Development of Entropy based Composite Drought Index (CDI) for the assessment of drought condition: A case study of Cholistan, Pakistan

By

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CERTIFICATE

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DEDICATION

This thesis is dedicated to my loving parents who have taken much pain to prosper my life.

ACADEMIC THESIS: DECLARATION OF AUTHORSHIP

I, Aqsa Anwar declare that this thesis and the work presented in it are my own and have been generated by me as the result of my own original research.

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ACKNOWLEDGEMENTS

Glory is to Allah, the Almighty and the Magnificent, perfect in His creations, enlightening us with the gift of knowledge and enabling us to complete our tasks successfully; Blessings upon Prophet Muhammad (peace be upon him) for guiding us towards the right path.

I offer my gratitude to the last Prophet MUHAMMAD (Peace be upon Him and His progeny), who has given the lesson of LOVE, HUMANITY, PARITY, and JUSTICE and also broke the cage of servitude through His golden sayings; to seek knowledge is obligatory for every Muslims.

The saying of the Prophet (Peace be upon Him and His progeny) "Acquire knowledge from cradle to grave" emphasizes the importance of knowledge.

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Aqsa Anwar

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
P	Precipitation
MODIS	Moderate Resolution Imaging Spectroradiometer
ET	Evapotranspiration
LST	Land Surface Temperature
NDVI	Normalized Difference Vegetation Index
PMD	Pakistan Meteorological Department
CDI	Composite Drought Index
SPI	Standard Precipitation Index
MWC	Maximum Wet Condition
MDC	Maximum Dry Condition
FAO	Food and Agriculture Organization
GRACE	Gravity Recovery and Climate Experiment
SPEI	Standardized Precipitation Evapotranspiration Index
MDI	Multivariate Drought Indices
PSDI	Palmer Drought Severity Index
VSWI	Vegetation Supply Water Index

ABSTRACT

Drought is serious and complex natural phenomena that can affect life on the planet in several ways. Droughts can be divided into hydrological (dry condition in rivers and groundwater), meteorological (no or less rainfall) and agricultural (low moisture content in soil) and each type of drought was historically assessed through several indices developed by using their most related variables. However, by the consideration of different variables belongs to different drought indices is momentous to develop a composite drought index (CDI) which incorporates all possible variables belongs to an individual type of droughts. The main objective of the study was to build a modified CDI by considering four variables i.e., precipitation, land surface temperature (LST), Normalized Difference Vegetation Index (NDVI) and evapotranspiration, subsequently validated with standard precipitation index (SPI). Cholistan Desert, Pakistan, was selected for the development of CDI. The satellite products of MODIS TERRA i.e. NDVI, LST and observed precipitation and temperature data obtained from Pakistan Meteorological department (PMD) during selected years 2001, 2005, 2010 and 2015, were utilized. Primarily, the offered CDI was established on the similarities found through the weighted measure (entropy weighted Euclidian distance) and the variance from the potential dried and wettest conditions of the designated study area (Cholistan Desert). The results obtained from developed CDI values indicate that 2001 was the driest year and November is the driest month during whole selected data series (2001, 2005, 2010 and 2015). Further, the obtained results show that the monthly based CDI monthly has a significant correlation with the monthly SPI with least correlation coefficient of 0.90, however, the correlation of CDI with six (6) monthly

SPI was not significant. Overall, results showed that the CDI countered to the variability occurred in the discrete attributes of the drought. It also noticed that the established CDI unbiased, flexible and substantially sound index that can potentially overcome several uncertainties in climate data and conditions of the study region.

Chapter 1

INTRODUCTION

1.1 Background

All around the globe, due to the intervention of climate changes, drought events are a severe problem in the recent era. It is one of the thoughtful ecological issues that affect economic as well as social forms of life in agro-based countries, like Pakistan. Droughts have very diverse meanings which vary according to the problems faced by the people. Like for the farmers, drought is less moistness in the crops. Similarly, low water level in waterways like rivers, canals, ponds and lakes etc, is also a drought as far as hydrology concerns. In the same way crops damage due to deficiency of water directly affects the economy of any state which is also a drought. Thus, it is very hard to describe, what actually drought is.

According to (Wilhite et.al, 2014), drought is a dangerous phenomenon which develops slowly and has extended effects. It can be classified into many types based on the time period for which it has lasted, its intensity, and the area affected. Some major known drought types, which includes meteorological droughts, agricultural droughts, and hydrological droughts, are briefly described, according to the definitions given by San Diego State University, California on their official portal, as follows:-

1.1.1 Meteorological droughts

The duration and intensity of dry period is affected on meteorological drought. Definition of meteorological drought is depending on region due to atmospheric condition. Different countries define meteorological drought in a different way according to climate.

a. According to USA in year 1942, proposed less than 2.5 mm of rainfall in 48 hours.

b. According to Great Britain in year 1936, continuous fifteen days with daily precipitation less than 0.25mm is said to be meteorological drought.

c. Similarly in Libya (1964) annual precipitation which is less than 180 mm is considered as meteorological drought.

d. A period of six days without rain is considered as meteorological drought according to Bali (1964)

1.1.2 Agricultural droughts

Such types of droughts associate with numerous features of meteorological/ hydrological droughts to agricultural effects and aiming on oil water deficits, rainfall shortages, reduced reservoir/ groundwater levels or needed for irrigation, and so forth.

1.1.3 Hydrological droughts

These kinds of droughts generally happens due to the extended precipitation deficits that influence water supply (i.e., lake levels, reservoir, streamflow and groundwater), which potentially causing substantial social impacts. Since geographically areas are interrelated by hydrologic systems, so the effect of meteorological drought may prolong well beyond the limits of the precipitation scarce area.

1.2 Some Major Droughts Examples in World

Availability of water is continuously effecting by the changes in climatic & economic development and due to the urbanization and population growth around the world. Every populous/ inhabitant sector on the globe faces extremely high water scarcity. As around 80 percent of local water is consumed domestically, agriculture and in business domains etc every year, and a portion of that water may also stream back into channels after it's being consumed but still the demand generates race where it is desirable. These water-stressed areas are supposed to be the most susceptible areas for the periodic droughts and with the long-lasting over usage of water resources or poor management of available water in less rainfall years put a particular country into a state of crisis or drought.

Here are some examples of severe droughts that have happened in the past:

a. In Australia, a drought named "Millennium" had persisted country-wide from the year 1995 till late 2009. This drought affected maximum part of the southern Australia, containing its major cities and biggest agrarian regions. The said drought was occurred due to the low rainfall conditions in late 1996 till 1997 and had got severed particularly in the year 2001 and 2002.

b. In northeastern region of Spain, there was a very severe drought in the year 2008 that the Barcelona, capital of Catalonia in the Kingdom of Spain, had to import water by ships from France.

c. From the year 2002 to 2008, NASA’s Gravity Recovery and Climate Experiment (GRACE) twin satellites program found that nowhere on Earth had such groundwater falloff as greater as in northern India. It is then intimated that the huge irrigation is the reason of the loss of 108 cubic kilometers groundwater in Punjab, Haryana, Delhi and Rajasthan. For maximum agricultural production, any area is depend on the irrigation system, so timely measurement of sustainability of groundwater usage is necessary , otherwise it will be cause of agricultural destruction and extreme drinking water shortage which may affect the 114 million people of the region. But in July 2012, around half of India’s residents temporarily faced an energy catastrophe due to a massive grid failure. It was claimed by some experts that this is happened due to the severe drought which had affected the northern India. As low precipitation limits the quantity of power carried by hydroelectric dams, so the local farmers used extra power than normal to start water pumps for irrigation for their crops.

d. During 2006 till 2011, Syria had faced its most horrible crop and drought disaster in its history. The GRACE satellite has shown a frightening rate of fall in total water storage of the Tigris & Euphrates river basins, which was at that time is the second-fastest rate of loss in groundwater storage after India. Other than numerous different religious, political and economic and social factors that have caused Syrian military battle many experts claim that this loss in water availability, mismanagement of resources and agronomic catastrophes was laid a base to population displacements/ migration to nearest cities, which further resulted as unemployment, economic disturbances, food insecurity.

1.3 Droughts in Pakistan

The climate of an Indian sub-continent is mainly categorized as tropical monsoon and the whole region is generally renowned for the variation of rainfall both in terms of magnitude and spatial distribution. Mainly two types of precipitation systems are being seen in this region (a) Northeast or the winter monsoon and (b) Southwest or summer monsoon. Pakistan also falls in this region which faces severe amount of rain in summer monsoon and in winter due to western turbulences. According to the estimate major parts of South Asia faces 70 to 80% of the annual rainfall in summer monsoon (IMD, 2009) and in our country (Pakistan), 60 to 70% annual rainfall happens in summer monsoon during the months of July to September (Chaudhry, 1997).

In Pakistan, droughts are supposed to occur due to numerous types of failures of rainfall in summer monsoon and it is also stated that El Nino and La Nina events have severe effects on monsoon. In a small history of Pakistan, it experiences several droughts in different provinces (National Drought Monitoring Centre PMD, 2014).

Drought is very usual in Pakistan when monsoon season fails to deliver adequate precipitation to the country. The drought of years 1998-2002 is considered as the worst drought in the history of Pakistan. The drought had begun in 1997 due to development of El-Nino which had got intense in the year 1998 and touched its peak in 2000 till 2001.

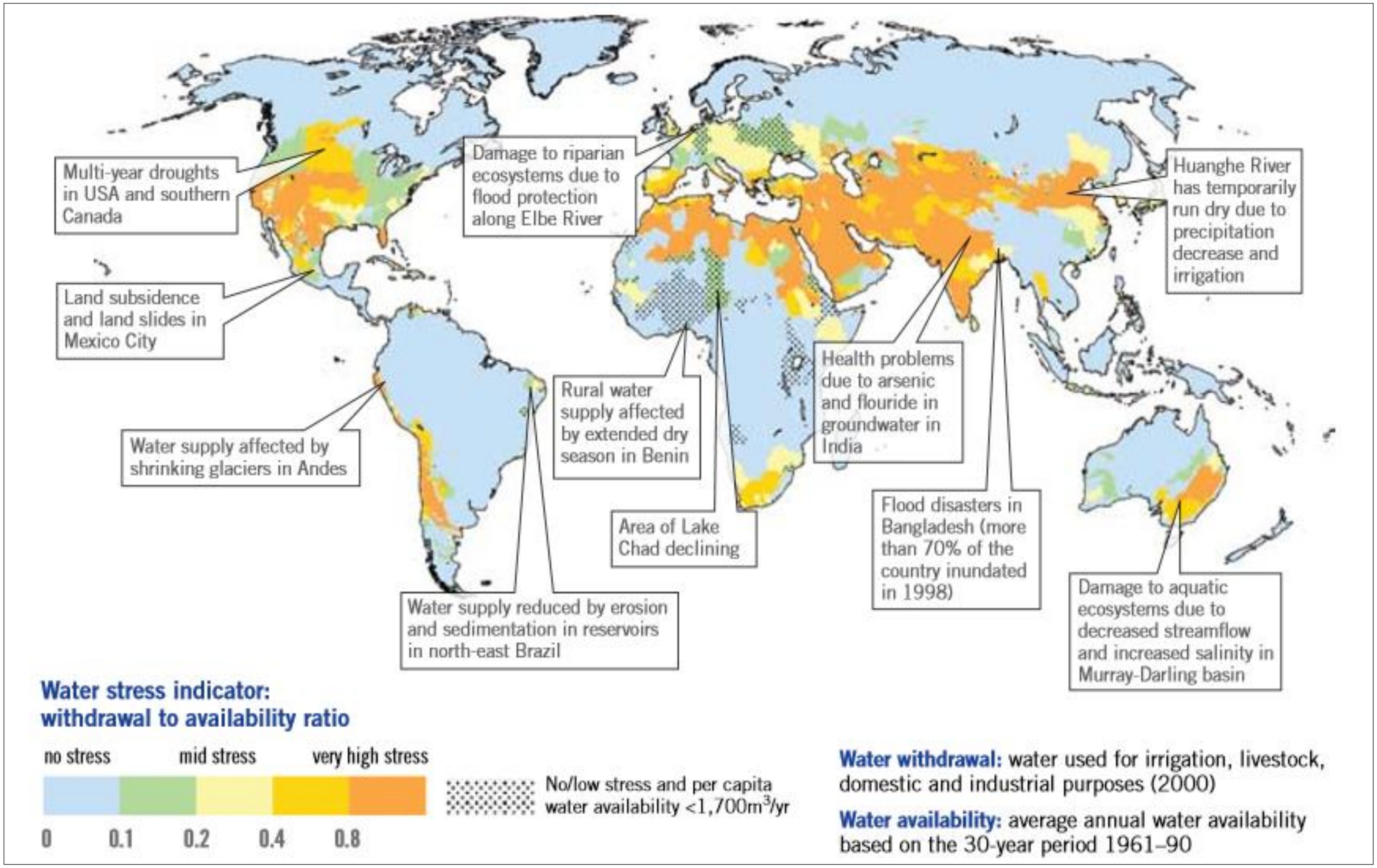


Figure 1.1. Water stress around the world (source: B.C. Bates et al. "Climate Change and Water IPCC," Technical Paper VI of the Intergovernmental Panel on Climate Change).

After 2001 it started fading gradually in 2002. The World Bank notified the government that this particular drought would predictably hit the economy of the country so it denoted several million dollars to aid the nation in this horrified drought situation (Haider, 2006).

1.4 Role of Remote Sensing and GIS in Drought Studies

Satellite-based remote sensing practice has been extensively used in the past few decades for many environmental monitoring activities on the local or global scale. Remote sensing can be used for monitoring the ongoing condition during the disaster event and can able to provide a pre & post event picture of the disaster by providing the baseline data over which further analysis can be done. Whereas GIS techniques offer an appropriate platform to integrate and analyze the various types of data collected from different sources for disaster monitoring (Chopra, 2006).

Droughts impact on every nation's agriculture is an existent issue nowadays but its timely quantification is not difficult now. With the help of satellite-based remote sensing data, drought can easily be quantified 4 – 6 weeks earlier and can be delineated more accurately. Droughts effect on agriculture can also be identified before the harvesting of the crop, which plays a most vital role in global food security and trading (Kogan, 1995). So by the rapid advancements and developments in space technology, problems like drought identification, monitoring and mitigation can be dealt efficiently.

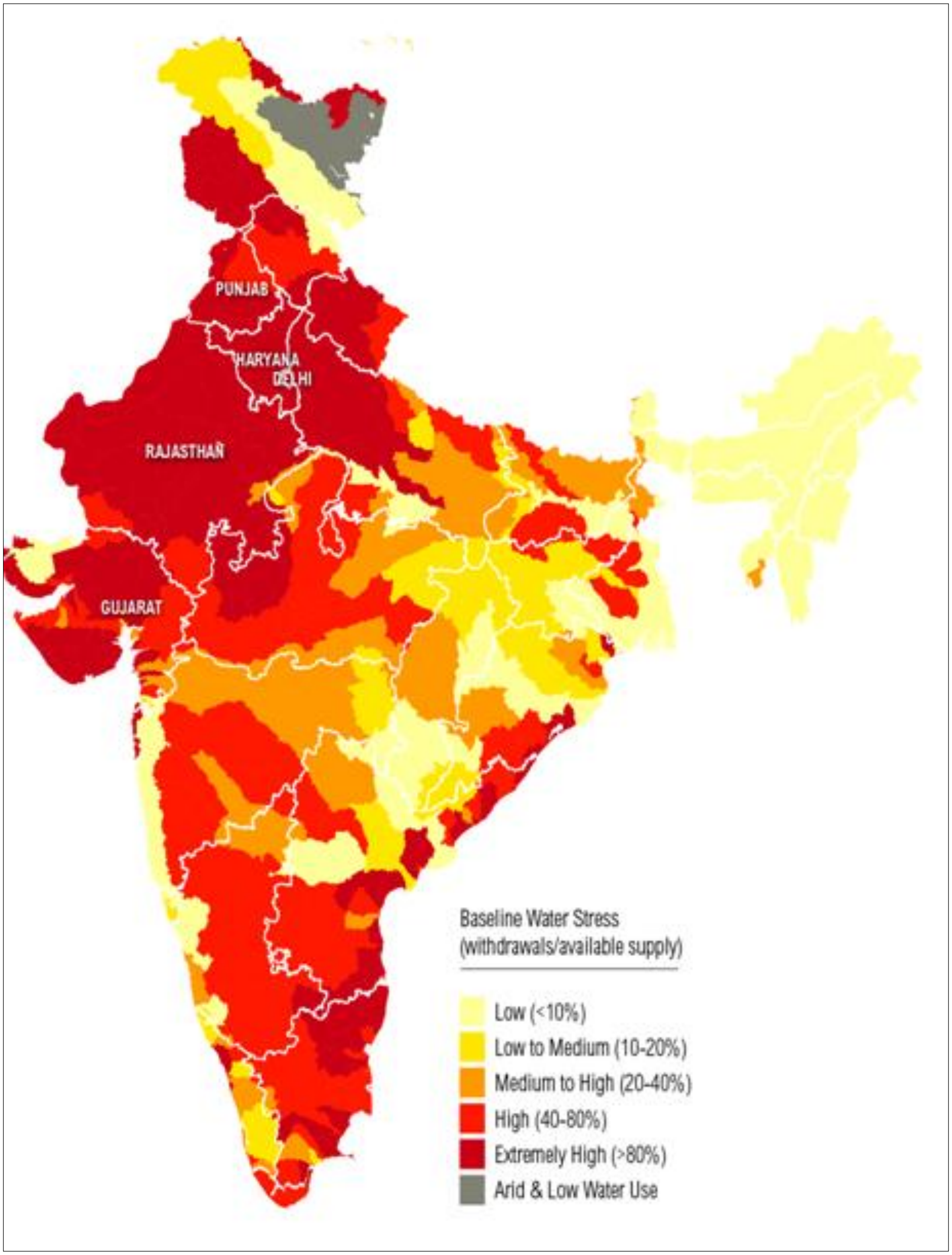


Figure 1.2. Water scarcity in India (source: http://www.indiawatertool.in).

