasing rainfall variability, sea-level rise, and extreme events (floods, droughts, and heatwaves) (GCRI, 2019). Climate change in Pakistan is predicted to have a significant influence on Pakistan's water resources, which in turn will have an impact on food supply, health, and the sustainability of the environment. There is a greater likelihood of impact in the southern states, where water resources are already under strain, due to climate change-related shifts in water demand (Shakoor *et al.*, 2015; Eckstein *et al.*, 2020).

Balochistan and Sindh are more drought-prone than Punjab, Khyber Pakhtoonkhwah, and Gilgit Baltistan, which have only seen one or two major drought events every decade since the 19th century. This has led to food shortages, which are getting more common (GOP, 2007). Droughts are a severe hazard in Pakistan every four to five years, according to rainfall patterns. The 1998-2002 drought in Pakistan is one of the worst in the country's recent climatic history. Compared to prior years, there was a significant decrease in rainfall in Pakistan during this time period. Balochistan was the worst-hit province, with 88 percent of its land area being directly destroyed, compared to 18 percent in Sindh. However, there was a mild trend of drought in 2004-05. Pakistan's upper regions comprising Punjab, Khyber Pakhtunkhwa, Gilgit Baltistan, and AJK were affected by minor droughts in the mid-2009-10 period. (Sajjad *et al.*, 2007)

Pakistan's dry regions, such as Balochistan and Sindh Province, are particularly vulnerable to drought, which is one of nature's most serious threats. Pakistan's ability to adapt to climate change has left it more vulnerable. Pakistan's dry geography makes it vulnerable to the effects of climate change. A wide range of weather-related issues have plagued Pakistan, including floods, droughts, severe temperatures, and a water crisis. (Zahra *et al.*, 2018) Drought has far-reaching consequences, but floods and other natural disasters have a limited influence. Droughts affect everyone, but the poorest and most vulnerable in emerging agrarian economies, such as Pakistan, are particularly vulnerable because they rely heavily on rainfall for their survival.

Arid climate conditions in Pakistan's Balochistan and Sindh provinces make them more vulnerable to hydrological concerns. Due to the severe drought, about 3.49 x 10^5 Pakistanis are in need of immediate help, including immunizations and livestock fodder (Federal Bureau of Statistics, 1998). It has been determined that Balochistan is the poorest province in Pakistan, with 62 percent of the overall population suffering from extreme poverty. Balochistan's economy relies heavily on agriculture, with 85 percent of the population relying on it. Balochistan and Sindh have endured a number of severe droughts over the past half-century including 1967–1969, 1971–1973; 1973–1975; 1994; 1998; 2002; 2004; 2005; 2013; 2016; and 2018–2019. Most fruit orchards have been decimated by the protracted drought. Approximately two million animals were killed as a result of the drought (Ashraf *et al.,* 2015). Sindh and Balochistan have also seen worsening heatwaves, which has exacerbated the frequency and intensity of droughts. The hydrological cycle of Balochistan and Sindh may be significantly affected by changes in the climate. Balochistan and Sindh's seasonal circumstances are more likely to be disrupted, resulting in a hotter and longer summer and a shorter winter. (Zahid *et al,* 2012)

1.2. Satellite-based vegetation index:

In the last few decades, satellite-based remote sensing has delivered Earth observations with relatively high spatial resolution and high temporal resolution. It is possible to measure the atmospheric and land surface parameters over wide areas using remote-sensing photographs. The utilization of remote sensing data for large-scale drought monitoring has resulted. Satellite-based vegetation indices, for example, have been developed to monitor and identify drought on a local to global level. Drought-related vegetation stress is being assessed and evaluated with ground observations by researchers who are constantly attempting to improve drought monitoring technologies (Khan *et al*., 2018). In recent years, a variety of hybrid drought indexes have been established by combining climatic, satellite, and environmental data. Many satellite-based devices have also been utilized to acquire remote sensing data that can be used to analyze a variety of drought-related variables such as soil moisture and precipitation. Increasingly, satellite-based microwave and radar equipment are also being used to measure soil moisture and precipitation (Masitoh *et al.*, 2019).

Compared to other drought indices, satellite-based VHIs are frequently used to monitor droughts and to measure vegetation growth activities, particularly in large areas with limited water resources. Drought occurrence can be evaluated spatially using satellite data. Remotely sensed drought indices have been established and used for a wide range of purposes including the duration of the drought, the intensity, the severity, and the spatial extent. This study was carried out by Khan *et al.*, (2018). As land surface temperature (LST) conditions have changed over the past few decades, the NDVI has become one of the most often used and effective vegetation indexes to monitor the plant status and moisture condition of any area (Bajgain *et al.*, 2015). To better understand droughts and their effects on vegetation, indices such as NDVI and LST can be used (VHI). A negative relationship exists between the NDVI-LST slope and the time at which VHI reaches low levels in drought situations (Nemani *et al.*, 2015).

The Vegetation Health Index (VHI) has proven to be more capable and more suitable in identifying drought than other remote sensing-based vegetative drought indices. The trends of global and regional drought areas for various drought severity levels, based on satellite-based vegetation health indices (VHIs), were studied by Kogan *et al.*, 2013. This study specifically looked at the 2010 and 2011 Russian and American droughts, which were both extremely severe. Other studies have shown the changing characteristics of drought and have also detected the vegetation responses to weather-related variations using VHIs, which can be used to provide references for vegetation growth activity monitoring and water resources management in the study of Li *et al.*, 2013 and Pei *et al.*, 2018. The VHIs is one of the most important indices for detecting drought characteristics, quantifying the effects of drought, monitoring regional vegetation development, and assessing agricultural production. VHIs can also be used to predict wildfires, crop productivity, malaria cases, and develop insurance policies for drought-related losses.

Among other uses, Vegetation Indices (VIs) are simple and useful tools for measuring vegetation cover, vigor, and growth dynamics. To accurately measure the severity of droughts, these indicators have been widely utilized in remote sensing applications. Drought-related vegetation stress can be detected and monitored using satellite-based remote sensing indices like the vegetation condition index (VCI) and the temperature condition index (TCI). When droughts occur, the VCI measures water-related stress, while the TCI measures temperature-related stress (Masitoh *et al.*, 2019).

1.3. Vegetation Health Index (VHI):

Monitoring and detecting droughts using satellite-based data is common practice with the Vegetation Health Index (VHI). The vegetation health index (VHI) is based on the near-infrared and visible spectrum information (Normalized Difference Vegetation Index, NDVI); and the thermal condition index (TCI), which is based on the brightness temperature of the top of the atmosphere's thermal infrared (TIR) or on the LST derived from TIR (LST). The weighted average of VCI and TCI is then used to compute VHI. However, the optimum weights of the TCI and VCI are usually not known and VHI is usually estimated attributing a weight of 0.5 to both (Masitoh. F, *et al., 2019).*

1.4. Food security:

Food security is a complex concept and it can be attained at the individual, household, national, regional and global levels, when all people, at all times, have physical and economic access to proper, safe and nutritious food to fulfill their daily intake needs and food choices for an active and healthy life (FAO, 1996). Food insecurity, hunger and poverty has become the most important worldwide concerns and hazard of the 21st century. Approximately half of the world's population lives beneath the poverty line. Around 805 million people across the world are enduring extreme hunger, yet the world food supply has doubled during the past three decades (FAO, 2014). About 3 billion People in the globe earn less than 2.50$ a day. Around 1.3 billion people in whole world are impacted by poverty and survive on less than 1.25$ a day. One billion children are affected due of poverty worldwide. According to UNICEF, over 22,000 children die each day due to hunger. One of the key factors for undernourishment, malnutrition and hunger is drought, which influence mainly agricultural production. Long term droughts such as, Pakistan endures extreme droughts in 1998 to 2002 and is results in agricultural losses, hunger and poverty.

Drought coping options are limited for impoverished people especially those whose livelihoods are predominantly dependent on natural resources (Fleshman *et al.*, 2007). Coping techniques changes based on the prevailing ecological and socio-economic conditions including local agro-ecology, levels of education, gender, income, availability of support systems and services (Mfitumukiza *et al.*, 2017). These capabilities play a significant role to indicate how individuals and communities may cope with the impacts of drought and sustain the functioning of their socio-economic systems (Robeyns *et al.*, 2005)

1.5. Significance of study:

As a result of climate change, Pakistan is one of the most vulnerable countries to droughts. Having a desert climate, Pakistan is a vulnerable country when it comes to climate change. Floods, droughts, high temperatures, and a lack of water have all been common occurrences in Pakistan. This is based on the findings of Khan *et al.*, 2018, one of Pakistan's greatest natural threats is drought, particularly in the Balochistan and Sindh provinces. In 1967–1969, 1971, 1973–1975, 1994, 1998–2002, 2004–2005, 2013–2016, and 2018–2019, Balochistan and Sindh were subjected to a series of severe droughts that had a devastating effect on the region's economy and livelihoods. Using satellite-based data, the Vegetation Health Index (VHI) is frequently used to monitor and detect droughts. To better understand how droughts affect Pakistan's vegetation cover, as well as how droughts affect food and associated issues, it is important to assess the impact of droughts on Pakistan's vegetation cover and investigate the impact of droughts on food and related issues.

1.6. Problem statement:

Sindh and Balochistan are the most drought prone regions of Pakistan that experienced extreme drought conditions in the history of Pakistan. These droughts leaves its severe impact on livelihoods and economy especially it has great negative impact on vegetation cover of these areas. So there is a great need to analyse the impact of droughts on vegetation health in order to mitigate the worse impact of droughts.

1.7. Aims and objectives:

Aim: Analysis of Vegetation Health Index (VHI) in Sindh and Balochistan and related food security issues in Pakistan.

The objectives of following study are:

- ✓ Analysis of Vegetation Health Index (VHI) during 1998-2019.
- ✓ Estimating the Change detection of NDVI-VHI during drought periods.
- ✓ Investigating the Food security issues due to droughts.

CHAPTER. 2

LITERATURE REVIEW

2. Literature Review:

Various studies have been carried out to analyze Vegetation health index during droughts. According to Rizqi *et al.*, (2016), VHI collects overall vegetation health, which in turn suitable to indicate agricultural drought extent. Vegetation Health Index (VHI), a vegetative drought index based on satellite data, is studied using long term sequence of 2000, 2005, 2010, and 2015 dry season. The results show that VHI decreased more than 50 percent, from 30.86 in 2000 to 14.66 in 2015. This figure indicated drought extent intensified in research area, from mild drought to severe drought. The severity was mainly triggered by the rising LST from 27°C in 2000 to 40°C in 2015. In addition, there was a decreasing tendency of NDVI values in recent years, leading agricultural fields more susceptible to drought.

A study was carried out in Iasi, Romania, in which they Identify drought extent using NVSWI and VHI. In this study they used remote sensing images from the Landsat 8 OLI, taken in May and June 2017. VHI was developed through a combination of Vegetation Condition Index (VCI), one of the important vegetation indicators when monitoring weather-related variations, such as droughts, and Temperature Condition Index (TCI), which reflects the stress of temperature, that both indices can be successfully used to determine the spatiotemporal extent of agricultural drought. VHI indicate that in both months, May and June, is "no drought". It can be concluded that VHI is a very good indicator for studying extreme drought. (Macarof *et al.*, 2018)

According to (Shafiq *et al.*, 2007), in Balochistan province occurrence of droughts is the most common phenomenon; however, the multiyear recurrent drought during 1998–2002 was considered as the longest dry spells and is the most devastating in the history of the Pakistan. It damaged almost 80 percent fruit orchards and affected almost 22 districts out of 29 in the province (GoB, 2007). In addition, 1.91 million people had been affected by this drought and of 9.31 million livestock head were effected, 1.76 million had perished during 2001.

(Virgilio *et al.*, 2018) uses Vegetation Health Index (VHI) for monitoring and characterizing droughts. NDVI and LST from 1982 to 2009 were used to calculate VCI, TCI and VHI, which are then correlated with the multiscale drought indicator SPEI (Standardized Precipitation-Evapotranspiration Index) with the aim of assessing the effect of drought on each contribution.

Results of the correlations between VCI-SPEI and TCI-SPEI show that the relative contributions of VCI and TCI to vegetation health depend on vegetation cover: the effect of drought is more evident in the case of VCI in semiarid climate classes (regions where the limiting factor to vegetation growth is water); while the effect of drought is more obvious in TCI for moistier climate classes (regions where the limiting factor is solar radiation). This leads to the conclusion that by maximizing the correlations between VHI and SPEI, over a climatological period, it is possible to evaluate the relative roles of VCI and TCI to VHI for different climate regions.

Remote sensing and GIS-based agricultural drought can be better identified and monitored by VHI composed of LST, NDVI, VCI, and TCI drought indices. Agricultural drought occurs once in every 1.36–7.5 years during the main rainy season, but the frequency, duration and severity are higher (10–11 times) in the lowland area than the mid and highlands area (2–6 times) during the last 15 years. This study suggests that the effect of drought could be reduced through involving the smallholder farmers in a wide range of on and off-farm practices. This study may help to improve the existing agricultural drought monitoring systems carried out in Africa in general and Ethiopia in particular. It also supports the formulation and implementation of drought coping and mitigation measures in the study area. (Eskinder *et al.*, 2018)

A study was carried out in Brantas Watershed located in East Java by Rusydi *et al.*, (2019). This research aimed to determine the influence of LST and NDVI to VHI in dry season of 2008 - 2017. The data used were MODIS Vegetation Indices (MOD13A1) and MODIS Land Surface Temperature (MOD11B1). The influence of LST and NDVI to VHI in the Brantas Watershed was analysed using correlation and regression testing. The LST - NDVI correlation of Brantas Watershed was negative (-0.73). The high temperature distribution was dominant in the low-density vegetation areas. The LST - VHI correlation was 0.35, and NDVI - VHI correlation was 0.63. This shows that the impact of land surface temperature (LST) on vegetation was weak. Drought indicated by VHI was more likely to be influenced by internal conditions of vegetation and other environmental elements.

Correlation between the Normalized Difference of Vegetation Index (NDVI) and Land Surface Temperature for urban area of Mashhad was carried out by Gorgani *et al.*, 2013. They used satellite images from Landsat. The objectives of this study was to investigate the relationship between LST and NDVI. NDVI is used to examine the relation between thermal behavior and vegetation cover amount. Finally, regression technique is used to obtain the correlation between LST and NDVI. Study concluded that the correlation between NDVI and LST and regression coefficient from NDVI to LST is negative.

Stephen *et al.*, (2019) in his study introduces an analytical framework for understanding the impacts of droughts and floods on food security. He finds out that natural disaster triggers a sequence of "entitlement failures," which can result in a famine unless public action intervenes to mitigate these impacts.

According to estimates of IFAD (2012), there are approximately 925 million starving people across the world and hence there is need to double food production by 2050. Further, the report identifies that 40 percent of the world's cultivable land is degraded due to various reasons inclusive of climate change such as less rainfall, droughts. Due to the demand and supply gap of food products, the inflation rate is increasing and resultantly, poor people have to spend between 50 and 80 percent of their income on food (IFAD, 2012).

According to official figures (GOP 2001; Bhatti 2003) 1.3 million people and 2,664 villages in the arid zone of Tharparkar, Umerkot, and Dadu districts have been effected by the waves of droughts in 1998-2002. 5 million cattle heads and 1.3 million population have been effected by this drought. The drought of 2001 is considered as the worst drought in the history of Pakistan, which reduced the economic growth rate to 2.6 % as compared to an average growth rate of over 6%. This drought also reduces the country`s ability to produce hydroelectricity that caused an additional loss of nearly 1.2 billion US dollars.

