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Development of a Space-enabled Drought Management Support System for the Five Drought-Prone Districts in Kerala State, in the Wake of the Global Climate Change and the Projected Impacts.

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Executive Summary

Kerala, the south-western State of the Indian Peninsula has a unique topography, geology and climate. The length of the State considering the shape of the State as a scalene triangle with its base on the long coast is 560 km. Width varies from a minimum of 15 km to a maximum of 120 Km. Within this variable width, the topographic regions can be divided into high, mid and lowland regions. The State receives an average annual rainfall of about 3000 mm but is affected by occasional localized drought events, owing to high slope of the terrain facilitates the fast runoff of rainwater to the Arabian Sea. Decreasing forest area/land cover owing to urbanization can be attributed to be the main cause for rapid runoff. In this scenario, a drought risk mapping of six northern districts of Kerala has been attempted using Geospatial Techniques. The temporal variations in the vegetation health index of the State over several years were determined. The maximum negative anomaly from the mean vegetation health index was classified as risk map. The daily and 16-day composite anomaly was also monitored using automated tools and risk zones identified on a daily basis. Normalized Difference Vegetation Index (NDVI) is the major parameter used to measure vegetation health obtained from MODIS, Terra satellite products MOD13Q1, MOD02QKM. The mean Normalized Difference Vegetation Index (NDVI) of Kerala state over 17-years was calculated. The 16-day composite anomalies of NDVI from its long term mean NDVI over the same period was found. Based on NDVI anomaly maps, the spatial and temporal distribution of drought affected areas in Northern Kerala were identified. High negative NDVI anomaly areas are susceptible to drought. This information, when integrated with land use/land cover map helps to identify the drought risk for specific crops grown in the area. A web-based tool is developed which can help in real time monitoring of drought. Satellite images are automatically downloaded periodically, which will be processed to show the NDVI anomaly maps. These maps also show a spatial classification of the drought affected area into very severe, severe, moderate, slight, very slight and no drought areas. Crop-based statistics are also made available which will be useful for making agricultural and water management decisions for individual crops.

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Abbreviations

NDVI	Normalized Difference Vegetation Index
VCI	Vegetation Condition Index
PDSI	Palmer Drought Severity Index
CMI	Crop moisture Index
SPI	Standardized Precipitation Index
SWSI	Standardized Water Supply Index
TCI	Temperature Condition Index
PHP	Hypertext Preprocessor
GDAL	Geospatial Data Abstraction Library
MODIS	Moderate Resolution Imaging Spectro-radiometer
IMD	Indian Meteorological Department
HDF	Hierarchical Data Format
USGS	United States Geological Survey

1. INTRODUCTION

1.1. BACKGROUND

Droughts are periods of time when natural or managed water systems do not provide enough water to meet the established human and environmental uses because of natural shortfalls in precipitation or stream flow (Werick *et al.*, 1994); and the basic reason for this being reduction in the rainfall availability for a prolonged period, lasting long enough to produce a serious hydrologic imbalance in the water use sectors. Agriculture is perhaps the commonest area or activity that is severely affected by the vagaries of the climatic variables of any region. Drought may be monitored by assessing the degree of departure of a defining variable such as precipitation, soil moisture etc, from the average of the climatic variable selected, over some time period. This is usually done by comparing the current situation to the historical average, often based on a 30-year (or more) period of record. The departures are then interpreted as drought severity indices. One of the popular drought indices is Standardized Precipitation Index (SPI) developed by McKee *et al*, 1993 which is adopted and used by National Drought Monitoring Centre (NDMC, USA; www.ndmc.org).

1.2. DROUGHT: DEFINITIONS

Drought is a natural disaster occurring due to the water deficiency from normal demands. It should be considered relative to some long-term average condition rather than absolute condition (Wilhite and Svoboda, 2000). Drought is considered by many to be the most complex but least understood of all-natural hazards, affecting more people than any other hazard (Hagman, 1984). Drought is also defined as a prolonged abnormally dry period when there is not enough water for user's normal needs, resulting in extensive damage to crops and a loss of yields (Wilhite, 2005). Drought is a normal, recurring feature of climate; it occurs in virtually all climatic regimes. According to WMO (2006), drought occurs in both dry and humid regions. It must be considered relative, rather than absolute condition that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalance that adversely affect land resource production systems. Drought is often perceived as a creeping hazard as it develops slowly and has a prolonged duration (Smith, 2013). Drought is a regional phenomenon and its characteristics differ from one climate regime to another (Iglesias and Buono, 2009). An extreme climatic condition like drought poses severe damage to crops, livestock and humans and the associated economic repercussions are huge. Unlike other natural disasters, drought impacts large areas and for extended periods of time. Hence it is important to monitor the duration, frequency and spatial extent of drought using relevant indices to provide planners with useful information required to plan for disaster response measures (WMO, 2006). Since drought as a condition of precipitation deficit start as a reduction in soil moisture, agriculture is the sector that is affected first (WMO, 2006). 68% of the net sown area in India is vulnerable to drought conditions. A decrease in 17.9% of food grain production during the drought of 1987, has led to a 3.2% decline in agricultural GDP of the country (Murthy and SeshaSai, 2010).

India Meteorological Department (IMD) defines meteorological drought as a situation when the seasonal rainfall over the area is less than 75% of its long-term average. Rainfall deficits between 26%-50% is classified as moderate drought, and that more than 50% is classified as severe drought (India Meteorological Department). On an average, 28% of the geographical area in India is considered to be vulnerable to drought (Samra, 2004). The country has witnessed worst droughts in the years 1918, 1972, 1987, 2002 and 2009 (Indian Agricultural Statistics Research Institute, 2014). There has been an increase in the area affected by moderate droughts in the country, since 1951 (Kumar *et al.*, 2013). Even with an average annual rainfall of about 3000 mm, the state of Kerala is affected by occasional localized drought events. The state has experienced drought conditions in the years 1982-83, 1983-84, 1986-87, 1987-88, 2000-01and 2008-09 (Dinesan, 2013). A total of 693 villages in the state were affected by drought in the last ten years (Government of Kerala, 2012).

In many countries such as Australia, China, India and the United States of America, drought occurs over a portion of the country each year. Drought is related to the timing and effectiveness of the rains; thus, each drought year is unique in its climate characteristics and impacts. Therefore, it is impossible to make a definition of drought that can be universally accepted (Wilhite, 1993).

Drought definitions are of two types: (1) conceptual, and (2) operational. Conceptual definitions help understand the meaning of drought and its effects. For example, drought is a protracted period of deficient precipitation which causes extensive damage to crops, resulting in loss of yield.

Operational definitions help to identify the beginning, end, and degree of severity of drought. To determine the beginning of drought, operational definitions specify the degree of departure from the precipitation average over some time period. This is usually accomplished by comparing the current situation with the historical average. The threshold identified as the beginning of a drought (e.g., 75% of average precipitation over a specified time period) is usually established somewhat arbitrarily.

Operational definitions are used to analyze drought frequency, severity, and duration for a given historical period. Such definitions, however, require weather data on hourly, daily, monthly, or other time scales and, possibly, impact data (e.g., crop yield). Climatology of drought for a given region provides a greater understanding of its characteristics and the probability of recurrence at various levels of severity. Information of this type is beneficial in the formulation of mitigation strategies.

1.3. TYPES OF DROUGHT

Various types of droughts are listed below.

1.3.1. Meteorological Drought

Meteorological drought is defined on the basis of the degree of dryness, in comparison to a normal or average amount, and the duration of the dry period. Definitions of meteorological drought must be region-specific, since the atmospheric conditions that result in deficiencies of precipitation are highly region-specific.

Differences in defining meteorological drought in different countries illustrates why it is not possible to apply a definition of drought developed in one part of the world to another. For instance, the following definitions of drought have been reported:

- United States (1942): Less than 2.5 mm of rainfall in 48 hours.
- Great Britain (1936): Fifteen consecutive days with daily precipitation less than 0.25 mm.
- Libya (1964): When annual rainfall is less than 180 mm.
- Bali (1964): A period of six days without rain.

Data sets required to assess meteorological drought are daily rainfall information, temperature, humidity, wind velocity and pressure, and evaporation.

1.3.2. Agricultural Drought

Agricultural drought links various characteristics of meteorological drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapotranspiration, soil-water deficits, reduced groundwater or reservoir levels, and so on. Plant water demand depends on prevailing weather conditions, biological characteristics of the specific plant, its stage of growth, and the physical and biological properties of the soil. A good definition of agricultural drought should account for the susceptibility of crops during different stages of crop development. Deficient topsoil moisture at planting may hinder germination, leading to low plant populations per hectare and a reduction of yield.

Data sets required to assess agricultural drought are soil texture, fertility and soil moisture, crop type and area, crop water requirements, pests and climate.

1.3.3. Hydrological Drought

Hydrological drought refers to a persistently low discharge and/or volume of water in streams and reservoirs, lasting months or years. Hydrological drought is a natural phenomenon, but it may be exacerbated by human activities. Hydrological droughts are usually related to meteorological droughts, and their recurrence interval varies accordingly. Changes in land use and land degradation can affect the magnitude and frequency of hydrological droughts.

Data sets required to assess hydrological drought are surface-water area and volume, surface runoff, stream flow measurements, infiltration, water-table fluctuations, and aquifer parameters.

1.3.4. Socio-Economic drought

Socio-economic definitions of drought associate the supply and demand of some economic good with elements of meteorological, hydrological, and agricultural drought. It differs from the other types of drought in that its occurrence depends on the processes of supply and demand. The supply of many economic goods, such as water, forage, food grains, fish, and hydroelectric power, depends on the weather. Due to the natural variability of climate, water supply is ample in some years, but insufficient to meet human and environmental needs in other years.

Socio-economic drought occurs when the demand for an economic good exceeds the supply as a result of a weather-related shortfall in water supply. The drought may result in significantly reduced hydroelectric power production because power plants were dependents on stream flow rather than storage for power generation. Reducing hydroelectric power production may require the government to convert to more expensive petroleum alternatives, and to commit to stringent energy conservation measures to meet its power needs.

The demand for economic goods is increasing as a result of population growth and economic development. The supply may also increase because of improved production efficiency, technology, or the construction of reservoirs. When both supply and demand increase, the critical factor is their relative rate of change.

Socio-economic drought is promoted when the demand for water for economic activities far exceeds the supply. Data sets required to assess socio-economic drought are human and animal population and growth rate, water and fodder requirements, severity of crop failure, and industry type and water requirements.

1.4. IMPACTS OF DROUGHT

Drought produces a complex web of impacts that spans many sectors of the economy and reaches well beyond the area experiencing physical drought. This complexity exists because water is integral to society's ability to produce goods and provide services.

Impacts are commonly referred to as direct and indirect. Direct impacts include reduced crop, rangeland, and forest productivity, increased fire hazard, reduced water levels, increased livestock and wildlife mortality rates, and damage to wildlife and fish habitat. The consequences of these direct impacts illustrate indirect impacts. For example, a reduction in crop, rangeland, and forest productivity may result in reduced income for farmers and agribusiness, increased prices for food and timber, unemployment, reduced tax revenues because of reduced expenditures, foreclosures on bank loans to farmers and businesses, migration, and disaster relief programs.

The types of drought impacts are described below.

1.4.1. Economic Impacts

Many economic impacts occur in agriculture and related sectors, because of the reliance of these sectors on surface and groundwater supplies. In addition to losses in yields in crop and livestock production, drought is associated with insect infestations, plant disease, and wind erosion. The incidence of forest and range fires increases substantially during extended periods of droughts, which in turn places both human and wildlife populations at higher levels of risk.

Income loss is another indicator used in assessing the impacts of drought. Reduced income for farmers has a ripple effect. Retailers and others who provide goods and services to farmers face reduced business. This leads to unemployment, increased credit risk for financial institutions, capital shortfalls, and eventual loss of tax revenue for local, state, and federal governments. Prices for food, energy, and other products increase as supplies are reduced. In some cases, local shortages of certain goods result in importing these goods from outside the drought-stricken region. Reduced water supply impairs the navigability of rivers and results in increased transportation costs because products must be transported by alternative means. Hydropower production may also be significantly affected.

1.4.2. Environmental Impacts

Environmental losses are the result of damages to plant and animal species, wildlife habitat, and air and water quality, forest and range fires, degradation of landscape quality, loss of biodiversity, and soil erosion. Some of these effects are short-term, conditions returning to normal following the end of the drought. Other environmental effects last for some time and may even become permanent. Wildlife habitat, for example, may be degraded through the loss of wetlands, lakes, and vegetation. However, many species eventually recover from this temporary aberration. The degradation of landscape quality, including increased soil erosion, may lead to a more permanent loss of biological productivity.

1.4.3. Social Impacts

Social impacts involve public safety, health, conflicts between water users, reduced quality of life, and inequities in the distribution of impacts and disaster relief. Many of the impacts identified as economic and environmental have social components as well. Population migration is a significant problem in many countries, often stimulated by a greater supply of food and water elsewhere. Migration is usually to urban areas within the stressed area, or to regions outside the drought area. Migration may even be to adjacent countries. When the drought has abated, the migrants seldom return home, depriving rural areas of valuable human resources. The drought migrants place increasing pressure on the social infrastructure of the urban areas, leading to increased poverty and social unrest.

1.5. HISTORY OF DROUGHT IN INDIA

Given the large size of the country and the very high time and space variability of the southwest monsoon rainfall, it is not surprising that no part of India can be regarded as free from the likelihood of drought. That is why there are parts of the country suffering from drought even in the best of the monsoon years. (e.g. Madhya Pradesh in 1988) or sometimes drought occurring in the usually very rainy north-eastern states of the country (e.g. in 2005)

The erratic nature of the Indian monsoon with long dry spells accompanied by high temperature is responsible for creating drought conditions. According to Joseph et al. (May 2016), an article in "The Indian Express", during 1870-1900s, there were very few droughts, followed by droughts once in 15 years during 1930-1950. There were 10 drought years during 1950-1990. Since 2000, there have been five drought years: 2002, 2004, 2009, 2014, 2015. States affected by drought in India are Maharashtra, Karnataka, Andhra Pradesh, Orissa, Gujarat and Rajasthan, Major population of these region depended on the rice crop of the winter season. Due to the failure of the monsoon, some parts of Bihar and Jharkhand along with Punjab and Haryana were also affected by drought. About 94 mha of area in India is classified as dry regions, inhabited by around 300 million people. Severe drought in 1917-18 led to complete drying up of river Jhelum in Kashmir. 22 large scale droughts were reported in the country, of which five were severe (Gupta *et al.*, 2011).

1.6. HISTORY OF DROUGHT IN KERALA

Kerala State belongs to a typical humid tropical region and the hydrology of the state essentially varies from that of the rest of India. The hydrological characteristics of the state present special situation, where the rainfall variations are seen to follow an annual cycle; also, the spatial variations are of micro-scale. Drought events exist for shorter periods, a few months or so; but cause severe losses to the crops in the agriculture sector and hit the power and drinking water systems badly. However, the scenario in rest of the country is apparently different where the drought conditions exist for prolonged periods.

Even though the state has an average annual rainfall of 3000 mm, drought has been a recurring phenomenon in recent years. This is mainly because of the spatial and temporal variations in the rainfall, highly undulating topography, low water retention capacity of soil, high population density and biological diversity, etc. Kerala had severe dry spells and drought in 1983, 1985, 1986 and 1987, even though the state has wet climate. There were dry spells of 5 and 4 weeks in 1985 and 1986, respectively, during the SW monsoon period. Damage due to drought was particularly significant in Kerala in 1987. About 1500 villages in 14 districts were affected, and 9.82 lakh hectares of crop land and 6 lakhs cattle were also affected. During January-May 1987, the entire Kerala region was affected by drought. About 30% of the paddy crop was lost, and cash crops like coconuts, aracanuts, cashews and bananas were damaged, resulting in a loss of Rs 1000 crores.

The State, the latter-day experience is, faces unprecedented difficulties related to the localized occurrence of drought and flood conditions in several districts. The alternating attacks of drought-after-flood-after-drought syndrome have to be tackled by following the suggestions promulgated by the UNCED (Agenda-21). Hence the need for a permanent State-level facility for carrying out observation, research and dissemination of information on a real-time basis in relation to the natural disasters of floods and droughts using Space Technology is greatly felt.

According to the Environmental Report for Kerala (2007), the state of Kerala experiences seasonal drought conditions every year during the summer months. Even in the years of normal rainfall, summer water scarcity problems are severe in the midland and highland regions. Severe drought conditions often result from the anomalies in monsoon rainfall combined with the various anthropogenic pressures. A study on the incidence of droughts based on the aridity index (Environmental Report for Kerala , 2007) shows that during the period 1871- 2000, the State of Kerala experienced 66 drought years, out of which, twelve each were moderate and severe droughts.

1.7. NEED FOR DROUGHT RISK EVALUATION AND MANAGEMENT

In drought management, making the transition from crisis to risk management is difficult because little has been done to understand and address the risks associated with drought. Droughts cause misery to both human and livestock population, accelerate degradation of natural resources and put a heavy pressure on governments' resources through relief measures. There are strong links between poverty and proneness of an area to drought. Widespread crop failure leading to acute shortages of food and fodder adversely affecting human and livestock health and nutrition, scarcity of drinking water accentuated by deteriorating ground water quality and declining water tables leading to large scale migration are the major manifestation of droughts. Drought risk reflects the probability of occurrence of drought as well as the magnitude of impacts. An effective drought risk management strategy would therefore aim to build resilience in human and ecosystem services during drought by minimizing the economic impacts.

1.8. PROBLEM STATEMENT

Drought is one of the major environmental disasters, which have been occurring in almost all climatic zones and damage to environment and economies of several countries has been extensive and death toll of livestock unprecedented. Drought damages are more pronounced or prominent in areas where there is a direct threat to livelihoods.

Even though Kerala has an average annual rainfall of 3000 mm, drought has been a recurring phenomenon in recent years. This is mainly because of the spatial and temporal variations in the rainfall, highly undulating topography, low water retention capacity of soil, high population density and biological diversity, etc. Actually, based on historic remote sensing data one can identify the vegetation Anomaly/drought condition of a particular AOI through different digital image processing techniques, which is time consuming and tedious. But, the web application developed in this study helps to generate drought maps and district wise drought information at real-time in the web server using PHP and Python Scripts, which will be handy for policy makers for identifying the vegetation anomaly of any area, as this web application can be easily configured for any Area of Interest (AOI) due to its configurable architecture and its flexibility. Drought maps generated through the web interface would provide a pictorial representation which is easily understandable by the policy makers. They can easily obtain the required information and use it to develop drought response strategies and actions. Such an interface would provide information to analyse the drought magnitude, spatial extent and associated impacts. Integration of the drought maps with land use based information increases its usefulness in the agricultural sector.

1.9. OBJECTIVE

- Development of a Space Enabled Drought Management Support System for five drought prone districts of Kerala state.

REVIEW OF LITERATURE

2.1. REMOTE SENSING AND GIS IN DROUGHT STUDIES

The mitigation of the effects of disasters requires relevant information regarding the disaster in real time. Also, the possible prediction and monitoring of the disaster requires rapid and continuous data and information generation or gathering. Since disasters that cause huge social and economic disruptions normally affect large areas or territories and are linked to global change, it is not possible to effectively collect continuous data on them using conventional methods. The space technology or remote sensing tools offer excellent possibilities of collecting this vital data. This is because the technology has capability of collecting data at global and regional scales rapidly and repetitively and the data is collected in digital form. The technology further provides an excellent communication medium.