Several remote-sensing-based drought indices are widely used to monitor the drought rather than using observational data because of it easily accessible and inexpensive. There are a lot of drought indices based on remote sensing can be used for drought valuation, e.g. TCI (Temperature Condition Index), VCI (Vegetation Condition Index), NDVI (Normalized Difference Vegetation Index) (Hansen, Krylov, & Tyukavina,2016).

There are a number of advantages of using these remotely sensed data over conventional ground truthing work. The main advantages of using remote sensing data are listed as follows:-

a. Provides continuous spatial measurements across large topographical areas.

b. Provides data for remote locations where deployment of weather stations or field visit.

c. Frequent revisit time for image acquisition like several satellites acquires image data every 1-2 days or a 1-2 week basis for the same location.

d. Provides historical records/ conditions for a specific area.

1.5 Problem statement

Climate change is causing adverse effects on human beings and environment. Greenhouse gas emission is a big reason for climate destruction and Pakistan is one of the countries of the world which will be affected badly in coming era. Drought phenomenon is a serious problem due to the climate issues and negatively affects agricultural and hydrological conditions. The drought occurrence can prove to be a very critical situation for Pakistan as its economy is largely dependent on agriculture. There are number of indices have been established for the study of droughts through all over the world, which is very effective for the drought assessment. Satellite-based technology is very useful for monitoring drought situation. The aim of this research is the development of a drought index which includes multiple drought factors and will be useful for monitoring the temporal variation in drought.

1.6 Objective of the Study

As drought is a natural hazard which causes extensive damage to agriculture and badly affects human life, so studies related to drought are important for its environmental impacts. Drought indices e.g. Standardized Precipitation Evapotranspiration Index (SPEI), Normalized Difference Vegetation Index (NDVI) and Standardized Precipitation Index etc are useful for monitoring and measuring different kinds of droughts i.e. meteorological, hydrological, and agricultural encompassing all parameters like precipitation, NDVI, evapotranspiration and Land Surface Temperature (LST). It is also suitable for managing drought hazard in climate change. The basic goal of this proposed research is to develop a drought index which includes multiple drought factors and will be useful for monitoring the temporal variation in droughts. The objectives of the study are categorized as follows:-

a. To development of Composite Drought Index (CDI) using entropy weighted Euclidian distance method by the integration of NDVI, LST, Evapotranspiration and Precipitation

b. Comparison between CDI, developed by using multiple variables, with SPI, only based on precipitation.

1.7 Traditional use of Remote Sensing for Drought Monitoring

NDVI is a quantitative indicator of the relative richness and activity of green vegetation, which is well correlated with several biophysical characteristics of vegetation, i.e, % green cover, green biomass, chlorophyll content and leaf area index (LAI). It is widely used to assessing vegetation structure, composition, distribution, and stratification. Geographical and sequential distributed rainfall and its impacts on NDVI can be supportive for drought investigation (Imran et. al, 2016).

1.8 Other Indices Based Studies for Drought Monitoring

Numbers of studies have been conducted on drought assessment and mapping by using different remote sensing and GIS-based indices. Drought characteristics are necessary for describing its severity, impacts and hazard assessment (Zargar et. al, 2011) such severities can be evaluated by using drought indices. Several researchers have been carried out studies to establish the different indices for measuring droughts using rainfall, snowpack, stream flow and other water supply etc to estimate drought severity in context of agriculture and hydrology of the region.

McKee et. al, (1993) introduced the SPI index to measure the precipitation shortfall for various period, projecting the effects of precipitation shortage on the accessibility of various water supplies and developed SPI for the accumulative monthly scale to reflect the time-based behavior of the drought. The SPI is designed by measuring the change of the precipitation from the mean for a specific time scale and then dividing with the Standard Deviation.

Usually, NDVI is used for the monitoring of drought condition using red and near infrared (NIR) radiations and having NDVI values range between -1 to +1. As NDVI presented by (Rouse et.al, 1974). A high NDVI index links to the zones of high degrees of evapotranspiration which signifies the thick vegetative cover, considerable soil wetness and penetrable soil. A minor index value links to zones of slight evapotranspiration rate that characterises bare ground or slight vegetation, relatively negligible soil moisture and impervious soils. (Nagarajan et. al, 2003).

Further, the SPEI index is another renowned index for climatic drought which is based on the temperature, precipitation data. It described the temperature effects on the drought assessment (Vicente-Serrano et. al, 2010).

Indeed, the droughts could affect the economy of the country largely therefore, the spatiotemporal variations are essential for sustainable development. Therefore, Wang et. al, (2015) analysed spatiotemporal variations for drought severity in China and compared three indices such as SPI, SPEI and self-calibrating Palmer Drought Severity Index (sc-PDSI) by using precipitation and air temperature on monthly basis and stated that SPEI is more accurate than that of Standardized Precipitation Index (SPI) whereas self-calibrating Palmer Drought Severity Index (sc-PDSI) is milder than actual drought severity. Due to disastrous condition, the forecasting of drought behavior on human beings is necessary. For this purpose, a Tivariate Copula Model with the integration of different indices has been proposed for forecasting of drought. The Standardized Precipitation Evapotranspiration Index (SPEI) has been used for drought transitional properties and related impacts of climate indices in the Pearl River basin, China (Xiao et. al, 2016). Furthermore, Park et. al, (2016) used drought factors based on remote sensing extracted from the Moderate Resolution Imaging Spectro-radiometer (MODIS) and Tropical Rainfall Measuring Mission (TRMM) satellite sensors and produced drought distribution maps which further compared with the U.S. Drought Monitor (USDM) maps.

A multivariate Composite Drought Index (CDI) has been proposed based on entropy weighted Euclidian distance. The TERRA MODIS (NDVI and LST) and in-situ data (rainfall and runoff) have been used for Composite Drought Index (CDI) (Waseem et. al, 2015). Similarly, Multivariate Standardized Precipitation Index (MSPI) (Bazarfshan et. al, 2014) and aggregate Drought Index (ADI) Keyantash and Dracup (2004), also has been developed by using principal component analysis (PCA).

Deepthi et. al, (2014) conducted a study on Multivariate Drought Indices (MDI) for integrated drought assessment. During her study, she developed a new multivariate, multiscalar drought index (MDI) based on entropy weights and then compared it with the Palmer Drought Severity Index (PDSI) within Texas for the time period of 1950 – 2012. From this research, it was concluded that the proposed MDI was found well to map/ quantify drought situations in a specified region. Similarly, Godfrey et. al, (2016) proposed a methodology for integration of agricultural, hydrological and meteorological droughts over a region of Tibetan Plateau. Basically, this research is focused on drought analysis in a typical cold river basin of Tibetan Plateau from 1983 – 2012. In this study, a Rainfall, Snow, and Glacier melt (RSG) standardized anomaly (SA) index was introduced and different droughts indicators were overlaid for droughts hotspot identification. According to the author more research is needed on how best various droughts can be combined other than just overlaying.

Lifu et. al, (2012) studied drought occurrences by using different drought indices namely Palmer drought severity index (PDSI), Z-index and standard precipitation index(SPI) in the Continental United States during 2011 and 2012. In this study, a correlation between remote sensing based combined drought indices and in situ station based drought indices were found and it is inferred that different indices are suitable for different climatic regions. A.P.M Cunha et. al, (2015) has monitored dynamics of vegetative droughts in the semiarid region of Brazil. This research validates the methodology of using remote sensing based Terra-MODIS Normalized Difference Vegetation Index (NDVI) and land surface temperature (LST) products for near-real-time observation of drought situation. This method of integration of land surface reflectance and thermal properties is known as Vegetation Supply Water Index (VSWI) and is tested on the semiarid region of Brazil which shows a high correlation of VSWI with precipitation and soil water content, particularly in dryness. Elaheh et. al, (2016) proposed a methodology for the development of comprehensive drought index and its evaluation by using thirteen normally used drought indices which were aggregated to make a universal drought index named MASH.

Chapter 2

MATERIALS AND METHODS

This study aims for drought assessment of Cholistan desert in Punjab province of Pakistan by using entropy-based Composite Drought Index. For this purpose different type of remote sensing and meteorological data were used and a methodology was developed to accomplish this task. This study is important because it proposes a method for timely mapping of drought condition for better management practices.

2.1 Study Area

In this study, the Cholistan Desert was selected which includes three districts named, Bahawalnagar, Bahawalpur and Rahim Yar Khan located in Punjab province, Pakistan. Total area of this region is about 26,000 km^2 and it is one of the major desert of Pakistan. Its boundary is attach to the Thar Desert in Sindh and some part in India. The word Cholistan was resultant of the Turkish word Chol, which means Desert. So, it can be said that Cholistan is Land of Desert. It is situated in the southern part of Punjab. It is portion of the Great Indian Desert. The Cholistan is 480 km long and 32 to 192 km wide.

2.2 Demography of Cholistan Desert

According to Pakistan Desertification Monitoring Unit (PADMU), Islamabad, about 70 Mha land of Pakistan is arid & semi-arid, which is around 80% of Pakistan’s total geographical land (PADMU, 1983).

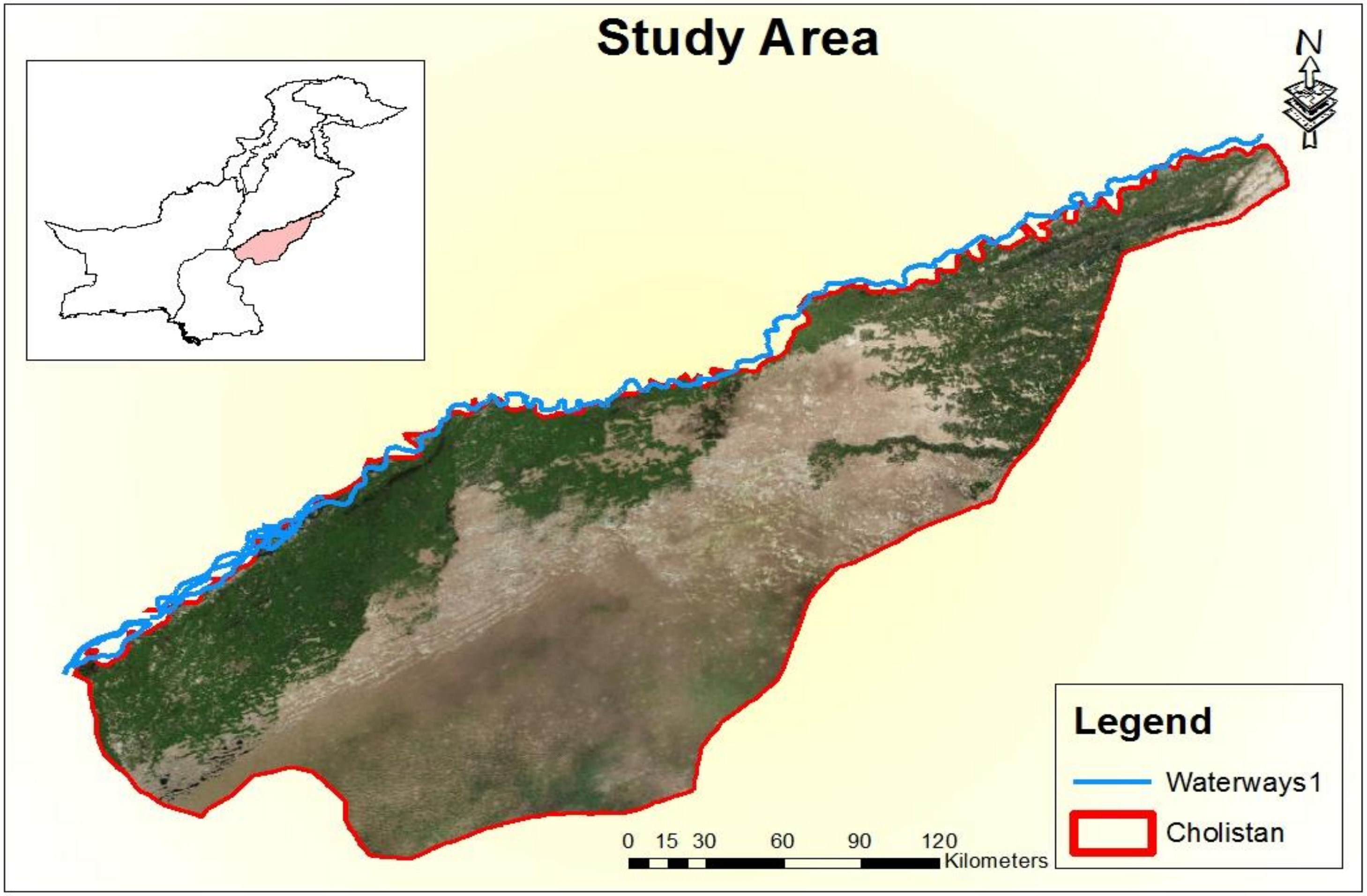


Figure 2.1. Study area Cholistan Desert.

Out of this above mentioned 70 Mha, 41 Mha area is reported to be arid in which approx. 11 Mha deserts where the climate is hyper-arid (Kahlown & Majeed, 2004). These deserts include Cholistan desert of around 2.6 Mha area, which is one of the big deserts in Punjab province. It consists of a loamy soil, sandy soil, sand dune and saline-sodic clayey soil. The reported population in this desert is about 0.11 million and livestock population is nearly 2.0 million. Low and sporadic rainfall (166 mm average annual), high temperatures (up to55° C in summer), low humidity, high rate of evaporation and strong summer winds are the main characteristics of the climate. The groundwater is mostly saline and unfit for human and livestock drinking (PCRWR, 2004).

2.3 Data Collection

Different types of physical/ climatic variables are used in this research, which are further categorized on the basis of their relationship with drought. The said categorized are listed as below:-

a. Y variables which are inversely proportional to drought condition
b. Z variables which are directly proportional to drought condition

Normalized difference vegetation index (NDVI) which is frequently is used for the assessment of vegetation condition and precipitation data which is the main factor for agriculture are found to be inversely proportional to the drought. As low precipitation causes agricultural drought, and high value favours the wet condition. Similarly, the high value of NDVI is an indicator of good vegetation health and vice-versa. Hence these parameters are used as Y variables in this research.

On the other hand, as high temperature favours drought conditions so MODIS (MOD11A2) Land surface temperature (LST) product and Evapotranspiration (ET) data, which are directly proportional to the droughts, are used as Z variables in this research.

Remotely sensed MODIS (MOD13A2 and MOD11A2) data is downloaded from the LP DAAC data portal for the selected years (2001, 2005, 2010 & 2015). However, Precipitation and temperature data for the selected region was taken from the Pakistan Meteorological Department, Islamabad. By using the Blaney-Criddle method, evapotranspiration is calculated from the air temperature and mean daily percentage of annual daytime hours for the 30^{o} latitude is calculated. Table 2.1 shows the dataset details.

2.3.1 Remote sensing data

MOD13A2 NDVI and MOD11A2 LST products of MODIS sensor of TERRA satellite had been used for this research. 92 images of MOD13A2 and 176 images of MOD11A2 of January to December for the years 2001, 2005, 2010 and 2015 were used. The images were acquired at an interval of 16 days for MOD13A2 and 08 days for MOD11A2. The details of MOD13A2 and MOD11A2 are given in Table 2.2.