CHAPTER. 3

Materials and Method

3. Materials and methods

3.1 Study Area (Sindh and Balochistan):

Pakistan's Sindh and Balochistan provinces have been designated as a research area. Sindh is a province in Pakistan's southeast. Sindh is Pakistan's third-largest province in terms of land area and second-largest in terms of population. Located at 25.8943° N, 68.5247° E, Sindh province is in western Pakistan. It has a north-south length of 579 kilometres. It has an area of approximately 1,40,915 square kilometres. Sindh boasts Pakistan's second-biggest economy, and Karachi, the province's capital and major city and financial centre, is the country's most populous city. A substantial chunk of Pakistan's industrial sector may be found in Sindh, which houses two of Pakistan's commercial seaports at Port Bin Qasim and Karachi. Sindh has a cold winter and a hot summer climate. May through August sees highs of around 46 degrees Celsius, while December and January are the coldest months with an average temperature of 2 degrees Celsius. Sindh's GDP per capita is three times that of the rest of the country, making it one of the richest provinces in Pakistan. Cotton, rice, wheat, sugar cane, bananas, and mangoes are the province of Sindh's most important crops. Rice, sugarcane, and wheat production in the region account for 41%, 31%, and 21% of national totals, respectively. 36.7–46.5 percent of the country's GDP is generated by the manufacturing sector. Sindh is also Pakistan's richest province in terms of natural resources, including gas, oil, and coal.

As Pakistan's hilly and dry region, Balochistan is located in the country's southwest. Its coordinates are 67 degrees east x 30 degrees north. Balochistan is located at 28.4907° N 65.0958° E on the globe. It covers around 347,190 square kilometers approximately (42.2% of Pakistan's total land area), makes it Pakistan's largest province. The terrain is rocky, with a number of plateaus varying in elevation. Plains, deserts, and the higher and lower highlands make up the province's geography. Temperatures in all three zones vary greatly: Plain zones have extremely hot and dry summers, while the higher and lower plateau regions have milder temperatures, but the lower plateau is severely chilly in the winter. There are few places in the world that are as hot and dry as a desert. Rainfall in Balochistan, Pakistan, occurs during both summer and winter due to the monsoon winds. Westerly disturbances tend to flow east of Balochistan at higher latitudes, hence the wettest places are found between 34 and 36 degrees North latitude. In lower regions, secondary precipitation is brought on by these westerly disturbances. The region of Balochistan receives between 200 and 350 millimeters of rain per year. Heavy rains in the summer and snow in the winter may contribute to this annual total. In the summer, the temperature can reach 50 °C in the more rural sections of this province. The Indus Basin runs through the province's northern region.

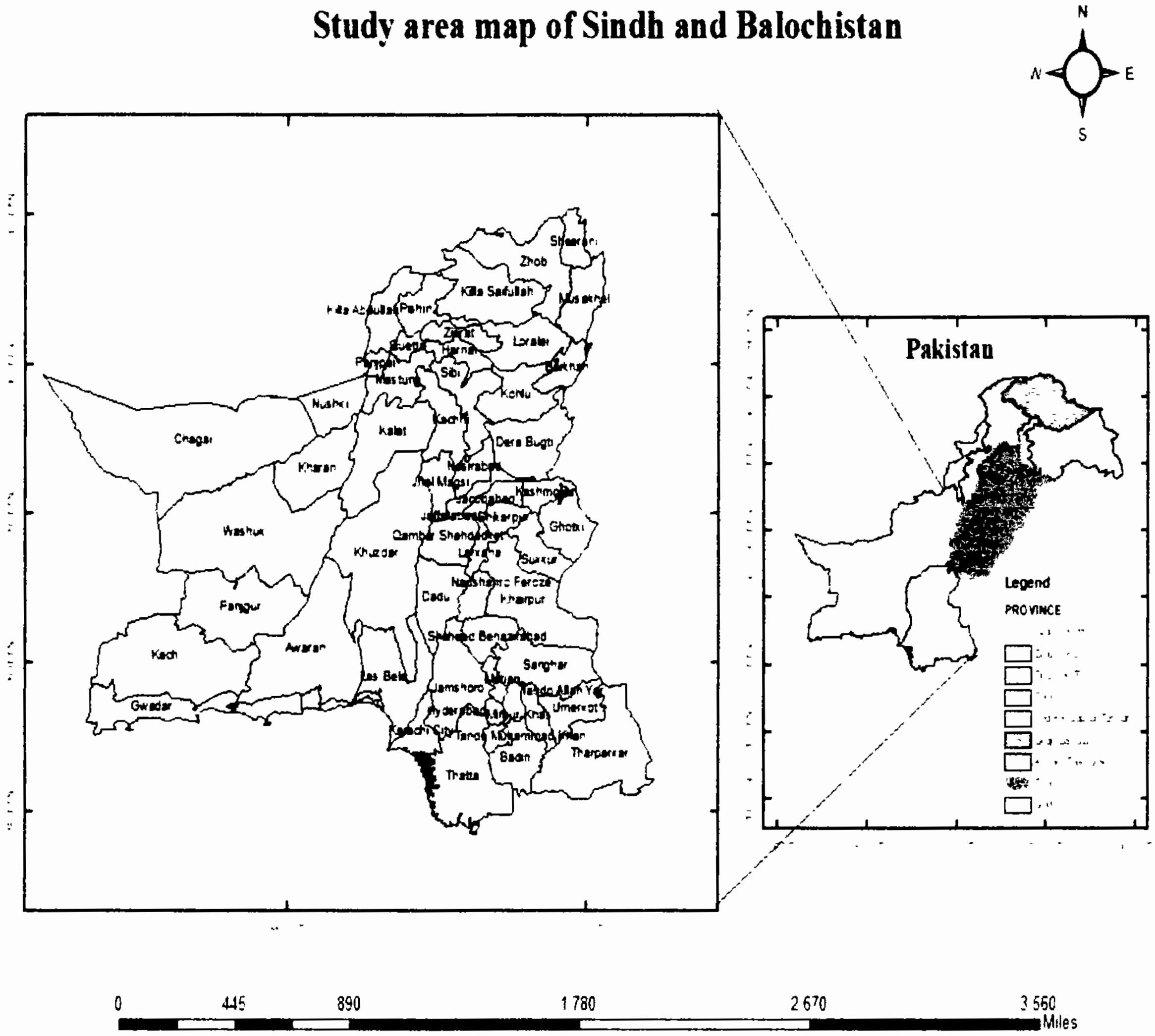

Figure 1. Location Map of study area

Summers in the upper highlands are extremely hot, while the winters are frigid. Colder winters can be found in the northern regions, which are closer to the Makran coast. Chaghi and

Kharan districts' desert regions get quite hot throughout the summer. The province's irrigated agriculture relies on both groundwater and surface resources, with around 47% of the cultivated land irrigated and the remaining 53% under Sailaba and Khushkaba farming (Government of Balochistan, 2009-10). The Lasbela canals, IBIS's Khirther and Pat Feeder, and the Pat Feeder are the primary sources of surface irrigation. Floodwater flowing through streams is another key source of surface water in this region. Sailaba diversion, storage dams and minor perennial irrigation schemes have captured roughly 30% of floodwater for crops. Karezes, springs, and tube wells also provide groundwater for irrigation purposes.

3.2 Data Acquisition:

In our study, data from Landsat images (Remote sensing data) is used as main source of data. Series of satellites has been launched into space that are providing space-based moderate-resolution remote sensing data continuously for more than four decades. From 23 July 1972, total eight series of Landsat satellites were launched into space for Earth Observation (EO) purposes. All satellites works properly in space except Landsat 6 that failed to achieve orbit. The rest of the satellites have provided a unique and exclusive resource for researcher to analyze and evaluate different applications in agriculture, cartography, geology, forestry, regional planning, surveillance, and education departments over the last four decades. In this study, we will use different satellite images from each Landsat series of 5, 7, and 8 to calculate VHI for three different major drought periods in Sindh and Balochistan. The acquisition years of Landsat data range were from 1998-2002, 2004-2005 and 2018-2019 from April to June, and only clear-sky images were considered. We can download different Landsat data for analysis through the USGS 'Earth Explorer' website that offer free Landsat data.

Landsat 5 TM and Landsat 7 ETM+ have 6 reflective bands (visible, near-infrared, and short-wavelength infrared, 30-m spatial resolution) and one band in the thermal infrared (TIR) region (Band 6). The thermal band has a natural spatial resolution of 120-m and 60-m for TM and ETM+, respectively, but it is delivered by USGS at 30-m after cubic convolution resampling. The Landsat 8 OLI sensor has 9 reflective bands with 30-m spatial resolution, and Landsat 8 TIRS sensor has two bands in the TIR region (Band 10 and Band 11). These two bands see heat, it report on the ground itself instead of measuring the temperature of air, such as mostly weather stations do, which is often hotter (NASA Landsat Science). These thermal bands of Landsat 8 have a 100-m natural spatial resolution but resampled and published at 30 m by USGS.

Table 1: Data types and sources

Sr. No	Types of Data	Source
1	Landsat images	United states geological survey (USGS)
2	Food data	Food and Agricultural Organization
3.	Software use	ArcGIS, ERDAS Imagine, XLSTAT

Landsat 4-5 Thematic Mapper (TM) images consist of total 7 spectral bands with a spatial resolution of 30 meters for Bands 1 to 5 and 7. Spatial resolution for thermal infrared (Band 6) is 120 meters, but is resampled to 30-meter pixels. Approximate scene size of TM is 170 km north-south by 183 km east-west (106 mi by 114 mi).

Table 2: Specification of Landsat 4-5 TM (Thematic Mapper)

Bands	Band Designations	Wavelength (µm)	Resolution (m)
Band 1	Blue	0.45-0.52 µm	30 m
Band 2	Green	0.52-0.60 µm	30 m
Band 3	Red	0.63-0.69 µm	30 m
Band 4	Near Infrared (NIR)	0.76-0.90 µm	30 m
Band 5	Short wave infrared (SWIR)	1.55-1.75 µm	30 m
Band 6	Thermal infrared (TIR)	10.40-12.50 µm	120 (30) m
Band 7	Panchromatic	2.08-2.35 µm	30 m

Landsat 7 Enhanced Thematic Mapper Plus (ETM+) images consist of total 8 spectral bands with a spatial resolution of 30 meters for Bands 1 to 7. For Band 8 (panchromatic), the resolution is 15 meters. For increased radiometric sensitivity and dynamic range, all bands can collect one of two gain settings (high or low), while Band 6 collects both high and low gain for all scenes. Approximate scene size of ETM+ is 170 km north-south by 183 km east-west (106 mi by 114 mi).

Table 3: Specification of Landsat 7 ETM+ (Enhanced Thematic Mapper Plus)

Bands	**Band Designations**	**Wavelength (μm)**	**Resolution (m)**
Band 1	**Blue**	0.45-0.52 μm	30 m
Band 2	**Green**	0.52-0.60 μm	30 m
Band 3	**Red**	0.63-0.69 μm	30 m
Band 4	**Near Infrared (NIR)**	0.76-0.90 μm	30 m
Band 5	**Short wave infrared (SWIR-1)**	1.55-1.75 μm	30 m
Band 6	**Thermal infrared (TIR)**	10.40-12.50 μm	60 (30) m
Band 7	**Short wave infrared (SWIR-2)**	2.08-2.35 μm	30 m
Band 8	**Panchromatic**	.52-.90 μm	15 m

Landsat 8 Operational Land Imager (OLI) **and Thermal Infrared Sensor** (TIRS) images from this satellite have a spatial resolution of 30 meters. New band 1 (ultra-blue) is extremely valuable for coastal and aerosol research. Cirrus cloud identification requires the usage of the new band 9. This satellite has a resolution of 15 meters in Band 8 (panchromatic). At 100 meters, thermal bands 10 and 11 acquire data that can be used to accurately measure surface temperatures. There are approximately 170 km of north-south and 183 km of east-west coverage areas in this Landsat image, therefore (106 mi by 114 mi).

Table 4: Specification of Landsat 8 OLI and TIRS

Bands	Band Designations	Wavelength (µm)	Resolution (m)
Band 1	Coastal Aerosol	0.43 - 0.45 µm	30 m
Band 2	Blue	0.45 - 0.51 µm	30 m
Band 3	Green	0.53 - 0.59 µm	30 m
Band 4	Red	0.64 - 0.67 µm	30 m
Band 5	Near Infrared (NIR)	0.85 - 0.88 µm	30 m
Band 6	Short wave infrared (SWIR-1)	1.57 - 1.65 µm	30 m
Band 7	Short wave infrared (SWIR-2)	2.11 - 2.29 µm	30 m
Band 8	Panchromatic	0.50 - 0.68 µm	15 m
Band 9	Cirrus	1.36 - 1.39 µm	30 m
Band 10	Thermal infrared (TIRS-1)	10.6 - 11.19 µm	100 m
Band 11	Thermal infrared (TIRS-2)	11.50 - 12.51 µm	100 m

3.3 Data processing:

More specifically, the multispectral/thermal data from Landsat 5, 7, and 8 were used to create NDVIs and LSTs for the study area. Radiometric calibration will be utilized to translate all of these measurements into sensor spectral radiance. We will also use atmospheric adjustment to remove light atmospheric effects from processing thermal bands for absolute temperature measurements. They were used to calculate indices of moisture vegetation/vegetation condition (VCI) and temperature vegetation/condition (TCI). VHI, a vegetation drought index, is derived from combining VCI and TCI data. It measures the severity and extent of agricultural drought throughout the year and may be applied at any time of year.

3.3.1 Normalized Difference Vegetation Index (NDVI)

NDVI is a one of the best numerical indicator that can be used to analyze remote sensing measurements and assess whether the observed area contain dense green vegetation or not. NDVI uses visible band (Vis) and near infrared band (NIR) of electromagnetic spectrum. It is one of the most frequent index of vegetation index (VI) used (Valor and Caselles 1996; Sobrino *et al.* 2004; Karnieli *et al.* 2010). NASA researcher developed NDVI strategy that is now commonly known as Normalized Difference Vegetation Index (NDVI). For NDVI calculations we use the ratio between the maximum absorption of radiation in red spectral region (Red) and the maximum reflectance in near-infrared (NIR) spectral region of different satellites.

We can calculate NDVI by following equation

$$\mathbf{NDVI} = \frac{(\mathbf{NIR} - \mathbf{RED})}{(\mathbf{NIR} + \mathbf{RED})}$$

For Landsat 5 (TM), 7 (ETM+) data, NDVI = (Band 4 – Band 3) / (Band 4 + Band 3)

For Landsat 8 (OLI) data, NDVI = (Band 5 – Band 4) / (Band 5 + Band 4)

Where NIR is near infrared reflectance and RED is visible red reflectance spectral regions. The NIR band has a wavelength range of (750-1300 nm), Red band has (600-700 nm). For Landsat, NDVI values range between −1 and +1. NDVI values for water are under 0, exposed soils somewhere around 0 and 0.1, and vegetation have more than 0.1 NDVI values. Rise in the positive NDVI esteem implies greener the vegetation. Generally, we obtain following result of NDVI:

Table 5. NDVI class interval for vegetation cover

Classes	NDVI values	Classification
1	-1 to 0	represent Water bodies
2	-0.1 to 0.1	represent Barren rocks, sand, or snow
3	0.2 to 0.5	represent Shrubs and grasslands or senescing crops
4	0.6 to 1.0	represent Dense vegetation or tropical rainforest

3.3.2 Vegetation Cover Index (VCI)

When it comes to tracking weather-related changes like droughts, the Vegetation Condition Index (VCI) is one of the most useful vegetation indicators. The Vegetation Condition Index (VCI) is computed by using NDVI data. Using percentages, the VCI shows where the observed value falls in relation to prior year's lowest and highest values. The lower the VCI rating, the worse the condition of the vegetation is. Drought severity and impact on plants can be accurately determined using VCI (Kogan *et al.,* 1995). The VHI can be used in conjunction with other indicators to anticipate vegetation cover conditions. The VCI data can be calculated by following equation.

$$\mathbf{VCI} = \frac{\mathbf{NDVI - NDVImin}}{\mathbf{NDVImax - NDVImin}} \times \mathbf{100}$$

Where,

NDVI = NDVI value of current month.

NDVImin , **NDVImax** = the minimum and maximum NDVI values, respectively, throughout the period of observation.

VCI results values ranges between 0 and 100, where good vegetation cover and low degree of drought condition results in high VCI values, whereas smaller values of VCI indicates poor vegetation cover and higher degree of drought (Sha *et al.,*2013; Dutta *et al.,* 2015). The VCI contains both real-time as well as historical information of the NDVI.