The satellite or remote sensing techniques can be used to monitor the current situation- before, during or after disaster. They can be used to provide baseline data against which future changes can be compared while the GIS techniques provide a suitable framework for integrating and analyzing the many types of data sources required for disaster monitoring.

In recent years, the ever-increasing population and overstress on natural resources, soil degradation, decrease in water resources, and future projected climate change scenarios have become important areas of concern. The main goal of global agriculture is to feed 6 billion people, a number likely to double by (Kogan, 2000). The first requirement of living creature is food, and a setback in agricultural and fodder production leads to socio-economic unrest especially in developing countries. Therefore, management of natural resources in developing as well as developed countries requires information on the state and changes in a range of biophysical variables. Droughts has been viewed as such a disaster where in a shortfall in precipitation has led to substantial reduction in production levels thereby leading to conditions which causes large scale migration and death of men and animals. Therefore, there is a need for proper quantification of drought impacts and monitoring and reporting of drought development in economically and environmentally sensitive areas. The impact of drought on society and agriculture is a real issue but it is not easily quantified. Reliable indices to detect the spatial and temporal dimensions of drought occurrences and its intensity are necessary to assess the impact and also for decision-making and crop research priorities for alleviation (Seiler *et al*., 1998). The development and advancements in space technology, to address issues like drought detection, monitoring and assessment have been dealt with very successfully and helped in formulation of plans to deal with this slow onset disaster. With the help of environmental satellite, drought can be detected 4-6 weeks earlier than before and delineated more accurately, and its impact on agriculture can be diagnosed far in advance of harvest, which is the most vital for global food security and trade (Kogan,1990).

Several indices have been developed for the quantification of drought based on the type of drought. Palmer Drought Severity Index developed by Palmer (1965), is the most widely used drought index based on the demand and supply concept of the water balance equation. Palmer (1968) derived another index, the Crop Moisture Index (CMI) by modifying PDSI to find out the severity of agricultural drought. Hydrological droughts characterized by low precipitation, lowering of groundwater tables, fall in the level of lakes and Surface Water Supply Index (SWSI) has assessed reservoirs. A brief review of these indices is given in the next section. With the advancements in remote sensing technology, the historical drought indices were over powered by the newly developed indices from remote sensing data that are considered to be real time. Also, the remote sensing has provided a complete coverage of extended regions with a spatial resolution of a few hundred meters to few kilometres.

Thus, for an accurate assessment of the occurrence extent and severity drought it is necessary to get a correct picture of the spatial and temporal distribution of a number of meteorological, hydrological and surface variables. Space observation having this potential has made a significant contribution in this field. The satellite sensors that have the capability to retrieve surface parameters with high spatial and temporal resolutions over large areas have provided a comprehensive view of the situation. Many drought studies have made an extensive use of the AVHRR derived data, as it monitors earth surface changes continuously, freely accessible and moreover it's widely recognized around the world.

2.2. METEOROLOGICAL DROUGHT INDICES AND DROUGHT DETECTION

Drought indices have been developed as a means to measure drought. A drought index assimilates thousands of data on rainfall, snow pack, stream flow and other water-supply indicators into a comprehensible picture. There are several indices that measure how much precipitation for a given period of time has deviated from historically established norms. Some of the widely used drought indices include Palmer Drought Severity Index (PDSI), Crop Moisture Index (CMI), Standardized Precipitation Index (SPI), and Surface Water Supply Index (SWSI).

2.2.1. Palmer Drought Severity Index (PDSI)

In 1965, W.C. Palmer developed an index to measure the departure of the moisture supply (Palmer, 1965). Palmer based his index on the supply-and-demand concept of the water balance equation, taking into account more than just the precipitation deficit at specific locations. The objective of the Palmer Drought Severity Index (PDSI) is to provide standardized measurements of moisture conditions so that comparison could be made between locations and between months. The PDSI is a meteorological drought index that is responsive to abnormal weather conditions either on dry or abnormally wet side. The index was specifically designed to treat the drought problem in semiarid and sub humid climates; with Palmer, himself cautioning that extrapolation beyond these conditions may lead to unrealistic results.

PDSI has been used in west –Hungary as soil moisture indicator and has been widely used in United States for drought monitoring. It has been utilised as a tool to trigger actions associated with drought contingency plans. Several researchers have given limitations of PDSI. The Palmer Drought Severity Index (Palmer, 1965) has a time scale of about 9 months (Guttman, 1998), which does not allow identification of droughts at shorter time scales. Moreover, this index has many other problems related to calibration and spatial comparability. McKee *et al.* (1993) suggested that PDSI is designed for agriculture but does not accurately represent the hydrological impacts resulting from longer droughts. Also, PDSI is applied within the United States and has less acceptance elsewhere (Kogan, 1990). To solve these problems, McKee et al. (1993) developed the Standardized Precipitation Index (SPI), which can be calculated at different time scales to monitor droughts in the different usable water resources. Moreover, the SPI is comparable in time and space (Hayes *et al.*, 1999).

2.2.2. Crop moisture index (CMI)

Three years after the introduction of his drought index, Palmer (1968) introduced a new drought index based on weekly mean temperature and precipitation known as Crop Moisture Index (CMI). It was specifically designed as an agricultural drought index. It depends on the drought severity at the beginning of the week and the evapotranspiration, soil deficit or soil moisture recharge during the week (Heim, 2000). It measures both evapotranspiration deficits(drought) and excessive wetness(more than enough precipitation to meet evapotranspiration demand and recharge the soil). CMI is designed to monitor short-term moisture conditions affecting a developing crop; therefore, CMI is not a good long-term drought-monitoring tool. The CMI's rapid response to changing short-term conditions may provide misleading information about long-term conditions. Nemani *et al.* (1993) used CMI for estimating surface moisture status, because CMI depicts changes in soil moisture situation more rapidly than PDSI. It was found that CMI indicates more favourable moisture conditions over a particularly wet or dry month even in the middle of a serious long-term wet or dry period.

2.2.3. Standardized Precipitation Index (SPI)

Tom McKee, Nolan Doesken and John Kleist of the Colorado Climate Centre formulated the SPI in 1993. The purpose is to assign a single numeric value to the precipitation that can be compared across regions with markedly different climates. Technically, the SPI is the number of standard deviations that the observed value would deviate from the long-term mean, for a normally distributed random variable. Since precipitation is not normally distributed, a transformation is first applied so that the transformed precipitation values follow a normal distribution. The SPI was designed to quantify the precipitation deficit for multiple time scales. These time scales reflect the impact of drought on the availability of the different water resources. Soil moisture conditions respond to precipitation anomalies on a relatively short scale while groundwater, stream flow, and reservoir storage reflect the longer-term precipitation anomalies. Thus, McKee *et al.* (1993) originally calculated the SPI for 3–, 6–, 12–, 24–, and 48–month time scales. The SPI calculation for any location is based on the long-term precipitation record that is fitted to a probability distribution, which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero (Edwards, 1997). A drought event occurs any time the SPI is continuously negative and reaches intensity of -1.0 or less. The event ends when the SPI becomes positive. Each drought event, therefore, has a duration defined by its beginning and end, and intensity for each month that the event continues. The positive sum of the SPI for all the months within a drought event can be termed the drought's "magnitude". The threshold for indicating severity of meteorological drought (Table 1) has been adopted from U.S. Drought Mitigation Centre.

Table 1. Standardized Precipitation Index classification

Standardized Precipitation Index	Description
-0.5 and above	No drought
- 0.5 to - 0.8	Abnormally dry
- 0.9 to -1.2	Moderate drought
-1.3 to -1.5	Severe drought
-1.6 to -1.9	Extreme drought
-2 or less	Exceptional drought

(Source:http://drought.unl.edu/monitor/spi)

2.2.4. Standardised Water Supply Index (SWSI)

Shafer(1982) to complement the Palmer Index for moisture conditions across the state of Colorado developed the Surface Water Supply Index (SWSI). This index compliments the Palmer index for moisture condition. It is dependent on the season; SWSI is computed with only snowpack, precipitation, and reservoir storage in the winter. During the summer months, stream flow replaces snowpack as a component within the SWSI equation.

SWSI has been used along with PDSI, to trigger the activation and deactivation of the Colorado drought plan. Though, SWSI is easy to calculate yet it has the limitation that values between basins or a region is difficult to compare (Doesken *et al*, 1991) (URL: www.drought.unl.edu)

2.3. SATELLITE BASED DROUGHT INDICES FOR DROUGHT CHARACTERIZATION

Drought indicators assimilate information on rainfall, stored soil moisture or water supply but do not express much local spatial detail. Also, drought indices calculated at one location is only valid for single location. Thus, a major drawback of climate based drought indicators is their lack of spatial detail as well as they are dependent on data collected at weather stations which sometimes are sparsely distributed affecting the reliability of the drought indices (Brown *et al.*, 2002). Satellite derived drought indicators calculated from satellite-derived surface parameters have been widely used to study droughts (Abbas *et al.*, 2014; Bakri and Suleiman, 2004; Cai *et al.*, 2010; Chopra, 2006; Jain *et al.*, 2009; Komuscu, 1999; Mu *et al.*, 2013; Thiruvengadachari and Gopalkrishna, 1993; Propastin *et al.*, 2008; Muhaimeed and Al-HednySuhad, 2013; Francis and Kayode, 2013; McKee *et al.*, 1995). Normalized Difference Vegetation Index (NDVI), Vegetation Condition Index (VCI), and Temperature Condition Index (TCI) are some of the extensively used vegetation indices.

2.3.1. Normalized Difference Vegetation Index (NDVI)

Tucker first suggested NDVI in 1979 as an index of vegetation health and density (Thenkabail *et al.*, 2004). NDVI is defined as:

$$NDVI = (NIR - RED) / (NIR + RED)$$

Where, NIR and RED are the reflectance in the near infrared and red bands. NDVI is a good indicator of green biomass, leaf area index, and patterns of production (Thenkabail et al. 2004; Wan *et al.*, 2004). NDVI is the most commonly used vegetation index. It varies from +1 to -1. Since climate is one of the most important factors affecting vegetation condition, AVHRR- NDVI data have been used to evaluate climatic and environmental changes at regional and global scales (Ji and Peters, 2004; Singh *et al.*, 2003; Li *et al*, 2004). It can be used not only for accurate description of continental land cover, vegetation classification and vegetation vigour but is also effective for monitoring rainfall and drought, estimating net primary production of vegetation, crop growth conditions and crop yields, detecting weather impacts and other events important for agriculture, ecology and economics (Singh *et al.*, 2003). NDVI has been used successfully to identify stressed and damaged crops and pastures but only in homogenous terrain. In more heterogeneous terrain regions their interpretation becomes more difficult (Vogt *et al.*, 1998; Singh *et al.*, 2003). Many studies in the Sahel Zone (Anyamba and Tucker, 2005), Argentina (Seiler *et al.*, 1998), South Africa (Unganai and Kogan, 1998) and Mediterranean (Vogt *et al.*, 1998), and Senegal (Li *et al.*, 2004) indicate meaningful direct relationships between NDVI derived from NOAA AVHRR satellites, rainfall and vegetation cover and biomass.

2.3.2. Vegetation Condition Index (VCI)

It was first suggested by Kogan (1997) (Thenkabail *et al.*, 2004; Vogt *et al.*, 1998). VCI is an indicator of the status of the vegetation cover as a function of the status of the vegetation cover as a function of the NDVI minimum and maxima encountered for a given ecosystem over many years. VCI is defined as:

$$VCIj = (NDVIj- NDVImin)/ (NDVImax- NDVImin) *100$$

Where, NDVImax, NDVImin is calculated from long-term record for a particular month and j is the index of the current month. The condition of the ground vegetation presented by VCI is measured in percent. The VCI values between 50% to 100% indicate optimal or above normal conditions whereas VCI values close to zero percent reflects an extreme dry month. VCI has been used by Unganai and Kogan (1998), for estimation of corn yield in South Africa; drought detection in Argentina ((Seiler *et al.*, 1998); drought monitoring over India (Singh *et al.*, 2003); monitoring droughts in the southern Great Plains, USA (Wan *et al.*, 2004); drought detection and monitoring in the Mediterranean region (Vogt *et al.*, 1998) and drought assessment and monitoring in Southwest Asia (Thenkabail *et al.*, 2004). These studies suggest that VCI captures rainfall dynamics better than the NDVI particularly in geographically non-homogeneous areas. Also, VCI values indicate how much the vegetation has advanced or deteriorated in response to weather. It was concluded from the above studies that VCI has provided an assessment of spatial characteristics of drought, as well as its duration and severity and were in good agreement with precipitation patterns.

2.3.3. Temperature Condition Index (TCI)

TCI was also suggested by Kogan (1997), (Thenkabail *et al.*, 2004). It was developed to reflect vegetation response to temperature i.e. higher the temperature the more extreme the drought. TCI is based on brightness temperature and represents the deviation of the current month's value from the recorded maximum. TCI is defined as:

$$TCIj= (BT\ max- BTj)/ (BTmax- Btmin) * 100$$

Where, BT is brightness temperature. Maximum and minimum BT values are calculated from the long-term record of remote sensing images for a particular period j. low TCI values indicate very hot weather. TCI has been used for drought monitoring in the USA, China, Zimbabwe and the Former Soviet Union. A study in Argentina for drought detection revealed that TCI was useful to assess the spatial characteristics, the duration and severity of droughts, and were in good agreement in precipitation patterns (Seiler *et al.*,1998). TCI has been related to recent regional scale drought patterns in South Africa (Kogan, 1997).

2.4. NDVI - RAINFALL RELATIONSHIP AS INDICATOR OF DROUGHT

Several studies have been devoted towards drought with the aid of satellite-derived information. Reflectance in the visible, near-infrared and thermal bands were combined into Vegetation Condition Index (VCI), Temperature Condition Index (TCI), and Normalized Difference Vegetation Index (NDVI), which considerably improved early drought detection, watch and monitoring of drought's impacts on agriculture. Using NOAA Advanced Very High-Resolution Radiometer (AVHRR) data, researchers have successfully extended satellite data analysis to large-area vegetation monitoring (Kogan, 1990) and biomass productivity estimates (Townshend and Justice, 1986). Since vegetation indices derived from the AVHRR sensor are directly related to plant vigour, density, and growth conditions, they may also be used to detect unfavourable environmental variables. The relationship between NDVI and rainfall is known to vary spatially, notably due to the effects of variation in properties such as vegetation type and soil background (Li *et al.*, 2002; Farrar *et al.*, 1994), with the sensitivity of NDVI values to fluctuations in rainfall, therefore, varying regionally. Vegetation amount and condition are a function of environmental variables such as rainfall.

Consequently, a strong relationship, involving a brief time–lag in the vegetation response to rainfall, would be expected between vegetation indices, such as the NDVI [(infrared reflectance (IR)-red reflectance (R))/ (IR + R)] and rainfall (Li *et al.*, 2002).

Many studies have focused on the relationship between the NDVI and rainfall. A study regarding the modelling of drought risk areas by using remotely sensed was carried out by C. Mongkolsawat *et al.* (2000) in Northeast Thailand, where drought has the most profound effect on the lives and regional economy. In this paper, the severity of drought was considered to be a function of rainfall, hydrology and physical aspect of landscape. Three different types of droughts i.e. meteorological, hydrological and physical drought were analysed after which an overlay matrix operation was performed that yielded the areas which faced drought risk wherein drought risk was classified into four classes. The result obtained was satisfactory confirming that the model developed in this study could help in the mapping of drought risk area in the Northeast Thailand.

Another study related to early detection of drought in East Asia was done by Song *et al.* (2004) NDVI from NOAA/AVHRR had been used wherein standard NDVI and up-to-date NDVI were calculated to derive difference NDVI image, to detect the intensity and agricultural area damaged by drought. The difference images were used to create drought risk maps. The study was successful in detecting and monitoring drought effects on agriculture.

Wilhelmi and Wilhite (2002) presented a method for spatial, Geographic Information Systems based assessment of agricultural drought vulnerability in Nebraska. It was hypothesized that the key biophysical and social factors that define agricultural drought vulnerability were climate, soils, land use and access to irrigation. The framework for derivation of an agricultural drought vulnerability map was created through development of a numerical weighting scheme to evaluate the drought potential of the classes within each factor. Results indicated that the most vulnerable areas to agricultural drought were non-irrigated cropland and rangeland located in areas with a very high probability of seasonal crop moisture deficiency.

A research done by Herrmann *et al.* (2005) investigates temporal and spatial patterns of vegetation greenness and explores relationships between rainfall and vegetation dynamics in the Sahel, based on analyses of NDVI time series and gridded precipitation estimates at different spatial resolutions. Overall positive trends in NDVI and rainfall over the period 1982 to 2003 were confirmed. Linear correlations between the two variables were found to be highly significant throughout the entire Sahel. Herrmann *et al.* (2005) thus considered that rainfall is the most important constraint to vegetation growth in this semi-arid zone, which justifies the attempt to predict vegetation greenness from rainfall estimates through linear regression.

Similarly, a case study relating to drought risk evaluation was carried out by Prathumchai *et al.* (2001), the objective of the study being to evaluate criteria for identifying drought risk areas. In this study, physical and meteorological factors were analyzed and drought risk areas were identified. Drought risk areas were calculated as a weighted linear combination of a set of input factors such as topography, soil drainage, ground water resource, irrigation area, annual evaporation, average annual rainfall and frequency of rainfall days. The relationship between NDVI change and drought risk level was calculated from the average NDVI change collected by masking each drought risk area. The study concluded that NDVI can be used as a main indicator to evaluate drought. However, the limitation of the study was that it was unable to consider change in species, type, age and characteristic of the vegetation.

Anyamba and Tucker (2005) analyzed seasonal and inter-annual vegetation dynamics in Sahel using NOAA-AVHRR NDVI. The study concentrated only on NDVI patterns in growing season, which was defined by examining the long-term patterns of both rainfall and NDVI. Year to year variability in NDVI patterns was examined by calculating yearly growing season anomalies. The correlation between NDVI and rainfall anomaly time series was found to be positive and significant, indicating the close coupling between rainfall and land surface response patterns over the region. A study by Wang *et al.* (2003) concentrated on temporal responses of NDVI to precipitation and temperature in the central Great Plains, USA. In this study, it was found that average growing season NDVI values were highly correlated with precipitation received during the growing season and seven preceding months. Relations between temperature and rainfall with NDVI were examined within growing season, across growing seasons and across years. It was concluded that precipitation has the primary influence on NDVI and by inference, on productivity.

2.5. SPI BASED DROUGHT IDENTIFICATION

Hayes *et al.* (1999) used the standardized precipitation index (SPI) to monitor the 1996 drought in the United States of America. Hayes et al. (1999) shows that the onset of the drought in the USA in 1996 could have been detected one month in advance of the Palmer Drought Severity Index (PSDI). The SPI is consistent with regard to the spatial distribution of rainfall that occurs with great variability in South Africa due to geographical location, orography and the influence of the oceans. Using that index to develop climatology of the spatial extension and intensity of droughts an additional understanding of its characteristics and an indication of the probability of recurrence of drought at various levels of severity. Ji and Peters (2004) undertook a study relating to assessing vegetation response in the northern Great Plains using vegetation and drought indices. The study aimed to determine the response of vegetation to moisture availability through analysis of monthly AVHRR-NDVI and SPI over grass and cropland cover types in the northern U.S. Great Plains. The study focused on three major areas namely relationship between NDVI and SPI at different time scales, response of NDVI to SPI during different time periods within a growing season and regional characteristics of the NDVI-SPI relationship. The relationship between vegetation and moisture availability was clarified by analysing the covariance of NDVI and SPI time series with the scatter plots and Pearson correlation analysis. It was found that NDVI response is not sufficiently sensitive to 1- or 2- month SPI and the scales longer that 6 months tend to reduce the covariation of SPI and vegetation vigour. It was found that the 3- month SPI has the highest correlation to the NDVI, because the 3- month SPI is best for determining drought severity and duration. Also, it was found that seasonality has a very significant effect on the relationship between the NDVI and SPI.