Table 2.1. Dataset used.

Type	Specifications	Source	Details
Remotely Sensed Data	MOD13A2 & MOD11A2	LP DAAC Data Portal	Satellite Imagery
Meteorological Data	Precipitation, Temperature	Pakistan Meteorological Department, Islamabad	Monthly temperature and rainfall data for studied period
Mean daily percentage of annual daytime hours	Mean daily percentage of annual daytime hours for different latitude	Food and Agriculture Organization	North(30°) Latitude

Table 2.2. Specifications of used MODIS Products.

	Specifications	Details
MOD13A2	Area	~10 x 10 Lat/Long
	Dimensions	1200 x 1200 rows/columns
	Resolution	1 kilometer
	Projection	Sinusoidal
	Data Format	HDF-EOS
MOD11A2	Area	~1100 x 1100 Lat/Long
	Dimensions	1200 x 1200 rows/columns
	Resolution	1 kilometer
	Projection	Sinusoidal
	Data Format	HDF-EOS

2.3.2 Blaney-Criddle method

If un-measured data on pan evaporation is accessible locally, a theoretic technique (e.g. the Blaney-Criddle method) to compute the subject crop evapotranspiration ETo has to be used (Food and Agriculture Organization).

$$ET = p\,(0.46Tmean + 8) \qquad (1)$$

T mean is the mean of the daily temperature and p is mean daily percentage of annual daytime hours for the North (30°) Latitude.

2.3.3 Meteorological data

Metrological data was acquired from Pakistan Meteorological Department (PMD) Islamabad, which includes monthly average temperature and rainfall of years 2001, 2005, 2010 and 2015.

2.4 Methodology

This research was carried out by using a proposed systematic methodological flowchart presenting Figure 2.4. To carry out proposed methodology, satellite imagery of MODIS Terra sensor was downloaded for the years 2001, 2005, 2010 and 2015.

MODIS satellite gives two, MOD13A2 & MOD11A2 products for NDVI and LST data with spatial resolution of 1 km and temporal resolution of 16-and 08-days, respectively. The study area was clipped by using Batch processing in ESRI based ArcGIS environment from downloaded images. As MOD13A2 values were ranged between -2000 to 10000, whereas NDVI values vary between -1 to 1, so images were multiplied by the scale factor of 0.0001. Similarly, the scale factor of LST is 0.02 which was multiplied by the MOD11A2 images for rescaling. The unit of the LST in MOD11A2 product was Kelvin which was converted into standard temperature unit (Centigrade℃). Furthermore, the acquired precipitation and calculated evapotranspiration data using Blaney-Criddle method (as discussed in section 2.3.2) was averaged on monthly basis along with the NDVI and LST values and were used in database DB_L for the selected time eq (2).This data was arranged in Y (NDVI and P) and Z (LST and ET) matrix (m×n) for the drought duration L (weekly, monthly or yearly) for t_i corresponding year. Yij and Zij is the average value of jth Y and Z variables respectively (j=1, 2, 3,…...n).

$$DB_L = \begin{matrix} t_1 \\ \vdots \\ t_m \end{matrix} \left[\begin{pmatrix} X_{11} & \cdots & X_{1n} \\ \vdots & \ddots & \vdots \\ X_{m1} & \cdots & X_{mn} \end{pmatrix} \middle| \begin{pmatrix} Y_{11} & \cdots & Y_{1n} \\ \vdots & \ddots & \vdots \\ Y_{m1} & \cdots & Y_{mn} \end{pmatrix} \right] \quad (2)$$

All data have different scale and dimensions, so, Y and Z matrix was normalized for same scale using Yij/∑Yij for X matrix and Zij/∑Zij for Y matrix. This process is used to transform different scales and units into the common measurable unit for the comparison purpose of the variables. Normalized values of the variables were free from the anomalies. These values were further arranged in a single matrix. Nij is the normalized value corresponding to matrix eq. (3)

$$NDB_L = \begin{matrix} t_1 \\ \vdots \\ t_m \end{matrix} \begin{pmatrix} N_{11} & \cdots & N_{1n} \\ \vdots & \ddots & \vdots \\ N_{m1} & \cdots & N_{mn} \end{pmatrix} \quad (3)$$

The idea of Shannon's entropy contributes a vital role in information theory and is used to mention to a general degree of uncertainty and disorder (Shnon, 1948). Entropy method measures the useful information related to the disorder. It provides better information on the variation among the specific variable. High divergence within the variables indicates small entropy, thus that variable gives more valuable information and the weight should be set high, accordingly. Similarly, small difference indicates high entropy and small weights (Qiu, 2002). As compared to variance, it can provide a useful measure of information and improved characterization (Rajsekhar et al, 2015).

$$EN_j = -\frac{1}{\ln(m)} \sum_{i=1}^{m} N_{ij} \ln(N_{ij}) \quad (4)$$

ENi is entropy corresponding variables.

-1/ln(m) is constant for all variables.

$$DS_j = 1 - EN_j \quad (5)$$

$$EW_j = \frac{DS_j}{\sum_{j=1}^{n} DS_j} \quad (6)$$

EWi is the weights for the individual variables.

Maximum wet condition (MWC) and maximum dry condition (MDC) is defined by the normalized data of the variables. Maximum values (NDVI and P) and minimum values (LST and ET) of the variables were defined the maximum wet condition (WMC).eq (6).

$$d_i^+ = d_1^+,\ d_2^+,\ d_3^+ \ldots\ldots\ldots\ldots\ldots.. d_n^+ \quad (7)$$

Similarly, maximum values (LST and ET) of directly and minimum values (P and NDVI) of inversely related variables were the maximum dry condition (MDC).eq (7)

$$d_i^- = d_1^-, d_2^-, d_3^- \ldots\ldots\ldots\ldots\ldots d_n^- \quad (8)$$

For the computation of CDI for the specific month, weighted Euclidian distance (S_i^+) between present condition (PC) and MWC and the weighted Euclidian distance (S_i^-) between present condition (PC) and MDC was calculated eq (7) to eq (10).

$$S_{ij}^+ = N_{ij} - d_i^+ \quad (9)$$

$$S_{ij}^- = N_{ij} - d_i^- \quad (10)$$

$$S_i^+ = \sqrt{\sum_{j=1}^{n} Ew_j}(S_{ij}^+)^2 \quad (11)$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} Ew_j}(S_{ij}^-)^2 \quad (12)$$

Furthermore, CDI was estimated by using the eq. (13). The ranged of CDI between 0 to 1. The classification of drought is shown in Table 2.3 (Waseem. et. al, 2015)

$$CDI_i = \frac{S_i^-}{S_i^- + S_i^+} \quad (13)$$

Table 2.3. Drought classification.

CDI	Drought intensity
<0.10	Extreme dry condition
0.10-0.20	Severe dry condition
0.20-0.30	Moderate dry condition
0.30-0.40	Mild dry condition
0.40-0.50	Near normal to normal
>0.50	Above normal

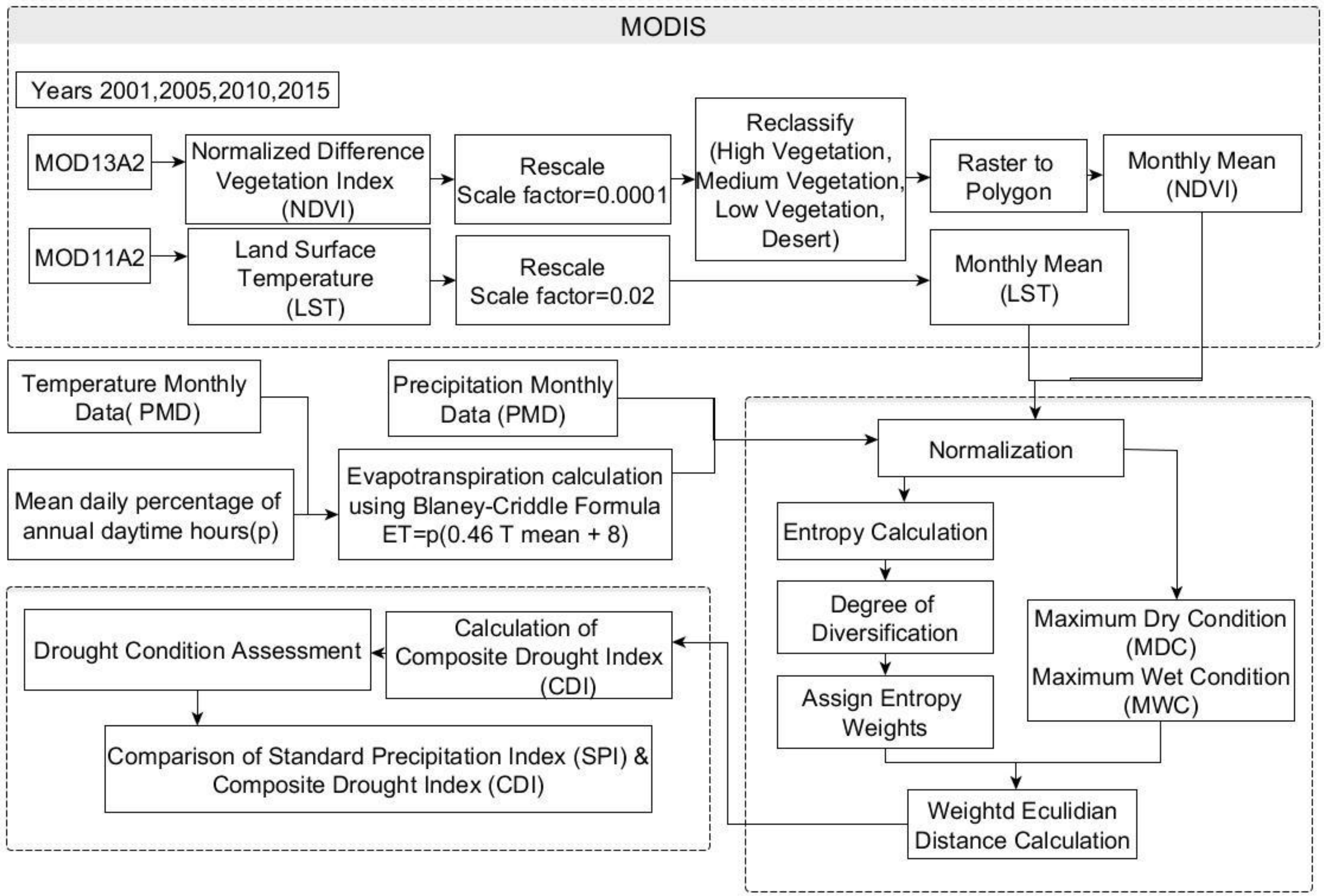


Figure 2.2.Methodology flow chart.

Chapter 3

RESULTS AND DISCUSSION

For the assessment of drought condition, LST, ET, P, and NDVI were found to be very significant factors. Since high value of NDVI indicates the good condition of agriculture and availability of water which is a fundamental factor for the agriculture growth, thus high precipitation ‘P’ prevents prevailing dry condition and help in agricultural (crops) growth. So, NDVI and P have an inverse relation to the drought condition. On the other hand, as water evaporates from the earth surface due to high temperature so high temperature causes evapotranspiration ‘ET’ which further results in a deficiency of water and dry condition. So, LST and ET have a direct relationship (directly proportional) to the drought condition.

Availability of water is a basic need for agriculture land. In the selected region, the agriculture, only exists along the river Indus. Another part of Cholistan is desert and there is no source of water for agriculture. That’s why variation in NDVI along the Indus belt is not significant for 2001, 2005, 2010 and 2010 due to access to water from the river. There was not a great variation in NDVI for the same month of the selected years. Classified images of NDVI in 4 classes are given below Figure 3.1, Figure 3.2, Figure 3.3, and Figure 3.4.

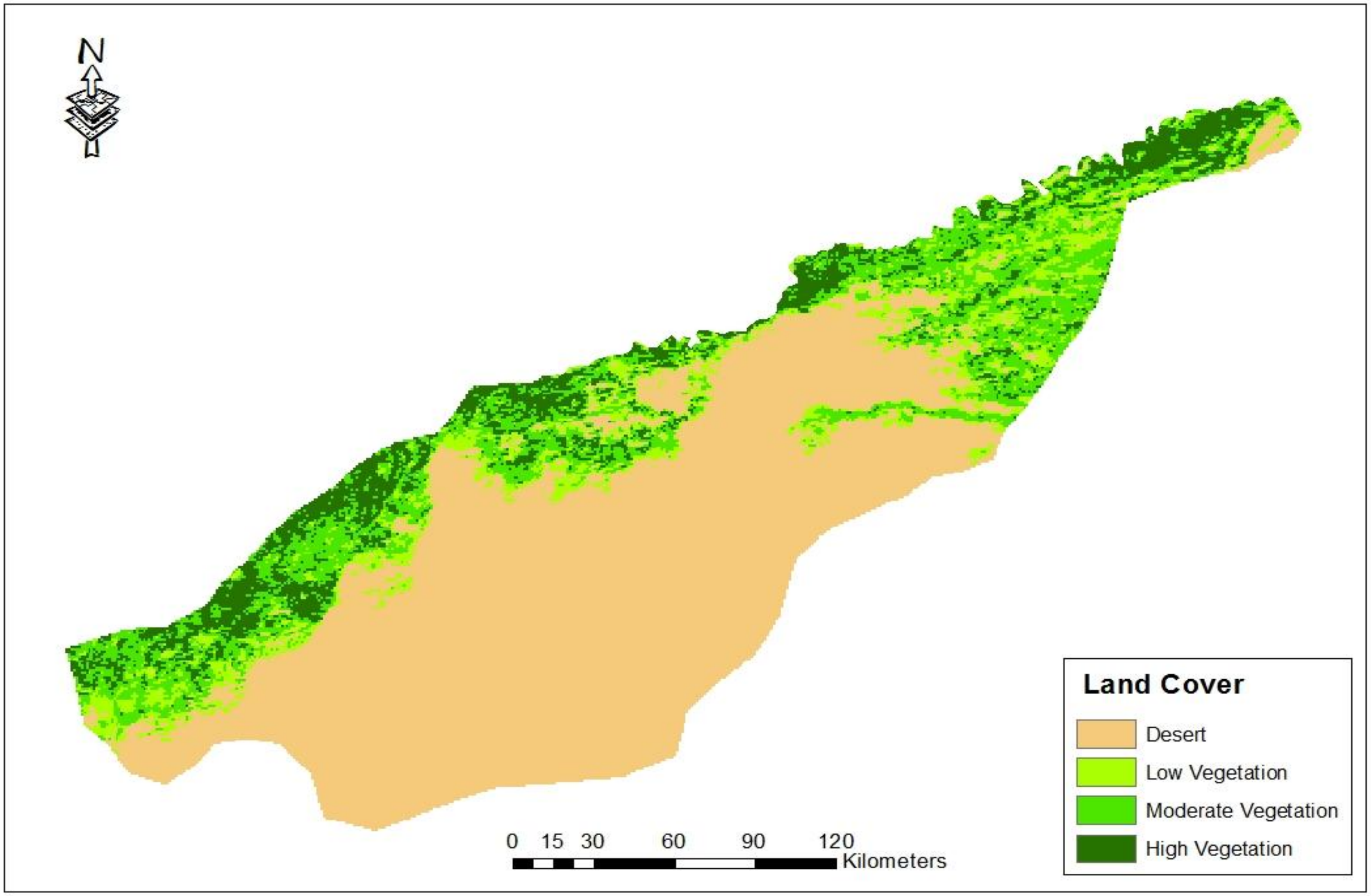


Figure 3.1. Classified NDVI of March 2001.