Table 6. Drought grades defined by the VCI

VCI Range	Numerical Index	Dryness Level
0-20	5	Extreme drought
20-40	4	Severe drought
40-60	3	Moderate drought
60-80	2	Light drought
80-100	1	Very light drought

3.3.3 Land Surface Temperature (LST)

At local and international level, LST plays a major role in physical processes of energy exchange and water balance in all surface-atmosphere studies (Li *et al.*, 2013). For analysis of different land surface conditions such as evapotranspiration, vegetation water stress and soil moisture, LST derived from thermal infrared data is very helpful in addition to providing rich temporal and spatial variability and be applied to many other purposes (Karnieli *et al.*, 2010). For LST calculation from Landsat images, the following steps have been followed (Figure 2). For LST calculation, we use thermal infrared (TIR) region (Band 6) for Landsat 5 and 7, and for Landsat 8 two bands in the thermal infrared region (Band 10 and Band 11) can be used for this purpose.

3.3.3.1 Conversion of the digital number (DN) to Top of Atmosphere Spectral radiance (Lλ) at the satellite level

Each object has temperature that is above absolute zero (K) so they emits thermal electromagnetic energy. The digital values (DN) of the images are converted to spectral radiance (Lλ) at the sensor level for the extraction of physical parameters from different Landsat such as Landsat-5 TM, Landsat-7 ETM+, and Landsat 8 OLI and TIRS images.

The following equation is used (USGS, 2019):

$$\mathbf{L\lambda} = \frac{\mathbf{(Lmax - Lmin)}}{\mathbf{Qcalmax - Qcalmin}} + \mathbf{Lmin - Oi}$$

Where,

Lλ = spectral radiance

Lmax = the maximum radiance (Wm-2 sr-1μm-1)

Lmin = the minimum radiance (Wm-2 sr-1μm-1)

Qcal = the DN value of pixel

Qcalmax = the maximum DN value of pixels

Qcalmin = the minimum DN value of pixels

Oi = the correction value for band 10

3.3.3.2 Conversion of TOA spectral radiance (Lλ) into brightness temperature (BT)

The TIRS Landsat band data should be converted from spectral region to brightness temperature (BT) after converting digital values (DN) values into at- sensor spectral radiance (USGS, 2019) by using metadata files of Landsat images for thermal constants values.

$$\mathbf{BT} = \frac{\mathbf{K2}}{\mathbf{ln}\,[(\mathbf{K1}/\,\mathbf{L\lambda}) + \mathbf{1}]} - \mathbf{273.15}$$

Where

***K*1** and ***K*2** = the thermal conversion constants specific to the band n.

Lλ = spectral radiance

In order to obtain results in degree Celsius (C°), we convert our brightness temperatures (BT) values by adding absolute zero which is equal to −273.15 ° approximately. We apply this equation for thermal band 6 in Landsat 5 (TM) and Landsat 7 (ETM+) to estimate LST values.

3.3.3.3 NDVI calculation

Normalized Difference Vegetation Index (NDVI) is one of the important tool to identify and analyze different land cover types of any area. NDVI has its ranges from -1.0 to +1.0. For NDVI calculations we use the ratio between the maximum absorption of radiation in red spectral region (Red) and the maximum reflectance in near-infrared (NIR) spectral region

$$\mathbf{NDVI} = \frac{\mathbf{(NIR - RED)}}{\mathbf{(NIR + RED)}}$$

For Landsat 5 (TM) and 7 (ETM+) data, NDVI = (Band 4 – Band 3) / (Band 4 + Band 3)

For Landsat 8 (OLI) data, NDVI = (Band 5 – Band 4) / (Band 5 + Band 4)

For further proportional vegetation (PV) and emissivity (ε) calculation, NDVI calculation is necessary.

3.3.3.4 Calculation of proportional vegetation (PV)

Calculation of proportional vegetation (PV) from NDVI values is next step. We can estimate area under each land cover type by using proportional vegetation (PV). By using NDVI of pure pixels we can develop vegetation and bare soil proportions.

$$\mathbf{Pv} = \left(\frac{\mathbf{(NDVI - NDVImin)}}{\mathbf{(NDVImax - NDVImin)}}\right)^2$$

Where,

NDVI = NDVI value of current month.

NDVImin , **NDVImax** = the minimum and maximum NDVI values, respectively, throughout the period of observation.

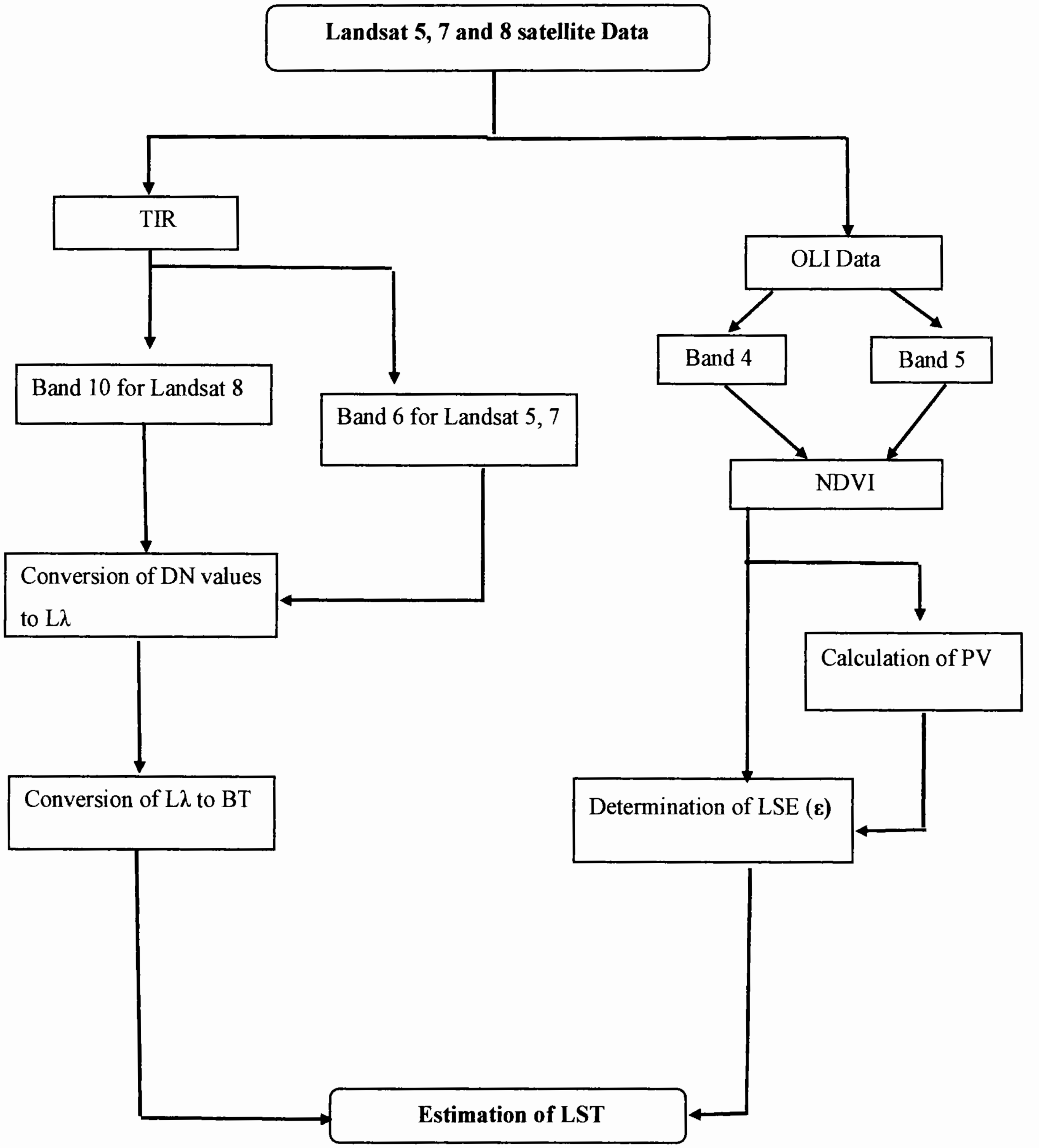

Fig. 2 Schematic flowchart of LST retrieval from satellite images

3.3.3.5 Calculation of land surface emissivity (ε)

Land surface emissivity (LSE) is a proportionality element that scales the black body radiance (Plank's law) to evaluate emitted radiance and it is also required to estimate land surface temperature (LST). The thermal energy can be transmit across the surface into the atmosphere by Land surface emissivity (LSE). In addition, the surface roughness, nature of vegetation condition are few factors on which the LSE is mostly dependent.

$$\varepsilon = (0.004 * PV) + 0.986$$

Where,

PV = the proportion of vegetation

3.3.3.6 Conversion of brightness temperature (Tb) to Land Surface Temperature (LST)

After computing the corresponding emissivity values from NDVI values for each pixel and PV, brightness temperature (BT) of band 10, land surface temperatures (LST) can be calculated by using following equation.

$$LST = \left(\frac{Tb}{\left(1 + \left[\left(\frac{\lambda TB}{\rho} \ln\varepsilon\right)\right]\right)}\right)^2$$

Where:

LST = the surface temperature in degrees Celsius (°C),

Tb= the brightness temperature in degrees Celsius (°C),

λ = shows the wavelength of the emitted radiance, where λ = 10.895 (for band 10) and λ = 12.0 (for band 11)

ε = represent the emissivity

$$\rho = h * \frac{c}{\sigma} = 1.43 \text{x}\ 10^{-2} \text{mK}$$

Where:

σ = represent the Boltzmann constant (1.38x 10^{-23}J / K),

h = shows the Planck's constant (6.626x 10^{-34}Js)

c = is speed of light (2.998x 10^{-8}m/s)

Table 7. Specific thermal conversion constants for band 6 of Landsat 5 (TM) and 7 (ETM+)

Landsat	**Variables**	**Value**
Landsat 5-TM	K1	607.76
	K2	1260.56
	Lmax	15.303
	Lmin	1.2378
	Qcalmax	255
	Qcalmin	1
Landsat 7-ETM	K1	666.09
	K2	1282.71
	Lmax	12.65
	Lmin	3.2
	Qcalmax	255
	Qcalmin	1

Table 8. : Specific thermal conversion constants for band 10 of Landsat 8 (OLI)

Variable	Description	Value
K1 **K2**	Thermal constants, Band 10	774.8853 1321.0789
Lmax **Lmin**	Maximum and Minimum values of Radiance, Band 10	22.00180 0.10033
Qcalmax **Qcalmin**	Maximum and Minimum values of Quantize Calibration, Band 10	65535 1
Oi	Correction value, Band 10	0.29

3.3.4 Temperature Cover Index (TCI)

The use of VCI has been widely increased as drought assessment tool by researchers, however, we cannot analyze drought conditions accurately with the help of using only VCI data, and for this we use TCI data for better analysis and measurement of different vegetation cover and its response toward in-situ temperature as additional information. The TCI can be calculated by using the following equation.

$$TCI = \frac{LSTmax - LST'}{LSTmax - LSTmin} \times 100$$

Where,

LST' = the composite temperature value of current month

LSTmin and **LSTmax** = the minimum and maximum LST values, respectively

In similar observation drought period, LSTmin and LSTmax are identified compositely by maximum and minimum pixel value. Vegetation stress can be better analyzed and understand with the help of TCI.

Table 9. Drought grades defined by the TCI

VCI Range	Numerical Index	Dryness Level
<10	5	Extreme drought
<20	4	Severe drought
<30	3	Moderate drought
<40	2	Light/mild drought
≥40	1	no drought

3.3.5 Vegetation Health Index (VHI)

Finally, the VHI was calculated to assess both vegetation stress and temperature to evaluate drought severity.

Drought classes for VHI are

Table 10. VHI classification in terms of droughts

Classification	VHI values	Droughts
1	VHI ≤ 40	In stress
2	40 < VHI ≤ 60	Normal vegetation
3	60 < VHI ≤ 100	Favourable conditions

The VHI can be calculated by following equation

$$VHI = \alpha * VCI + (1 - \alpha) * TCI$$

Where, VHI is correlated to VCI and TCI, since the contribution of temperature and moisture to vegetation cover/health are unknown at some time for some specific period, so the proportion was often assumed equal to simplicity (α equals to 0.5) (Macarof *et al.*,2018),. Bad and good vegetation health conditions have low and high VHI values, respectively. VHI values ranges from 0 to 100.

3.3.6 Change detection and food security issues:

To achieve second objective change detection of NDVI and VHI during drought period can be analyzed using NDVI and VHI values, for this purpose we need to reclassify our NDVI and VHI values into desired classes in ARGIS tool map. After classification we can calculate area of each individual class by multiply the value of count with length and width of given pixel of map and then we will covert our value in square km. Next step is to calculate percentage of our area, for this purpose we will divide our given area value of each class with sum of area of all classes and multiply this value with 100.For third objective we will use data from FAO to investigate the impact of droughts on food security and likelihood of people.

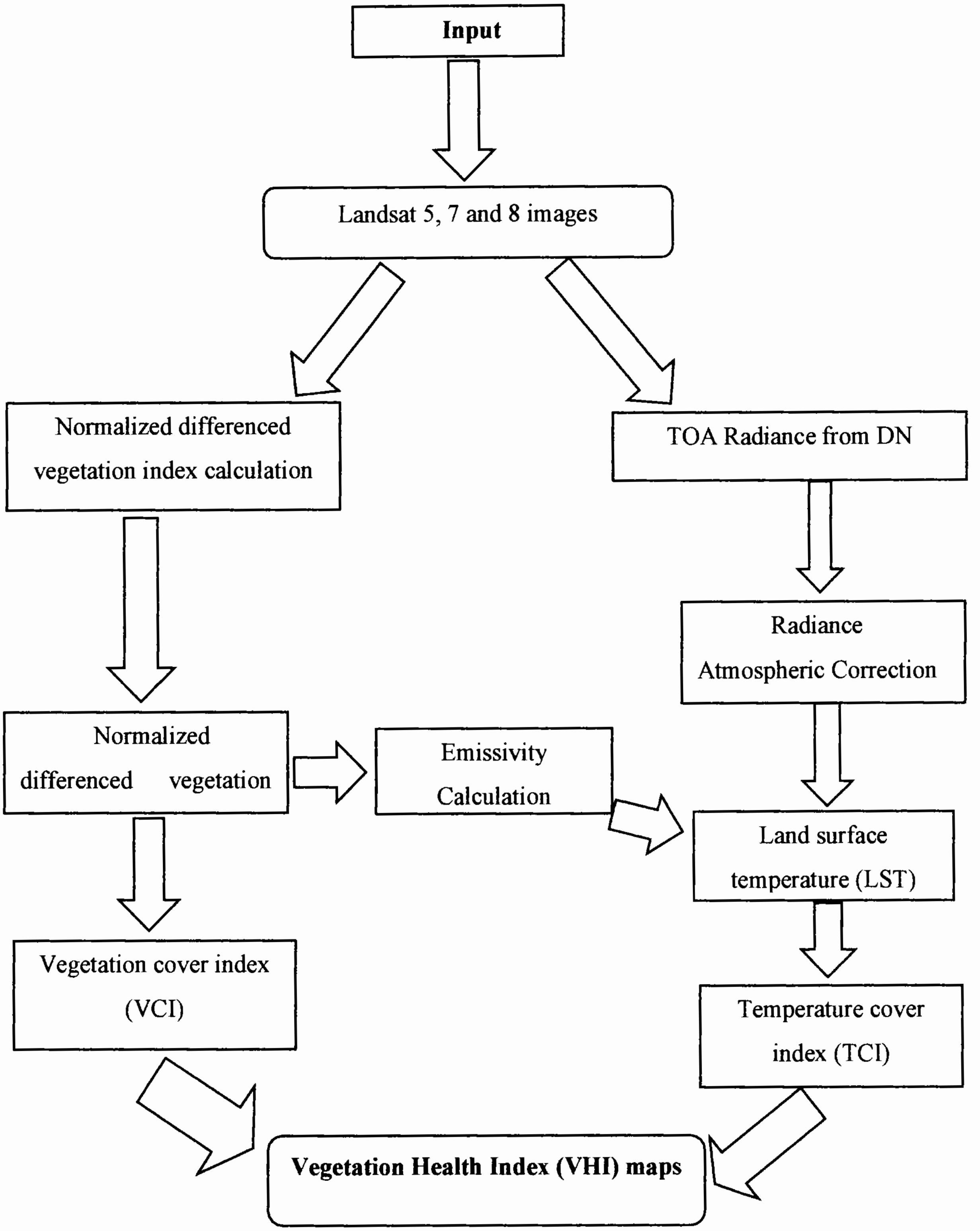

Fig. 3 Schematic flowchart of methodology applied to retrieve NDVI and LST from satellite images to obtain VHI map

CHAPTER. 4

Results and Discussion

4. Results and discussions

This chapter of the study deals with the discussion of results derived from USGS data which aid in the analysis of VHI, NDVI and LST and their impacts on vegetation. The following section also describe the impact of droughts on food security of Sindh and Balochistan.