A study was carried out by Chaudhari and Dadhwal (2004) to quantify the impact of drought on production of kharif and rabi crops using standardized precipitation index (SPI). SPI were computed at monthly (SPI-1), bi-monthly (SPI-2) and tri-monthly (SPI-3) time scales with the suggested Pearson Type III distribution. SPI values were then classified into seven categories suggested by Hayes, 1999. Correlation coefficients were computed between state-wise production of major kharif crops (1980-2001) and SPI values (SPI-1, SPI-2, and SPI-3). Production forecasts using SPI-3 showed good agreement with the statistics from state department of agriculture, thereby suggesting that SPI at different time scales can be used as a predicator of regional crop production in India.

Serrano and Moreno (2005) in his paper has analysed the usefulness of a drought index (the Standardized Precipitation Index) to identify droughts in different usable water resources. The analysis was done in the central Spanish Pyrenees (Aragon River Basin). Wu *et al*. (2007), revealed that the application of SPI of short time scales in arid and the areas with distinct dry season fails to detect the occurrence of drought situation. This behaviour of SPI is attributed to its non normal distribution caused by higher frequency of no rain cases.

2.6. RAINFALL ANOMALY BASED DROUGHT IDENTIFICATION

Meteorological drought indicates the deficiency of rainfall compared to normal rainfall in a given region. Places where long-term average rainfall is less, year-to-year variability is greater and so the likelihood of drought is greater. The major impact of drought is felt in semi-arid regions where the incidence of drought years is fairly high. According to the Indian Meteorological Department (IMD), meteorological drought is occurring when the seasonal rainfall received over and area is less than 75% of its long-term average value. Krishnamurthy and Shukla (2000) analysed the inter-annual and intra-seasonal variability of the summer monsoon rainfall over India and found that major drought years are characterized by large-scale negative rainfall anomalies covering nearly all of India and persisting for the entire monsoon season.

A large number of papers have analysed the inter-annual variability of the summer (June- September) mean monsoon rainfall averaged over India (Parthasarathy and Mooley 1978; Shukla, 1987), stating an inter-annual standard deviation of the mean seasonal rainfall to be 10% of the long-term mean value.

Thus, it can be concluded that these reviews highlight the numerous efforts made till date with developing relationship between various satellite and meteorological derived indices to point out a specific type of drought caused either by rainfall deficiency, or less vegetation vigour or low agricultural production. In the present study, both meteorological indices (SPI) and satellite based drought indices (NDVI) have been used to assess the drought risk. Relationship between NDVI and SPI have been derived and related with crop yield to study the risk. Ancillary data such as crop yields has been included in the study so that an analysis could be carried out about how crop yield changes as response to rainfall and eventually combine agricultural drought and meteorological drought so as to get a combined drought risk.

3. STUDY AREA

3.1. LOCATION OF STUDY AREA

Northern Kerala (17,465 km²) encompassing the districts of Kasaragod, Kannur, Kozhikode, Malappuram, and Wayanad located between 10° 20' and 12° 47' North latitudes and 74° 51' and 76° 54' East longitudes were selected for the study (Figure 1). It is situated between the Arabian Sea to the west and the Western Ghats to the east. Geographically, Kerala roughly divides into three climatically distinct regions. These include the eastern highlands (rugged and cool mountainous terrain), the central midlands (rolling hills), and the western lowlands (coastal plains).

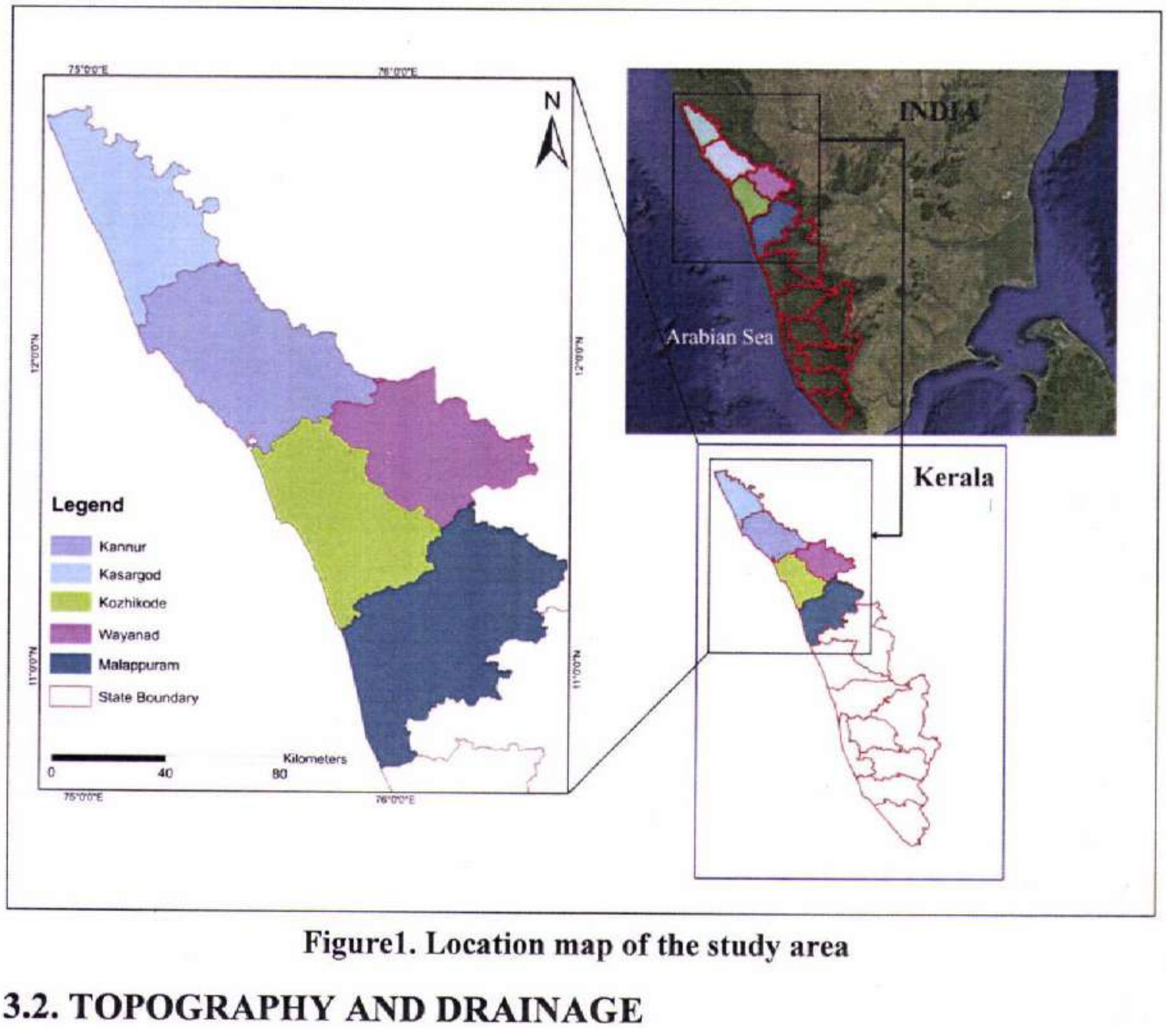


Figure1. Location map of the study area

3.2. TOPOGRAPHY AND DRAINAGE

The topography consists of a hot and wet coastal plain gradually rising in elevation to the high hills and mountains of the Western Ghats. Eastern Kerala consists of land encroached upon by the Western Ghats; the region thus includes high mountains, gorges, and deep-cut valleys. The wildest lands are covered with dense forests, while other regions lie under tea and coffee plantations (established mainly in the 19th and 20th centuries) or other forms of cultivation. The nature of the terrain and its physical features, divides an east west cross section of the state into three distinct regions-hills and valleys, midland and plains and the coastal region.

There are mainly three broad physiographic divisions in the State, viz. high lands, midlands and low lands. The low land is adjacent to the coast and extends up to an altitude of 7.5 m MSL. The high land is on the eastern part consisting of the hills and mountains of the Western Ghats and it extends from 7.5 m MSL to 75 m MSL and above. In between the high lands and the low lands is the midland having an undulating topography which extends from 7.5 m MSL up to 75 m MSL. Low land covers 10.24 %, midland 41.76 % and high land an area 48 % of Kerala State.

3.3. CLIMATE

Northern Kerala, located in the humid tropics, is known for green landscape, evergreen forests, serene water bodies, rolling mountains and narrow valleys. With high rainfall, chains of backwater bodies, many rivers, reservoirs, lakes, ponds, springs and wells, the State is considered by many as the land of water. These districts have a humid climate with an oppressive hot season from March to the end of May. South west monsoon (June to September) and North-east monsoon (October to November) are the two monsoon seasons of the State of which South west monsoon is more predominant. About 85% of the annual rainfall receives during the monsoon period between June and November (70% during South west and 15% during the North-east monsoon) and the remaining 15% only during the non-monsoon period between December and May as summer showers.

3.4. SOILS

Climate topography, vegetation and hydrological conditions are the dominant factors of soil formation. On the basis of the morphological features and physico-chemical properties, the soils of the State have been classified into red loam, laterite coastal alluvium, riverine alluvium, Onattukara alluvium, brown hydromorphic, saline hydromorphic, Kuttanad alluvium, black soil and forest loam.

3.5. MAJOR CROPS/ AGRO ECONOMIC ZONES

Cash Crops like coconut, rubber, tea, coffee, pepper, cardamom, arecanut, ginger, nutmeg, cinnamon etc. and food crops, paddy, tapioca etc. gives the agricultural sector of

Kerala a distinct flavour. The agro-climatic conditions in Kerala suite the cultivation of a variety of seasonal and perennial crops. Paddy cultivation is the part and parcel of our culture and it is the State's major food crop. Despite these facts, the area and production of paddy continues to decline over the years.

4. MATERIALS AND METHODS

4.1. DATA ACQUISITION

Data has been acquired mainly from two sources, NDVI derived from satellite sources and rainfall obtained from ground rain gauge stations.

4.1.1. Moderate Resolution Imaging Spectro-radiometer (MODIS)

NASA's MODIS Earth observation system is one of the richest sources of remote-sensing data for monitoring of environmental dynamics (Neteler 2005, Lunetta et al. 2006, Ozdogana and Gutman 2008). The Moderate-resolution imaging Spectro radiometer (MODIS) is the sensor used in this system and it capture data within every 1-2 days, in 36 spectral bands ranging in wavelength from 0.4 μm to 14.4 μm and at varying spatial resolutions (2 bands at 250 m, 5 bands at 500 m and 29 bands at 1 km). MODIS images are typically distributed as HDF (Hierarchical Data Format) 10 by 10 arc degree-tiles, projected in the Sinusoidal projection. Once download all the tiles of interest, we can mosaic them into a single image. MODIS NDVI images is also used to identify changes in land cover, deforestation, damages caused by global warming or even fine long-term succession processes. The MODIS data set can be accessed via different data platforms like Reverb, GloVIS, DataPool.

4.1.2. Meteorological Data

Daily rainfall data has been collected from Indian Meteorological Department (IMD) for a period of 116 years ranging from 1901-2016. Rainfall data collected from 18 stations in Malabar districts over different periods starting early as 1901 to till 2011 were pre-processed and Standard Precipitation Index values are calculated. SPI model of NDMC is downloaded and used to calculate SPI. SPI maps were generated from the SPI so created. The location of rainfall station is plotted in figure 2.

Table 2. Rainfall data details for study area

No	Station Name	District	Year
1	Hosdurg	Kasaragod	1951-2016
2	Kasaragod	Kasaragod	1951-2008
3	Kudulu	Kasaragod	2009-2016
4	Kannur	Kannur	1901-2016
5	Thalassery	Kannur	1951-2016
6	Irikkur	Kannur	1951-2016
7	Thaliparamba	Kannur	1951-2016
8	Vadakara	Kozhikode	1901-2016
9	Quilandy	Kozhikode	1901-2016
10	Kozhikode	Kozhikode	1901-2016
11	Mananthavadi	Wayanad	1951-2016
12	Vythiri	Wayanad	1901-2016
13	Ambalavayal	Wayanad	1980-2016
14	Manjeri	Malappuram	1901-2016
15	Nilambur	Malappuram	1901-2016
16	Perinthalmanna	Malappuram	1901-2016
17	Ponnani	Malappuram	1901-2016

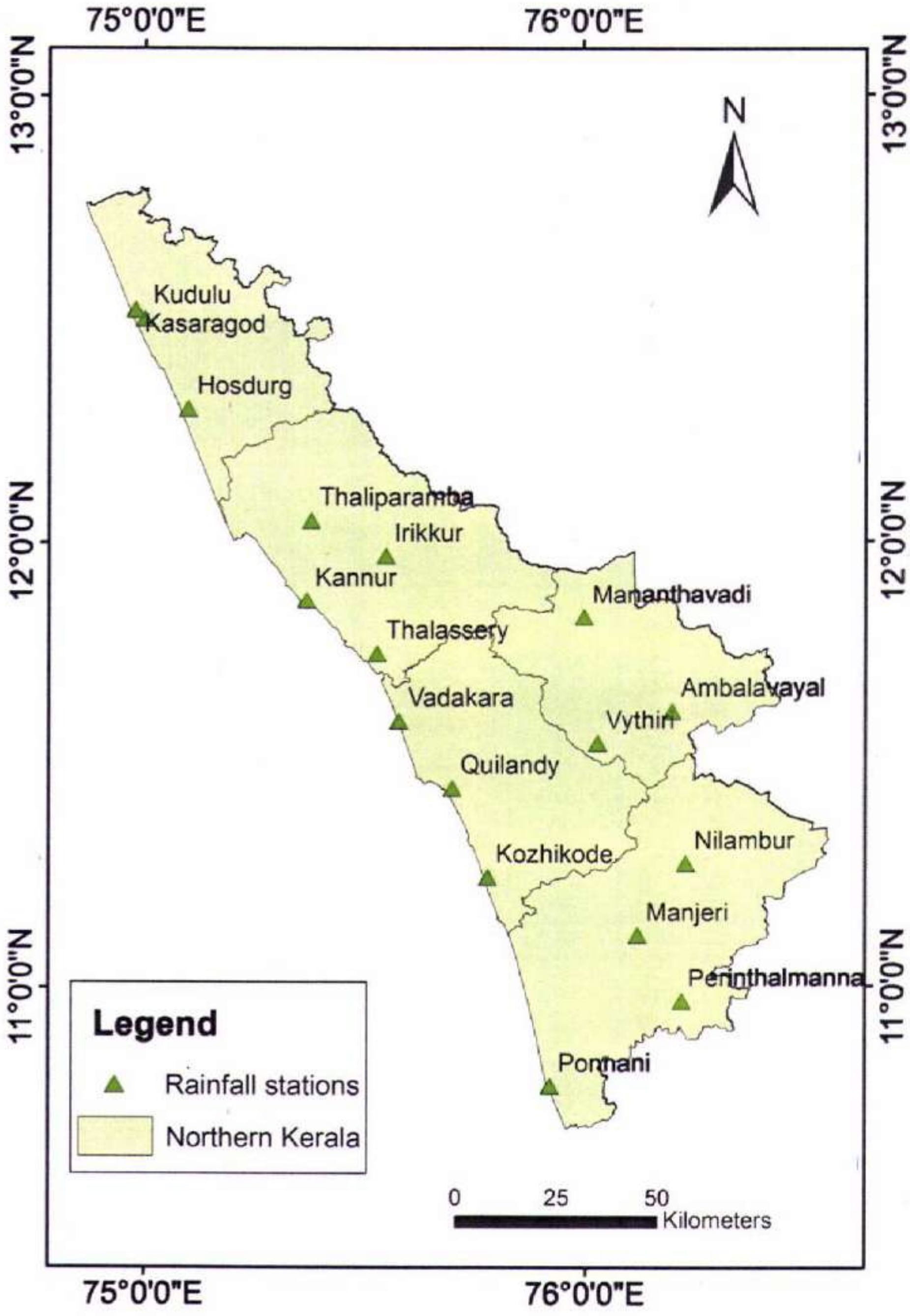


Figure 2. Raingauge stations for the study area.

4.1.3. Ancillary Data

4.1.3.1. Toposheets

The vector shape file enclosing the study area is created using free Quantum GIS software. The study area was delineated from georeferenced toposheets in Quantum GIS. Details of toposheets used are given in Table 3.

Table 3. Toposheets used for the present study

SL. no	Districts	Toposheet No:
1	KASARAGOD	48 L/14,48 P/2,48 P/6,48 L/15,48 P/3,48 P/7,48 P/4, 48 P/8
2	KANNUR	48 P/4,48 P/7,48 P/11,48 P/8,48 P/12,48 P/16,49 M/5,49 M/9, 49 M/13,48 M/10
3	KOZHIKODE	48 M/10,49 M/9,49 M/13,49 M/14,49 M/11,49 M/15,58 A/2, 58 A/3,49 M/16
4	WAYANAD	49 M/13,58 A/1,58 A/5,49 M/14,58 A/2,58 A/6, 58 A/3
5	MALAPPURAM	58 A/2,49 M/15,58 A/3,58 A/7,58 A/11,49 M/16,58 A/4,58 B/8, 49 N/13,58 B/1,58 B/5,49 N/14,58 B/2

4.1.3.2. Land use/Land cover

The land use/ land cover map of Northern Kerala (2010) is classified using IRS-P6 LISS III data of the year 2010.

4.2. Methodology

The methodology of this work is shown below. Satellite based vegetation index **NDVI** derived from MODIS and meteorology based index **SPI** are the two major indices used in this study. NDVI itself does not reflect drought or non drought conditions (Owrangi *et al.*, 2011). But Anomaly of NDVI from its long term mean was classified to determine the agricultural drought risk (Murad and Islam, 2011).

IRS data is used for Land use/ Land cover classification.16-day composite 250m resolution Terra MODIS data [MOD13Q1] from the year 2000 to 2017 were downloaded and re-projected using NASA's free MRT tool. The NDVI of the study area were extracted from the re-projected data. NDVI Anomaly map generated from NDVI using the equation. NDVI Correlation and regression techniques are used to verify if there is a relation between SPI and NDVI Anomaly.