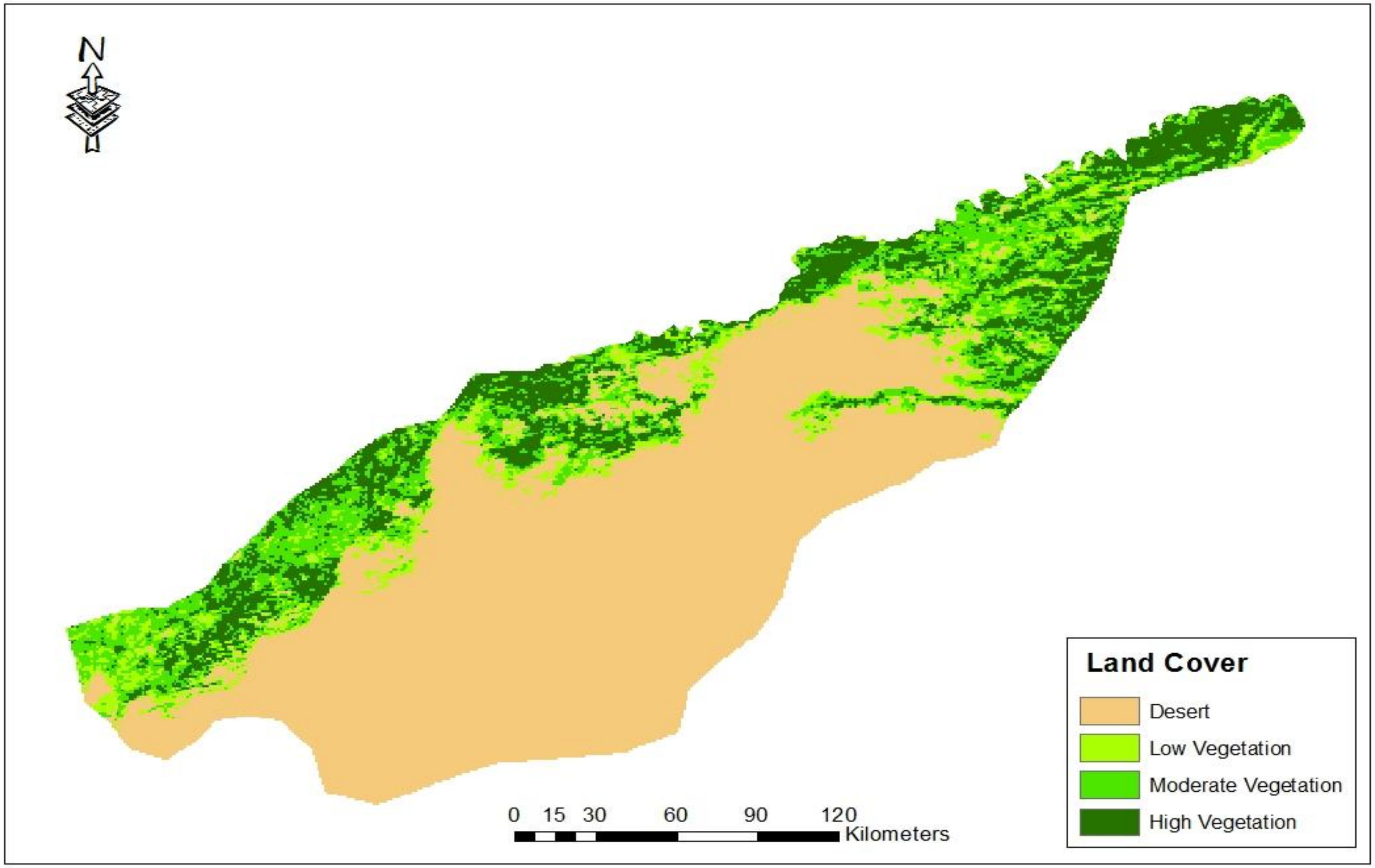


Figure 3.2. Classified NDVI of March 2005.

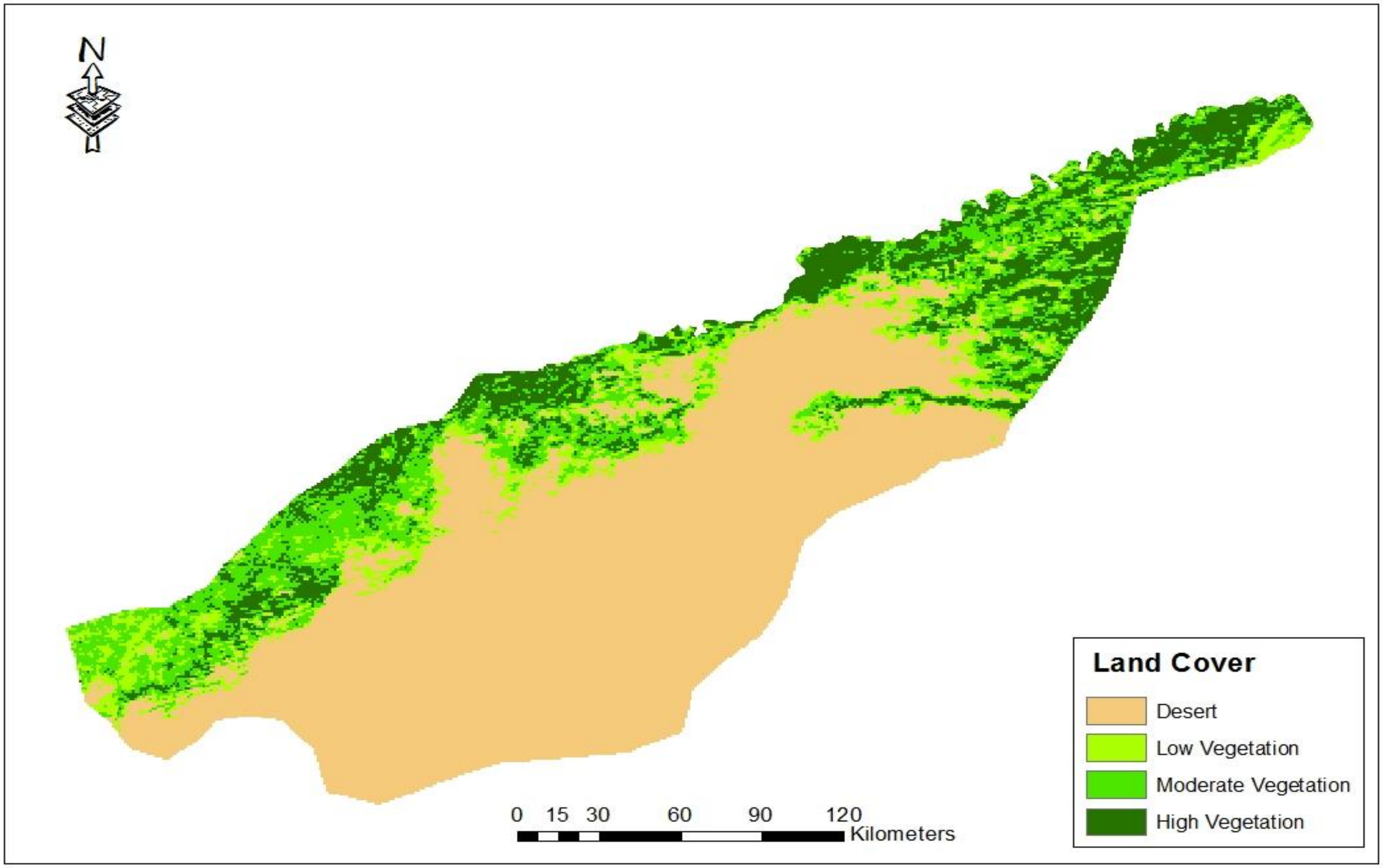


Figure 3.3. Classified NDVI of March 2010.

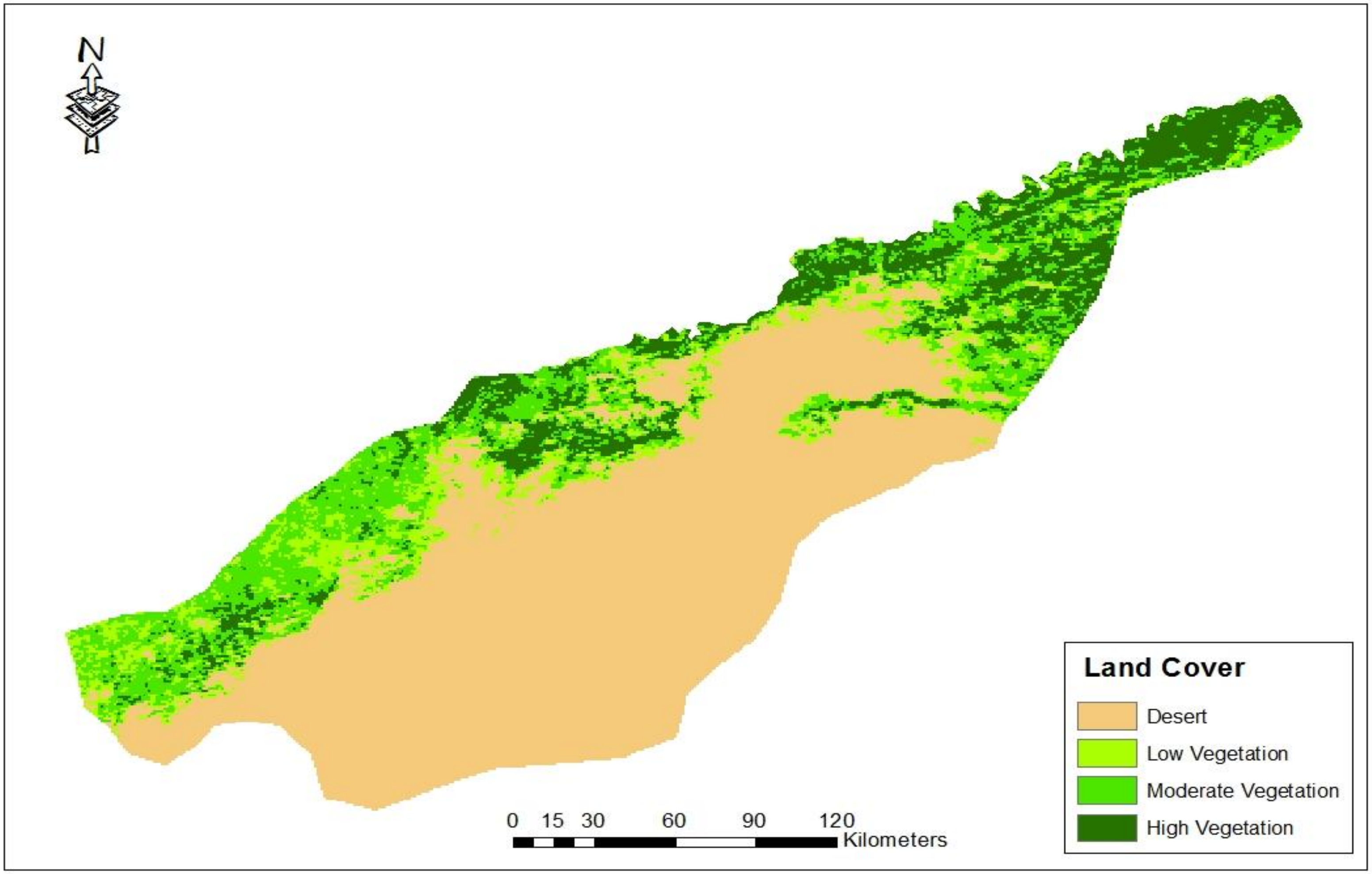


Figure 3.4. Classified NDVI of March 2015.

3.1 Normalized and CDI Calculated data

Table 3.1 depicts the arranged monthly averages of LST, ET, P, and NDVI, for the calculation of CDI. Due to scale and units difference, the data was normalized to transform on the same scale, as discussed in section 2.4 and is shown in Table 3.2. Normalized data were further used to define maximum dry and wet condition (MWC and MDC) for that specific month (e.g March) and is shown in Table3.3. The maximum values of directly affected variables (LST and LST) were 0.266 in the month March 2010 that was the maximum dry condition (MDC) whereas the maximum wet condition (MWC) for LST and ET was in the March 2015 with the values of 0.231 and 0.241respectively.

Similarly, NDVI and P were the inversely proportional to the drought condition. The maximum dry condition (MDC) for the NDVI and P was in March 2010 with 0.227 and 0.014 respectively. But the maximum wet condition (MWC) of NDVI for the month of March was 0.280 in the 2005 and for the maximum wet condition (MWC) was 0.563 in the month March 2015.

Entropy weights were calculated from the eq. (4) to eq. (6), mentioned in section 2.4 and the results are shown in Table3.4 below. The estimated weights for LST, ET, P, and NDVI were found 0.0031, 0.0007, 0.9723 and 0.0046 respectively; whereas, precipitation (P) was assigned the highest weight due to the existence of large uncertainties in data series as compared to other factors, therefore LST, ET, and NDVI were given less weights. By using the proposed methodology and normalized data, MWC, MDC, entropy weights, and the relative distance of PC from MWC and MDC, finally, the CDI has been calculated for each month. Table 3.5 shows an example of calculated CDI for the month of March. From the table, it is observed that March 2010 was the dry having estimated CDI is 0.001 and 2015 was wet having estimated CDI value is 0.9926.

Table 3.1. Monthly average data of March for variables (LST, ET, P, and NDVI).

Years	LST	ET	P	NDVI
2001	35.96	4.92	5.67	0.37
2005	34.06	4.88	25.6	0.42
2010	37.09	5.29	1.07	0.34
2015	32.14	4.78	41.67	0.37

Table 3.2. Normalized data of Match for variables (LST, ET, P, and NDVI).

Years	LST	ET	P	NDVI
2001	0.258	0.248	0.077	0.247
2005	0.245	0.246	0.346	0.280
2010	0.266	0.266	0.014	0.227
2015	0.231	0.241	0.563	0.247

Table 3.3. The possible MWC and MDC values for the month of March.

March	LST	ET	P	NDVI
MWC	0.231	0.241	0.563	0.280
MDC	0.266	0.266	0.014	0.227

Table 3.4. Entropy Weights for the month of March.

March	LST	ET	P	NDVI
Entropy Weights	0.0031	0.0007	0.9723	0.0046

Table 3.5. Calculated CDI for the month of March.

Years	Si+	Si-	CDI
2001	0.4792	0.0621	0.1148
2005	0.2139	0.3274	0.6048
2010	0.5413	0	0
2015	0.0039	0.5413	0.9926

3.2 Monthly trend of used Parameters

CDI was calculated for all months from January to December for the specified years (2001, 2005, 2010 and 2015) and it was inferred that for the month of January, monthly average of LST for the selected region was 24, 19, 20, and 22 for years 2001, 2005, 2010, and 2015 respectively. Since January is a winter month so there were no considerable variations in LST during the mentioned years. Similarly, no variations were found for the evapotranspiration and NDVI data in this specific month. However, for the precipitation, there was significant precipitation in the year 2005 with a monthly average of 7.87 mm and in the year 2001 with 0 mm monthly average basis. Thus the drought condition is severe in January 2001 due to no precipitation and there was a wet condition in January 2005 as because of high precipitation.

In February, there was no such great variation in LST, ET, and NDVI for the selected years, whereas monthly precipitation again triggers in the month of February with 2.53, 42.47, 3.93, and 10.37 for the year 2001, 2005, 2010, and 2015 respectively. Thus, the month of February for 2001 was dry and having drought conditions Figure 3.5 shows the situation of the month of the January and February for the selected years.

LST for the month of March was 36, 34, 37 and 32 for years 2001, 2005, 2010 and 2015 respectively. Whereas, the NDVI of selected region was 0.247, 0.280, 0.227and 0.247 for 2001, 2005, 2010 and 2015 and ET was 147.6, 146.4, 158.7 and 143.4 for 2001, 2005, 2010 and 2015 respectively. Again significant variations were founding aforementioned parameters. On the other hand, precipitation variations had greatly effected on drought condition. Maximum precipitation occurred during 2005 with 41.67 mm whereas minimum precipitation occurred in 2010 with 1.07mm. Thus, the month of March 2010 was dry as compared to March 2001, March 2005 and March 2015. Similarly, LST, ET, and NDVI had not variation again in the month of April, but Precipitation variation was responsible for drought as shown in Figure 3.6.

For the month of May again no variation in LST, ET, and NDVI, whereas monthly precipitation for 2001, 2005, 2010 and 2015 was24, 6.8, 6.57, and 14.87mm respectively. According to this dry condition were in 2010 for the month of May as compared to the other years in the same month.

The month of June also had a disorder in precipitation which was a cause of the dry condition in June 2005 and wet condition in June 2015. Figure 3.7 has shown CDI for the month of May and June for 2001, 2005, 2010 and 2015.