4.1 Analysis of Normalized Difference Vegetation Index (NDVI):

For agricultural applications, NDVI is considered as one of the most commonly used method for measurement of vegetation cover and its health. We can use NDVI data to determine the relationship between Spectral and temporal variability and the changes in vegetation cover rate. This data can easily be used to detect vegetation changes and production of green vegetation of any area throughout its drought period. NDVI has its range from -1.0 to +1.0. After conversion of digital values to spectral radiances, we can calculate NDVI of each datasets.

4.1.1 1998-2002 drought period:

When due to any environmental factors, water content in soil decreases, (unavailability of water); the percentage of green vegetation cover tends to vanish slowly, then the values of NDVI also decreases .The images for NDVI from 1998 to 2002 are shown in Figure 2.

The variation of NDVI over the period of 1998 to 2002 was analyzed to access the change in vegetation pattern in Sindh and Balochistan. When the water content in soil decreases, the green vegetation tends to vanish and the reason can be any environmental factors (stress by water scarcity, less rainfall, high air temperature), that leads to drought conditions, as a result NDVI values decreases such as in 1998, 1999 and 2000. .

In 1998, NDVI ranges from -0.483 to 0.478, whereas in 1999 NDVI values ranges from -0.98 to 0.09. The NDVI values from 0.6 to 0.9 correspond to thick and dense vegetation cover that can be found in temperate and tropical forests. In 1998, 1999, the maximum NDVI values are 0.478 and 0.099 respectively such as shown in table 11, which means in these two years no areas of Sindh and Balochistan had dense vegetation. Majority of these areas were consist of rocks, sand, shrubs and grasslands, that has moderate NDVI values, ranges from -0.1 to 0.5 (table. 11).

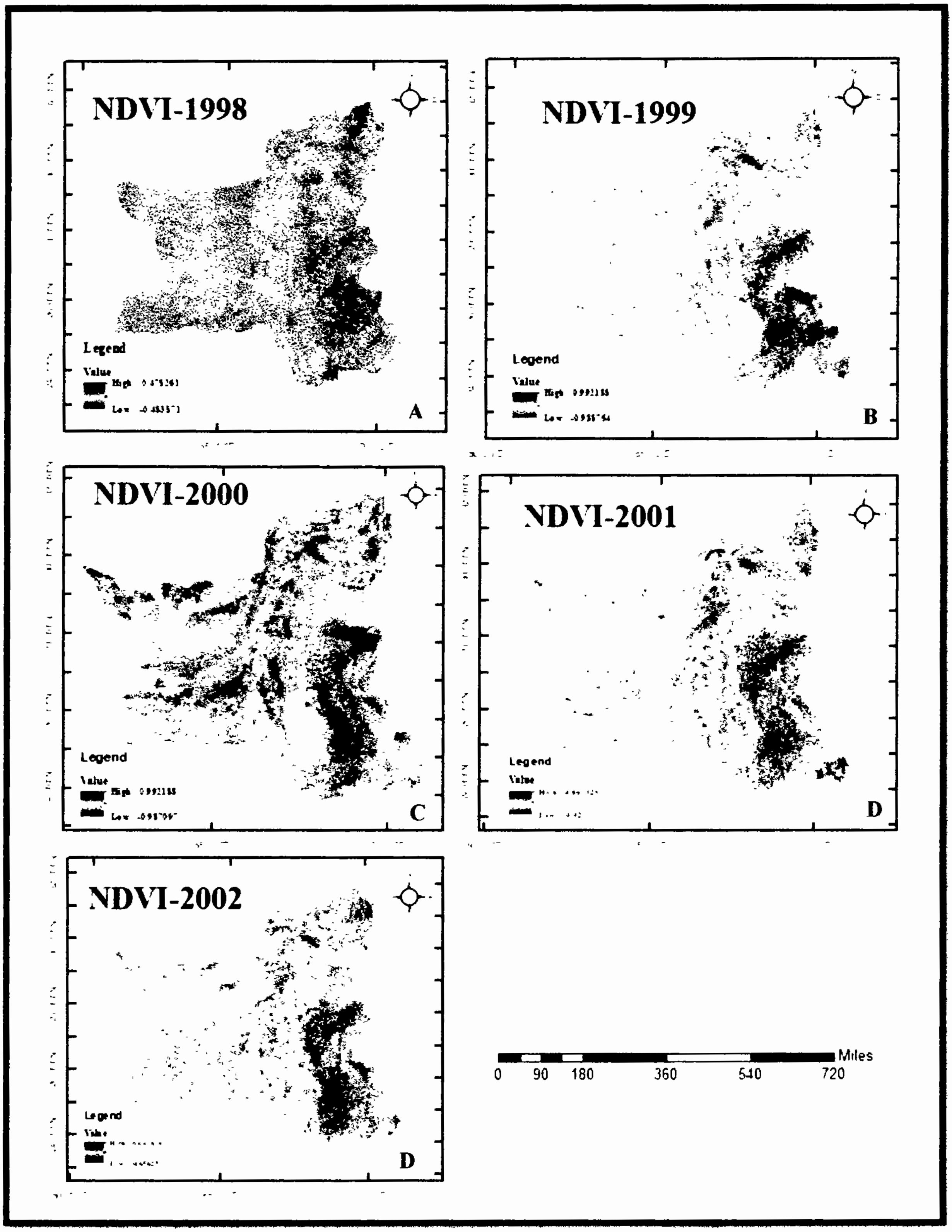

Figure 4 Spatio-temporal distributions of NDVI during drought period of 1998–2002 in Sindh and Balochistan. (A) NDVI trend in 1998, (B) NDVI trend in 1999, (C) NDVI trend in 2000, (D) NDVI trend in 2001, and (E) NDVI trend in 2002

In 2000, 2001 and 2002, NDVI values for vegetation land cover has been improved as compared to the NDVI of previous years. High NDVI value indicates Areas with high vegetation density have high values of NDVI while areas with low vegetation cover have low values of NDVI. In 2000, NDVImin and NDVImax values are -0.987 and 0.992 respectively, in 2001 NDVImin and NDVImax are -0.92 and 0.0867 respectively, whereas in 2002, NDVImin and NDVImax has values of -0.656 and 0.643 respectively. The maximum values of NDVI in these three years shows that vegetation has been improved in these three years as compared to 1998 and 1999.

The above Figure 2: showed the yearly average NDVI maps of Sindh and Balochistan. The NDVI pattern fluctuates up and down throughout the years of study. There was a significant change in the NDVI values in 1998 and 1999. In 1998 the NDVI values shows that there is no dense vegetation in the whole Balochistan province except in some upper parts including Musakhel, Ziarat, Harnai and some areas of Quetta, Sheerani, Pishin and Killa Abdullah, whereas in Sindh the NDVI values of Khairpur, Larkana, Thatta, Jacobabad, Shikarpur, Qambar Shahdadkot and north-east part of Dadu are extremely low that means there is no vegetation in these areas due to unavailability of water in the soil.

In 1999, there is an improvement in overall NDVI values but the maximum NDVI value is lower as compared to 1998. Some cities of Balochistan that have extremely low NDVI values are Zhob, some areas of Killa Saifullah, Dera Bugti and upper part of Sheerani, whereas in Sindh the NDVI values of Khairpur, some areas of Jamshoro, Shaheed Benazirabad, Lasbella, Thatta and lower part of Badin are extremely low indicating no vegetation in these areas due to unavailability of water in the soil.

In 2000, 2001 and 2002 NDVI values for vegetation covers has been improved as compared to the NDVI of previous years as shown in Figure 2. In 2000, there is an improvement of vegetation condition in Sindh and Balochistan except Khairpur, east part of Thatta, some lower areas of Badin and Tharparkar of Sindh and Kacchi, Sibi, East part of Killa Abdullah and some areas of Washuk and Nushki of Balochistan that shows low values of NDVI.

Figure 2 shows that the vegetation cover of 2001 is less than 2000 in Balochistan. Cities that shows low values of NDVI include some areas of Kohlu, Sheerani, Zhob, East part of Musakhel of Balochistan and some areas of Larkana, Shikarpur, Qambar, Khairpur, Shahdadkot, Shakkar, Ghotki, Mirpur Khas, Sanghar and Thatta of Sindh.

In 2002 vegetation condition has been improved then previous drought year that shows low NDVI values of Balochistan. Some cities of Balochistan that have extremely low NDVI values includes west of Killa Abdullah, upper areas of Zhob and Sheerani, whereas in Sindh the NDVI values of Larkana, some areas of Jacobabad, Qambar Shahdadkot, Lasbella, and lower part of Badin and Tharparkar are extremely low indicating no vegetation in these areas due to water scarcity.

4.1.2 2004-2005 drought period:

The pattern of variation for NDVI over the period of 2004 to 2005 is shown in Figure 3. In 2004, NDVImin and NDVImax are -0.984and 0.992 respectively, in 2005 the NDVImin and NDVImax are -0.941and 0.980 respectively. Vegetation condition in 2004 is less than 2005 as shown in Figure 3. Overall vegetation cover in Sindh and Balochistan has been improved in 2005.

In 2004 some areas that include south-east part Khairpur, some lower parts of Thatta, Badin and Tharparkar of Sindh and west part of Killa Abdullah of Balochistan shows lower NDVI values that represent lower vegetation cover in these areas. Majority of these areas were consist of rocks and sand with little to no vegetation cover.

In 2005, NDVI values shows that there is an improvement in overall vegetation of Sindh and Balochistan as compared to previous year with less vegetation cover, but in 2005 more areas are tend to show low values of NDVI. In Balochistan; west of Washuk, some areas of Chagai, Nushki, Kalaat, Kacchi, Sibi, Dera Bugti, Barkhan, Jhal Magsi, Jaffarabad, Muakhel, Zhob, Sheerani and Killa Saifullah shows extremely low values of NDVI, whereas in Sindh, Khairpur, Larkana, Jacobabad, Qambar Shahadadkot, Ghotki, Shukkur, Shikarpur, Tharparkar, Thatta, Badin, Shaheed Benazirabad, and some areas of Dadu, Naushahro Feroz have low NDVI values with no vegetation cover due to water scarcity in soil.

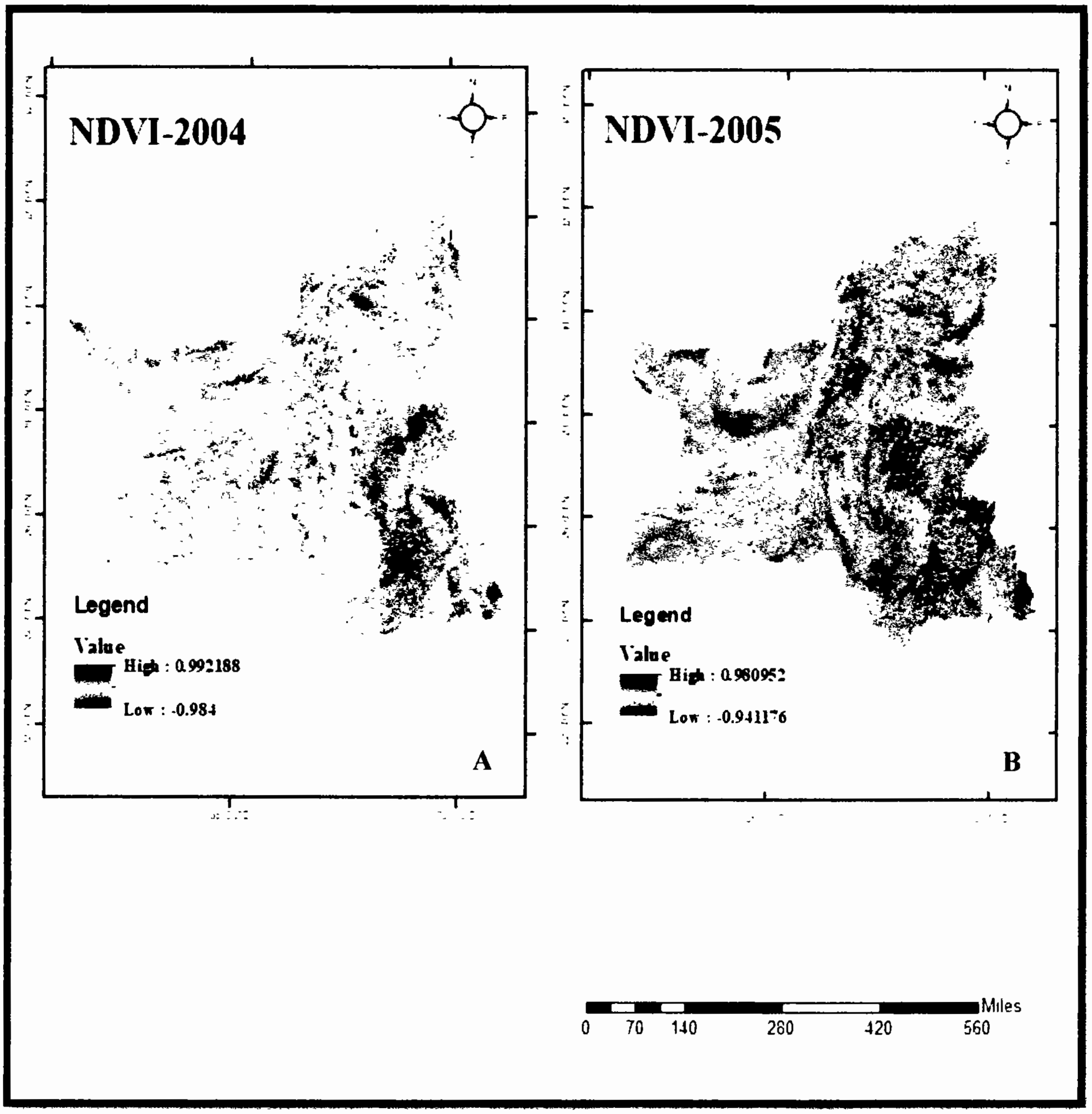

Figure 5. Spatio-temporal distributions of NDVI during drought period of 2004–2005 in Sindh and Balochistan. (A) NDVI trend in 2004, and (B) NDVI trend in 2005

4.1.3 2018-2019 drought period:

Figure 4 shows the pattern of variation for NDVI over the drought period of 2018 to 2019. In 2018, NDVI ranges from -0.644 to 0.629 and in 2019 the *NDVImin* and *NDVImax* are -0.5469 and 0.775 respectively (Table. 11). Maximum value of NDVI has been improved in 2019 from 0.629 to 0.775 as compared to previous year.

In Balochistan, some areas of Chagai, Washuk, Nushki, Kacchi, Sibi, Dera Bugti, Musakhel, Zhob, Sheerani, Mastung, Panjpai, Killa Abdullah and Killa Saifullah have low to no vegetation cover with extremely low values of NDVI, whereas in Sindh, Khairpur, Jacobabad, Shikarpur, Tharparkar, Thatta, Badin, Kashmore and some areas of Dadu, Larkana, Sanghar, Tando Muhammad Khan have low NDVI values that represent no vegetation cover in 2018.