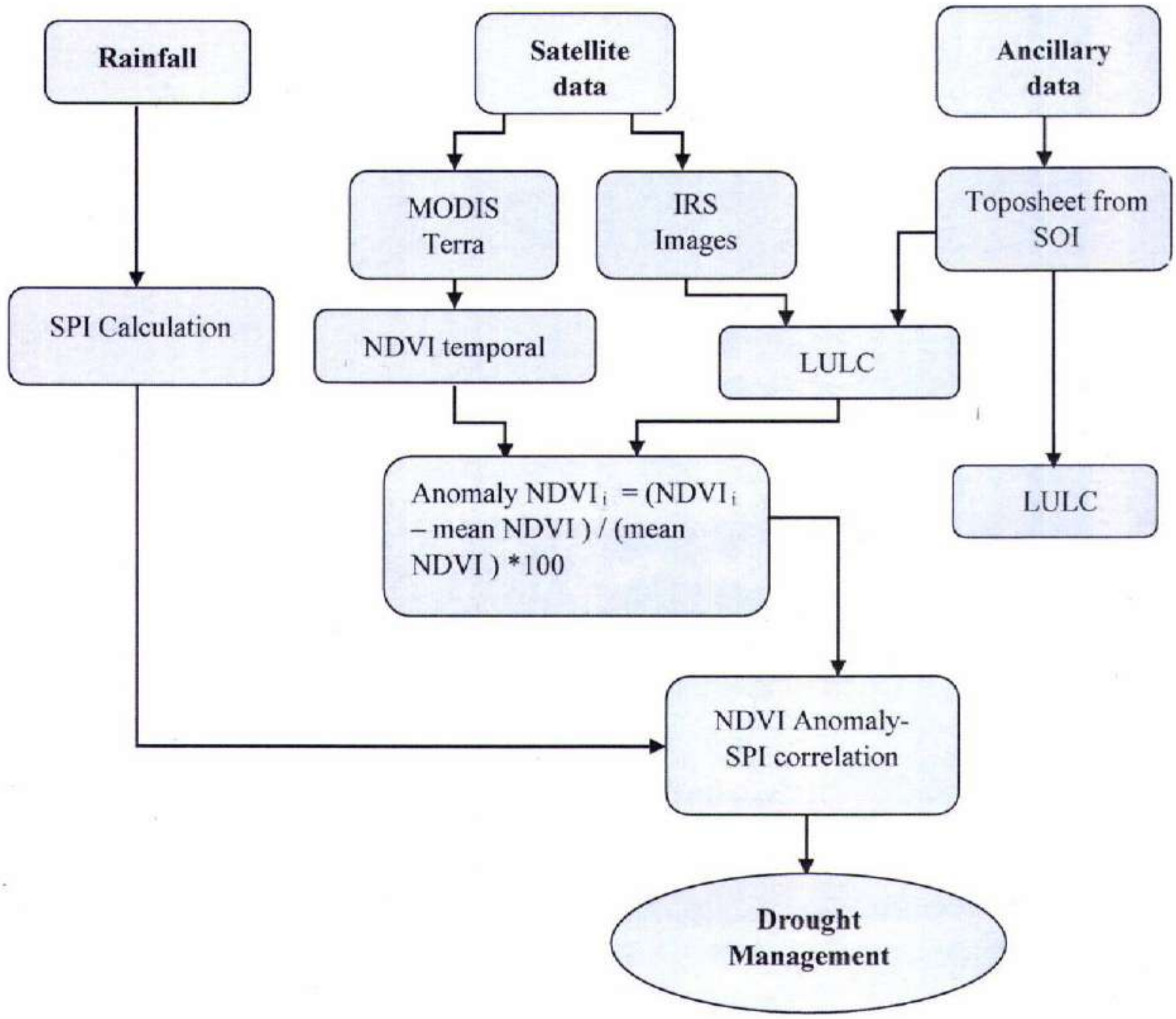


Figure 3: Workflow of present study.

4.2.1. Pre-processing of Satellite data

Data preprocessing is done using Modis Reprojection Tool (MRT). MRT enables users to read data files in HDF-EOS format (MODIS Level-2G, Level-3, and Level-4 land data products), specify a geographic subset or specific science data sets as input to processing, perform geographic transformation to a different coordinate system/cartographic projection, and write the output to file formats other than HDF-EOS.

The MODIS Reprojection Tool is available for use by all registered users. The MODIS Tool will undergo further development to correct problems as they are detected, incorporate additional functionality, and be modified to enhance computational performance. The funding support for this work comes from the NASA Earth Science Data and Information Systems (ESDIS) Project.

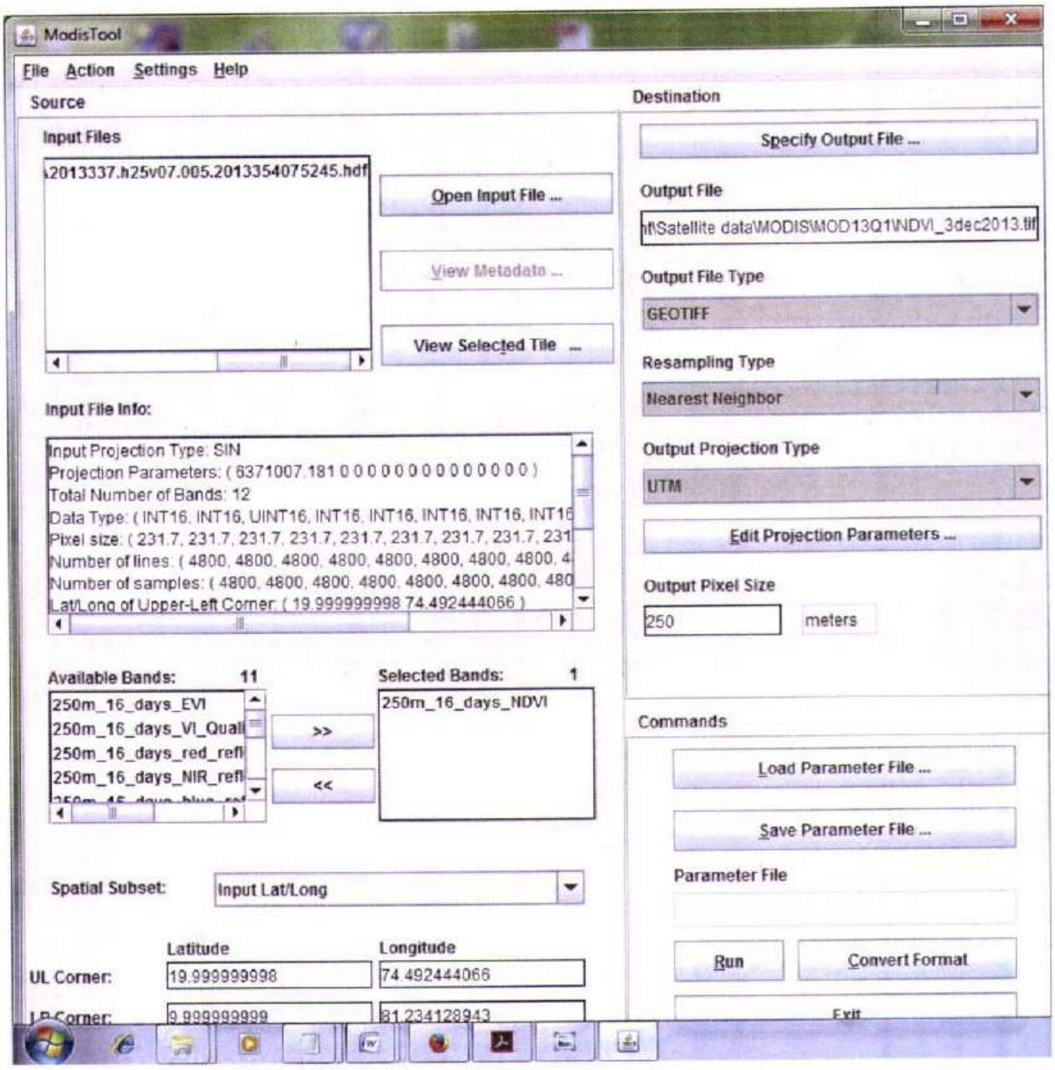


Figure 4: Reprojection of HDF to GEOTIFF using MRT

4.2.2. Post processing of satellite data for NDVI Indices and Anomaly

The 16-day composite 250-m resolution Terra MODIS data [MOD13Q1] and daily NDVI product [MOD02QKM] from the year 2000 to 2017 were downloaded and re-projected using NASA's MRT tool. The NDVI of the study area were extracted from the re-projected data. The mean NDVI of the area over the years 2000-2016 for each 16-day period was calculated to be used as a reference.

The equations used for calculation of mean NDVI and NDVI anomaly are as follows

$$\text{Mean NDVI} = (\text{NDVI}_i + \text{NDVI}_{i+1} + \text{NDVI}_{i+2} + \text{NDVI}_{i+3} \ldots + \text{NDVI}_{i+n-1})/n$$

where, NDVI_i is the NDVI of the same16-day period over year 'i'.

The satellite images may be present in multiple frames or in a single image. If the image of the study area is present in multiple images, the images are merged and the study area is extracted using GDAL packages and Python using the shape file created using Quantum GIS.

NDVI Anomaly is calculated by using the 16-day composite product MOD13Q1.

$$\text{Anomaly NDVI}_i = (\text{NDVI}_i - \text{mean NDVI}) / (\text{mean NDVI}) * 100$$

where, Anomaly NDVI_i is the NDVI Anomaly in i^{th} day. NDVI_i is the i^{th} NDVI and mean NDVI is the average of NDVI during the period of study.

The threshold values used in this study to classify drought risk using NDVI anomalies was given in Table 4.

Table 4. Drought Risk Classification using NDVI anomalies (Murad and Islam, 2011)

Percent of NDVI Anomalies	Class
0% to -10%	Slight Drought
-10% to -20%	Moderately Drought
-20% to -30%	Severe Drought
Above -30%	Very Severe Drought

4.2.3. Computation of Standardized Precipitation Index (SPI)

Monthly SPI of rainfall were generated by the SPI model of NDMC, USA. All input files must follow 3-column format: Year, Month and Monthly Precipitation Value. Precipitation total is given in mm. A zero will work; a missing data flag or -9999 will not.

The program is already compiled and all libraries are included (it was compiled in C++ for PC) a runoff SPI_SL_6.exe would give the SPI values.

4.2.4. Relationship between NDVI Anomaly and SPI

NDVI time series data for each of the 15 Rain gauge stations was extracted from the 17 years NDVI time series images using Quantum GIS software. Correlation coefficient between NDVI Anomaly and monthly SPI has been calculated for each of the rain stations. Temporal pattern of SPI and NDVI Anomaly has also been analysed to see variation in vegetation according to rainfall.

4.3. OPEN SOURCE TOOLS USED

4.3.1. Hypertext Pre-processor (PHP)

PHP (recursive acronym for PHP: Hypertext Pre-processor) is a widely-used open source general-purpose scripting language that is especially suited for web development and can be embedded into HTML. PHP code are executed on the server, and the result is returned to the browser as plain HTML.

4.3.2. Geospatial Data Abstraction Library (GDAL)

The Geospatial Data Abstraction Library (GDAL) is a computer software library for reading and writing raster and vector geospatial data formats, and is released under the permissive X/MIT style free software license by the Open Source Geospatial Foundation. As a library, it presents a single abstract data model to the calling application for all supported formats. It may also be built with a variety of useful command line interface utilities for data translation and processing. Projections and transformations are supported by the PROJ.4 library.

4.3.3. Python

Python is a widely used high-level programming language for general-purpose programming, created by Guido van Rossum and first released in 1991. An interpreted language, Python has a design philosophy which emphasizes code readability (notably using whitespace indentation to delimit code blocks rather than curly brackets or keywords), and a syntax which allows programmers to express concepts in fewer lines of code than possible in languages such as C++ or Java. The language provides constructs intended to enable writing clear programs on both small and large scale.

Python features a dynamic type system and automatic memory management and supports multiple programming paradigms, including object-oriented, imperative, functional programming, and procedural styles. It has a large and comprehensive standard library.

Python interpreters are available for many operating systems, allowing Python code to run on a wide variety of systems.

4.3.4. NumPy

NumPy is a library for the Python programming language, adding support for large, multi-dimensional arrays and matrices, along with a large collection of high-level mathematical functions to operate on these arrays. The ancestor of NumPy, Numeric, was originally created by Jim Hugunin with contributions from several other developers. In 2005, Travis Oliphant created NumPy by incorporating features of the competing Numarray into Numeric, with extensive modifications. NumPy is open-source software and has many contributors.

4.3.5. Map Server

MapServer is an open source development environment for building spatially enabled internet applications. It can run as a CGI program or via MapScript which supports several programming languages (using SWIG). MapServer was developed by the University of Minnesota - so, it is often and more specifically referred as "UMN MapServer", to distinguish it from commercial "map server". MapServer was originally developed with support from NASA, which needed a way to make its satellite imagery available to the public.

4.4. AUTOMATION FOR DROUGHT RISK MAPPING

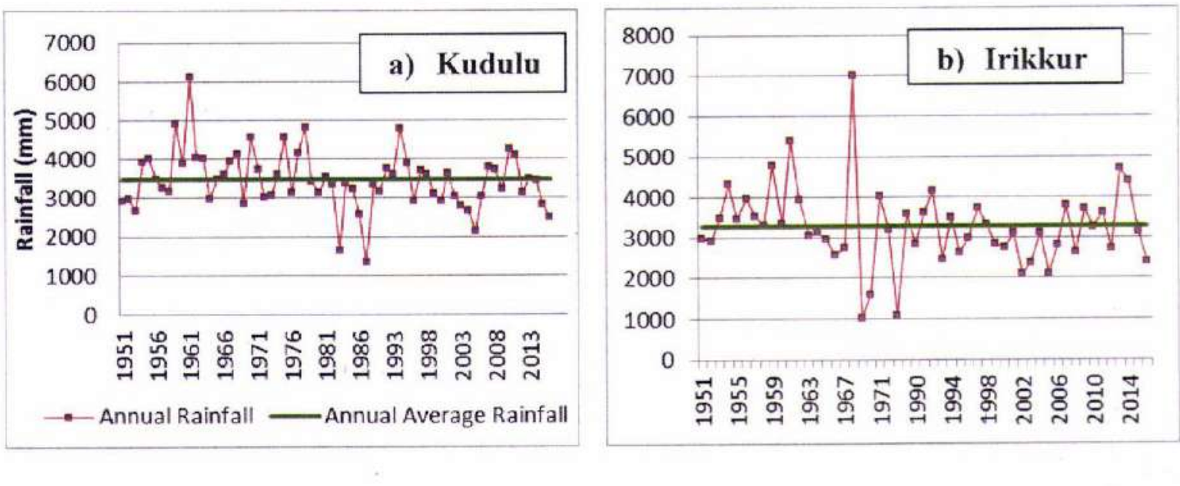
Initially, PHP Script is written for searching and downloading the latest vegetation indices (MOD02QKM, 250 m resolution daily product and MOD13Q1, 250 m 16-day composite product) from the MODIS Terra satellite in the AOI (Gopinath, 2015). These images can be downloaded for any AOI by changing the boundary inside the PHP script and then re-projected to Universe Transverse Mercator (UTM) projection system using NASA MRT Swath re-projection tool. It is also possible to change the coordinate system of image through this script. As the Satellite images for the AOI may cover multiple tiles, the tiles were merged and the AOI is cut using GDAL libraries and Python. NDVI Image for the AOI is then generated by using the Red and NIR image and saved in TIFF format. The mean NDVI of the area for each 16-day period [MOD13Q1] was calculated to be used as the reference. NDVI anomaly is calculated from the difference of NDVI and its long term NDVI mean for the same period (Gopinath et al., 2015). GDAL library with Python is used for these raster operations. The generated NDVI and NDVI anomaly maps are automatically updated in the map file and published in the website using Open Layers. These operations are repeated every 10 minutes daily for processing satellite data. PHP script is also written for searching of NDVI, 16-day composite NDVI anomaly maps for a particular date. The process repeated every ten minutes interval for processing of Satellite data.

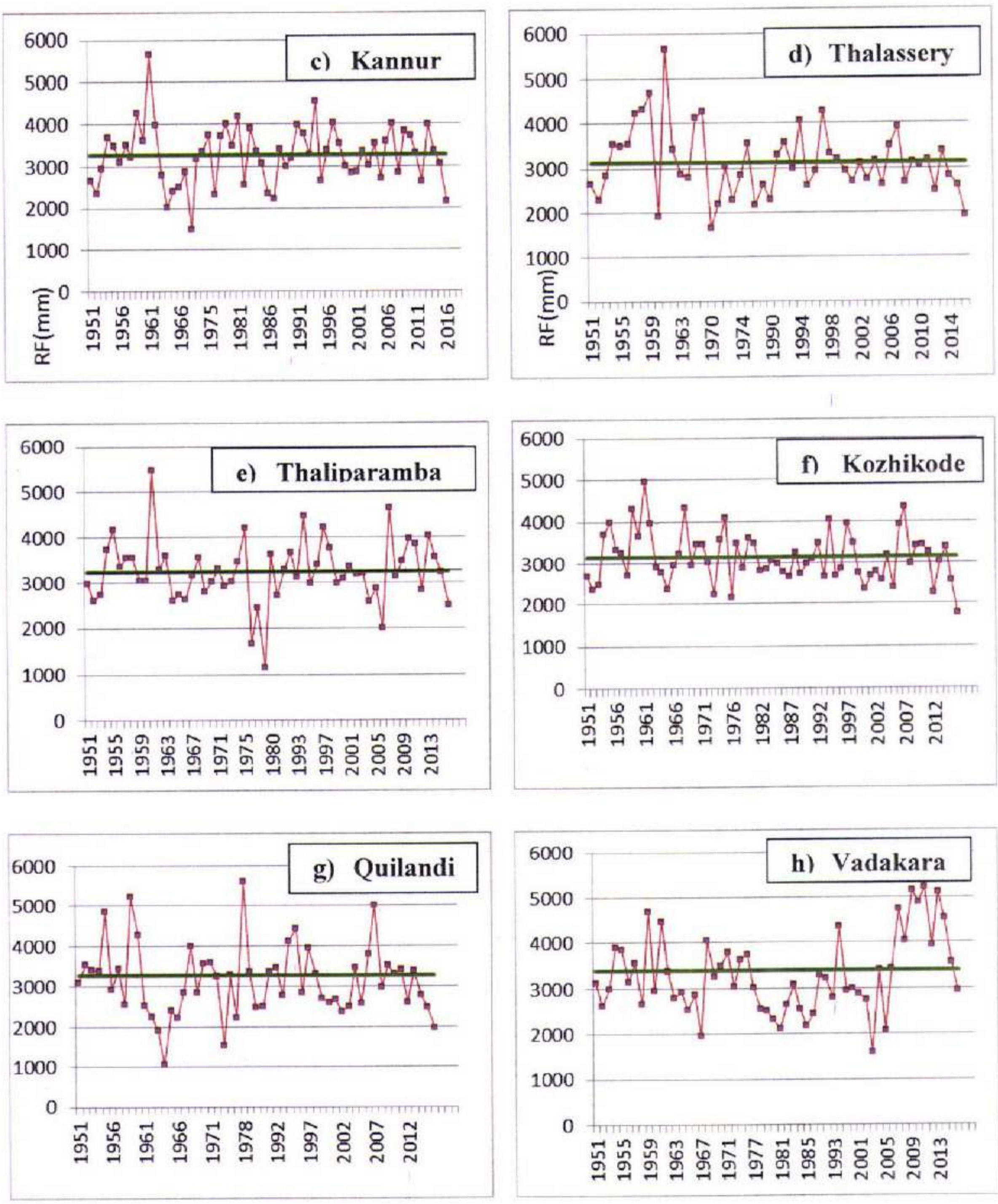
5. RESULTS AND DISCUSSION

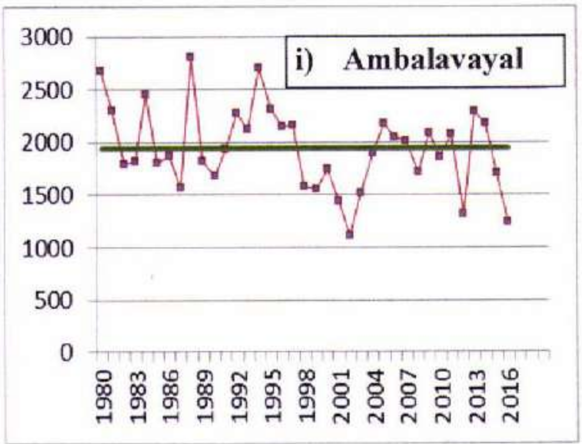
5.1. RAINFALL ANALYSIS

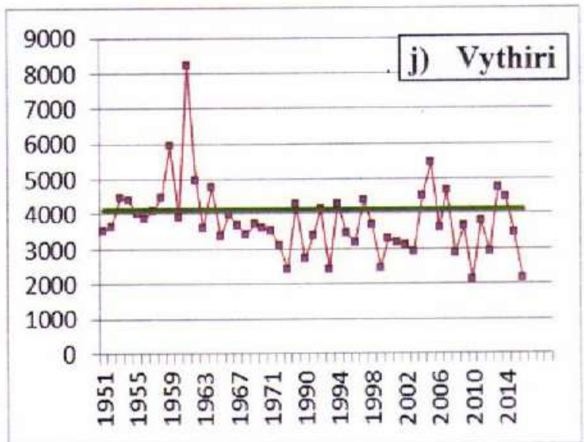
In accordance with the station wise annual rainfall data of 15 stations (Figure 5) over the year 1951 to 2016, mean annual rainfall (Kandiannan *et al.*, 2008) of each station is calculated. Among these stations Vythiri of Wayanad district is having maximum rainfall of 8233 mm (observed in 1961) and Irikkur of Kannur district with a minimum rainfall of 1039 mm (observed in 1969). For most of the stations 1961 is the year with maximum rainfall and minimum rainfall year is different for each station. For the station Kudulu of Kasaragod district, 1983 and 1989 are the years with low rainfall. As far as Irikkur is concerned, 1969 and 1974 are low rainfall years. For Kannur station, 1969 is the year with minimum rainfall. For Thalassery, 1970 and for Thaliparamba, 1976 and 1979 are minimum rainfall years. As far as Kozhikode district is concerned Kozhikode, Quilandi and Vadakara are the three stations with minimum rainfall year in 2016, 1964 and 2003 respectively. For Wayanad district Ambalavayal, Vythiri and Mananthavadi are the stations observed. Minimum rainfall years for Ambalavayal is 2002, Vythiri is 2016 and 2010, and for Mananthavadi it is 1973 and 2003. For Malappuram district Manjeri (2016), Ponnani (2008, 2009, 2016), Perinthalmanna (1964, 1966, 2016) and Nilambur (1967, 1969, 2016) are the stations observed with minimum rainfall years.