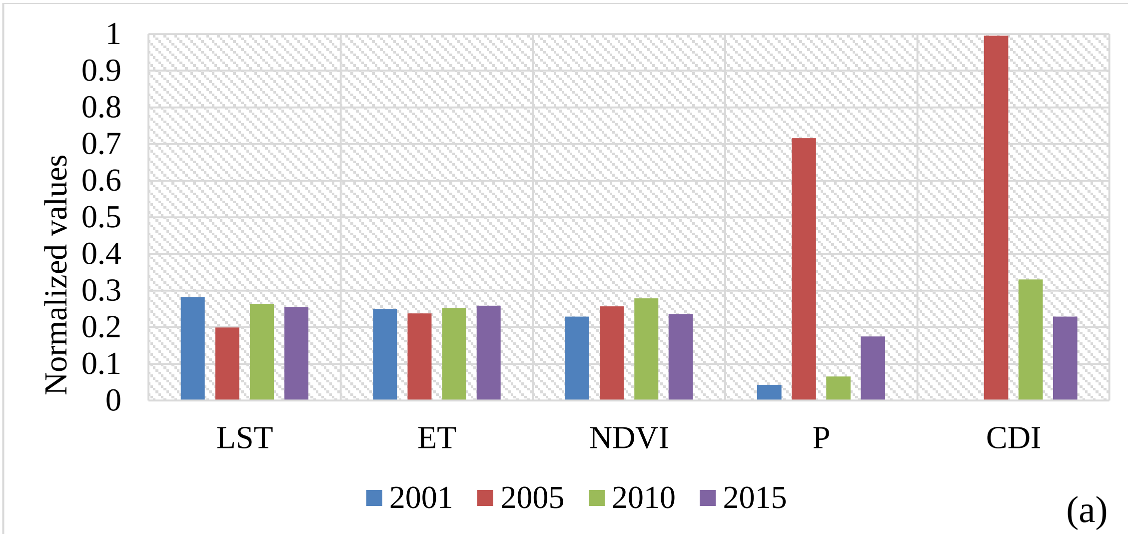
All months perceived same trends related to LST, ET and NDVI variation in these years, while precipitation showed diverse effects. Figure 3.8 shows the condition of variables for July and August. The month of July of 2001 had wet condition having high precipitation 77.43mm.There was also great variation in August with no precipitation in 2005 and high precipitation with 198.43mm in 2015. Thus the dry situation was worst in 2005 whereas condition was wet in 2015.

For the month of September dry condition was prevailed in 2001 with low precipitation 0.98 mm and in 2015 precipitation was high 78.23 mm, which was good for wetness. October, November, and December were the months of very low precipitation. So, in October, there was no precipitation in 2001 and 2005, 1.67mm and 0.77mm precipitation were recorded in 2010 and 2015 respectively. Figure 3.9 is representation of the variation of variables with CDI for the month of September and October for the years.

Similarly, there was no precipitation in 2001, 2010 and 2015 and 0.83mm precipitation was recorded in 2005 which was also very low but as compared to 2001, 2010 and 2015, it was quite high. That's why the year 2005 had shown wet condition and 2001, 2010 and 2015 were sever dry month of November. For the month of December, there were also dry conditions in 2005 and 2015 when there was no precipitation and wet condition in 2010 with 2mm although it was very low in comparison to 2001. 2005 and 2015 it is sufficient for wetness. Figure 3.10 has shown the conditions of variables along calculated CDI for the November and December.

3.3 CDI Response

Monthly average data of Z variables (LST and ET) and Y variables (P and NDVI) were used for the calculation of CDI for the selected study area and with the help of this, monthly drought condition is estimated for the selected years. Figure 3.11 below shows the graph of CDI values estimated for all given months of the year 2001, 2005, 2010 & 2015. From this graph it is found that May & July of the year 2001 was wettest with 0.917 & 0.961 values respectively.



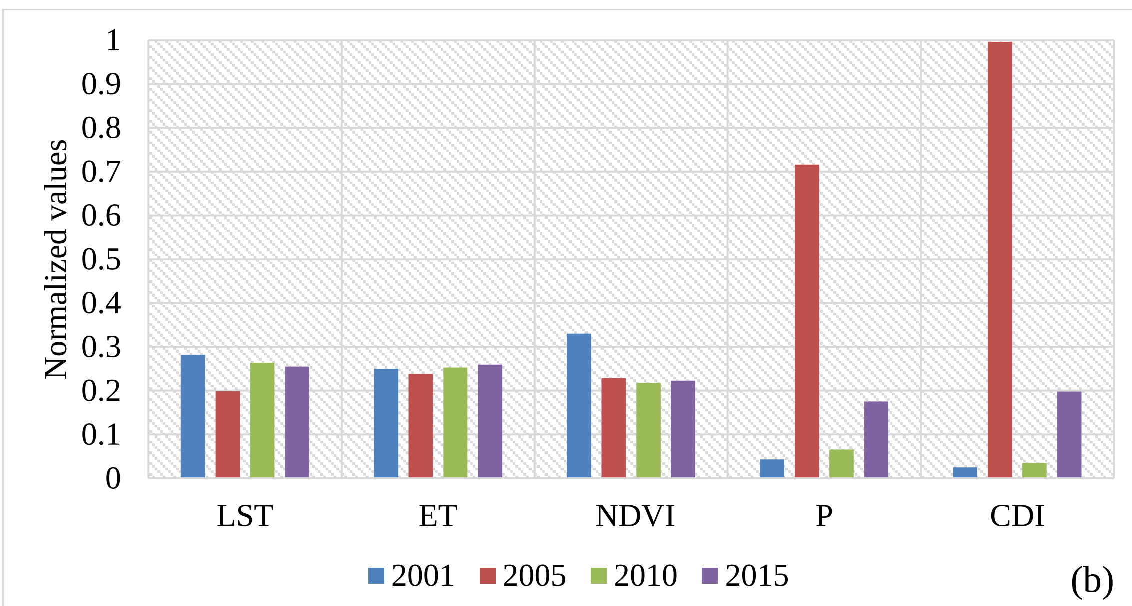


Figure 3.5. Normalization of variables and calculated composite drought index for (a) January & (b) February.

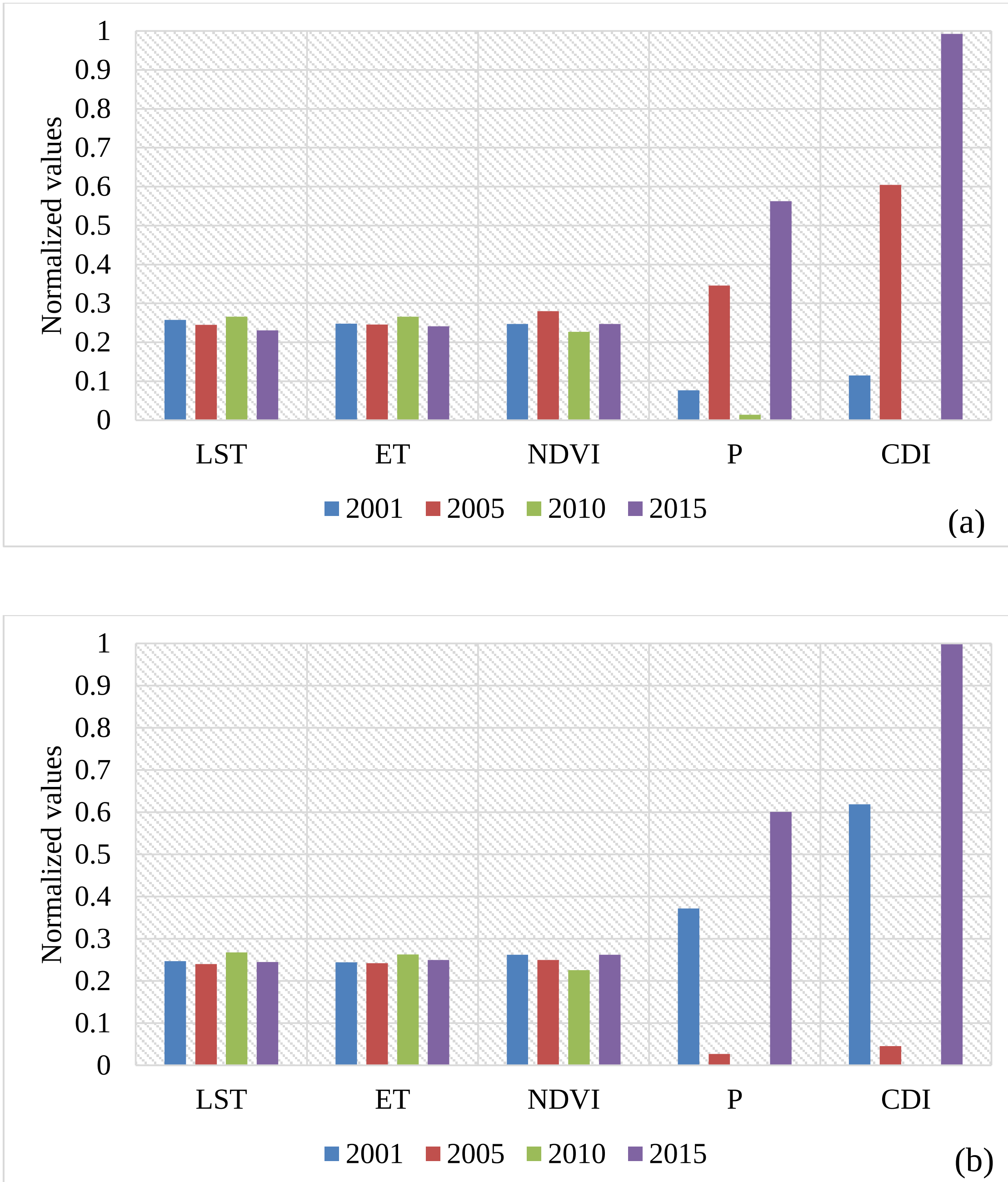


Figure 3.6. Normalization of variables and calculated composite drought index for (a) March & (b) April.

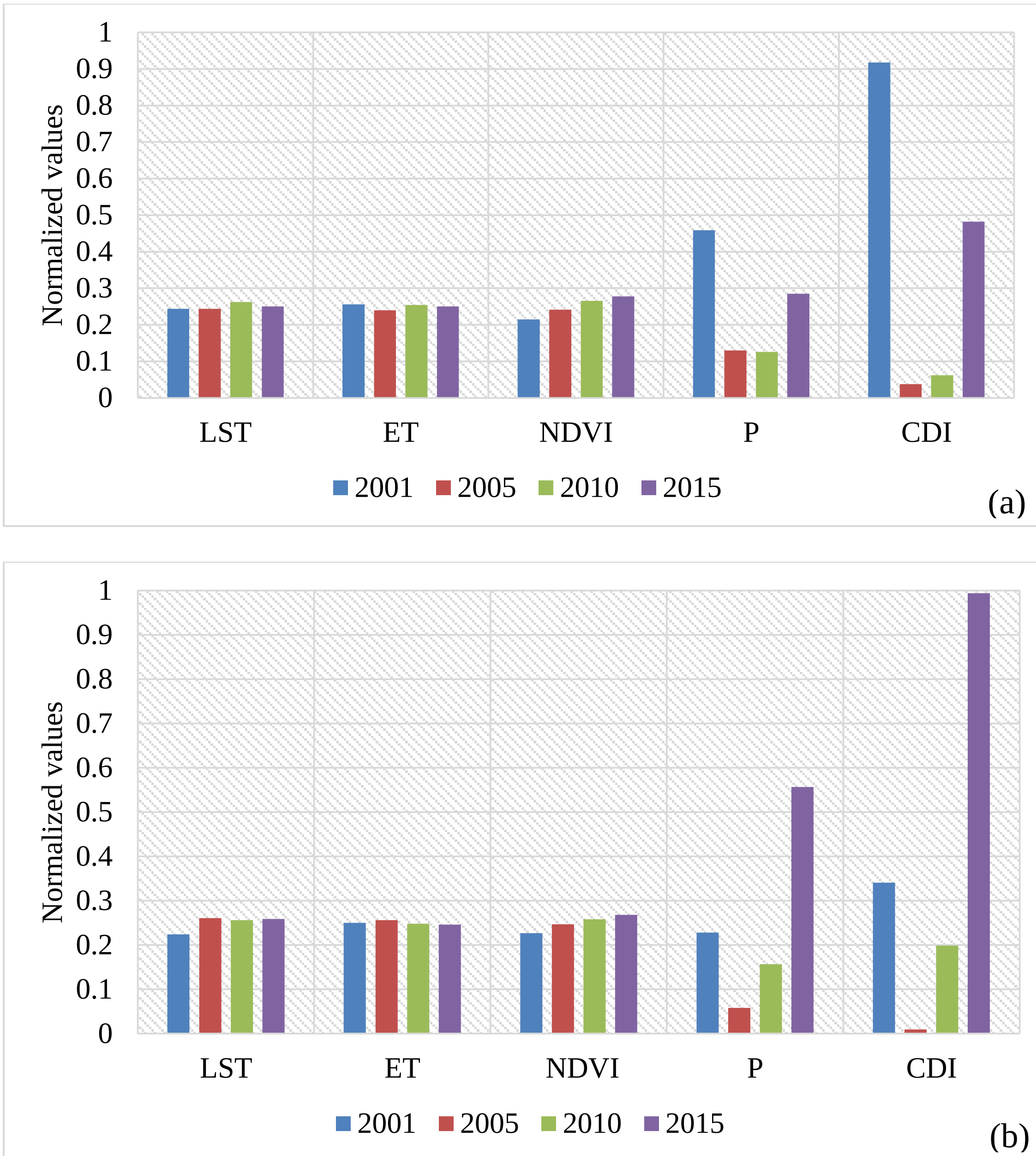


Figure 3.7. Normalization of variables and calculated composite drought index for (a) May & (b) June.

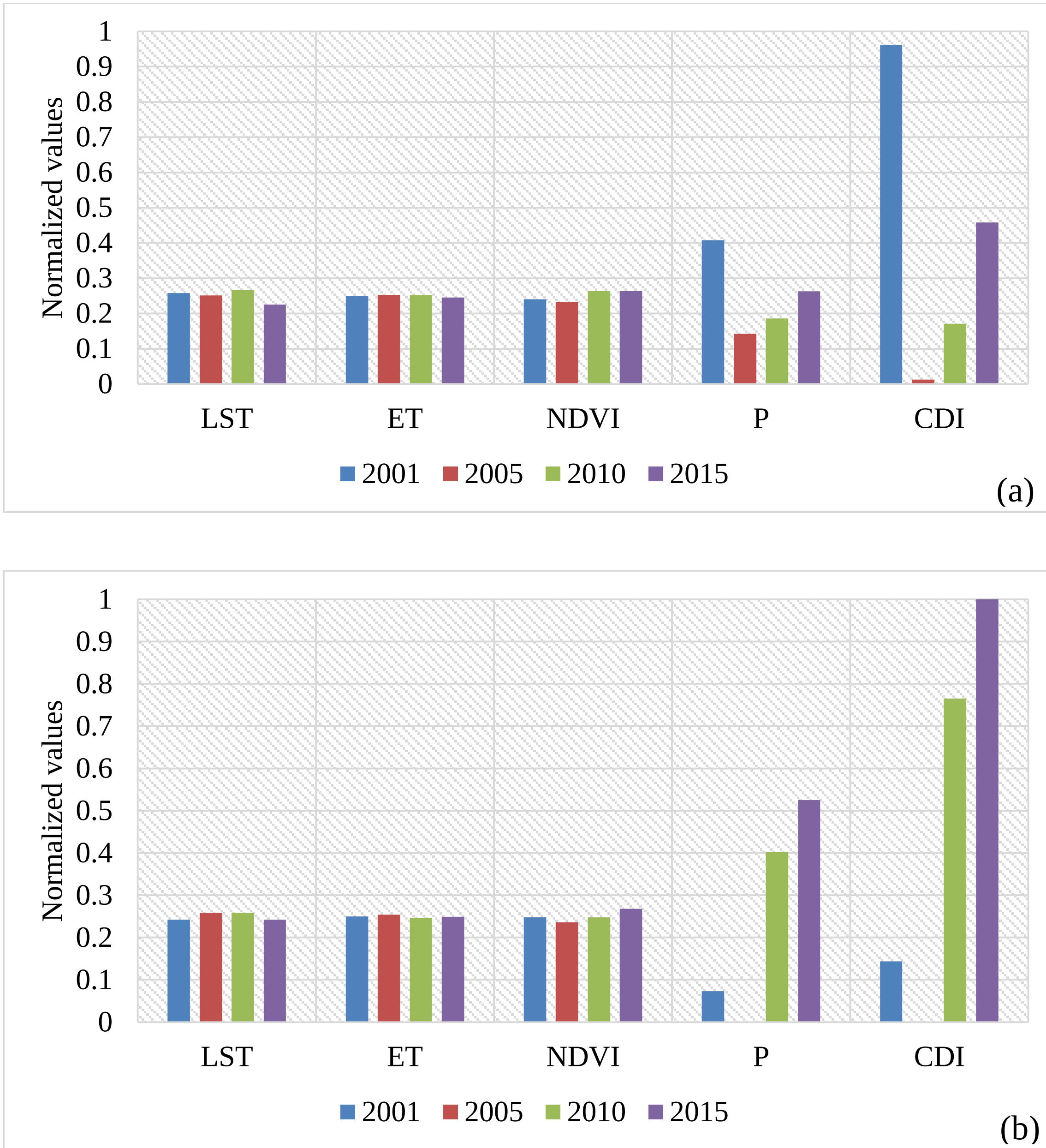


Figure 3.8. Normalization of variables and calculated composite drought index for (a) July & (b) August.