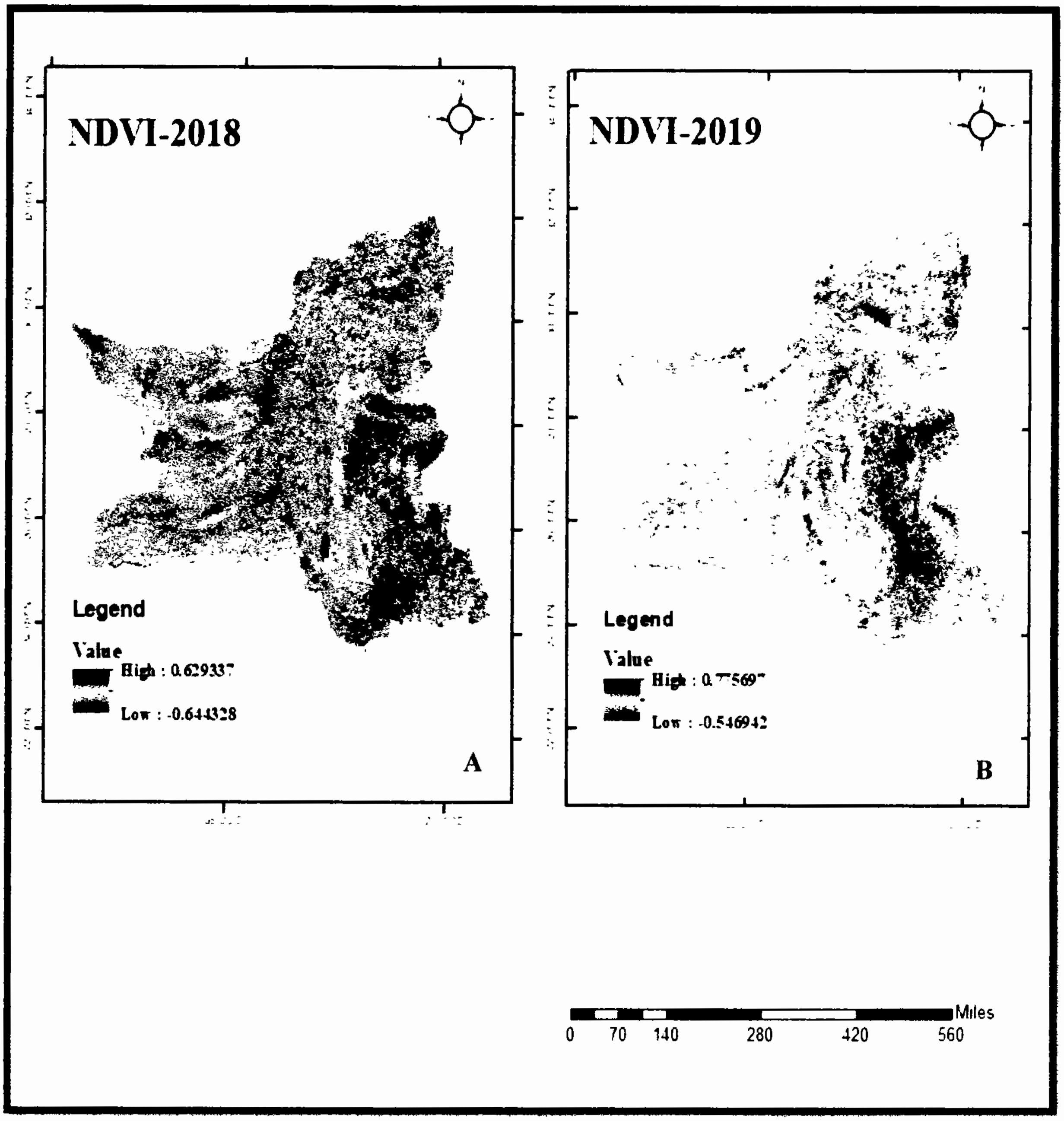

Figure 6 Spatio-temporal distributions of NDVI during drought period of 2018–2019 in Sindh and Balochistan. (A) NDVI trend in 2018, and (B) NDVI trend in 2019

In 2019 overall NDVI values are decreased as compared to previous drought year (Figure 6b). In Sindh, Khairpur, Shikarpur, lower areas of Tharparkar, Thatta, Badin, Kashmore and some areas of Dadu, Larkana, Sanghar, Jamshoro and Qambar Shahdadkot have low NDVI values that represent no vegetation cover, whereas as in Balochistan, some areas of Washuk, Nushki, Dera Bugti, Zhob, Sheerani, Musakhel, Pishin, Gwadar, Khuzdar, lower parts of Kech, Awaran and west part of Killa Abdullah have low to no vegetation cover with extremely low values of NDVI due to low water content in soil that leads to drought condition in these areas.

Overall NDVI values of 2018 and 2019 shows that vegetation condition in 2019 has been improved than previous year. NDVImax value has been increased from 0.629 to 0.775, whereas NDVImin values shifted from -0.644 to -0.546. (Figure 6a-b)

Table 11. Maximum and Minimum NDVI during 1998-2002, 2004-2005, and 2018-2019

No	**Drought year**	**NDVI-Max**	**NDVI-Min**
1	1998	0.47826	-0.4838
2	1999	0.09921	-0.9887
3	2000	0.99218	-0.9870
4	2001	0.86792	-0.920
5	2002	0.6438	-0.6562
6	2004	0.9921	-0.984
7	2005	0.9809	-0.9411
8	2018	0.6293	-0.6443
9	2019	0.7756	-0.5469

4.2 Analysis of Land surface temperature (LST):

Land Surface Temperature (LST) is one of the most critical elements in the physical process of surface energy and water balance at both local and global dimensions, impacting species and ecosystems at both local and global scales. LST monitors the emission of thermal radiation from the land surface, where the incoming solar energy interacts with and heats the ground, or the surface of the canopy in vegetated areas, as one of the most important Earth System Data Records (King *et al.*, 1999). For this reason, LST is an excellent indicator of energy partitioning between the ground surface and the atmosphere.

4.2.1 LST of 1998-2002 drought period:

For analysis of surface condition temperature has been playing a significant role in obtaining useful information. Figure 5 presents the distribution of LST in the Sindh and Balochistan from 1998 to 2002.The analysis of LST of urban areas using the highest and lowest values is currently the commonly used method for LST spatial distribution analysis (Mengmeng *et al.*, 2017).Land Surface Temperature (LST) has been derived using Brightness Temperature (BT) and Land Surface Emissivity (LSE). For all types of land surface temperature analysis degree Celsius (°C) is considered as basic unit for temperature, since original LST was calculated in Kelvin so we need to convert all values from Kelvin (K) to °C and results are presented in °C.

In 1998, 1999, 2000 and 2001, LST has maximum and minimum values of -3.899°C and -97.981°C respectively. The maximum and minimum values of LST in these four years are same as shown in table.12, whereas in 2002, LST has maximum and minimum values of 1.763°C and -68.615°C respectively as tabulated in the Table 12. The analysis shows that there is an increase in temperature from -3.899°C to 1.763°C in 2002 as compared to previous years which are not favorable and it clearly shows that region is affecting from environmental changes (Figure 7e).

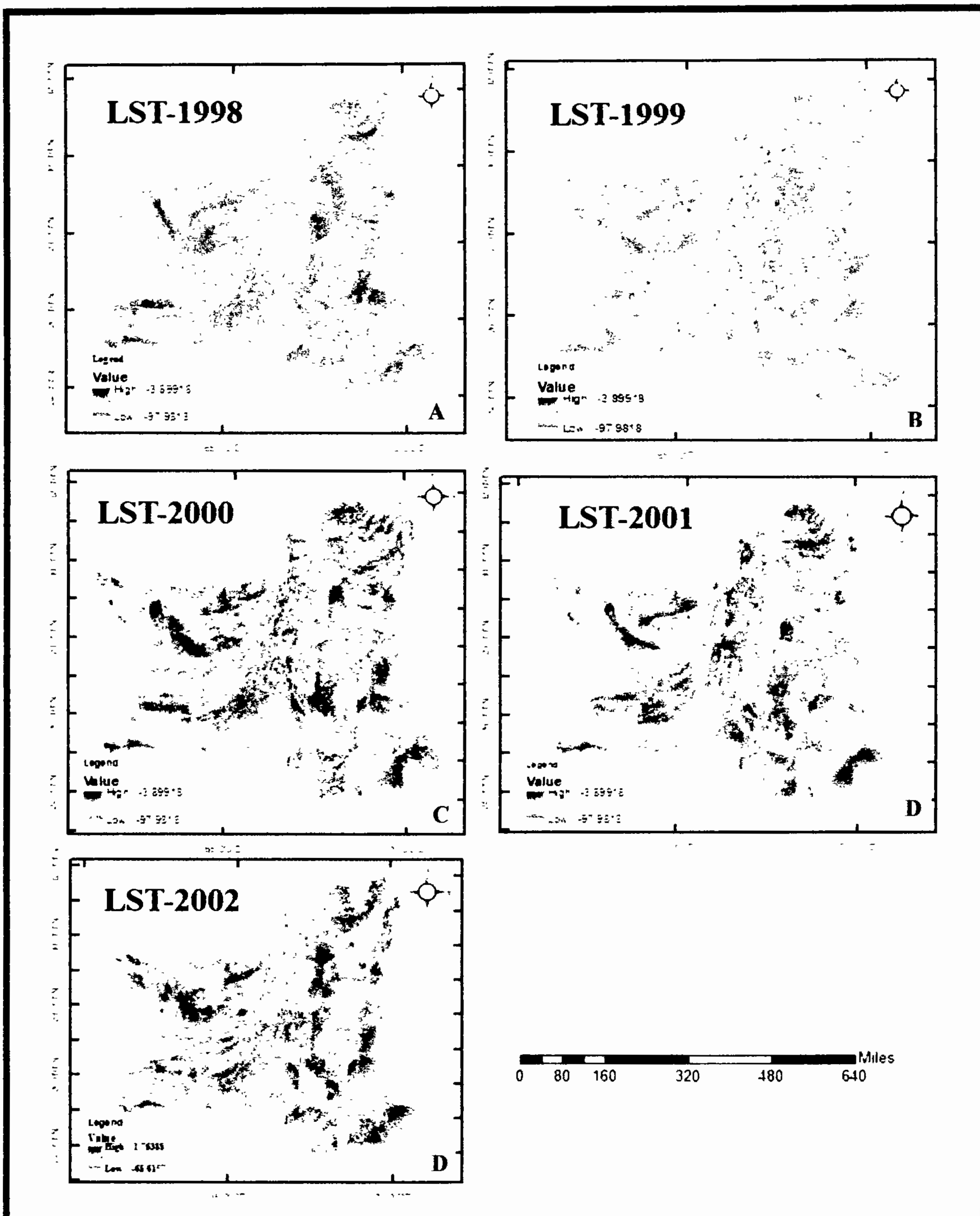

Figure 7. Drought Severity Categories based on LST Index during drought period of 1998–2002 in Sindh and Balochistan. (A) LST trend in 1998, (B) LST trend in 1999, (C) LST trend in 2000, (D) LST trend in 2001, and (E) LST trend in 2002

4.2.2 LST of 2004-2005 drought period:

In 2004 LST has maximum and minimum values of 1.763○C and -147.434○C respectively, where as in 2005 the maximum and minimum values of LST are 1.763○C and -132.26○C respectively.

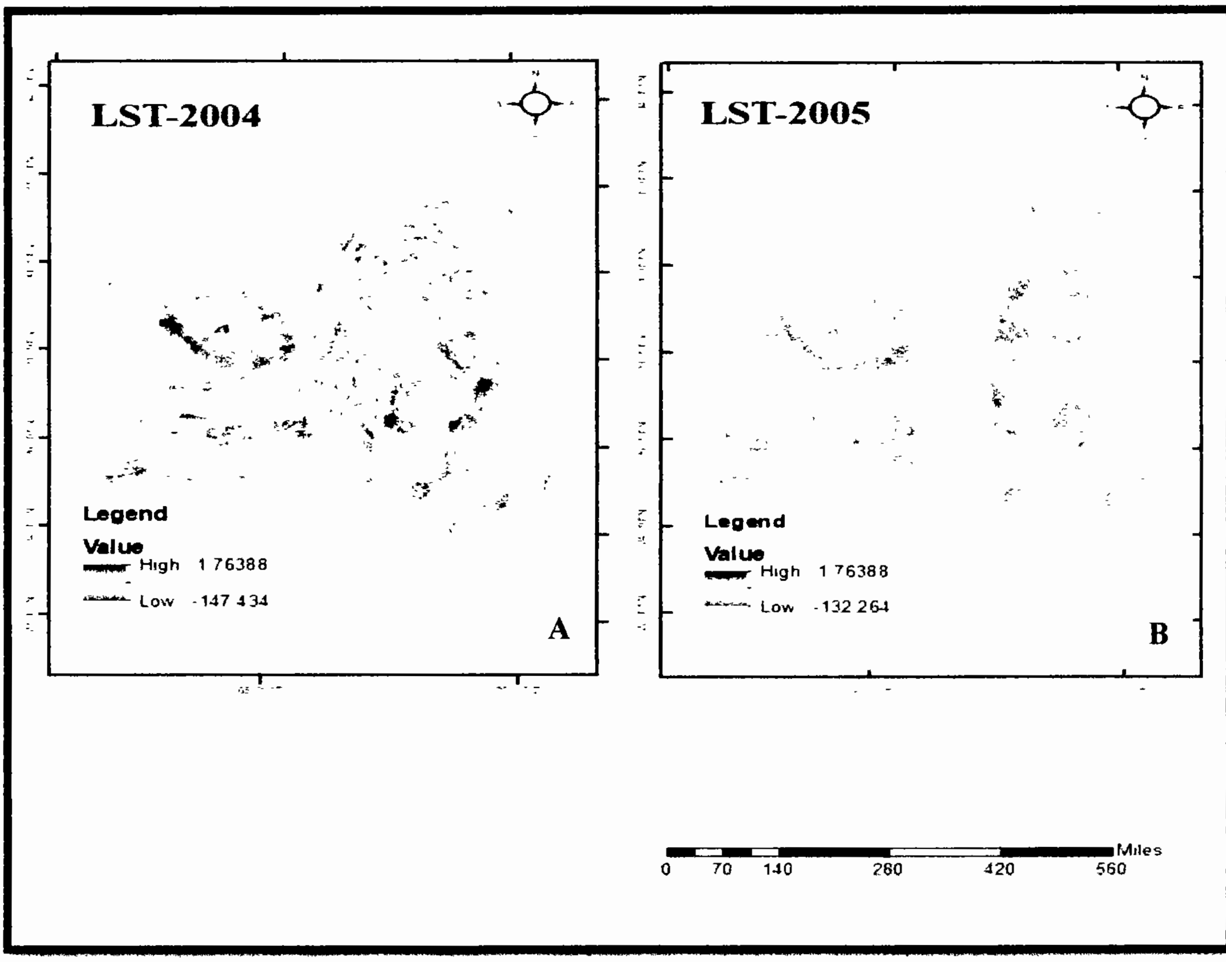

Figure 8. Drought Severity Categories based on LST Index during drought period of 2004–2005 in Sindh and Balochistan. (A) LST trend in 2004, and (B) LST trend in 2005

These data shows that maximum values of LST for both drought years are same but minimum values of LST of 2004 has been drastically decreased in 2005 as compared to 2004. In 2005 majority of areas of Sindh and Balochistan shows lower values of LST that means temperature in 2005 has been increased in majority of areas of study area as compared to 2004.