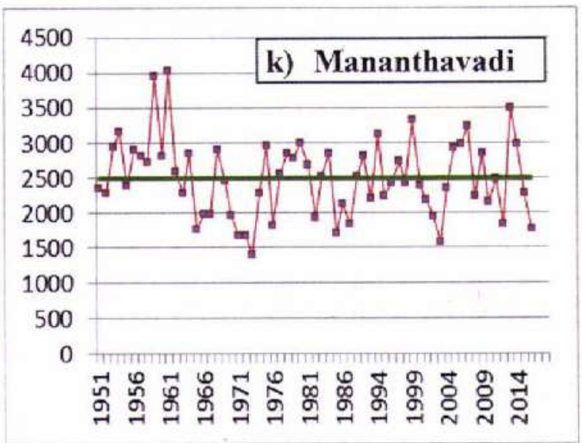
Table 5 shows the maximum negative deviation from mean rainfall over the year 1951-2016 for the available raingauge stations of study area. All the stations show negative deviation and this negative deviation is high for Ambalavayal station of Wayanad district.

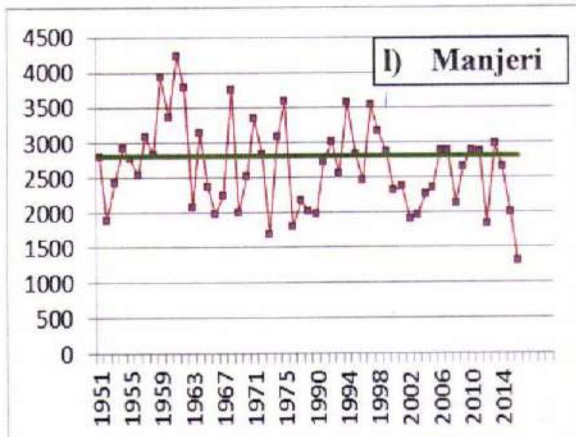


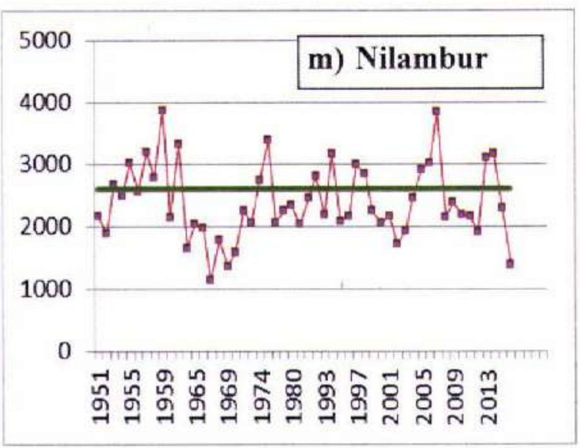

c) Kannur
d) Thalassery
e) Thaliparamba
f) Kozhikode
g) Quilandi
h) Vadakara
RF(mm)
0
1000
2000
3000
4000
5000
6000

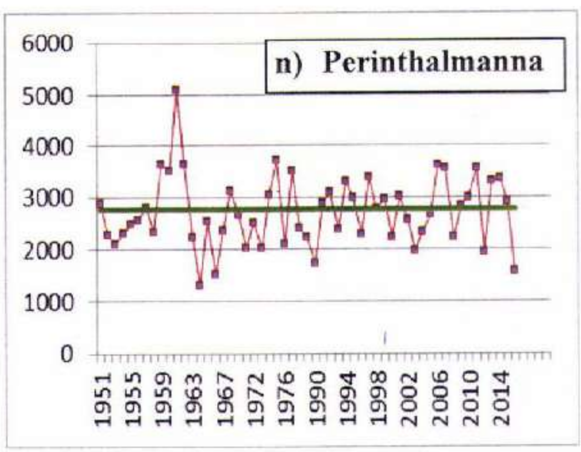

i) Ambalavayal
3000
2500
2000
1500
1000
500
0
1980 1983 1986 1989 1992 1995 1998 2001 2004 2007 2010 2013 2016


j) Vythiri
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1951 1955 1959 1963 1967 1971 1990 1994 1998 2002 2006 2010 2014


k) Mananthavadi
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1951 1956 1961 1966 1971 1976 1981 1986 1994 1999 2004 2009 2014


l) Manjeri
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1951 1955 1959 1963 1967 1971 1975 1990 1994 1998 2002 2006 2010 2014


m) Nilambur
5000
4000
3000
2000
1000
0
1951 1955 1959 1965 1969 1974 1980 1993 1997 2001 2005 2009 2013


n) Perinthalmanna
6000
5000
4000
3000
2000
1000
0
1951 1955 1959 1963 1967 1972 1976 1990 1994 1998 2002 2006 2010 2014

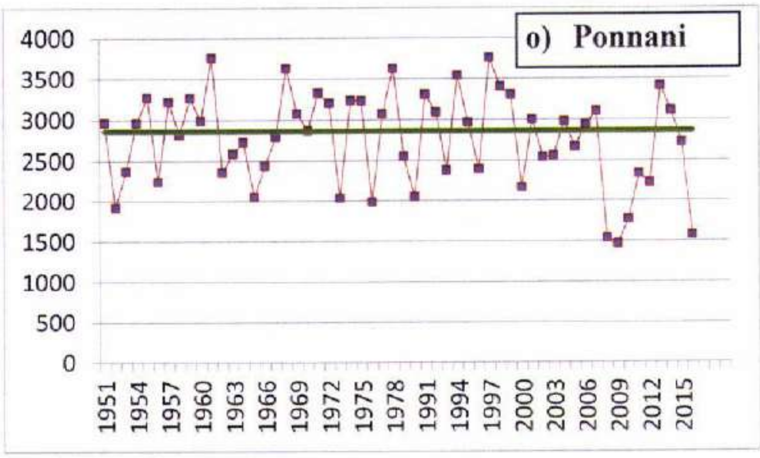


Figure 5: Annual rainfall deviation from Mean Rainfall (1951 – 2016) for a) Kudulu, b) irikkur, c) Kannur, d) Thalassery, e) Thaliparamba, f) Kozhikode, g) Quilandi, h) Vadakara, i) Ambalavayal, j) Vythiri, k) Mananthavadi, l) Manjeri, m) Nilambur, n) Perinthalmanna and o) Ponnani stations of study area.

Table 5. Maximum Deviation (–ve) from mean Rainfall (1951-2016)

Station Name	Mean	Deviation from Mean
Kudulu	3459.82	-2134.42
Irikkur	3262.25	-2226.25
Kannur	3261.70	-1764.4
Thalassery	3130.22	-1462.52
Thaliparamba	3241.60	-2087.6
Kozhikode	3145.97	-1391.67
Quilandi	3279.53	-2222.63
Vadakara	3394.07	-1796.97
Vythiri	4116.38	-1976.28

Ambalavayal	1941.31	-832.81
Mananthavadi	2495.79	-1096.99
Manjeri	2810.37	-1516.97
Nilambur	2590.49	-1437.09
Perinthalmanna	2762.39	-1449.49
Ponnani	2855.72	-1316.42

For the year 2016, each station shows a negative deviation of rainfall from the average rainfall (Figure 6). Only Vadakara station received the rainfall above 2500 mm. Ambalavayal, Manjeri and Nilambur are the stations below 1500 mm rainfall and only the Vadakara station (2960 mm) shows low deviation and Vythiri (2176 mm) shows maximum deviation from annual average rainfall.

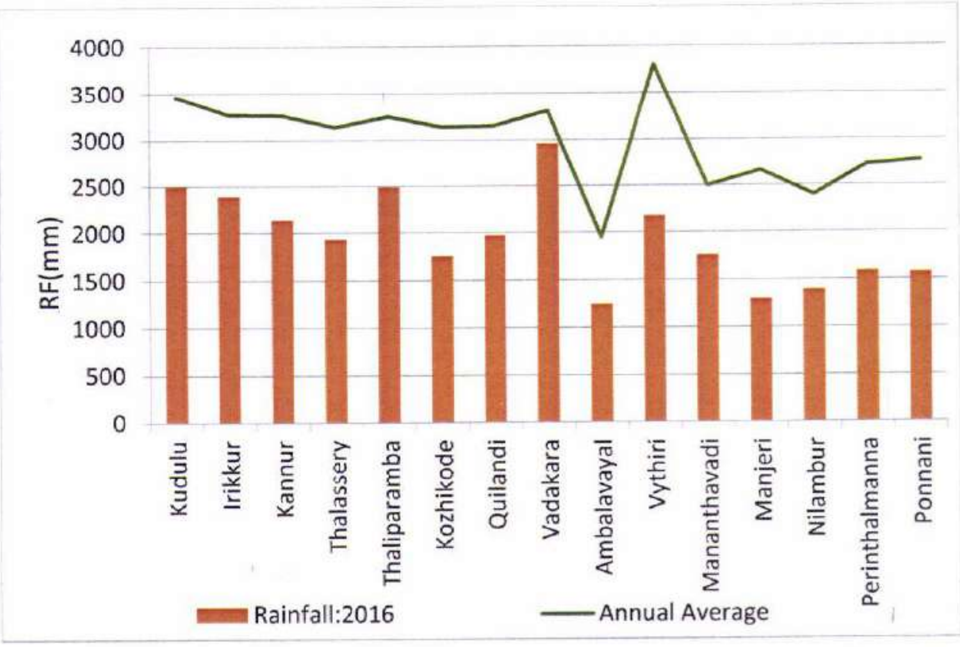
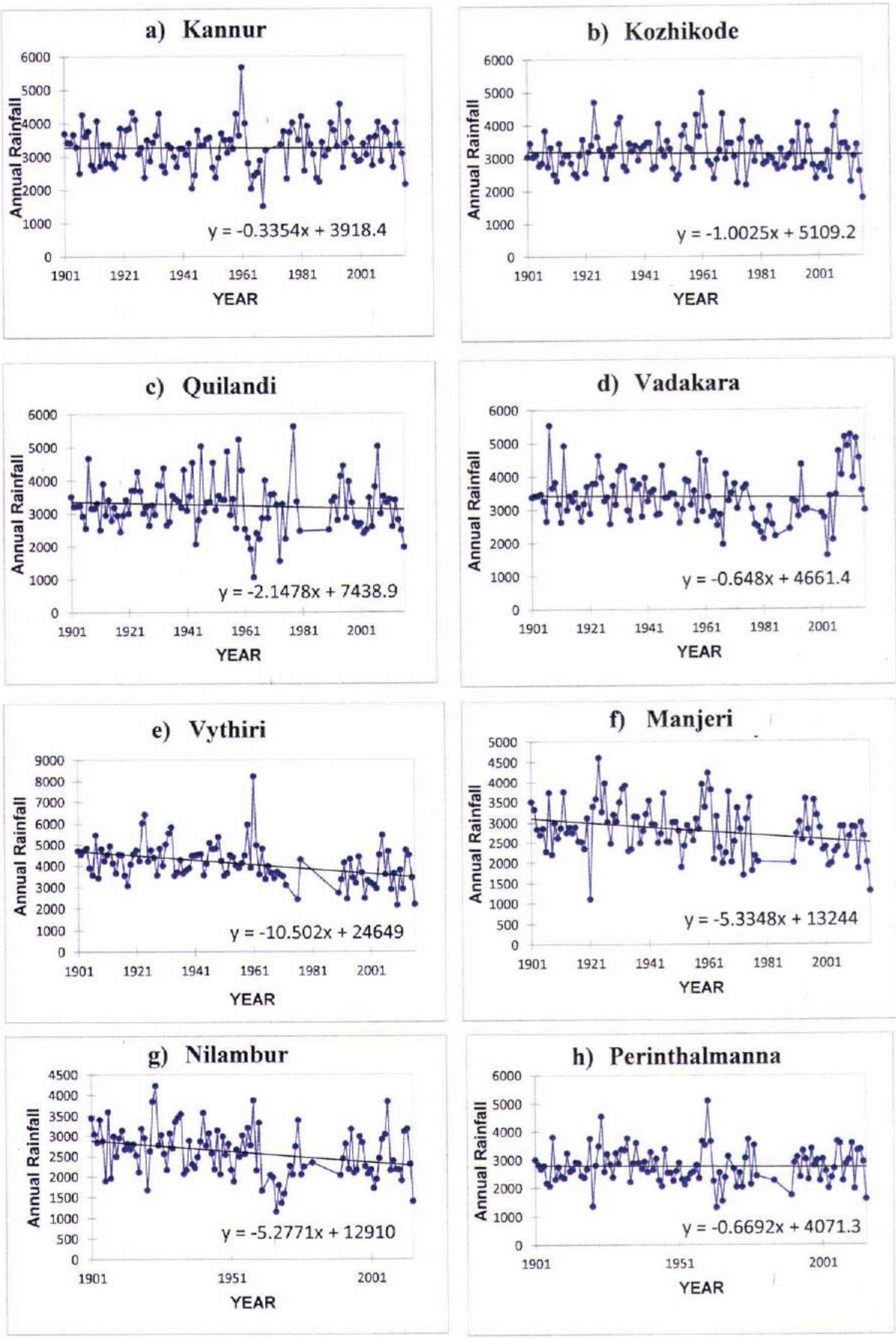


Figure 6: Station wise Annual Average Rainfall with latest rainfall (2016)

The trends in annual precipitation data (Krishnakumar et al., 2009) of stations with data 1901 to 2016 is detected using Mann Kendall test and it is shown in Figure 7. Only stations Vythiri, Vadakara, Manjeri and Ponnani shows statistically significant decreasing trend, all other stations do not show statistically significant result.


a) Kannur
Annual Rainfall
YEAR
y = -0.3354x + 3918.4
b) Kozhikode
Annual Rainfall
YEAR
y = -1.0025x + 5109.2
c) Quilandi
Annual Rainfall
YEAR
y = -2.1478x + 7438.9
d) Vadakara
Annual Rainfall
YEAR
y = -0.648x + 4661.4
e) Vythiri
Annual Rainfall
YEAR
y = -10.502x + 24649
f) Manjeri
Annual Rainfall
YEAR
y = -5.3348x + 13244
g) Nilambur
Annual Rainfall
YEAR
y = -5.2771x + 12910
h) Perinthalmanna
Annual Rainfall
YEAR
y = -0.6692x + 4071.3

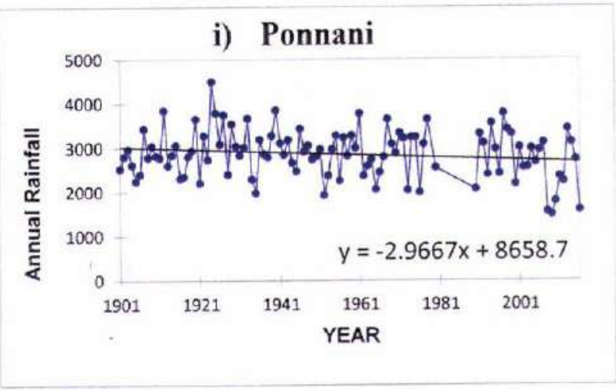


Figure 7. Rainfall trend for a) Kannur, b) Kozhikode, c) Quilandi, d) Vadakara, e) Vythiri, f) Manjeri, g) Nilambur, h) Perinthalmanna and i) Ponnani stations of study area.

Table 6. Result of Mann-Kendall test for Annual Rainfall of Northern Kerala

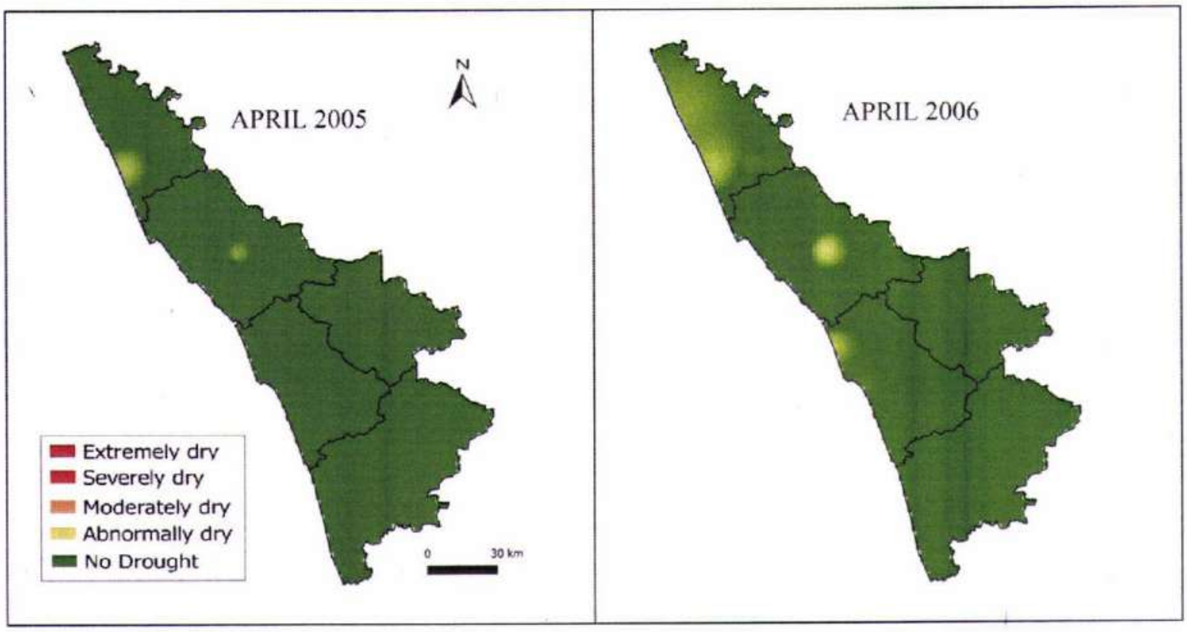
Mann-Kendall test						
Station Name	**Mann-Kendall Statistic (S)**	**Kendall 's Tau**	**Var (S)**	**p-value (two tailed test)**	**alpha**	**Test Interpretation**
Kannur	-8.000	-0.019	1104.00	0.810	0.05	Accept H0
Kozhikode	-28.000	-0.065	1104.00	0.399	0.05	Accept H0
Quilandi	-14.000	-0.042	784.00	0.617	0.05	Accept H0
Vadakara	-102.000	-0.304	784.00	0.000	0.05	Reject H0
Vythiri	-112.000	-0.333	784.00	< 0.0001	0.05	Reject H0
Manjeri	-66.000	-0.196	784.00	0.018	0.05	Reject H0
Nilambur	-110.000	-0.327	784.00	< 0.0001	0.05	Reject H0
Perinthalmanna	-22.000	-0.065	784.00	0.432	0.05	Accept H0
Ponnani	-10.000	-0.030	784.00	0.721	0.05	Accept H0

Rainfall trend analysis over the year 1901 to 2016 is detected using Mann Kendall test, the following results in Table 6 were obtained for nine stations of Northern Kerala. If the P value is less than the significance level alpha = 0.05, H0 is rejected.