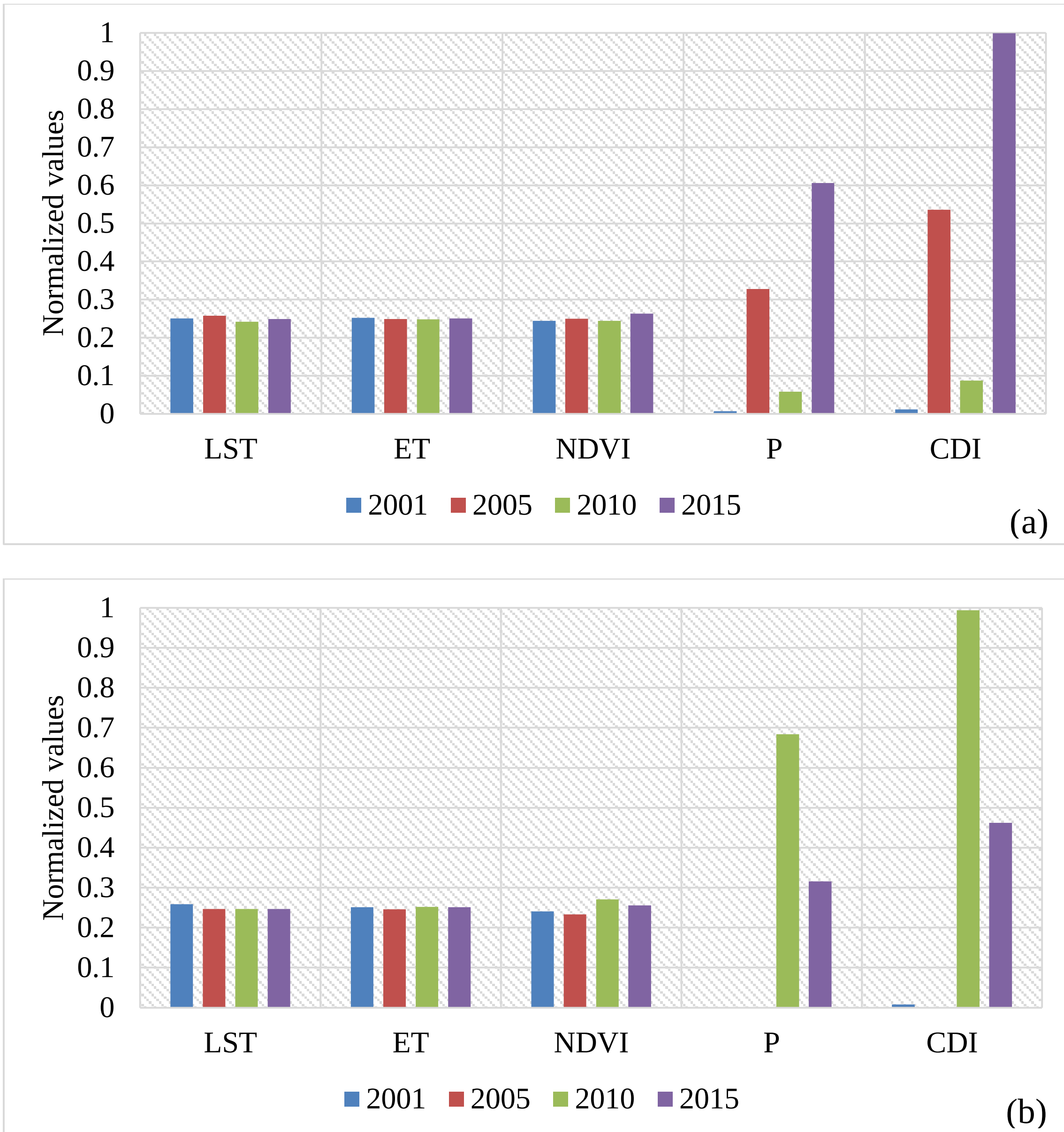


Figure 3.9. Normalization of variables and calculated composite drought index for (a) September & (b) October.

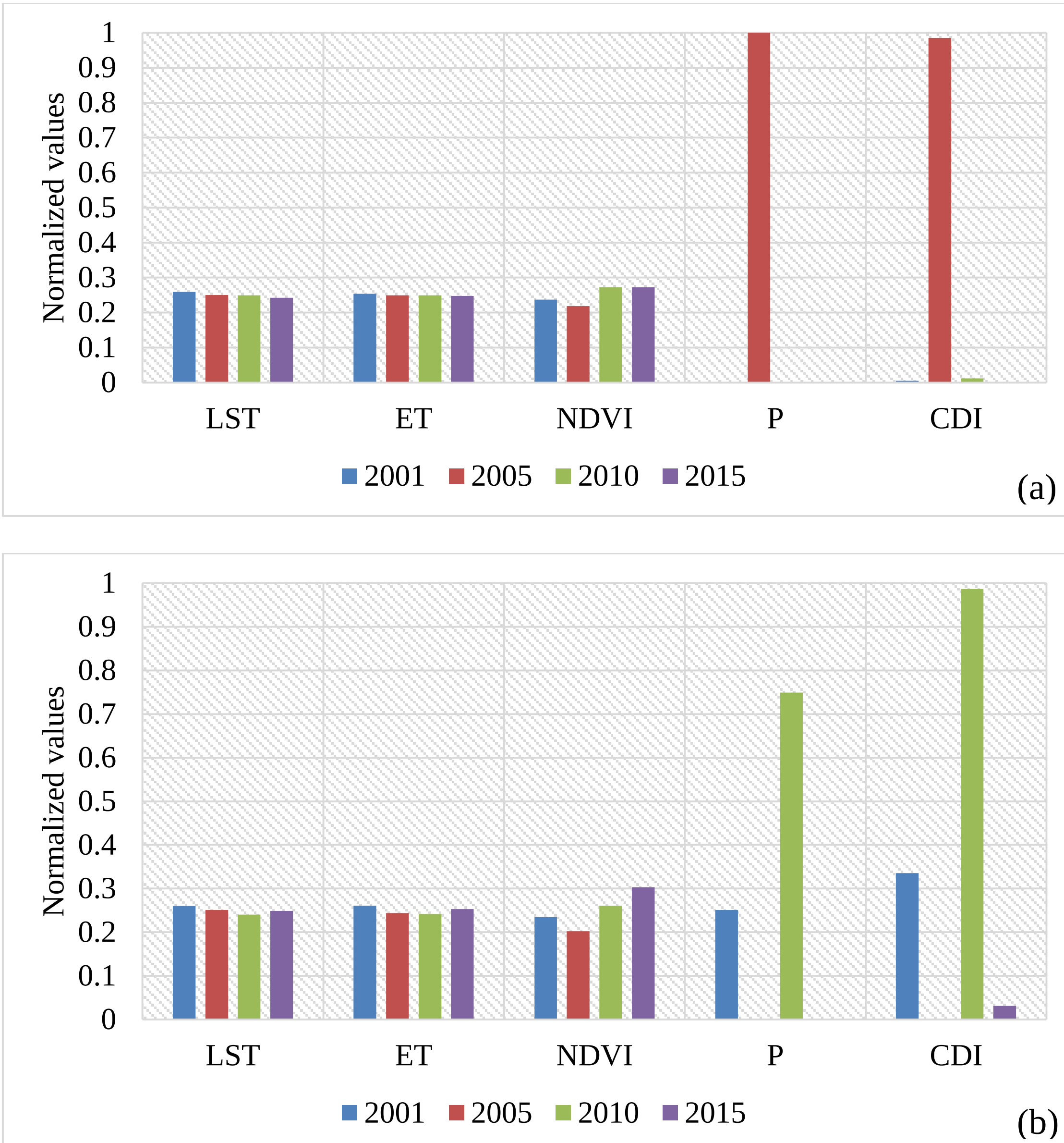


Figure 3.10. Normalization of variables and calculated composite drought index for (a) November & (b) December.

Similarly January, February, and November with 0.995, 0.999 and 0.985 respectively in 2005, October and December with 0.994, 0.986 respectively in 2010, March, April, June, August and September with 0.992, 0.998, 0.993, 0.999 and 0.999 values respectively in the year 2015, were found to be wettest. Likewise, the driest months during 2001 were January, February, September, October, and November with CDI 0.0003, 0.0009, 0.011, 0.007 and 0.004 respectively. In 2005 the driest months were April, May, June, July, August, October, and December with CDI 0.045, 0.037, 0.009, 0.012, 0.000, 0.0003 and 0.0004 respectively. Similarly, the driest months of 2010 were February, March, April, May, and November with CDI 0.034, 0, 0.001, 0.0610.087 and 0.011 respectively. November and December of 2015 were the driest with CDI 0.014 and 0.031.

After calculation of monthly CDI for each month of the selected years, the average of these monthly CDI values was calculated to check the overall trend of dryness/ wetness. Figure 3.12 shows the graph of monthly average CDI for all said years 2001, 2005, 2010 and 2015. The graph shows that February and November were the driest months as these two months show significant dip for CDI, whereas August was the wettest month as it shows a substantial peak of CDI for all years. Similarly, CDI of all months were averaged on the basis of years to check the overall yearly trend of wetness/ dryness. Figure 3.13 shows this yearly trend of CDI which shows that year 2001, 2005 & 2010 were the dry years as CDI has equally low values for these years, whereas 2015 was a wet year.

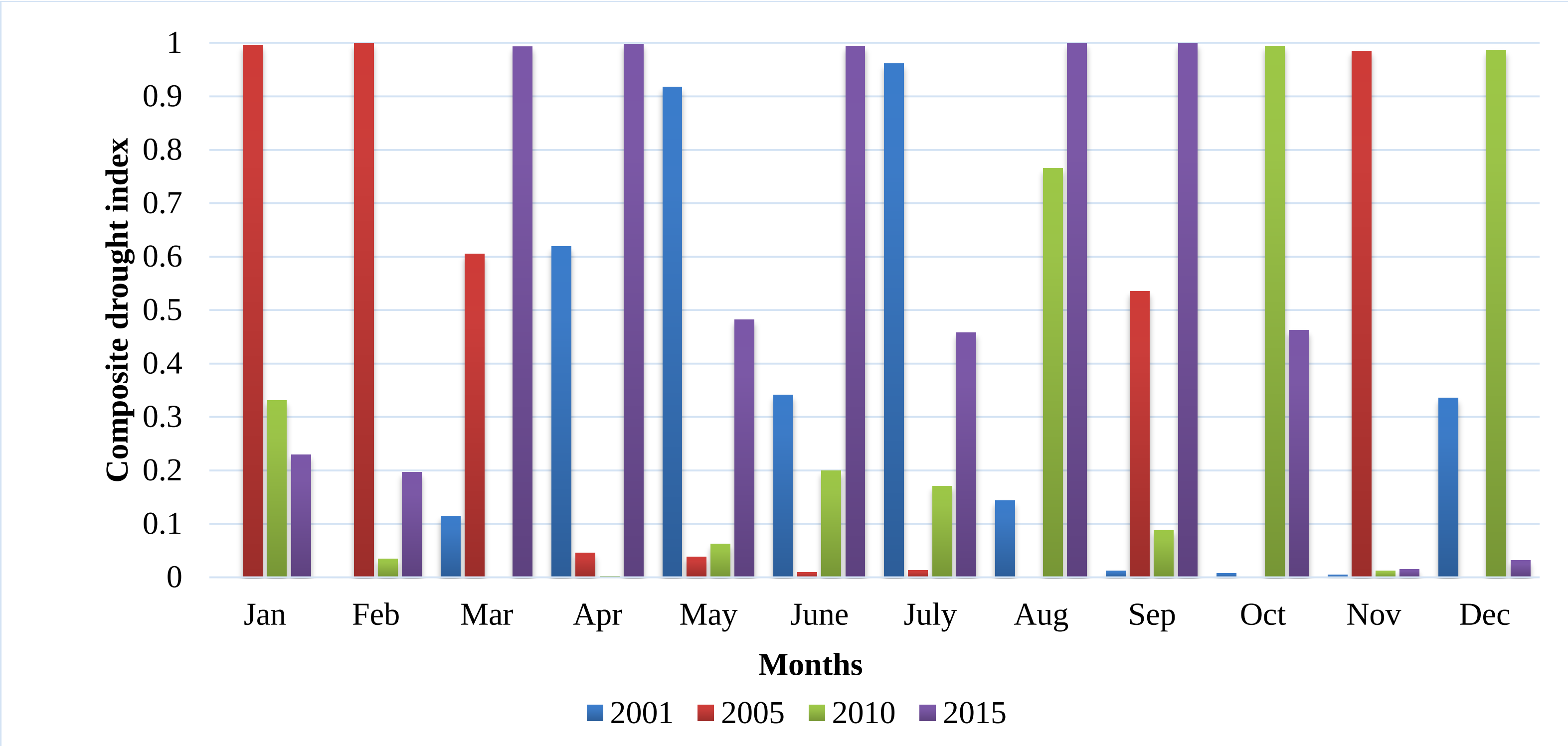


Figure 3.11. Composite drought index response of all years.

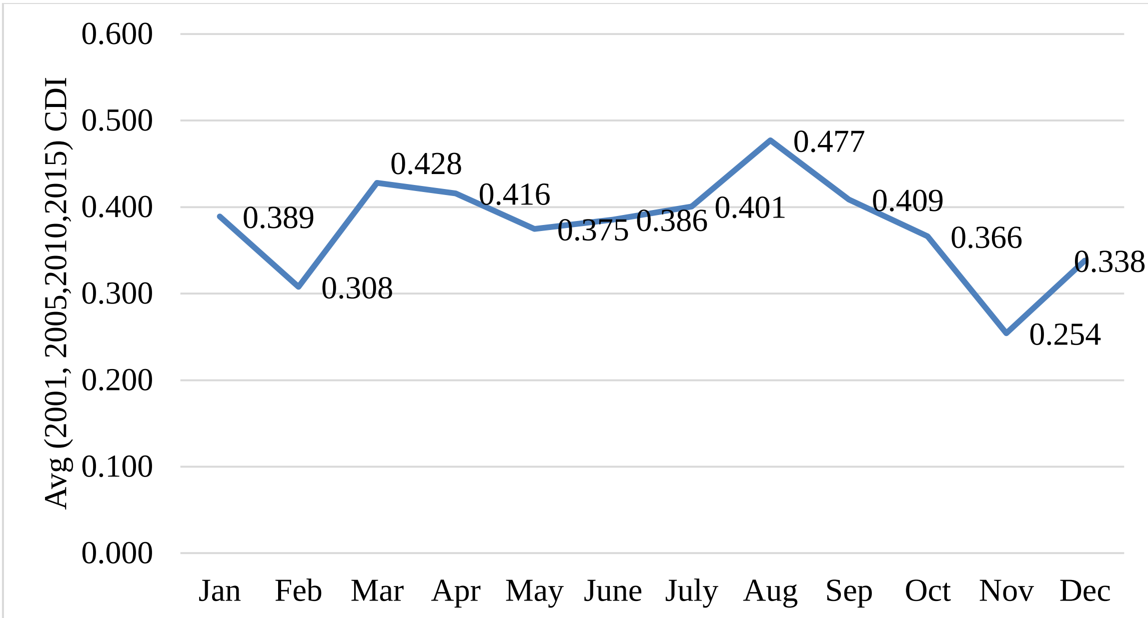


Figure 3.12. Monthly average composite drought index.