4.2.3 LST of 2018-2019 drought period:

In 2018 LST has maximum and minimum values of 45.600◦C and 22.888◦C respectively, where as in 2019 the maximum and minimum values of LST are 51.697◦C and 3.086◦C respectively. These data shows that maximum values of LST in 2019 has been increased from 45.6◦C to 51.6◦C as compared to 2018, that means there is an increase of 6◦C in overall LST as compared to previous year

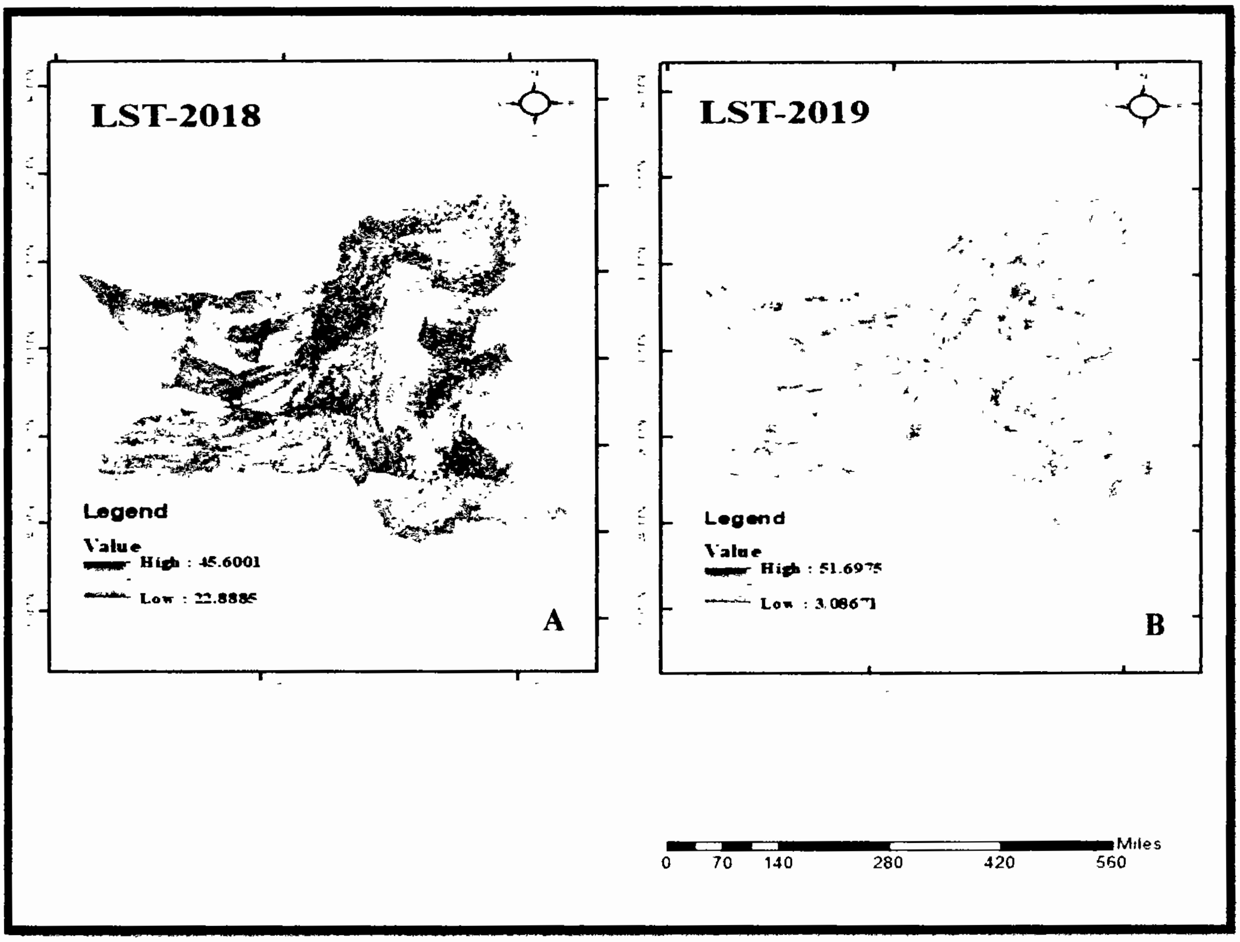

Figure 9. Drought Severity Categories based on LST Index during drought period of 2018–2019 in Sindh and Balochistan. (A) LST trend in 2018, and (B) LST trend in 2019

In 2018 maximum areas of Sindh and Balochistan falls under the lower values of LST. Minimum values of LST in 2019 has been decreased from 22.8◦C to 3.08◦C that means there is a decrease in overall minimum LST as compared to 2018.

Table 12. Maximum and Minimum LST during 1998-2002, 2004-2005, and 2018-2019

No.	Drought year	LST-Max (°C)	LST-Min (°C)
1	1998	-3.8991	-97.9818
2	1999	-3.8991	-97.9818
3	2000	-3.8991	-97.9818
4	2001	-3.8991	-97.9818
5	2002	1.7638	-68.6157
6	2004	1.7638	-147.434
7	2005	1.7638	-132.264
8	2018	45.600	22.8885
9	2019	51.697	3.08671

4.3 Analysis of Vegetation Health Index (VHI):

The Vegetation Health Index (VHI) has a key capacity to detect agricultural drought, as well as assume the vegetation and temperature conditions of a region. The Vegetation Condition Index (VCI), which measures the state of vegetation based on Normalized Difference Vegetation Index (NDVI), which measures the amount of vegetation cover and second, the Land Surface Temperature (LST) that is used to calculate the Thermal Condition Index (TCI) are used to calculate VHI. Farmers and decision-makers need to recognize the severity of drought in order to predict the possible disaster losses and to plan for drought relief measures in the future, especially for severe drought. To protect natural resources, it was critical to know the state of vegetation in each given area and how it responds to environmental changes.

4.3.1 VHI of 1998-2002 drought period:

To analyze VHI during growing season, the spatial and temporal variations of vegetation growth activity in past decades were analyzed by using regional average values and Sen's slopes of the VCI, TCI for each individual year between 1998 and 2002 in Sindh and Balochistan region.

Figure 10 showed annual spatial and temporal distribution of VHI for summer season in years of 1998-2002. VHI has been classified into 3 classes which are, in stress (0-40), Normal Vegetation (40-60), Favorable Vegetation cover (60-100).

In 1998, the VHI values ranges from 1.517 to 100. Vegetation condition of Sindh and Balochistan for this year can be seen in Figure 10. Map shows that almost all areas of Sindh and Balochistan experienced no droughts in 1998, which means climatic conditions were favorable for vegetation except few areas that experience some light to moderate intensity droughts such as in Balochistan, Middle part of Killa Abdullah experience extreme droughts in 1998, whereas north part of Chagai, Gwadar, Killa Saifullah, Ziarat, Khuzdar also experiences some Moderate drought conditions in 1998. In Sindh Mirpur Khas, Umerkot and Khairpur districts experience Moderate to Severe droughts, whereas some areas of Thatta, Badin and Jacobabad are identified as areas that experienced Light to moderate droughts in 1998. (Figure 10a)

In 1999, VHImin and VHImax values are 0 and 100 respectively. In this year Sindh and Balochistan experienced light to extreme drought conditions. The drought severity in 1999 has been increased as compared to 1998. (Figure 10). In Balochistan Sheerani, Zhob, Musakhel and some areas of Loralai, Wasuk, middle region of Nushki, Barkhan, Kohlu, Sibi, Killa Saifullah, and Awaran, Chagai, north parts of Kech, Khuzdar, south areas of Panjgur and areas such as Killa Abdullah, Pishin, Zhob, Harnai, Panjpai, Las Bella and Dera Bugti experienced Light to Extreme droughts in 1999. In Sindh Khairpur, Shaheed Benazirabad, Sanghar, Larkana, Naushahro Feroz, Tando Allah Yar, Badin, Hyderabad, Shikarpur and some regions of Thatta, Tando Muhammad Khan, Mirpur Khas, Matiari, Umerkot, Tharparkar, Ghotki, Jacobabad, Dadu and Jamshoro and some east part of Kashmore were the most affected regions of Sindh that experienced light to extreme droughts during this year. Rest parts of Sindh and Balochistan shows normal to favorable vegetation conditions in 1999. VHI map of 1999 clearly shows that majority regions of Sindh experienced some kind of drought conditions in 1999.

An improvement in drought condition can be seen in 2001 as compared to the previous drought years as shown in Figure 10.In Sindh Khairpur, Shaheed Benazirabad, Sukkur, Dadu, Naushahro Feroz, Hyderabad, Larkana, Tharparkar, Umerkot and Qambar Sahahdadkot were the most affected districts of Sindh that experienced moderate to extreme droughts during 2000. In Balochistan Kohlu, Khuzdar and Awaran and areas such as Killa Abdullah, Zhob, Musakhel, Nushki and Killa Saifullah, Chagai, Sibi, Washuk, Mastung, Kalaat and Ziarat are identified as areas that experienced Light to Severe droughts in 2000 due to water scarcity.

In 2001, the severity of drought increased in Sindh and Balochistan as compared to 2000, almost half of Sindh province experienced light to moderate drought condition, whereas in Balochistan light to severe intensity drought occurred during this drought year. Districts such as Naushahro Feroz, Kashmore, upper areas of Khairpur, Umarkot, Mirpur Khas, Tando Allah Yar, Mitiari, Sanghar, Tando Muhammad Khan, Thatta, Badin, Larkana and Jacobabad of Sindh province were most effected districts that experienced extreme drought conditions, whereas other districts of Sindh falls under favorable conditions for vegetation. In 2001 almost whole Balochistan province experienced some kinds of droughts ranges from light to severe intensity except regions such as some areas of Wasuk, Sibi, Jhal Magsi, Nasirabad, Nushki, Chagai, and Dera Bugti that shows favorable vegetation conditions during 2001 as shown in Figure 10(d).

The VHImin and VHImax values in 2002 are 0 and 100 respectively. In 2002, Sindh and Balochistan experienced severe to extreme drought conditions as compared to the previous four drought years. Almost each district of Sindh experienced extreme droughts except some region of Shaheed Benazirabad, Jamshoro, Naushahro Feroz, Thatta and Kashmore that shows some normal conditions for vegetation. In 2002, whole Balochistan province experienced moderate to extreme drought conditions that can be seen in Figure 10(e).

Figure 10 clearly shows that from 1998 to 2002, the drought conditions in 2001 and 2002 were worse than previous drought years. Due to less precipitation, the occurrence of agricultural droughts leads to high level of moisture stress in Sindh and Balochistan.

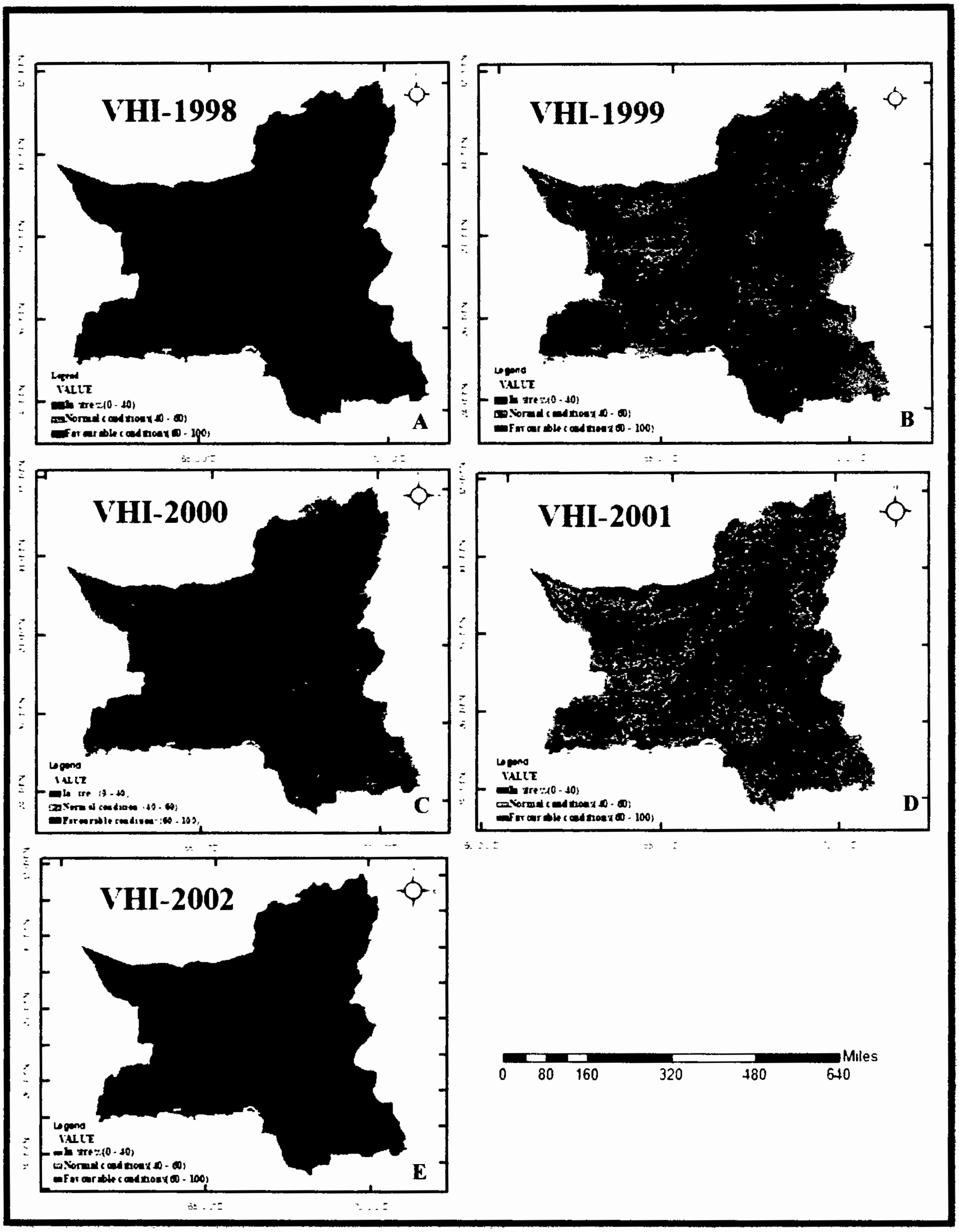

Figure 10. Spatio-temporal distributions of VHI during drought period of 1998–2002 in Sindh and Balochistan (A) VHI trend in 1998, (B) VHI trend in 1999, (C) VHI trend in 2000, (D) VHI trend in 2001, and (E) VHI trend in 2002

4.3.2 VHI of 2004-2005 drought period:

Figure 11a shows the drought conditions in Sindh and Balochistan during 2004-2005. In 2004 Sindh and Balochistan experienced more drought conditions as compared to 2005. The minimum and maximum value of VHI in 2004 is 0 and 100 respectively. Almost half region of Balochistan experienced extreme droughts including Chagai, Kalaat, Gwadar, Washuk, Quetta, Mastung, Panjgur, Gwadar, Kech, Nushki, Kohlu, Dera Bugti, Pishin, Killa Abdullah, Kharaan, Zhob, Las Bella, Ziarat, Barkhan and Khuzdar due to unavailability of water. In Sindh Tharparkar, Jamshoro, Qambar Sahahdadkot, Thatta, Khairpur, Dadu, Larkana, Sukkur, Sanghar, Umerkot, Hyderabad, Tando Allah Yar, Mirpur Khas, Naushahro Feroz, Badin, Tando Muhammad Khan and Karachi were more prominently effected by droughts in 2004.