Rejecting H0 indicates that there is a trend in time series, while accepting H0 indicated no trend was detected. Table 5 indicates that the null hypothesis was accepted for the stations Kannur, Kozhikode, Quilandi, Perinthalmanna and Ponnani. This means that there is no trend is seen for these stations. Null hypothesis was rejected for Vadakara, Vythiri, Manjeri and Nilambur which indicate there is a trend exist for these stations. The Mann Kendall test statistics (S) indicates that decreasing precipitation trend is seen for the above said stations.

5.2. SPATIAL PATTERN OF SPI

Figure 8 and 9 shows the spatial pattern of SPI based drought conditions of Northern Kerala for the years 2005, 2006, 2007, 2013, 2014 and 2016 for the month of April and May. During April month, abnormally dry condition is found in 2005, 2006, 2007, 2013 and 2014. April 2005 SPI map shows that abnormally dry condition in south west of Kasaragod and middle of Kannur district. In April 2006 SPI map, almost entire area of Kasaragod district, middle of Kannur and north west of Kozhikode district is under abnormally dry condition. In 2007 April, abnormally dry condition is found in south west of Kasaragod, middle of Kannur and Malappuram. In 2013 and 2014 April, abnormally dry condition is observed in Malappuram district. In April 2016, entire Kerala was under drought, the intensity of drought is high in Wayanad and Malappuram districts of Northern Kerala. It is observed that Kasaragod and Kozhikode are under abnormally dry condition, moderately and abnormally dry condition is found in Kannur district, moderately dry condition in Wayanad and severely dry condition in Malappuram district.



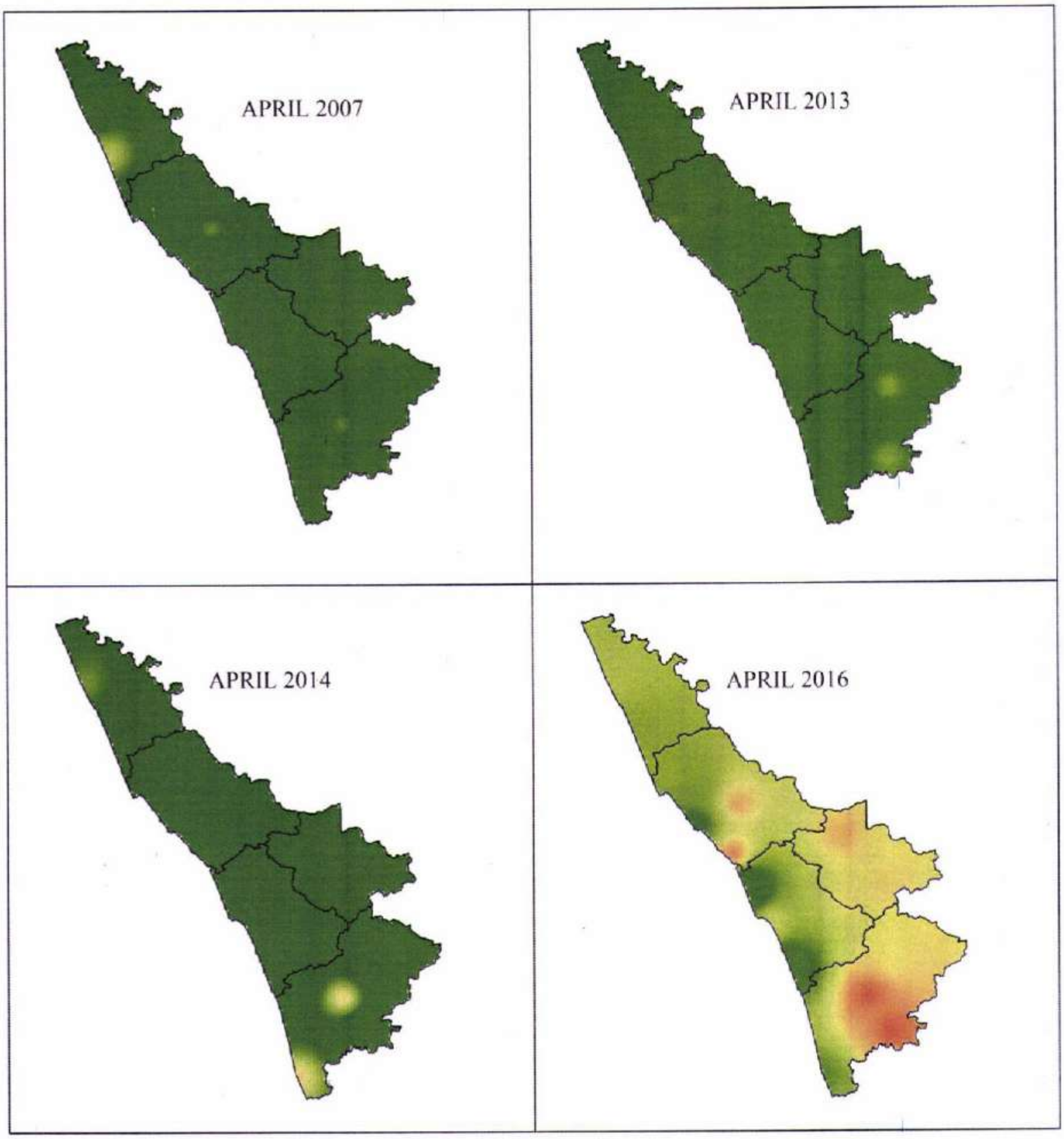
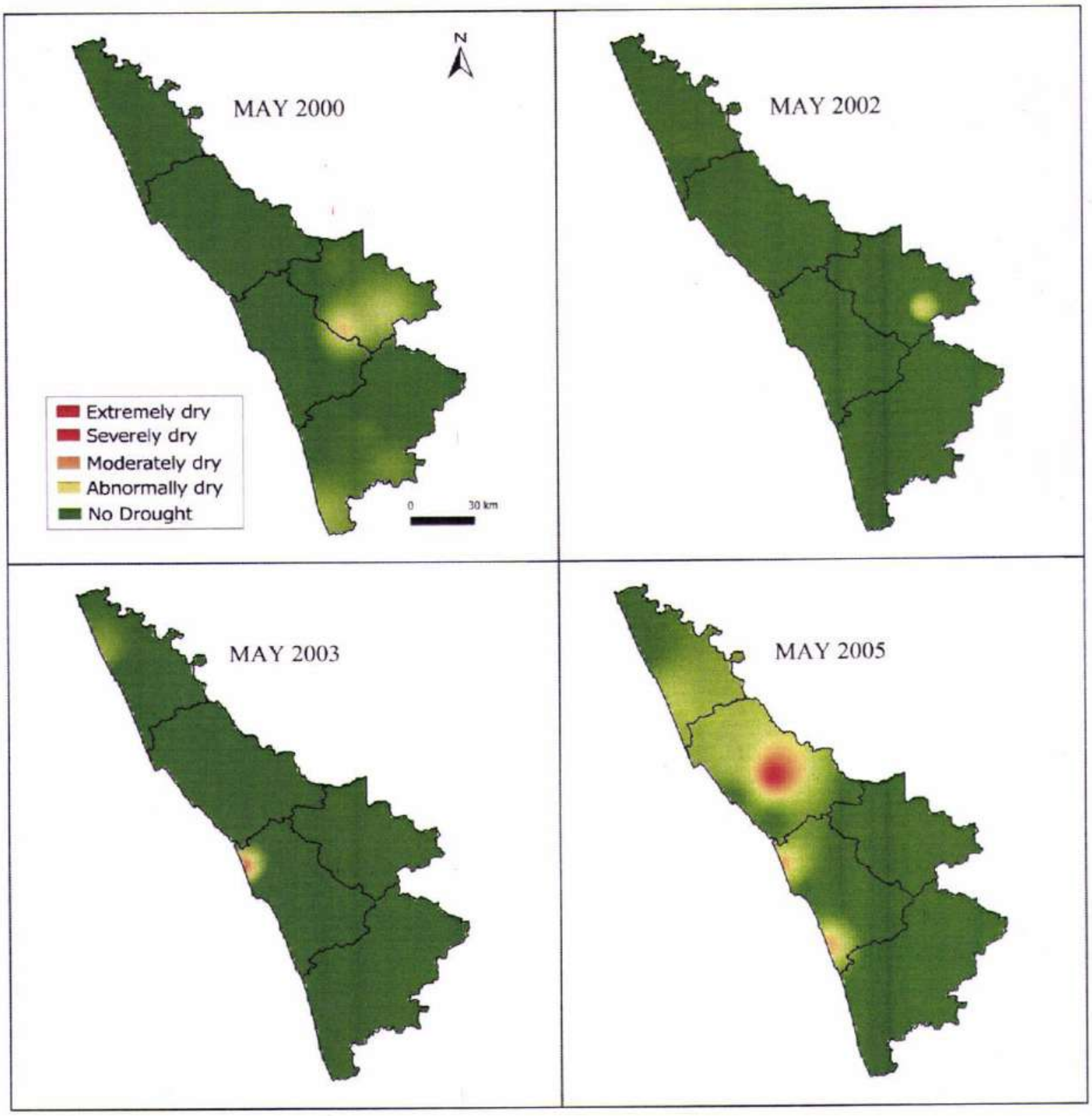
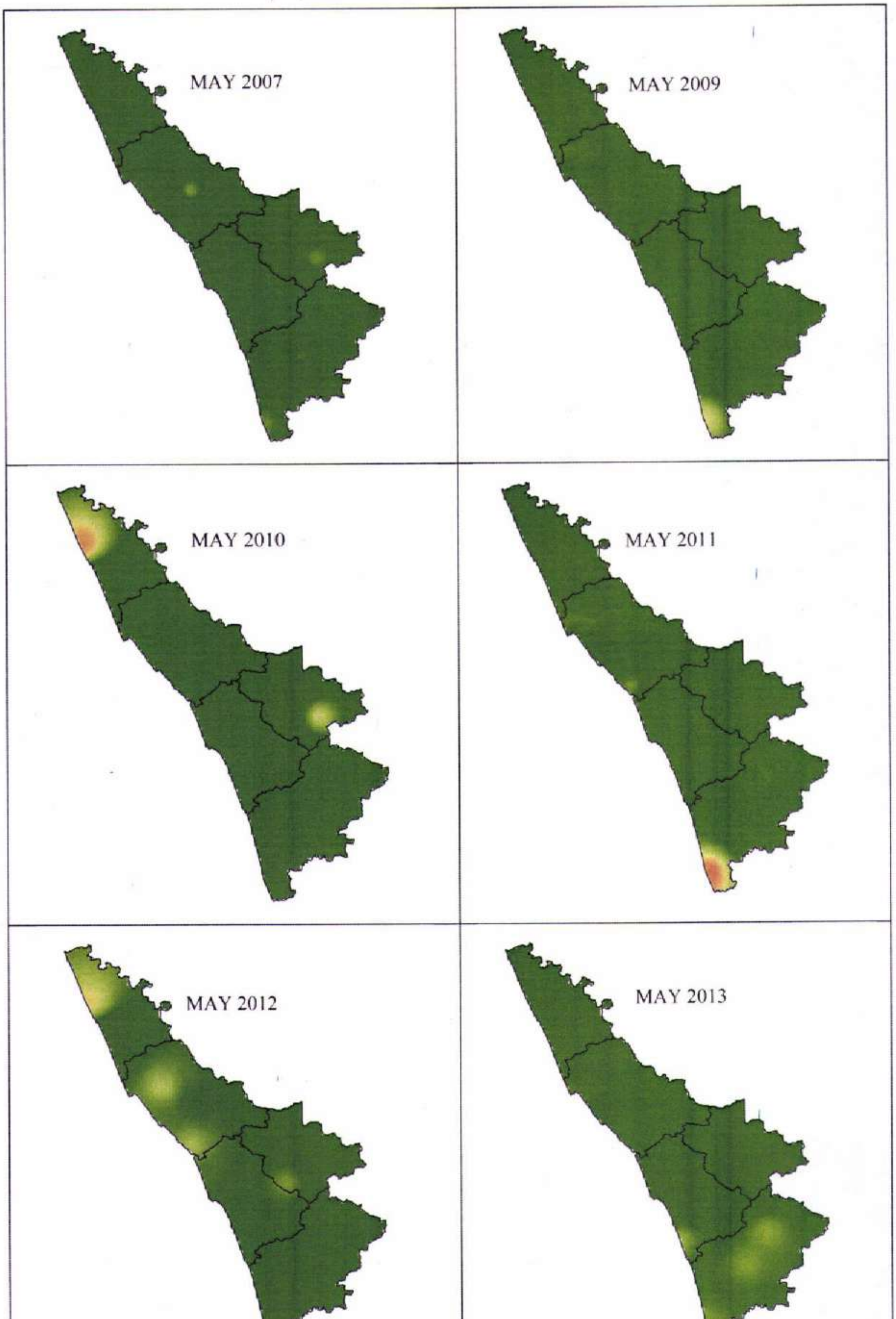


Figure 8: Spatial Pattern of SPI for April Month

For the month of May (Figure 9), dry condition is found in year 2000, 2002, 2003, 2005, 2007, 2009, 2010, 2011, 2012, 2013 and 2016. May 2000 was showing abnormally dry conditions for Wayanad and Malappuram districts. In May 2002, abnormally dry conditions are observed in lower parts of Wayanad district. In May 2003, moderately dry condition is observed in north west of Kozhikode district. In May 2005, Kannur and Kozhikode districts were having moderately dry condition. In May 2007, abnormally dry condition observed in middle areas of Kannur and lower areas of Wayanad district. In 2009, South west of Malappuram district is under abnormally dry condition. During May 2010, moderately dry condition is found in Kasaragod and abnormally dry in lower region of Wayanad district. In 2011 May, south west of Malappuram district is under moderately dry condition. During 2012, abnormally dry condition is observed in upper half of the Kasaragod, western part of Kannur and some parts of Wayanad district. For May 2013, abnormally dry condition is found in Malappuram district. In May 2016, middle of Malappuram is under moderately dry, Kannur and Wayanad under abnormally dry condition.




MAY 2007
MAY 2009
MAY 2010
MAY 2011
MAY 2012
MAY 2013

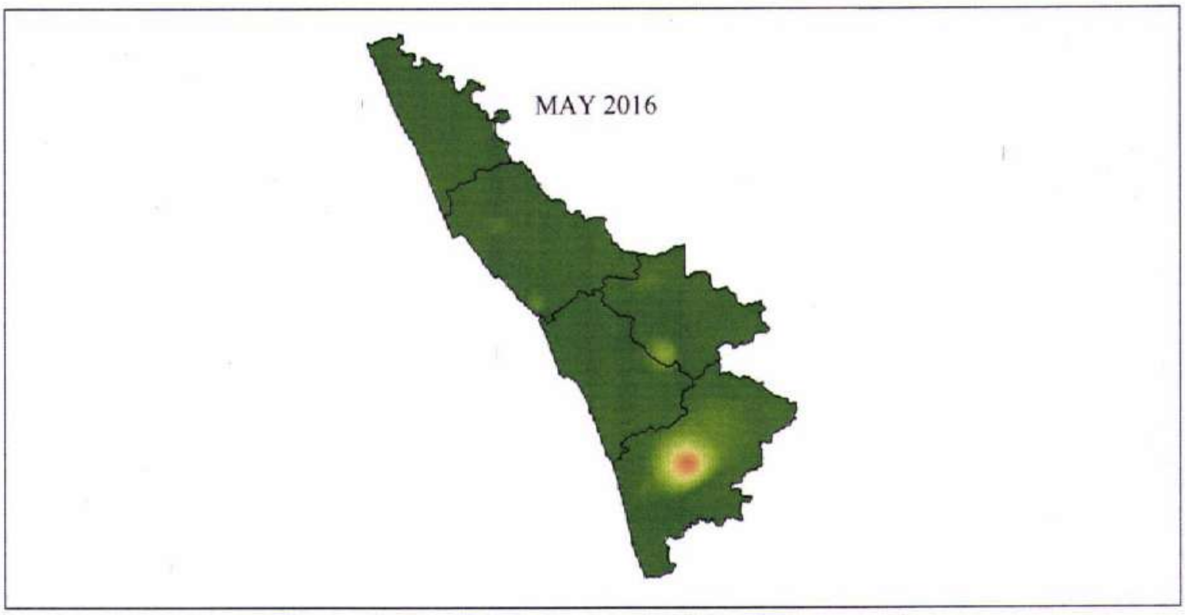


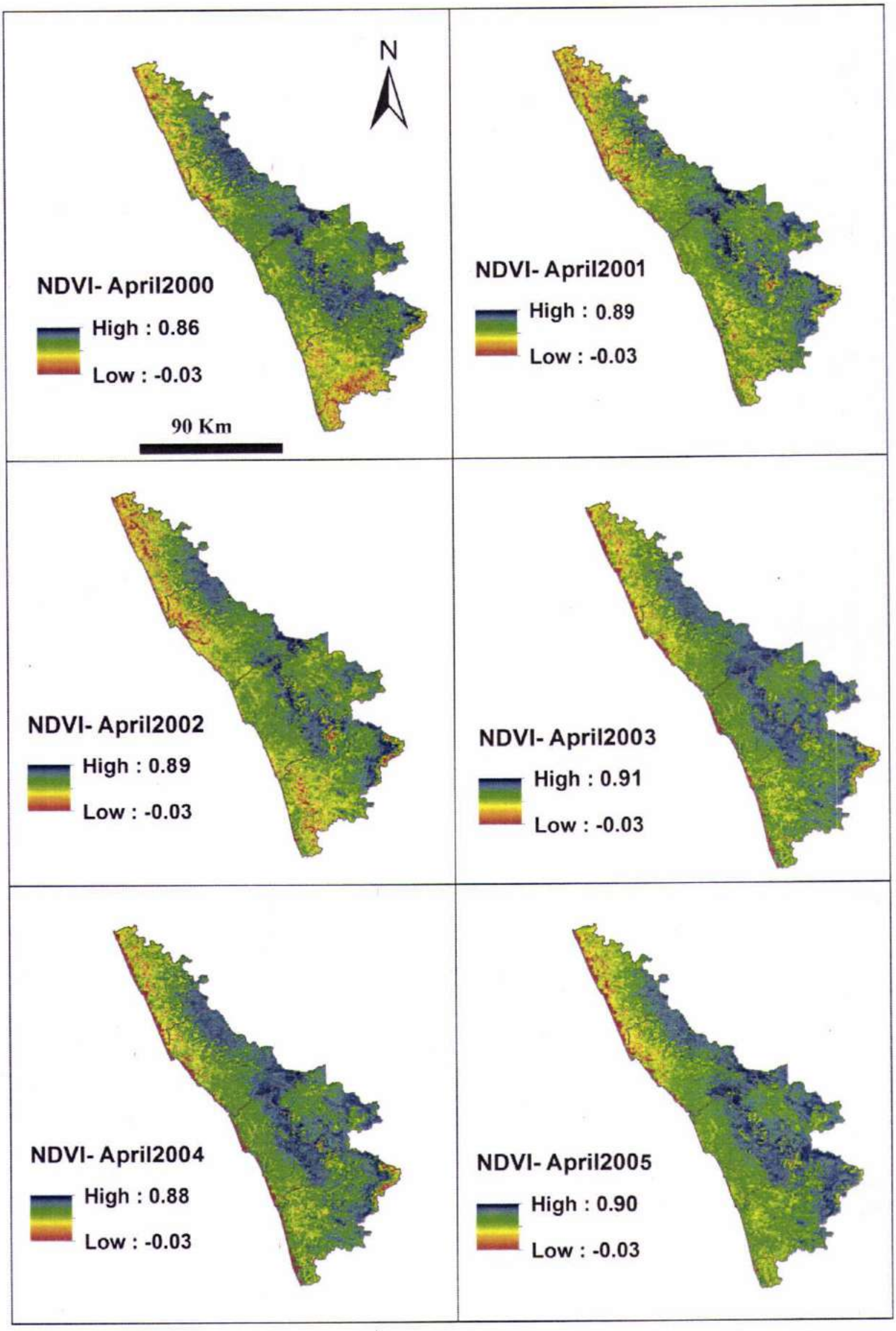
Figure 9: Spatial Pattern of SPI for May month