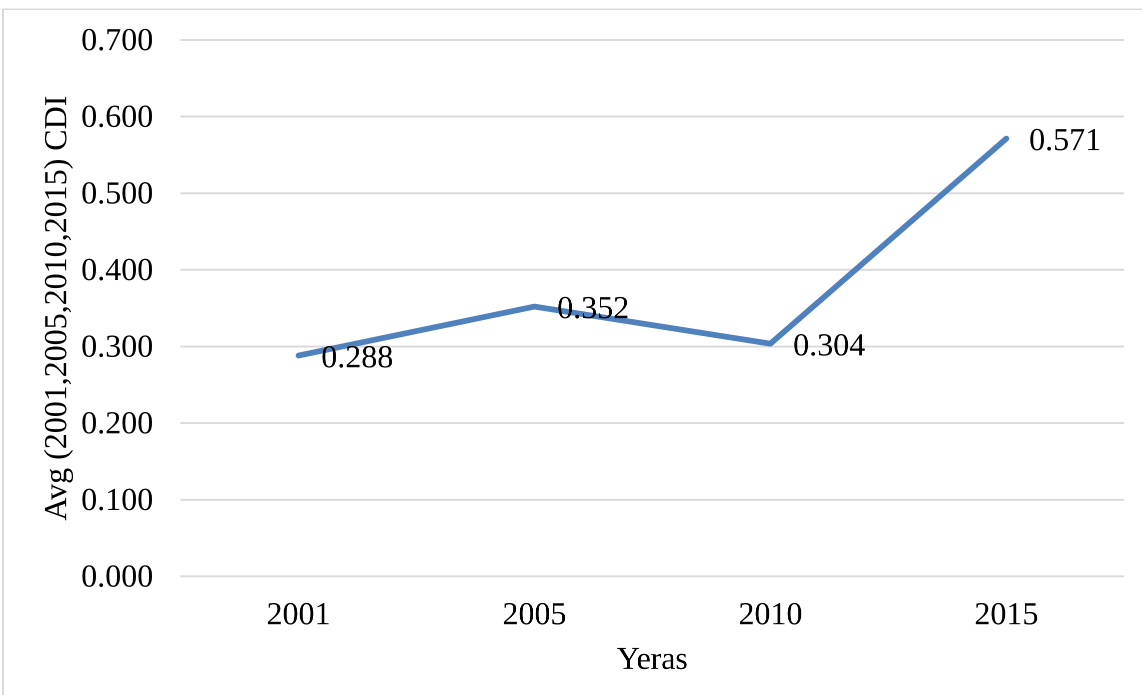


Figure 3.13. Yearly average composite drought index.

3.4 Monthly trend of Normalized P, SPI & CDI

Finally, the trend of normalized P, SPI (SPI-1, SPI-3, SPI-6, SPI-9) and CDI was observed by plotting all these on the monthly scale for the given years of 2001, 2005, 2010 and 2015. It is observed that normalized P, SPI-1, and CDI were strongly correlated with each other, as all showed the same dip for a same specific month and rises uniformly for the other same months. In the year 2001 both showed depression for the months of Feb, Jun & Sep whereas for the months of May & July these factors had risen drastically. Similarly for the years 2005 the graph showed dip in Apr, Aug and Oct and peaks in May, Sep and Nov. Year 2010 shows rise for the months of Aug, Oct and Dec, however, the fall was observed in Apr, Sep and Nov. On the other hand, the graph shows peaks in Mar, June, and Aug whereas dips were observed in May and July for the year 2015 has shown Figure 3.14. Similarly, the trend between normalized P, SP1-3 and CDI are observed which showed high correlation with each other in Figure 3.15. Whereas the correlation between normalized P and CDI with SPI-6 and SPI-9 was not significant as shown Figure 3.16. & 3.17.

3.5 Correlation between SPI and CDI

Furthermore, the correlation between CDI and SPI with (SP1-1, SPI-3, SPI-6 and SPI-9) was calculated. Figure 3.18 showed a strong correlation of CDI and SPI with 1-month. The correlation of CDI and SPI with 3-month, 6-month and 9-month were not highly significant and the low correlation was observed in the month of November for the selected years.

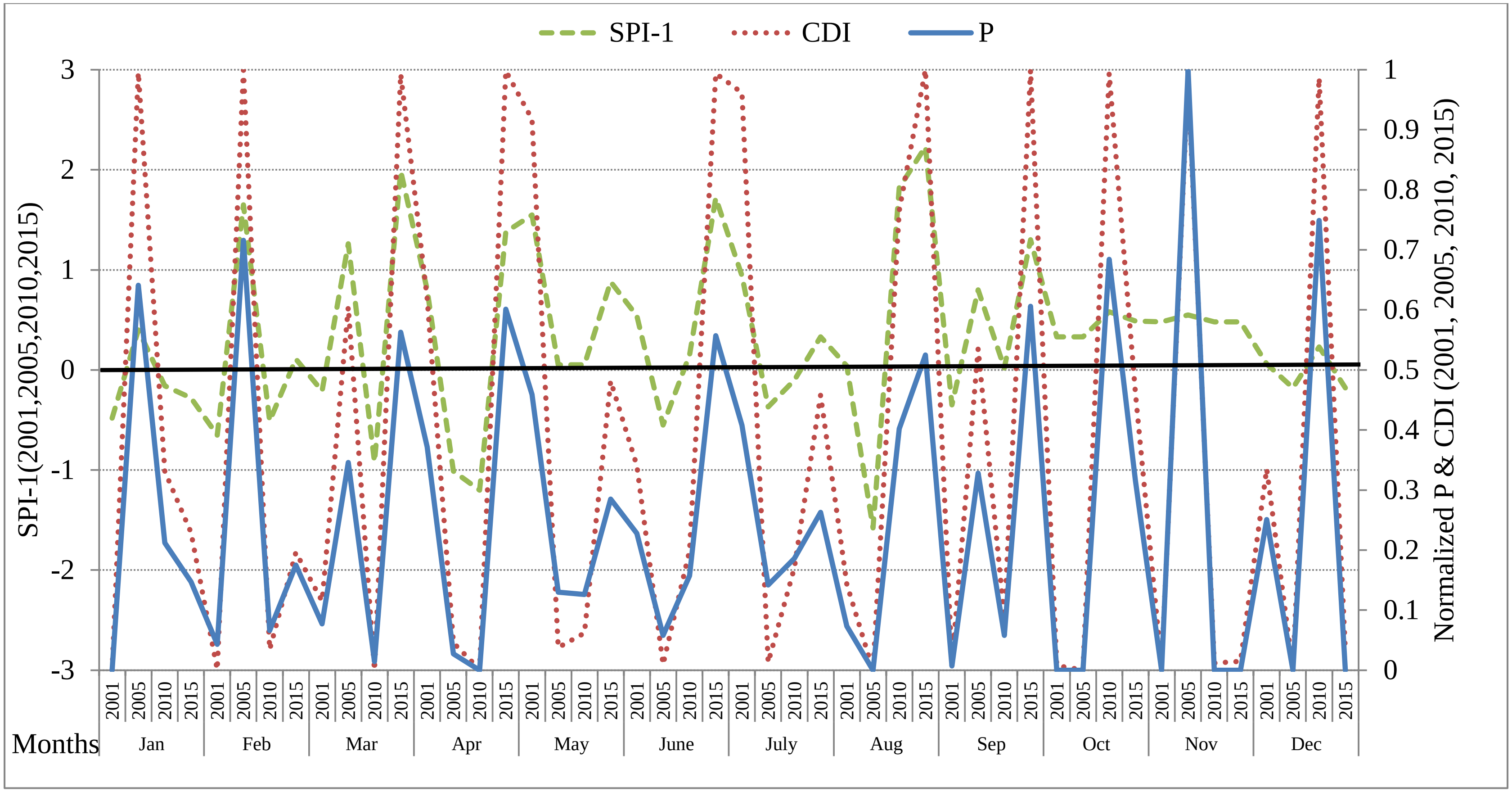


Figure 3.14. Monthly trend of normalized precipitation, standard precipitation index-1 & composite drought index.

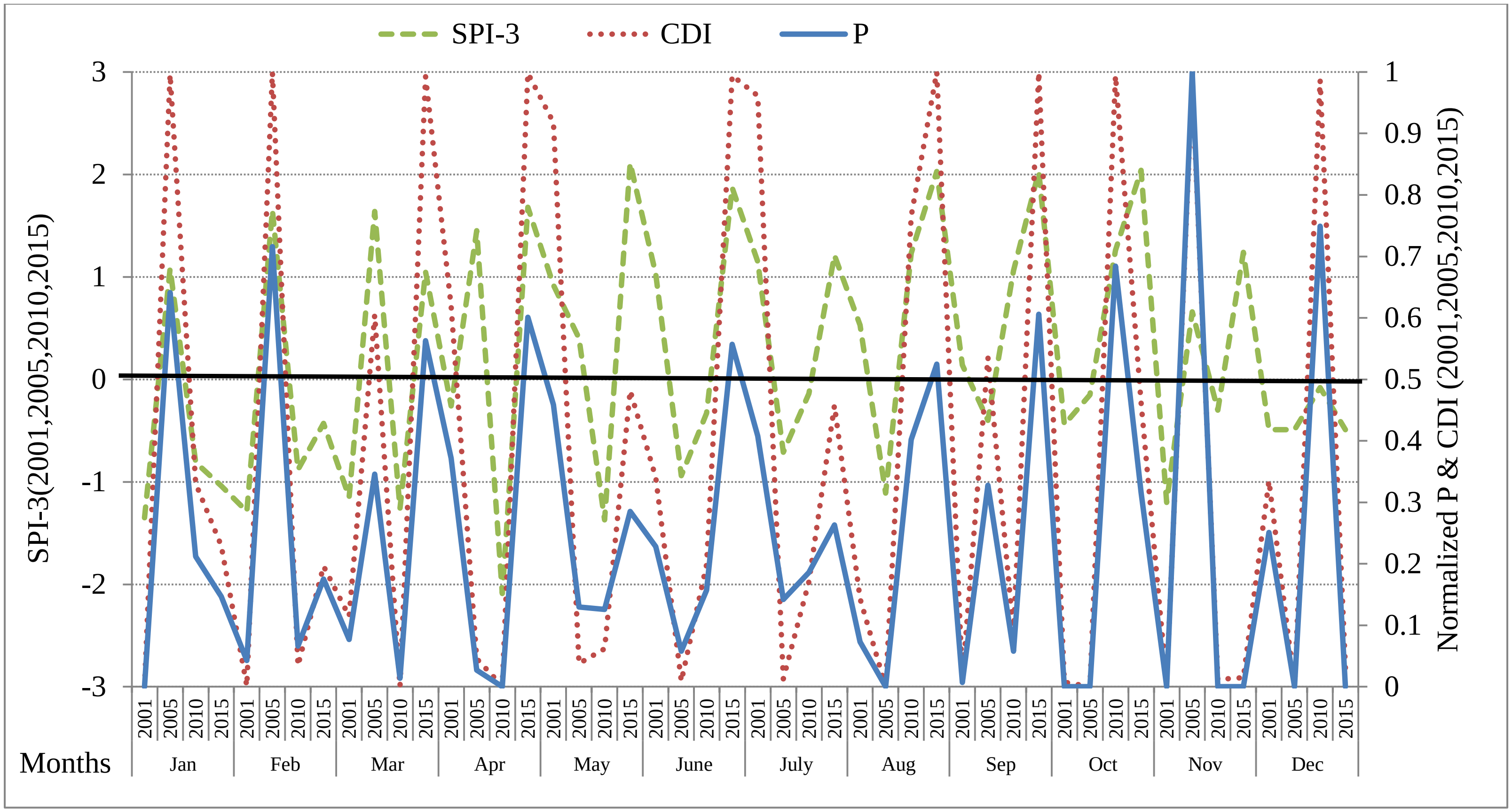


Figure 3.15. Monthly trend of normalized precipitation, standard precipitation index-3 & composite drought index.

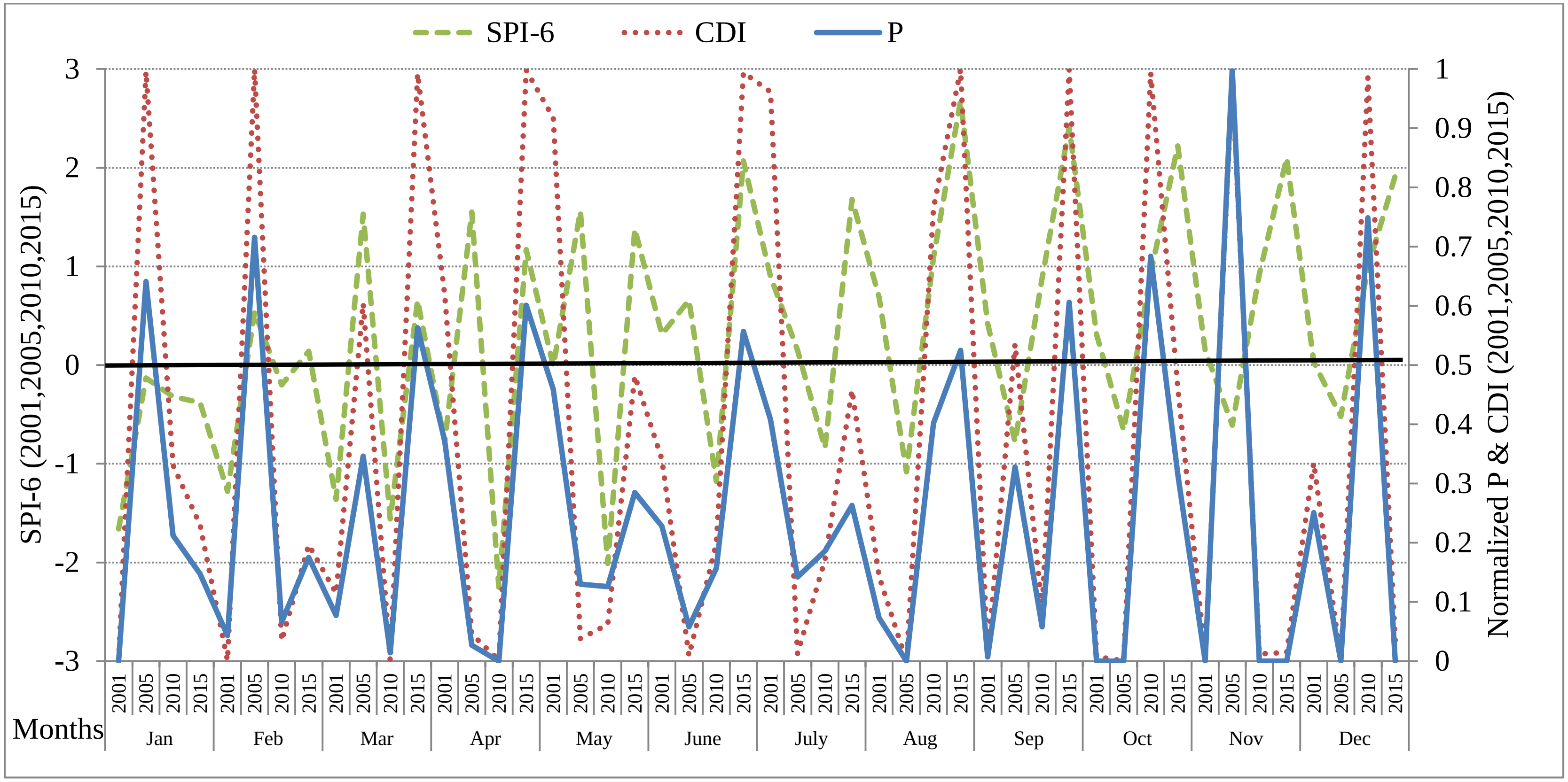


Figure 3.16. Monthly trend of normalized precipitation, standard precipitation index-6 & composite drought index.

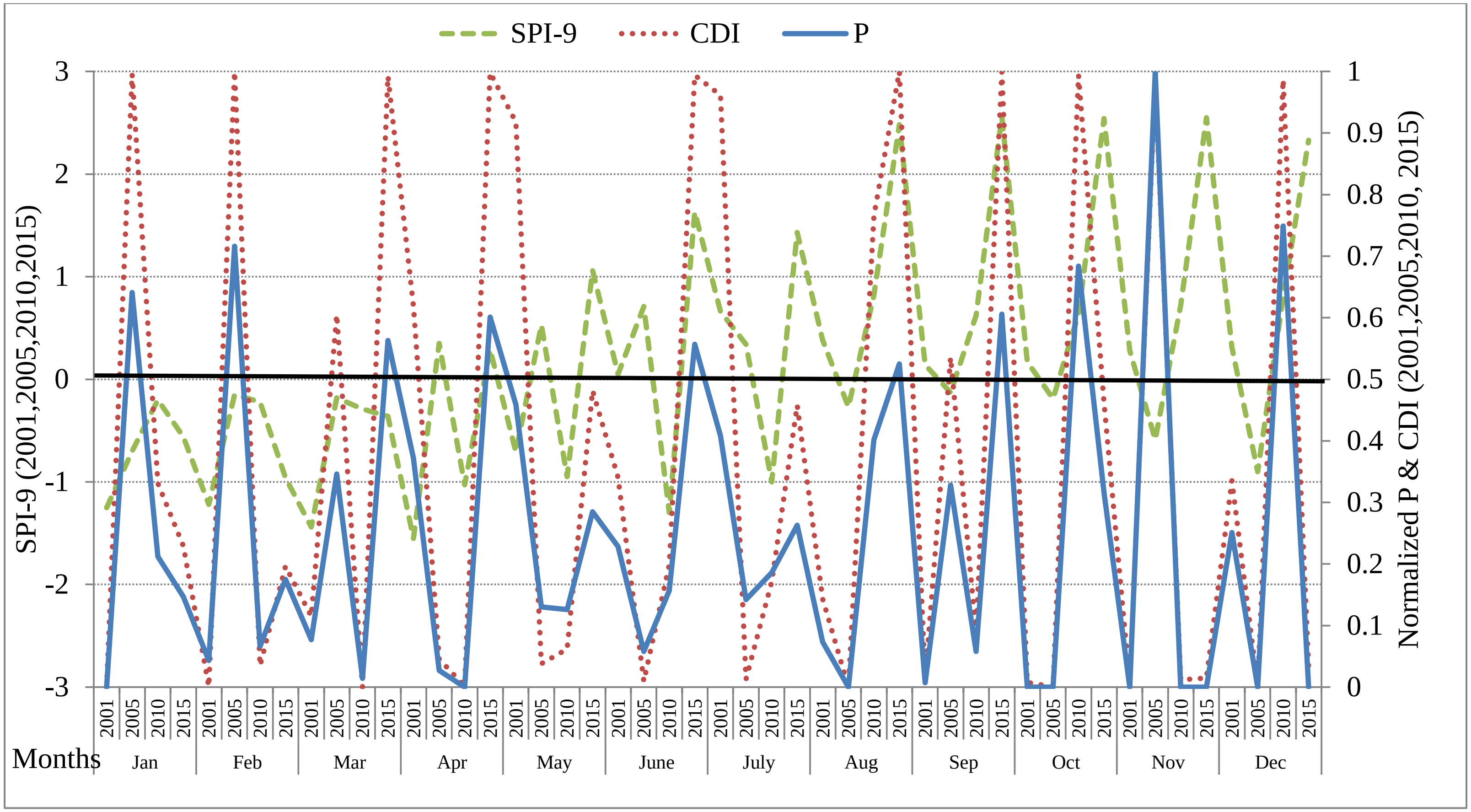


Figure 3.17. Monthly trend of normalized precipitation, standard precipitation index-9 & composite drought index.