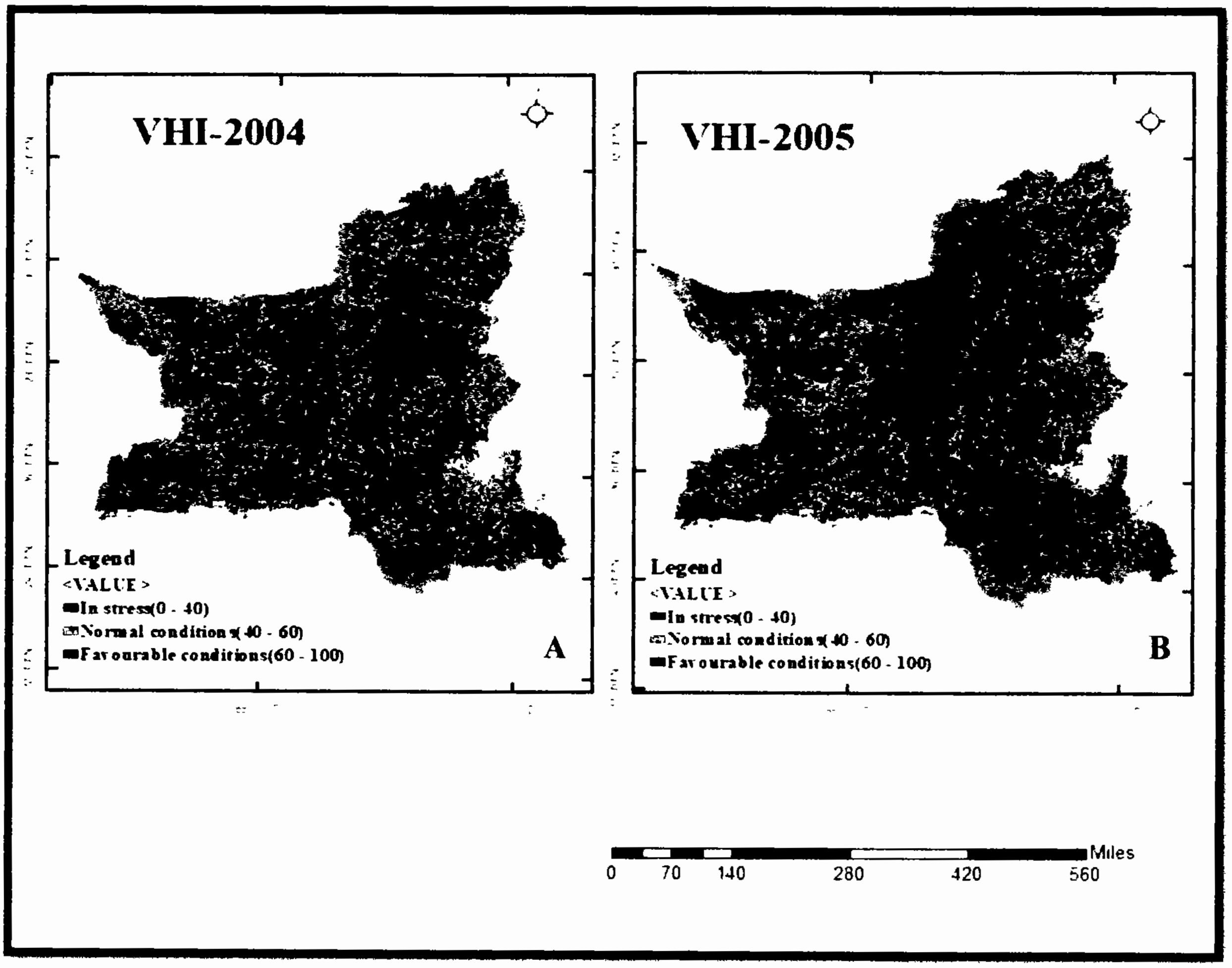

Figure 11. Spatio-temporal distributions of VHI during drought period of 2004–2005 in Sindh and Balochistan. (A) VHI trend in 2004, and (B) VHI trend in 2005

In 2005, an improvement in vegetation can be seen that represent no drought conditions (Figure 11b).The minimum and maximum value range of VHI in 2005 is 0 and 100 respectively. Drought conditions in Balochistan districts such as in Kalaat, Pishin, Quetta, Mastung, Nushki, north region of Chagai, Musakhel, some areas of Barkhan, Washuk, and Gwadar has been improved in 2005 as compared to 2004. These districts experienced severe droughts in previous year. Some districts of Balochistan that are highly effected by droughts are Kech, Awaran, Washuk, Zhob, Loralai, Barkhan, Sibi, Kachhi, Nasirabad, Jhal Magsi, Jaffarabad, Khuzdar and Panjgur.

In Sindh Tharparkar, Jamshoro, Khairpur, Thatta, Las Bela, Dadu, Qambar Sahahdadkot, Ghotki, Badin, Shaheed Benazirabad and Jacobabad experienced severe drought conditions in 2005. Overall drought condition in 2005 has been improved as compared to 2004 in which almost whole Sindh and Balochistan experienced moderate to severe drought conditions.

4.3.3 VHI of 2018-2019 drought period:

Figure 12 showed annual VHI spatial distribution for summer season in years of 2018-2019. In 2018, the minimum and maximum value of VHI is 0 and 100 respectively. In this year almost half region of Sindh and Balochistan experienced extreme drought conditions. The drought severity in 2019 has been increased as compared to 2018. (Figure 12). In Balochistan Zhob, Musakhel, Loralai, and some areas of Wasuk, Kohlu, Sibi, Killa Saifullah, Awaran, Chagai, north parts of Kech, Khuzdar and Panjgur, Killa Abdullah, Kech, Dera Bugti, Kachhi, Jhal Magsi and Pishin experienced extreme drought conditions in 2018. In Sindh Khairpur, Shaheed Benazirabad, Tando Allah Yar, Badin, Hyderabad, Sukkur, Jaffarabad, Qambar Shahdadkot, Tando Muhammad Khan, Tharparkar, Sanghar, south region of Karachi city, Matiari, Thatta, Las Bella, Dadu and east part of Kashmore were the most affected districts of Sindh that experienced extreme droughts during 2018.

The minimum and maximum value of VHI in 2019 is 0 and 100 respectively. In 2019, Sindh and Balochistan experienced severe to extreme drought conditions as compared to the previous drought year. Almost each district of Sindh experienced extreme droughts except some region of Shaheed Benazirabad, Ghotki, Sanghar and some south parts of Thatta, Sukkar, Khairpur, Jacobabad, Shikarpur, Tando Muhammad Khan, and some areas of Tharparkar and Badin with no drought conditions. In 2019, whole Balochistan province experienced moderate to extreme drought conditions including Gwadar, Kech, Washuk, Chagai, Nushki, Kalaat, Zhob, Loralai, Barkhan, Sibi, Kachhi, Quetta, Mastung, Panjpai, Killa Saifullah, Killa Abdullah, Kharan, Nasirabad, Kohlu, Jhal Magsi and Ziarat are the most prominent districts of Balochistan that experienced severe drought conditions as shown in Figure 12(b) .

VHI has been drastically decreased in 2019 as compared to 2018. From 2018 to 2019, the drought conditions in 2019 were worse than previous drought year. The occurrence of agricultural droughts were due to less amount of rainfall leading to unavailability of water in Sindh and Balochistan.

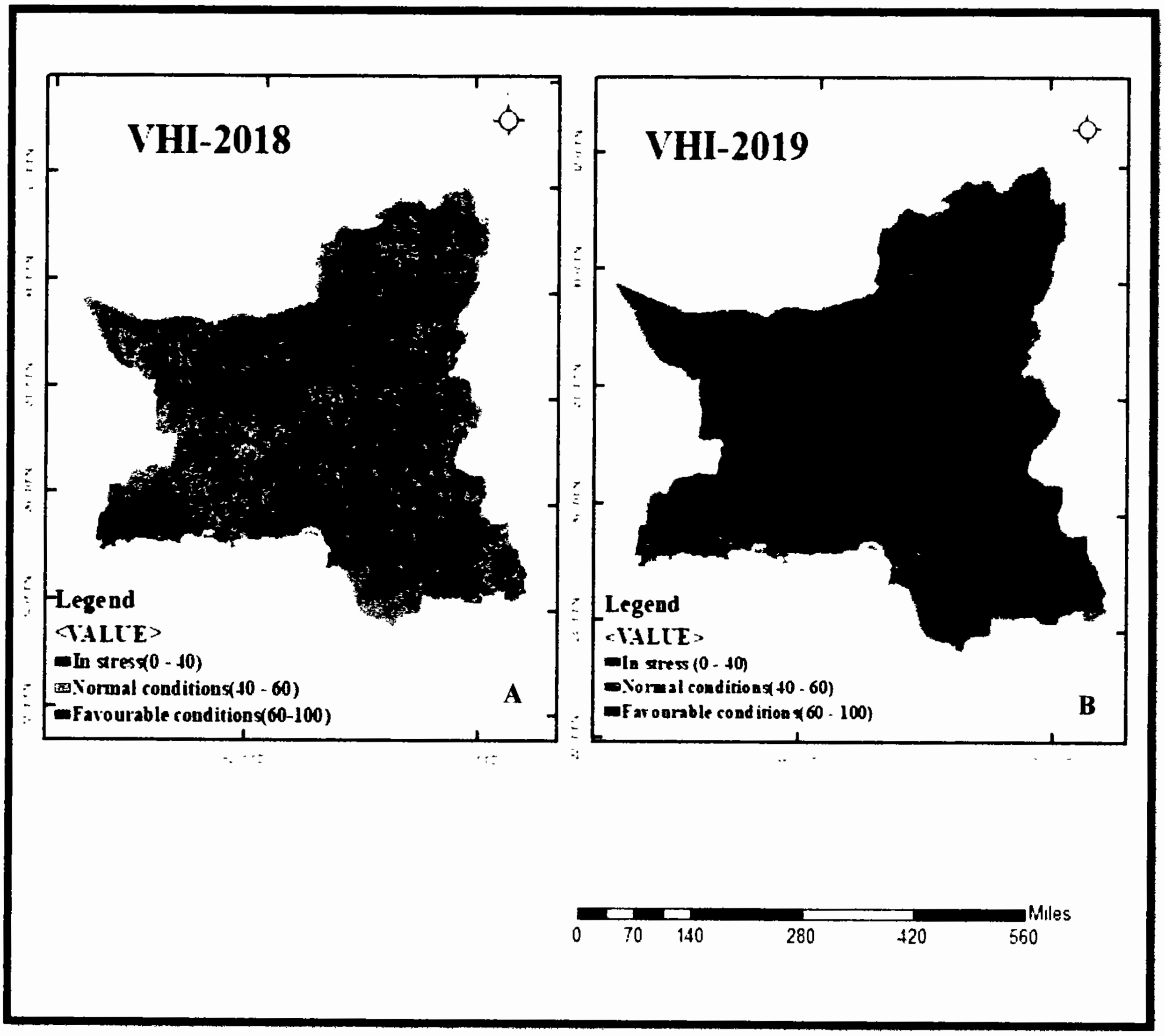

Figure 12. Spatio-temporal distributions of VHI during drought period of 2018–2019 in Sindh and Balochistan. (A) VHI trend in 2018, and (B) VHI trend in 2019

4.4 Area and percentage change detection of NDVI and VHI

4.4.1 Change detection of NDVI

The area and percentage change of NDVI is shown in Table 13. The area covered by vegetation was 12.8979km² in 1998 and 3702.798km² in 1999 which indicates removal of 0.748km² vegetation cover within one year. In 1998 low density vegetation cover, barren land and rocks covered an approximate area of 4587.1km², but in 1999 it has increased to 90666.2 km². Initially the percentage of vegetation cover in 1998 was 0.002% but in 1999 it changed to 0.751%, whereas the percentage of barren land and rocks has increased from 0.930% in 1998 to 18.401% in 1999, which means barren land area has increased in 1999 as compared to previous year due to less rainfall and drought conditions in Sindh and Balochistan. The total area change by vegetation cover from 1998 to 1999 was 3689.9 km² that is 0.74%.

In 1999 low density vegetation cover, barren land and rocks covered an area of 90666.2 km², but in 2000 it has increased to 136705.5km², which means that the area covered by barren land and rocks has increased from 18.40% to 27.74%. The percentage of vegetation cover in 1999 was 0.75% and in 2000 it was 1.09% that means area covered by dense vegetation has slightly increased as compared to previous year in Sindh and Balochistan. The total area change by vegetation cover from 1999 to 2000 was 1673.72km² that is only 0.339%. Data values clearly shows that barren land area has been increased throughout the drought period due to water scarcity.

The area covered by vegetation was 5376.52km² in 2000 and it has drastically decreased to 18.3975km² in 2001.the percentage of vegetation cover in 2000 was 1.09% which is 0.003% in 2001, which indicates removal of vegetation cover within one years. In 2000 low density vegetation cover, barren land and rocks covered an area of136705.5km², but in 2001 it has decreased to 27.744km². The percentage of barren land and rocks has decreased from 27.7% in 2000 to 0.52% in 2001, which means barren land area has decreased in 2001 as compared to previous year in Sindh and Balochistan. The total area change by vegetation cover from 2000 to 2001 was -5358.12km² that is -1.091% which means vegetation has been decreased in 2001 as compared to 2000.

In 2001 low density vegetation cover, barren land and rocks covered an area of 2608.12km², but in 2002 it has increased to 202.922 km², which means that the area covered by barren land and rocks has decreased from 0.52% to 0.04%. The percentage of vegetation cover in 2001 was 0.003% and in 2002 it was 0.004% that means there is no major difference in vegetation cover as compared to previous year in Sindh and Balochistan. The total area change by vegetation cover from 2001 to 2002 was 1.5516km² that is only 0.004%.

The second major drought in Sindh and Balochistan was from 2004 to 2005.The area covered by green vegetation cover was 1697.97 km² in 2004 and it has slightly increased to 13120.56 km² in 2005.the percentage of vegetation cover in 2005 is 2.66% which is 0.003% was 0.34% in 2004, which indicates that vegetation cover has been increased in 2005 as compared to previous drought year. In 2004 low density vegetation cover, barren land and rocks covered an area of9263.34 km², but in 2005 it has increased to 23019.48km². The percentage of barren land and rocks has increased from 1.880% in 2004 to 04.67% in 2005, which means barren land area has increased in 2005 as compared to previous year in Sindh and Balochistan. The total area change by vegetation cover from 2004 to 2005 was 1673.72km² that is 0.339 % which means vegetation has slightly increased in 2005 as compared to 2004.

2018-2019 was the third major drought period in Sindh and Balochistan. The area covered by green vegetation cover was 13010.95 km² in 2018 and it has slightly decreased to 9085.74 km² in 2019.the percentage of vegetation cover in 2018 is 2.64% and in 2019 its 1.84%, which indicates that vegetation cover has been decreased in 2019 as compared to previous drought year. In 2018 low density vegetation cover, barren land and rocks covered an area of196703.7 km², but in 2019 the area covered by barren land and rocks was drastically increased to481256.6km². The percentage of barren land and rocks has increased from 39.921% in 2018 to 97.67% in 2019, which means barren land area has increased in 2019 as compared to previous drought year in Sindh and Balochistan. The percentage change for barren land and rocks in 2018-2019 drought period is 57.75%, which means 57.75% area has been converted into barren land due to less availability of water and growing drought conditions in Sindh and Balochistan. The total area change by vegetation cover from 2018 to 2019 was -3925.2km² that is -0.796 % which means vegetation has slightly decreased in 2019 as compared to 2018.

From the above data analysis it is clear that all types of vegetation are affected by the drought conditions in Sindh and Balochistan. In terms of total vegetation area the maximum change is occurred on low density vegetation, barren land and rocks category. The high density vegetation is relatively less affected as compared to barren land.