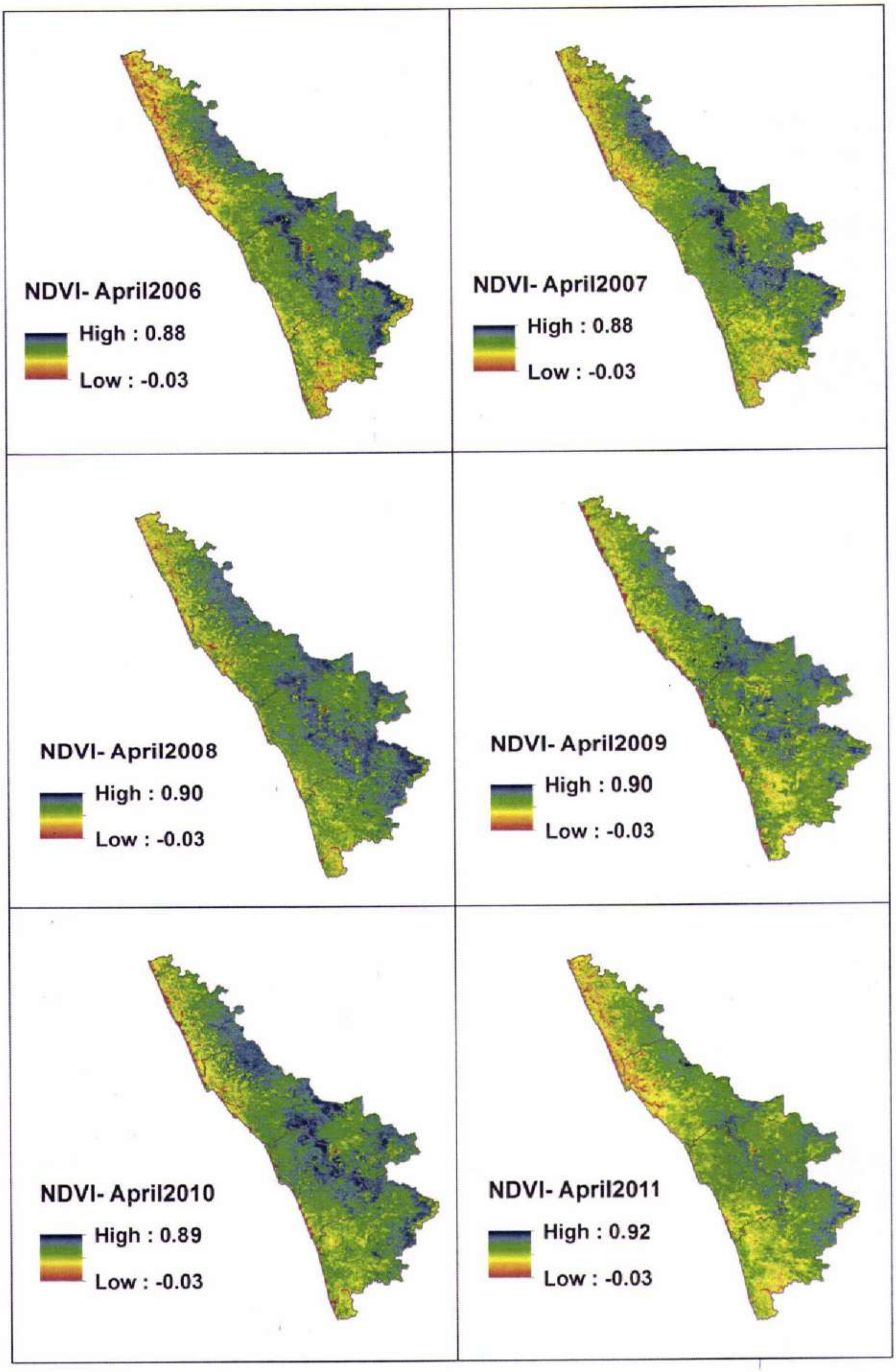
5.3. EVALUATION OF NDVI AND NDVI ANOMALY

5.3.1. Spatial Representation of NDVI

Figure 10 and 11 shows the spatial pattern of NDVI for the month of April and May over the year 2000 to 2016. Figures give an idea about the amount and distribution of vegetation which reflect the vegetation situation and greenness. Highly Vegetated areas are represented by blue colour, grassland or building in yellow colour and water and no vegetation in red colour. For April month, Pixel value of NDVI is found high in the year 2005 (0.87) and for May month it is high in 2007 (0.89). Both 2005 and 2007 is normal years.

NDVI has been found to be lowest due to the extremely unfavourable weather. From the figure 10 it is very much clear that Northern Kerala is highly vegetated area. Low vegetation is found in Kasaragod district and north-west of Kannur district. Wayanad and east of Kozhikode districts is the thick vegetated areas of Northern Kerala. The low NDVI values are found in the year 2011, 2013, 2014, 2015 and 2016 for the month of April. Compared to month of April, NDVI is low for May month. Low NDVI values are found in the years 2000, 2006, 2013, 2015 and 2016 for the month of May. High vegetation (NDVI) identified in 2003, 2007, 2009 and 2010.


N
NDVI- April2000
High : 0.86
Low : -0.03
90 Km
NDVI- April2001
High : 0.89
Low : -0.03
NDVI- April2002
High : 0.89
Low : -0.03
NDVI- April2003
High : 0.91
Low : -0.03
NDVI- April2004
High : 0.88
Low : -0.03
NDVI- April2005
High : 0.90
Low : -0.03


NDVI- April2006
High : 0.88
Low : -0.03
NDVI- April2007
High : 0.88
Low : -0.03
NDVI- April2008
High : 0.90
Low : -0.03
NDVI- April2009
High : 0.90
Low : -0.03
NDVI- April2010
High : 0.89
Low : -0.03
NDVI- April2011
High : 0.92
Low : -0.03

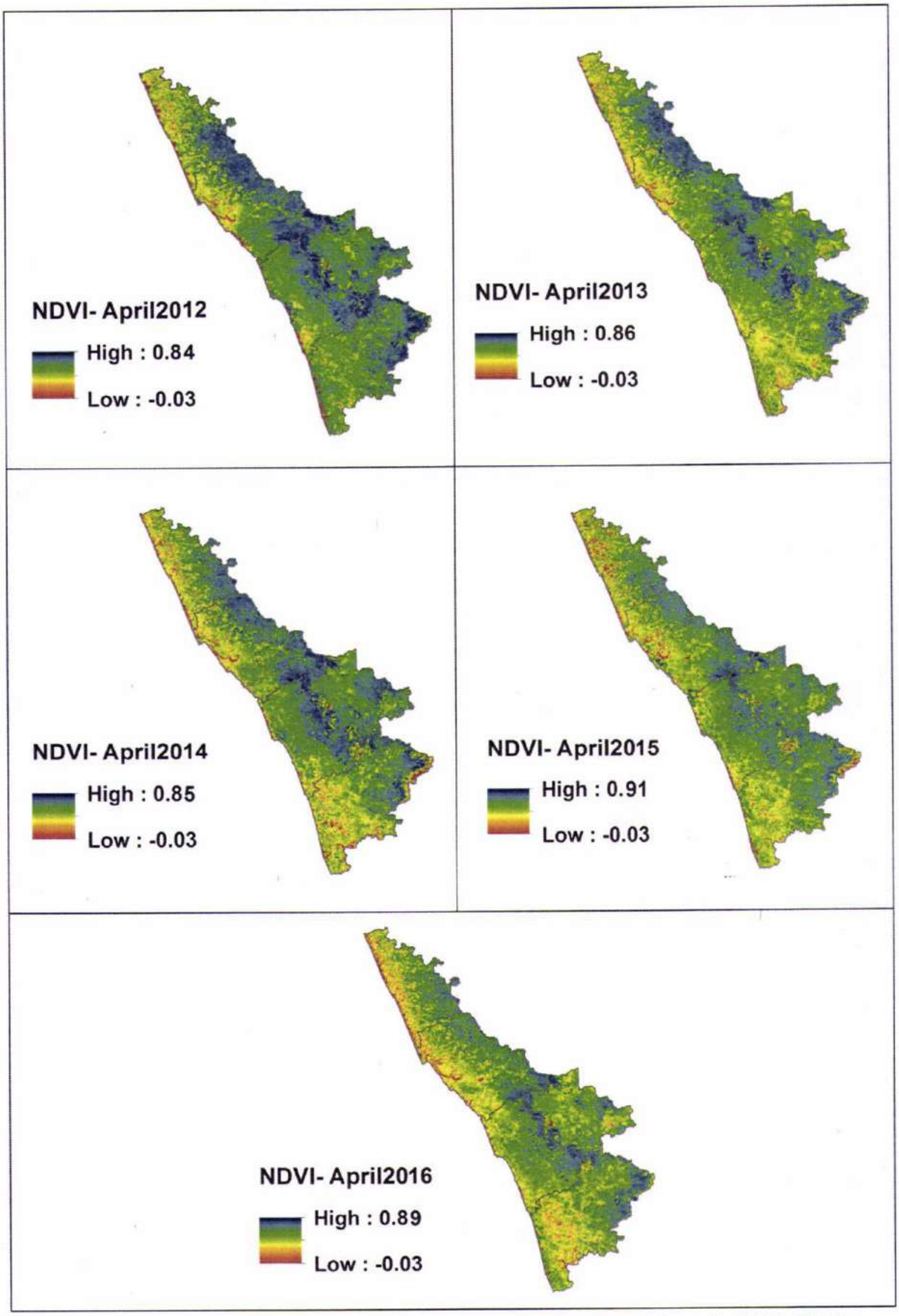
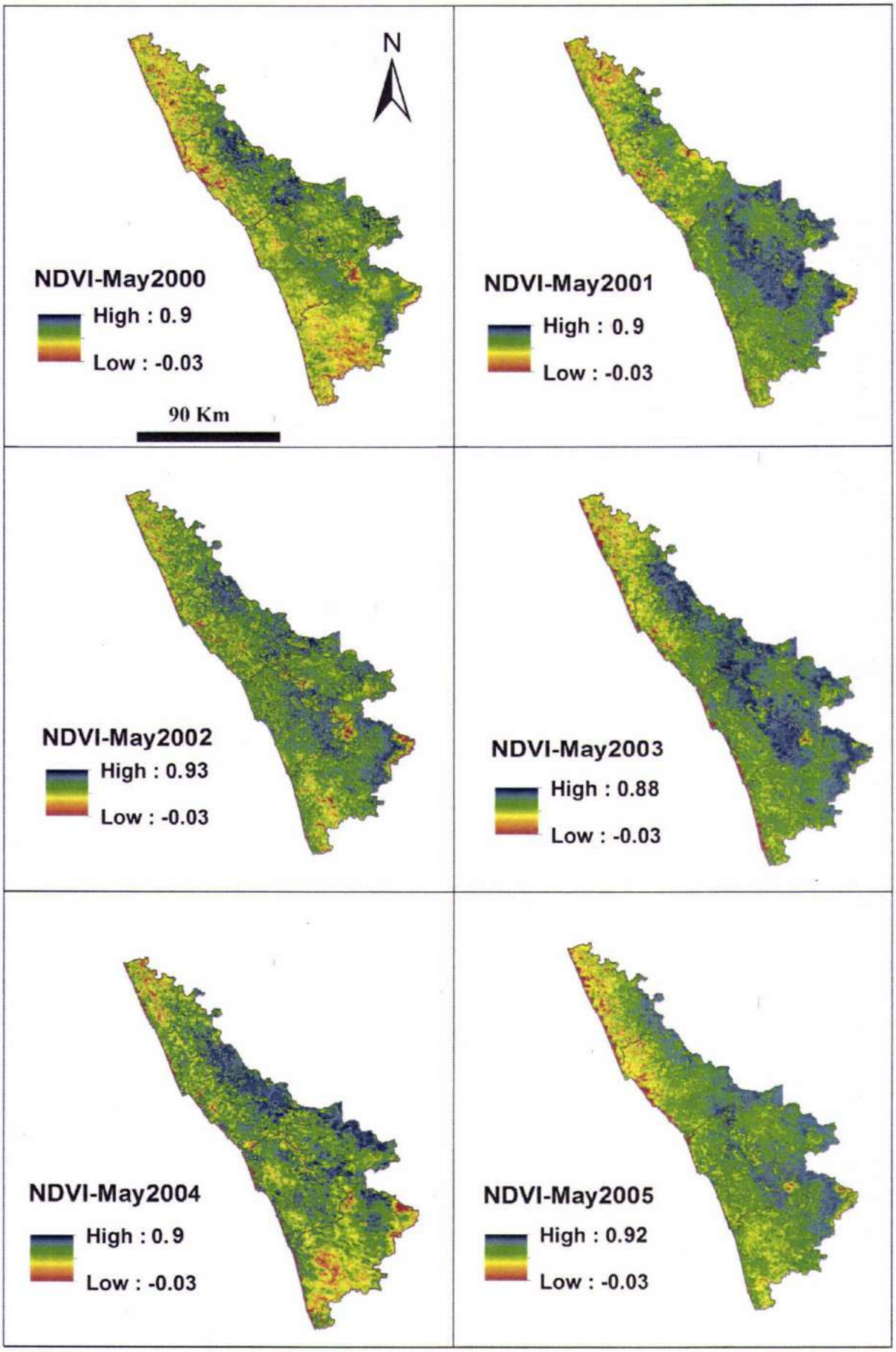
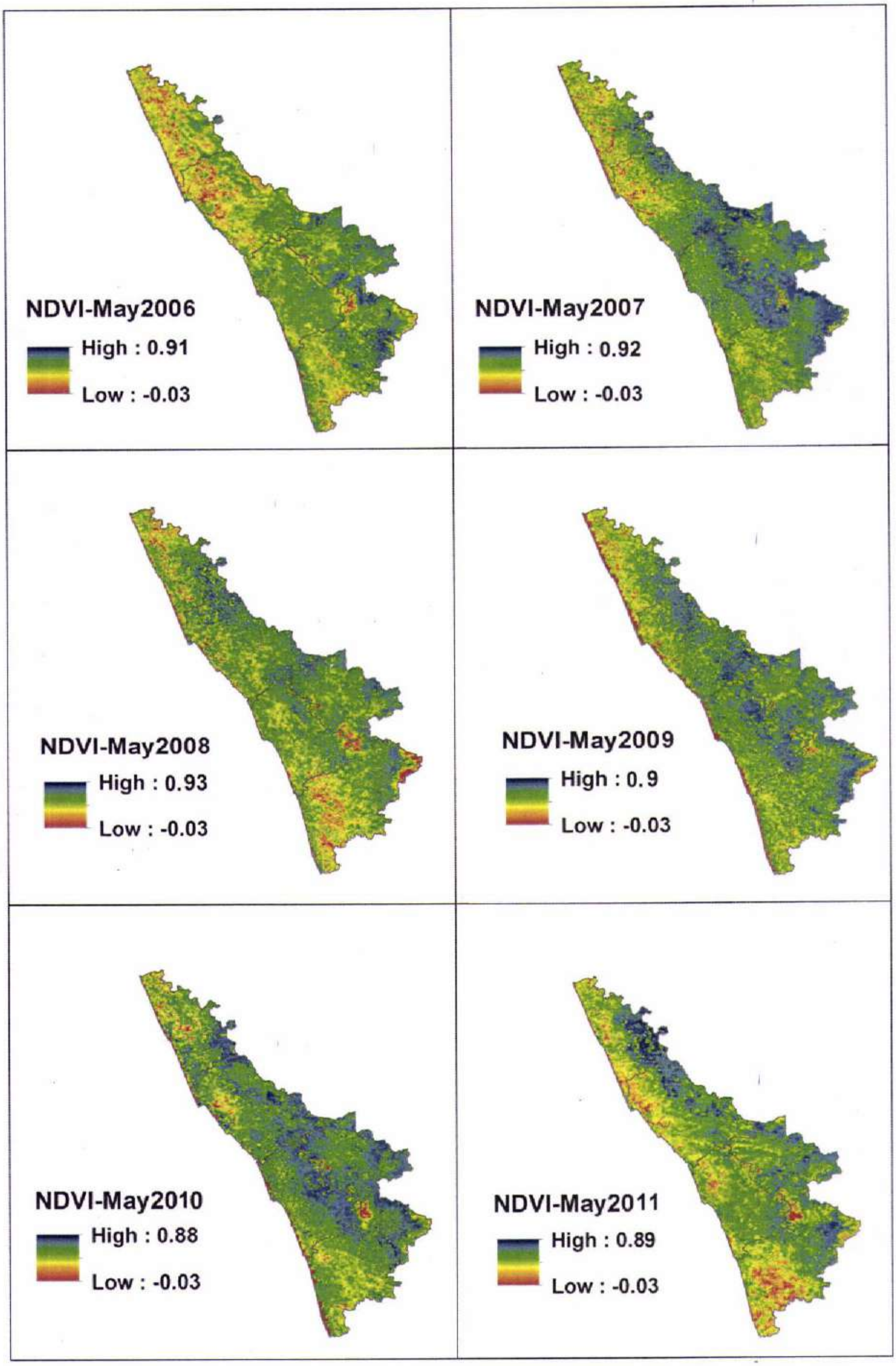


Figure 10: Spatial representation of NDVI for the month of April (2000-2016)