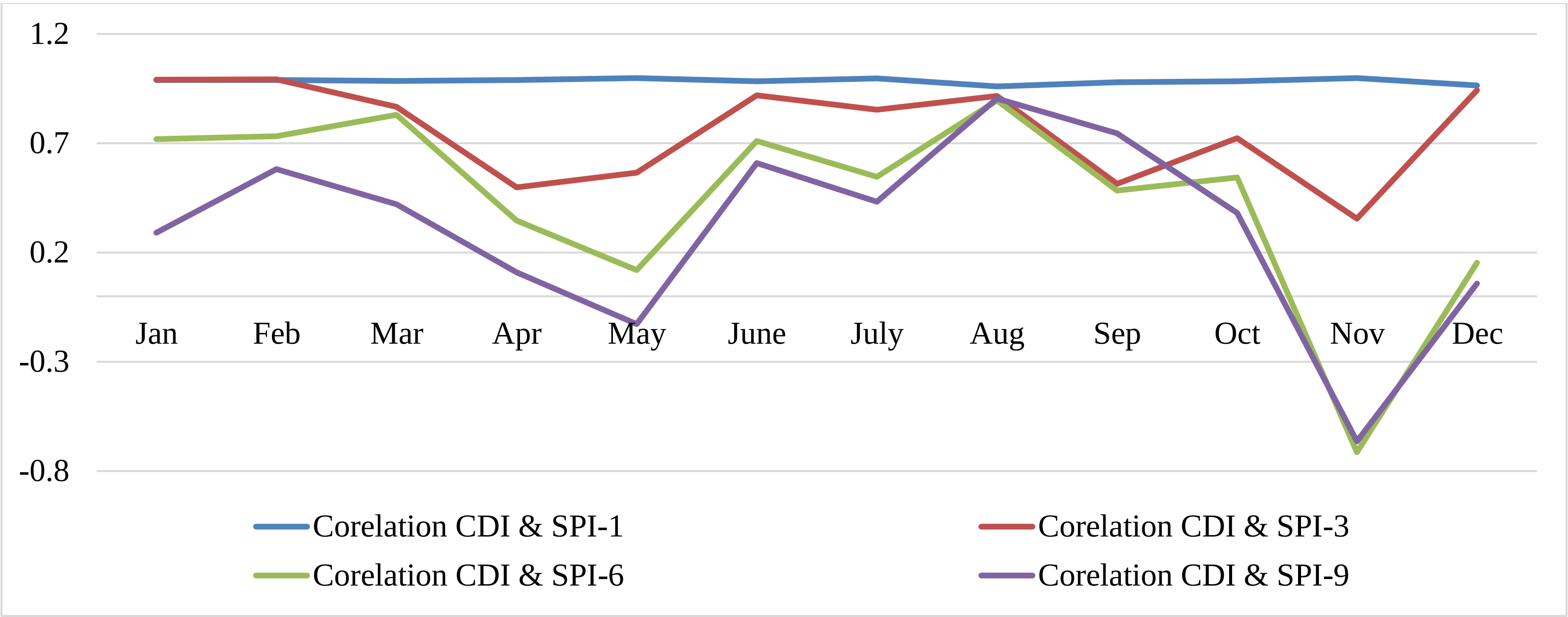


Figure 3.18. Correlation between standard precipitation index & composite drought index.

Chapter 4

CONCLUSION AND RECOMMENDATION

The study has examined the use of remote sensing data for the assessment of drought conditions in Cholistan desert area. The study has also investigated the relationship between NDVI, Rainfall, Temperature and Evapotranspiration condition for the study region. The conclusions and recommendations are given below based on the study.

4.1 Conclusions

Following conclusions are made through this research:-

a. CDI is found to be very flexible which can consider all types (Agricultural, Meteorological, and Hydrological) of drought to understand the cause of drought occurrence. As in this research, CDI is dependent on four types of parameters, namely NDVI, LST, ET & Precipitation, which were taken from remote sensing based platforms, so it is inferred from this study that remote sensing provides a time-efficient way of drought condition assessments.

b. Direct response of rainfall and other associated physical factors are mapped in this study and it is concluded that the Precipitation was the most sensitive variable in this selected study due to high variability, whereas LST, ET and NDVI had shown no significant differences in 2001, 2005, 2010 and 2015.

c. Figure 3.7 shows the response of CDI for all months of the given years which illustrates that the CDI below 0.5 represents dry condition whereas CDI above 0.5 represents a wet condition for the studied period of time. So it results from this graph that the November is the driest month for all specified year however 2001 was completely a drought year.

4.2 Recommendations

Recommendations are offered as follows:-

a. As CDI is found very useful in this study, so it is proposed to implement the same approach on an irrigated areas and wetlands so that the validity of the proposed approach can be tested against varying climatic conditions.

b. It is further suggested to improve CDI by using the soil moisture and groundwater depth data for the same area and compare the results with these results.

c. The same approach may be applied on the dominantly spatiotemporal agro-ecological zone.

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Appendices

Appendix-I. Monthly data for all parameters

Years	**LST**	**ET**	**P**	**NDVI**	For L = Jan
2001	23.55	3.3	0	0.32	
2005	19.04	3.3	7.87	0.36	
2010	20.27	3.33	2.6	0.39	
2015	21.96	3.29	1.8	0.33	
2001	28.32	3.89	2.53	0.62	For L = Feb
2005	20.02	3.7	42.47	0.43	
2010	26.57	3.94	3.93	0.41	
2015	25.58	4.02	10.37	0.42	
2001	35.96	4.92	5.67	0.37	For L = Mar
2005	34.06	4.88	25.6	0.42	
2010	37.09	5.29	1.07	0.34	
2015	32.14	4.78	41.67	0.37	
2001	40.75	6.09	15.67	0.22	For L = Apr
2005	39.645	6.03	1.13	0.21	
2010	44.195	6.56	0.01	0.19	
2015	40.365	6.2	25.27	0.22	
2001	42.20	7.47	24	0.17	For L = May
2005	42.14	7	6.8	0.19	
2010	45.21	7.42	6.57	0.21	
2015	43.28	7.29	14.87	0.22	
2001	37.44	7.65	27.93	0.22	For L = June
2005	43.63	7.84	7.1	0.24	
2010	42.72	7.61	19.23	0.25	
2015	43.19	7.53	68.33	0.26	

Years	**LST**	**ET**	**P**	**NDVI**	For L = July
2001	36.72	7.22	77.43	0.31	
2005	35.83	7.32	27	0.30	
2010	37.86	7.28	35.33	0.34	
2015	32.08	7.09	49.9	0.34	
2001	34.81	6.88	27.67	0.39	For L= Aug
2005	37.09	6.98	0	0.37	
2010	37.07	6.77	151.97	0.39	
2015	34.71	6.85	198.43	0.42	
2001	37.47	6.21	0.93	0.39	For L = Sep
2005	38.45	6.14	42.37	0.40	
2010	36.14	6.13	7.53	0.39	
2015	37.23	6.2	78.23	0.42	
2001	37.92	5.38	0	0.32	For L = Oct
2005	36.14	5.27	0	0.31	
2010	36.1	5.41	1.67	0.36	
2015	36.18	5.38	0.77	0.34	
2001	31.13	4.31	0	0.27	For L = Nov
2005	29.99	4.23	0.83	0.25	
2010	29.92	4.22	0	0.31	
2015	29.05	4.21	0	0.31	
2001	25.06	3.61	0.67	0.28	For L = Dec
2005	24.20	3.37	0.000	0.24	
2010	23.07	3.34	2	0.31	
2015	23.97	3.49	0.0	0.36	

Appendix-II. Normalized data for all parameters

Years	**LST**	**ET**	**P**	**NDVI**	For L= Jan
2001	0.278	0.250	0	0.229	
2005	0.225	0.250	0.641	0.257	
2010	0.239	0.252	0.212	0.279	
2015	0.259	0.249	0.147	0.236	
2001	0.282	0.250	0.043	0.330	For L = Feb
2005	0.199	0.238	0.716	0.229	
2010	0.264	0.253	0.066	0.218	
2015	0.255	0.259	0.175	0.223	
2001	0.258	0.248	0.077	0.247	For L = Mar
2005	0.245	0.246	0.346	0.280	
2010	0.266	0.266	0.014	0.227	
2015	0.231	0.241	0.563	0.247	
2001	0.247	0.244	0.372	0.262	For L = Apr
2005	0.240	0.242	0.027	0.250	
2010	0.268	0.263	0.000	0.226	
2015	0.245	0.250	0.601	0.262	
2001	0.244	0.256	0.459	0.215	For L = May
2005	0.244	0.240	0.130	0.241	
2010	0.262	0.254	0.126	0.266	
2015	0.250	0.250	0.285	0.278	
2001	37.44	7.65	27.93	0.22	For L = June
2005	43.63	7.84	7.1	0.24	
2010	42.72	7.61	19.23	0.25	
2015	43.19	7.53	68.33	0.26	

Years	**LST**	**ET**	**P**	**NDVI**	For L = July
2001	0.258	0.250	0.408	0.240	
2005	0.251	0.253	0.142	0.233	
2010	0.266	0.252	0.186	0.264	
2015	0.225	0.245	0.263	0.264	
2001	0.242	0.250	0.073	0.248	For L = Aug
2005	0.258	0.254	0	0.236	
2010	0.258	0.246	0.402	0.248	
2015	0.242	0.249	0.525	0.268	
2001	0.251	0.252	0.007	0.244	For L = Sep
2005	0.258	0.249	0.328	0.250	
2010	0.242	0.248	0.058	0.244	
2015	0.249	0.251	0.606	0.263	
2001	0.259	0.251	0	0.241	For L = Oct
2005	0.247	0.246	0	0.233	
2010	0.247	0.252	0.684	0.271	
2015	0.247	0.251	0.316	0.256	
2001	0.259	0.254	0	0.237	For L = Nov
2005	0.250	0.250	1	0.219	
2010	0.249	0.249	0	0.272	
2015	0.242	0.248	0	0.272	
2001	0.260	0.261	0.251	0.235	For L = Dec
2005	0.251	0.244	0.000	0.202	
2010	0.240	0.242	0.749	0.261	
2015	0.249	0.253	0.000	0.303	

Appendix-III. Wet and dry conditions

Conditions	LST	ET	P	NDVI	
MWC	0.225	0.249	0.641	0.279	For L = Jan
MDC	0.278	0.252	0	0.229	
MWC	0.225	0.249	0.716	0.330	For L = Feb
MDC	0.278	0.252	0.043	0.218	
MWC	0.231	0.241	0.563	0.280	For L = Mar
MDC	0.266	0.266	0.014	0.227	
MWC	0.24	0.263	0.601	0.262	For L = Apr
MDC	0.268	0.242	0.000	0.226	
MWC	0.244	0.24	0.459	0.278	For L = May
MDC	0.262	0.256	0.126	0.215	
MWC	0.224	0.246	0.557	0.268	For L = Jun
MDC	0.261	0.256	0.058	0.227	
MWC	0.225	0.245	0.408	0.264	For L = Jul
MDC	0.266	0.253	0.142	0.233	
MWC	0.242	0.246	0.525	0.268	For L = Aug
MDC	0.258	0.254	0	0.236	
MWC	0.242	0.248	0.606	0.263	For L = Sep
MDC	0.258	0.252	0.007	0.244	
MWC	0.247	0.246	0.684	0.271	For L = Oct
MDC	0.259	0.252	0	0.233	
MWC	0.242	0.248	1	0.272	For L = Nov
MDC	0.259	0.254	0	0.219	
MWC	0.24	0.242	0.749	0.303	For L = Dec
MDC	0.26	0.261	0	0.202	

Appendix-IV. Entropy weights for all months

Months	LST	ET	P	NDVI
January	0.0056	0.0056	0.9783	0.0001
February	0.0076	0.0034	0.9783	0.0005
March	0.0031	0.0046	0.9723	0.0007
April	0.0014	0.0037	0.974	0.0015
May	0.0025	0.0527	0.8557	0.0018
June	0.0067	0.0145	0.9567	0.0004
July	0.0206	0.0286	0.847	0.0008
August	0.001	0.0003	0.9555	0.0001
September	0.0005	0.0006	0.9725	0.0001
October	0.0003	0.001	0.9723	0.0001
November	0.0002	0.0021	0.9806	0.0001
December	0.0004	0.01	0.9466	0.0005

Appendix-V. CDI calculation for all months

Years	Si+	Si-	CDI	For L = Jan
2001	0.6340	0.0002	0.0003	
2005	0.0026	0.6340	0.9958	
2010	0.4242	0.2098	0.3308	
2015	0.4886	0.1454	0.2293	
2001	0.4781	0.0121	0.024	For L = Feb
2005	0.001	0.478	0.996	
2010	0.461	0.016	0.034	
2015	0.384	0.094	0.198	
2001	0.4792	0.0621	0.1148	For L = Mar
2005	0.2139	0.3274	0.6048	
2010	0.5413	0	0	
2015	0.0039	0.5413	0.9926	
2001	0.2261	0.3671	0.6188	For L = Apr
2005	0.5665	0.0270	0.0456	
2010	0.5932	0.0008	0.001	
2015	0.0010	0.5932	0.9981	
2001	0.0276	0.3080	0.9176	For L = May
2005	0.3048	0.0119	0.0377	
2010	0.3081	0.0203	0.0619	
2015	0.1609	0.1496	0.4818	
2001	0.3219	0.1663	0.3406	For L = Jun
2005	0.4881	0.0045	0.0092	
2010	0.3912	0.0971	0.1989	
2015	0.0029	0.4881	0.9939	

Years	**Si+**	**Si-**	**CDI**	For L = July
2001	0.0098	0.2455	0.9615	
2005	0.2457	0.0032	0.0128	
2010	0.2046	0.0421	0.1709	
2015	0.1335	0.1128	0.4579	
2001	0.4418	0.0738	0.1432	For L = Aug
2005	0.5138	0	0	
2010	0.1207	0.3932	0.7651	
2015	0.0000	0.5138	0.9999	
2001	0.5907	0.0071	0.0119	For L = Sep
2005	0.2745	0.3165	0.5355	
2010	0.5404	0.0520	0.0878	
2015	0.0002	0.5908	0.9995	
2001	0.6745	0.0051	0.0076	For L = Oct
2005	0.6747	0.0002	0.0003	
2010	0.0039	0.6746	0.9941	
2015	0.3628	0.3121	0.4624	
2001	0.9903	0.0047	0.0047	For L = Nov
2005	0.0149	0.9902	0.9850	
2010	0.9902	0.0119	0.0119	
2015	0.9902	0.0149	0.0148	
2001	0.4847	0.2443	0.3351	For L = Dec
2005	1	0.0004	0.0004	
2010	0.0098	0.7289	0.9866	
2015	0.7287	0.0233	0.0310	