Table 13. Area and percentage detection change of NDVI

Years	NDVI classes	NDVI Classes Area				Area and Percentage Change between two years	
		1998		1999		1998-1999	
		Km^2	%	Km^2	%	Km^2	%
1998-1999	Water, snow	488122	99.06	398353	80.847	-89769	-18.219
	Barren land, rocks	4587.1	0.930	90666 2	18.401	86079.1	17 470
	Vegetation	12.8979	0.002	3702.798	0.751	3689.9	0.748
1999-2000		1999		2000		1999-2000	
	Water, snow	398353	80.847	350640	71.163	-47713	-9 683
	Barren land, rocks	90666.2	18.401	136705.5	27 744	46039.3	9.343
	Vegetation	3702.78	0.751	5376.522	1.091	1673.724	0.339
2000-2001		2000		2001		2000-2001	
	Water, snow	350640	71.163	490095.6	99 470	139455.6	28.306
	Barren land, rocks	136705.5	27.744	2608.012	0 5293	-134094	-27 215
	Vegetation	5376.522	1.0911	18.3978	0.0037	-5358 12	-1.091

		2001		2002		2001-2002	
2001-2002	**Water, snow**	490095.6	99.470	492499.2	99.954	2403.6	0.484
	Barren land, rocks	2608.012	0.529	202.9221	0 041	-2405 09	-0.488
	Vegetation	18.3978	0.003	19.9494	0.004	1 5516	0.004
		2004		**2005**		**2004-2005**	
2004-2005	**Water, snow**	481760 7	97.775	456582	92.665	-25178.7	-5.110
	Barren land, rocks	9263.34	1.880	23019.48	4.671	13756.13	2.791
	Vegetation	1697.973	0.344	13120.56	2 662	11422 59	2.318
		2018		**2019**		**2018-2019**	
2018-2019	**Water, snow**	283007.4	57.437	2379.641	0.482	-280628	-56.954
	Barren land, rocks	196703.7	39.921	481256.6	97.673	284552.9	57.751
	Vegetation	13010.95	2.640	9085.748	1.843	-3925.2	-0.796

4.1.1 Change detection of VHI

The area and percentage change of VHI is shown in Table 14. The areas of Sindh and Balochistan covered with little to no vegetation cover and are under stress conditions due to droughts covered an area of 1384.39 km^2 in 1998 and 434771.4 km^2 in 1999 which indicates that 433387km^2 vegetation cover has been disappeared in previous one year. Data clearly shows that in 1998areas that had normal vegetation comprises of22202.02km^2 of Sindh and Balochistan and in 1999 it has increased to 2334960km^2. The percentage of normal vegetation cover in 1998 was 4.505% and in 1999 it was 47.38%, whereas the percentage of vegetation that is under stress has increased from 0.28% in 1998 to 4.505%., which means vegetation that was under stress conditions has increased in 1999 as compared to previous year due to less rainfall and drought conditions in

Sindh and Balochistan. The areas that comes under the category of favorable vegetation covers an area of 469135.6km² in 1998 and 2157489 km² in 1999. The total area change by vegetation cover under stress from 1998 to 1999 was 433387km² that is 8.542%.

In 1999areas that had normal vegetation covered an area of 2334960 km² of Sindh and Balochistan and in 2000 it has decreased to 116629.2 km². The percentage of normal vegetation cover in 1999 was 47.38% and in 2000 it was 23.67%, whereas the percentage of vegetation that is under stress has decreased from 8.823% in 1999 to 2.891% in 2000, which means less areas of Sindh and Balochistan were covered with vegetation that was under stress conditions in 2000 as compared to 1999. The areas that comes under the category of favorable vegetation covers an area of 2157489 km² in 1999 and 361845.1 km² in 2000. The total area change by vegetation cover under stress from 1999 to 2000 was -420523.67km² that is -5.93%.The areas of Sindh and Balochistan covered with little to no vegetation cover and are under stress conditions due to droughts covered an area of 434771.4 km² in 1999 and 14247.73 km² in 2000. From above analysis it is clear that areas that covers vegetation that is under stress and normal vegetation cover has been decreased in 2000 as compared to previous drought year.

The percentage of normal vegetation cover in 2000 was 2.891% and in 2001 it was 4.993%, which means normal vegetation cover is slightly increased in 2001, whereas the percentage of vegetation that is under stress has increased from 2.891% in 2000 to 4.993% in 2001. In 2000areas that had normal vegetation covered an area of 116629.2 km² of Sindh and Balochistan and in 2001 it has increased to 25123.6 km². The areas that comes under the category of favorable vegetation comprises an area of 361845.1 km² in 2000 and 116448.5 km² in 2001. The total area change by vegetation cover under stress from 2000 to 2001 was 108902.2km² that is 22.10%.The areas of Sindh and Balochistan covered with little to no vegetation cover and are under stress conditions due to droughts covered an area of 14247.73 km² in 2000 and 123149.9 km² in 2001. Above analysis clearly shows that areas that covers vegetation that is under favorable vegetation category has been decreased from 73.43% in 2000 to 23.63% as compared to previous drought year.

2001-2002 drought year is considered as the worst year as compared to the other drought years in Sindh and Balochistan The areas of that are covered with little to no vegetation cover and are under stress conditions due to droughts covered an area of 123149.9 km² in 2001 and 491687.9 km² in 2002 which indicates that 368538 km^2 vegetation cover has been disappeared within one year. Data clearly shows that in 2001areas that had normal vegetation comprises of 253123.6 km^2 of Sindh and Balochistan and in 2002 it has decreased to 1014.812 km^2. The percentage of normal vegetation cover in 2001 was 51.3% and in 2002 it was 0.20%, whereas the percentage of vegetation that is under stress has increased from 4.993% in 2001 to 99.79% in 2002, which means vegetation that was under stress conditions has increased in 2002 as compared to previous year due to less rainfall and drought conditions in Sindh and Balochistan. The areas that comes under the category of favorable vegetation covers comprises an area of 116448.5 km^2 in 2001 and 18.2133 km^2 in 2002. The total area change by vegetation cover under stress from 1998 to 1999 was 368538km^2 that is 74.79%. Given values and there percentages clearly shows that areas that had normal to favorable vegetation cover has been drastically decreased in 2002 as compared to the previous four drought years.

In 2004 and 2005 areas that comes under the category of normal vegetation covered an area of 292800 km^2 of Sindh and Balochistan. The percentage of normal vegetation cover in 2004 and 2005 are same and that was 61.51%, whereas the percentage of vegetation that is under stress has decreased from 23.7% in 2004 to 14.7% in 2005, which means less areas of Sindh and Balochistan were covered with vegetation that was under stress conditions in 2005 as compared to 2004. The areas that comes under the category of favorable vegetation covers an area of 70041.22 km^2 in 2004 and 1131237 km^2 in 2005. The total area change by vegetation cover under stress from 2004 to 2005 was -43082.5km^2 that is -9.0516%. Percentage of areas that are covered with good vegetation cover increased from 14.71% in 2018 to 23.76% in 2019, from this we can conclude that in 2018-2019 drought period 2019 was better as compared to 2018.

2018-2019 drought year is also considered as one of the worst drought period in Sindh and Balochistan with respect to food security issues. The areas that are covered with little to no vegetation cover and are under stress conditions due to droughts covered an area of 60161.13 km^2 in 2018 and 126314.5 km^2 in 2019 which indicates the removal of 66153.37 km^2 of green vegetation cover within one year. Data clearly shows that in 2018 and 2019,areas that had normal vegetation comprises of 306246.3 km^2 of Sindh and Balochistan The percentage of favorable vegetation cover in 2018 was 25.63% and in 2019 it was 62.15%, whereas the percentage of vegetation that is under stress has increased from 12.2% in 2018 to 25.63% in 2019, which means vegetation that was under stress conditions has increased in 2019 as compared to previous year due to less rainfall and drought conditions in Sindh and Balochistan. The areas that comes under the category of favorable vegetation covers comprises an area of 126314.5 km² in 2018 and 60161.13 km² in 2019. The total area change by vegetation cover under stress from 2018 to 2019 was 66153.37km² that is 13.42%. Given values and there percentages clearly shows that areas that had under stress conditions has been increased in 2019 as compared to the previous drought year.

From the above analysis of VHI area and percentage change detection it is clear that droughts effects all types of vegetation. In terms of total vegetation cover 2002, 2004 and 2019 considered as the worst years in drought history of Sindh and Balochistan due to their destructive effects on vegetation, food security and wellbeing of residents.

Table 13. Area and percentage detection change of VHI

Years	VHI classes	VHI Classes Area				Area and Percentage Change between two years	
		1998		1999		1998-1999	
		Km²	%	Km²	%	Km²	%
1998-1999	In stress	1384.394	0.280	434771.4	4.505	433387	8.542
	Normal	22202.02	4.505	2334960	47 389	2312758	42.883
	Favourable	469135.6	95 21	2157489	43 787	1688353	-51.425
1999-2000		1999		2000		1999-2000	
	In stress	434771 4	8.823	14247.73	2.891	-420523.67	-5.932
	Normal	2334960	47.389	116629.2	23 670	-2218330.8	-23 718
	Favourable	2157489	43.787	361845.1	73 437	-1795643.9	29.650

		2000		2001		2000-2001	
2000-2001	In stress	14247.73	2.891	123149.9	4.993	108902.2	22.102
	Normal	116629.2	23.670	253123.6	51.372	136494.4	27.702
	Favourable	361845.1	73.437	116448.5	23.633	-245397	-49.804
		2001		2002		2001-2002	
2001-2002	In stress	123149.9	4.993	491687.9	99.790	368538	74.796
	Normal	253123.6	51.372	1014.812	0.205	-252109	-51.166
	Favourable	116448.5	23.633	18.2133	0.003	-116430	-23.63
		2004		2005		2004-2005	
2004-2005	In stress	113123.7	23.767	70041.22	14.715	-43082.5	-9.0516
	Normal	292800	61.517	292800	61 517	0	0
	Favourable	70041.22	14.715	113123.7	23.767	43082.48	9.0516
		2018		2019		2018-2019	
2018-2019	In stress	60161.13	12.209	126314.5	25.636	66153 37	13.4261
	Normal	306246.3	62.153	306246.3	12.209	0	-49.944
	Favourable	126314.5	25.636	60161.13	62.153	-66153.4	36.51792

4.2 Food Security issues due to droughts:

Food security deals with how much people have access to sufficient amount of affordable and nutritious food with the state of having reliable source. The lack of food security and related issues due to drought conditions has strong economic and social impacts on citizens. First, ensuring food security within the country or region requires huge amount of money to ensure food is sufficient for everyone, and also helps to social safety programs that includes direct transfers of goods and food to poor citizens. In case if the food is not sufficient for citizens due to any factor such as droughts, floods or any other environmental factor, the government has to ensure food availability to all affected areas, According to the UN Food and Agriculture Organization (FAO), high rate of famine or hunger can cost an economy around 3-4 % of GDP of country. In case of Pakistan, studies suggest that malnutrition and its outcomes due to any environmental factor cost around 3 % of GDP (US$ 7.6 billion) every year.

The drought of 1998-2002 is considered as worst and most effecting in 50 years history of Pakistan. In 1997, El-Nino developed that results in drought conditions, but the intensity of drought increases in 1998 and reached its peak in 2000 till 2001 and thus gradually decreases in 2002. This extreme drought also leaves it its impacts on India and Afghanistan as well. The World Bank also warned that the drought would also effect economic growth of Pakistan.Balochistan and Sindh were the most effected provinces where the drought was at its peak, around 26 districts of Balochistan were suffering from severe famine as a result of this drought, and around 1.2 million people in the province were affected by the great drought. Nushki was one of the worst-affected areas, which lies close to the border with Afghanistan. At that time Nushki had not seen any rainfall for the last 5 years. During 1999-2000 alone, 143 persons and 2.5 million livestock heads died due to the severe drought conditions. In Balochistan this drought affected more than one-and-a-half million people and killed around two million animals. In Sindh, as a result of severe water shortages and dehydration around 127 people died, mostly in the Tharparkar region near the Indian border, nearly 60% of the inhabitants of Sindh migrated to irrigated land. In both Balochistan and Sindh tens of thousands of people were affected by this drought

The drought of 2004-2005 was an on and off phenomenon, the drought effected mostly the lower parts of Pakistan mainly Balochistan and Sindh, However no damage or death was reported during this drought period (Anjum *et al.*, 2012). In 2004, no rain fall was recorded in the Karachi as well as in Sindh province but during the month of October heavy rain lashed different parts of Sindh due to Cyclone Onil, but even that rainfall was not enough for the drought to die. In 2005, the drought conditions continued in the Sindh and Balochistan province including Karachi city, but a post-monsoon low pressure dumped heavy rains during 12 and 13 September. The drought intensity weakened but quickly re-gained its intensity and in 2006 fears of major drought like the "extreme drought of 1998-2002" caused fear among the people. In 2005, Pakistan received 40 % less rainfall than average levels in winter, while snowfall in many northern areas was also 20-25% below normal.

In 2018 Pakistan received reduced rainfall during the monsoon season (May to August) as compared to previous years, with Sindh 69.5 % and Balochistan 45 % below than average. This has resulted in acute water scarcity, and shortage of food and fodder. The Government of Pakistan estimates that around 5 million people in 26 districts were affected in Sindh and Balochistan by this drought. (Gov/UNCT, 20 Aug 2019).2018-2019 droughts affected around five million people in Sindh and Balochistan Provinces. More than 70 % of households reported to be food insecure and malnutrition rates having increased to 30 % in drought affected areas. Acute malnutrition effected Sindh and Balochistan during 2018-2019 making it a major public health problem in these districts, around 0.4 million children who are under the age of 5, more than half of all children aged 6-59 months in the 14 districts that are effected by drought in Balochistan,. From May to August 2019 around 396,000 of the approximately 738,000 children of age 6-59 months were suffering from acute malnutrition during this drought period

CHAPTER. 5

Conclusion and Recommendations

5.1 Conclusion

Droughts have always plagued Sindh and Balochistan. Droughts in these provinces can have a devastating effect on the local economy because of their geographic location and socioeconomic status. For this reason, Balochistan has felt the effects of the drought more acutely than Sindh, Pakistan's second-poorest province, due to its heavy reliance on agriculture (irrigated and non-irrigated) and cattle. Drought season saw a decline in both surface and subsurface water resources. Drought conditions in Balochistan province worsened as karezes, springs, and the majority of tube wells dried up between 1998 and 2002. The 1998-2002 drought is often regarded as Pakistan's worst and most debilitating in the country's fifty-year history. Since 1997, El-Nino has been causing droughts, although the intensity of the drought has increased in 1998 and reached its height in 2000-2001 and then progressively decreased in 2002. The lack of water during prolonged periods of drought causes a shortage of food. Both Sindh and Balochistan, two of the most badly affected provinces, have seen significant drops in their water tables as a result of periodic droughts and the overuse of groundwater resources, according to Ahmad *et al.*, 2016. Droughts in Sindh and Balochistan have caused farming households to lose revenue from both on and off the farm. Droughts contributed to the worsening of the situation by causing the loss of cattle. Due to drought circumstances, individuals were compelled to shift their livelihoods from farming to daily wage labor and small-scale commercial activity in urban areas. As male family revenue sources dried up, so did the number of activities in which children were involved and the number of women generating money at home. A shortage of funds and revenue drove farmers to seek out loans from a variety of sources to cover their basic family necessities, such as food, shelter, clothes and medical care as well as water for drinking and transportation. Drought conditions have affected all types of vegetation according to the aforementioned analysis of VHI and NDVI area and percentage change detection. Since they had such devastating impacts on the region's vegetation, food supply, and general well-being, the years 2002, 2004, and 2019 are regarded the worst drought years in Sindh and Balochistan history in terms of total vegetation. There has been a significant increase in the amount of low density vegetation, bare ground, and rocks in the overall vegetation area. High-density vegetation is less affected than barren areas in terms of climate change.

This part of Pakistan is desert and has suffered a severe severity of drought, so the government must take preventative measures to minimize the loss of life and property due to drought in this area, as shown on the VHI maps. Drought preparedness plans should be developed instead of crisis management policies. As droughts become more common, it's crucial to understand how and why they occur, as well as how to recognize and quantify drought patterns (Bates *et al.*, 2008). As a result, it is hoped that this study will serve as a starting point for subsequent drought research.

5.2 Recommendation

There must be a comprehensive response to drought. As different sections of Pakistan suffer from varying degrees of drought, less food is produced and hence a scarcity of food and other nutritional items is experienced. Several national and international proposals and efforts are required to combat the effects of climate change and food scarcity in Pakistan. The first step is to develop a long-term foreign strategy in order to participate in global efforts to minimize damaging greenhouse gas emissions at the trans-border level. The emission of these dangerous gases can be reduced locally by investing in public transportation, halting industrialization, promoting the green economy, and facilitating improved agricultural practices for farmers, among other measures. To begin with, succeeding Pakistani administrations must concentrate on modernizing agriculture, improving water management through the construction of dams and reservoirs, as well as limiting rapid population expansion. Large reservoirs must be built to retain excess water so that it may be used in times of drought and in the winter to prevent the country from being inundated by floods caused by uneven precipitation and the additional melting of glaciers during the summer season. There are several ways to teach people about climate change and its various components such as droughts and water conservation; this can be done through media.

CHAPTER. 6

References

6. References:

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INTERNATIONAL ISLAMIC UNIVERSITY ISLAMABAD

Title: Analysis of Vegetation Health Index (VHI) in drought prone areas of Pakistan and related food security issues

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