N
NDVI-May2000
High : 0.9
Low : -0.03
90 Km
NDVI-May2001
High : 0.9
Low : -0.03
NDVI-May2002
High : 0.93
Low : -0.03
NDVI-May2003
High : 0.88
Low : -0.03
NDVI-May2004
High : 0.9
Low : -0.03
NDVI-May2005
High : 0.92
Low : -0.03


NDVI-May2006
High : 0.91
Low : -0.03
NDVI-May2007
High : 0.92
Low : -0.03
NDVI-May2008
High : 0.93
Low : -0.03
NDVI-May2009
High : 0.9
Low : -0.03
NDVI-May2010
High : 0.88
Low : -0.03
NDVI-May2011
High : 0.89
Low : -0.03

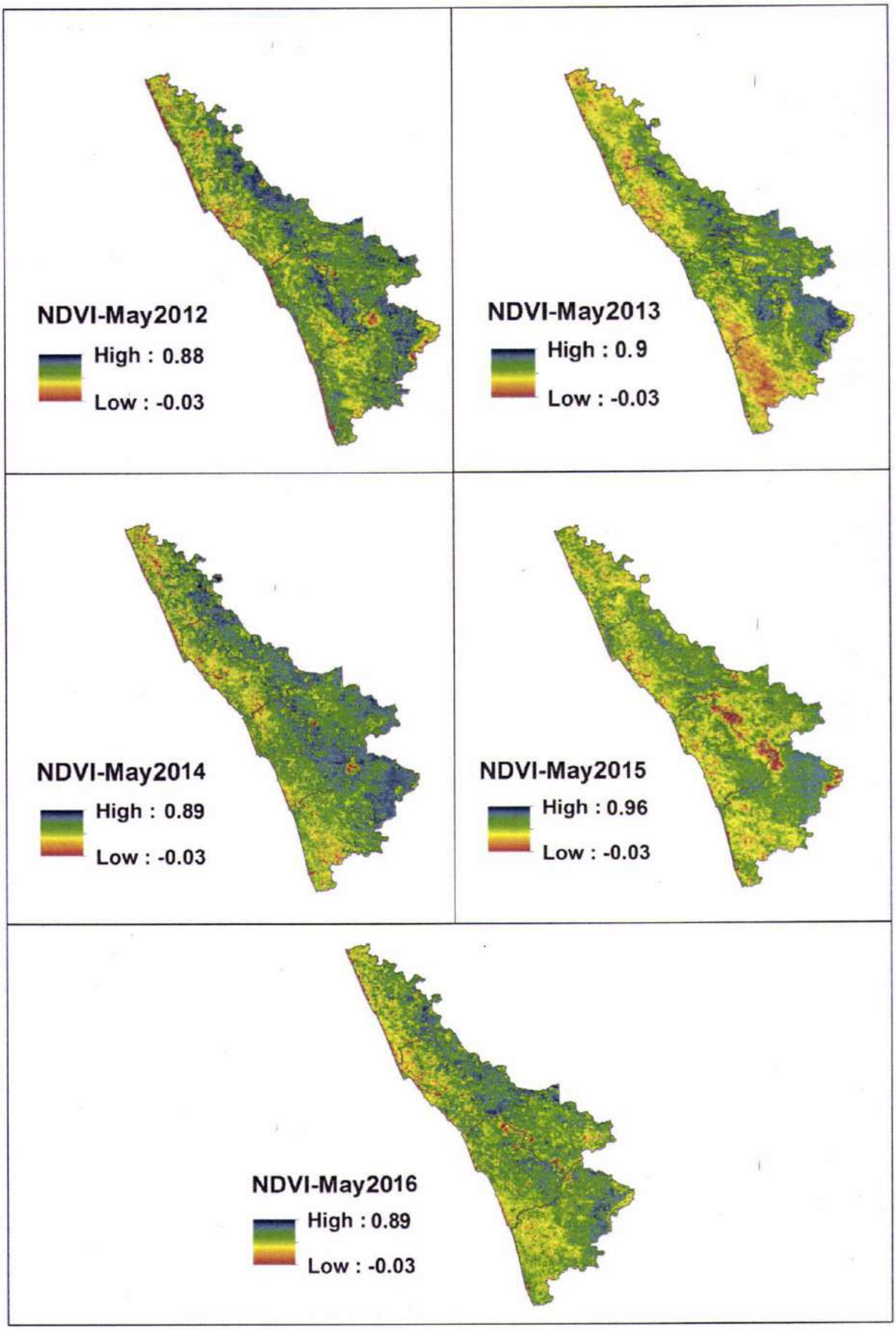


Figure 11: Spatial representation of NDVI for the month of May (2000-2016)

5.3.2. Spatial Representation of NDVI Anomaly

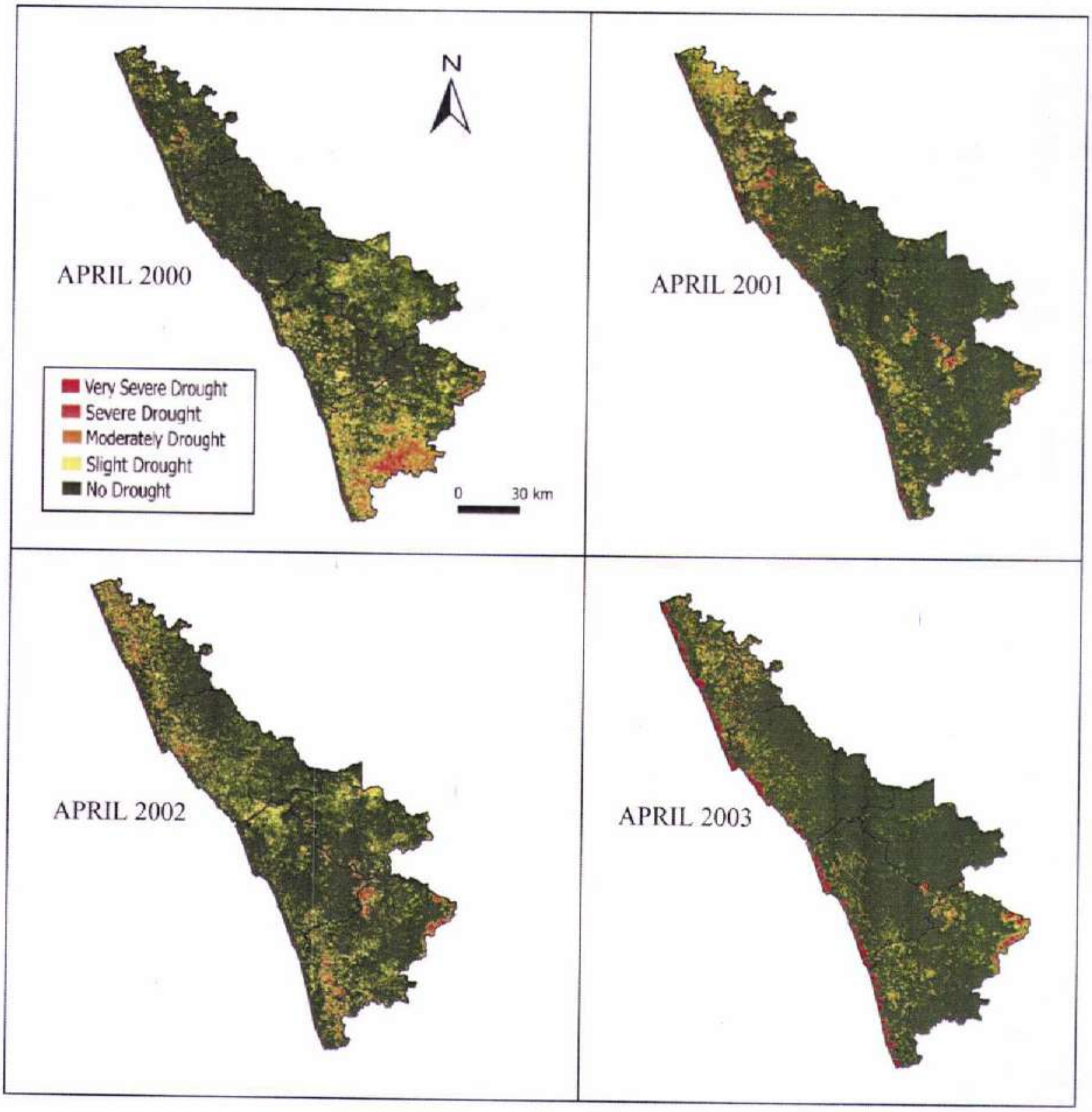
Figure 12 and 13 show the spatial pattern of NDVI Anomaly for the month of April and May over the year 2000 to 2016. Figures give you an idea about the intensity of NDVI Anomaly based drought for Northern Kerala.

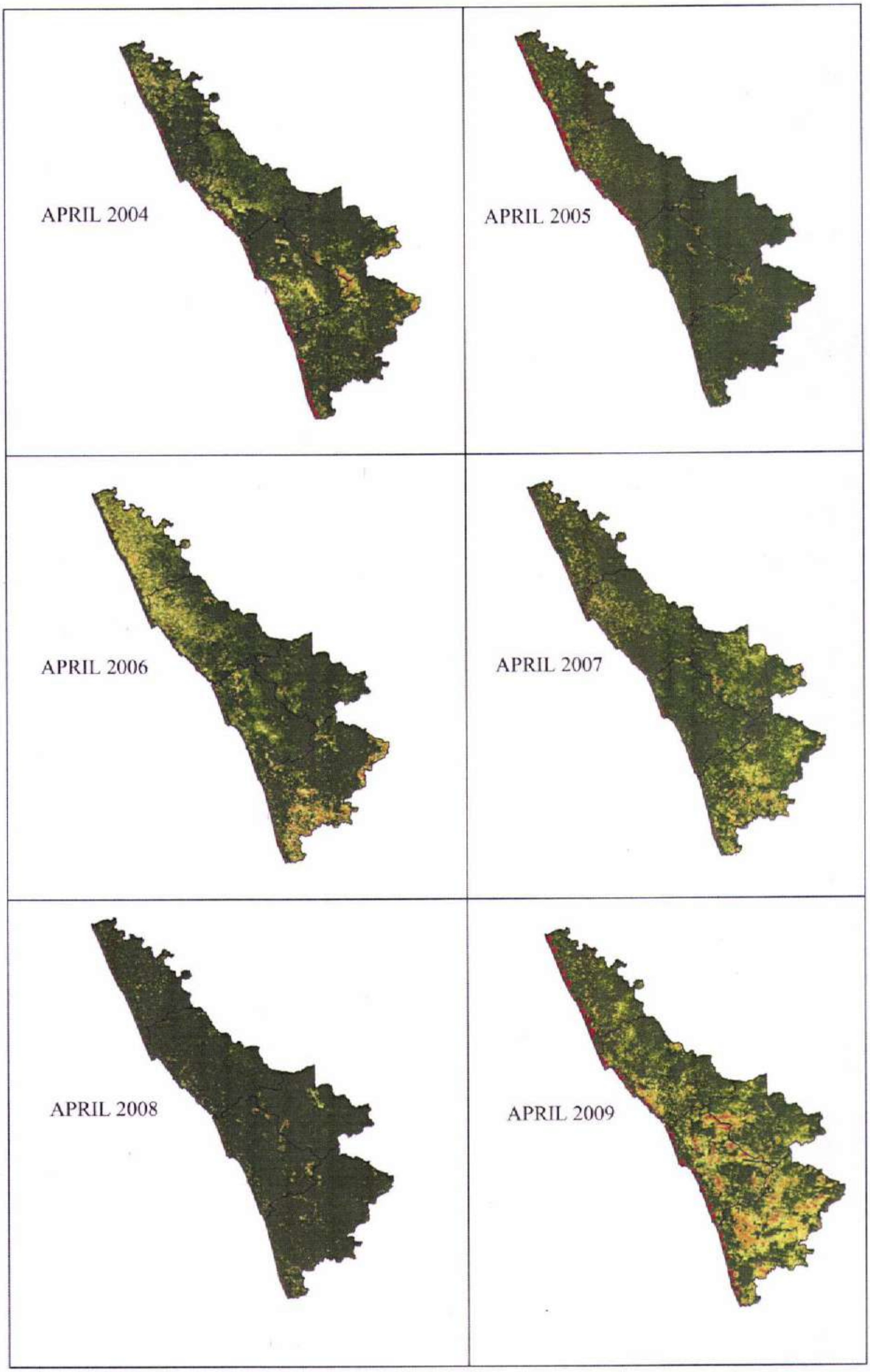
It is clear that for low rainfall years NDVI values were also low and 2000, 2013 and 2016 were classified as drought years. In 2000, for Kasaragod district Bedadka, Badiyadka, Mangalpady, KodomBellur, Madikkai are some of the drought affected panchayaths. Thrikkarippur, Cherukunnu, Ezhome and Madayi are some of the drought affected panchayaths of Kannur district. As far as Kozhikode district is concerned, Thiruvallur, Velom, Cheruvannur, Maniyur, Naduvannur, Nochad, Nanmanda, Kakkur, Kunnamangalam, Chathamangalam, Atholi, Balussery, Chakkittappara and Mavoor are the drought affected panchayaths. For Wayanad district, Thondernadu, Thavinjal, Mananthavadi, Edavaka, Vellamunda, Padinjarethara, Meenangadi, Ambalavayal and Nenmeni are some of the drought affected panchayaths. Edayoor, Kuttippuram, Moorkkanad, Puzhakkattiri, Mankada, Kottilangadi, Anakkayam, Thrikkalangode, Melattur, Angadippuram and Keezhattur are some of the drought affected panchayaths of Malappuram district.

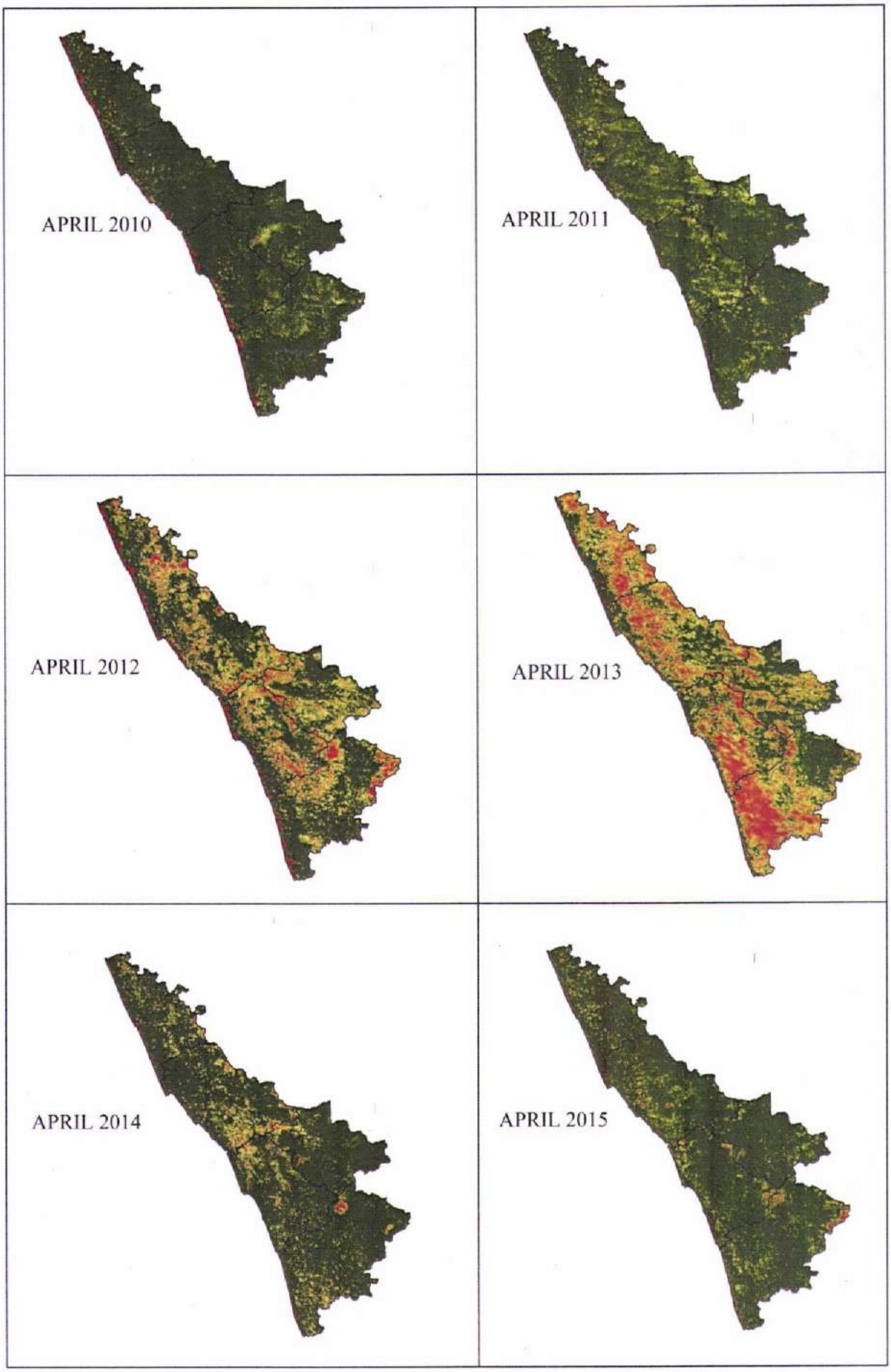
For the year 2013, almost entire region is under drought. Vorkady, Meenja, Bellur, Kuttikole, KayyurCheemeni, East Eleri, Kinanoor Karindalam are some of the drought affected panchayaths of Kasaragod district. For Kannur district, some of the drought affected panchayaths are Udayagiri, Pariyaram, Chapparapadavu, Kurumathur, Narath, Kolanchery, Munderi, Vengad, Kottiyoor and Mangattidom. As far as Kozhikode district is concerned, the panchayaths such as Kayanna, Ulliyeri, Balusseri, Atholi, Nanmanda, Kakkur, Narikkuni, Kakkodi, Chelannur, Kuruvattoor, Kunnamangalam, Peruvayal, Olavanna, Perumanna, Mavoor, Koduvally and Kizhakkoth are drought affected. Panchayaths Edavaka, Kottathara, Meenangadi, Sulthan Batheri, Meppadi and Kalpatta are some of the drought affected panchayaths of Wayanad district. For Malappuram district, the drought affected panchayaths identified are Vazhakkad, Cherukavu, Chelambra, Pallikkal, Munniyoor, Peruvalloor, Vengara, Urakam, Parappur, Kodur, Kottakal, Marakkara, Tennala, Ponmundam, Kuttippuram, Valanchery and Edayoor.

In 2016, every district of Northern Kerala is under drought condition. During May 2016, it is observed that the entire districts of Northern Kerala were under drought.

For Kasaragod district Cheruvathur, Neeleswaram, Thikkarippur, Padanna were some of the drought affected panchayaths. As far as Kannur district is concerned Thrikkarippur, Cherupuzha, Alacode are some drought affected panchayaths. In Kozhikode, Atholi, Kakkur, Kavilumpara, Perumannapanchayaths were drought affected. Sulthan Bathery, Muttil, Noolpuzha, Neenmeni are some of the drought affected panchayaths of Wayanad district. For malappuram district Kuzhimanna, Kondotty, Areekode, Pulppatta are drought affected panchayaths.




APRIL 2004
APRIL 2005
APRIL 2006
APRIL 2007
APRIL 2008
APRIL 2009


APRIL 2010
APRIL 2011
APRIL 2012
APRIL 2013
APRIL 2014
APRIL 2015

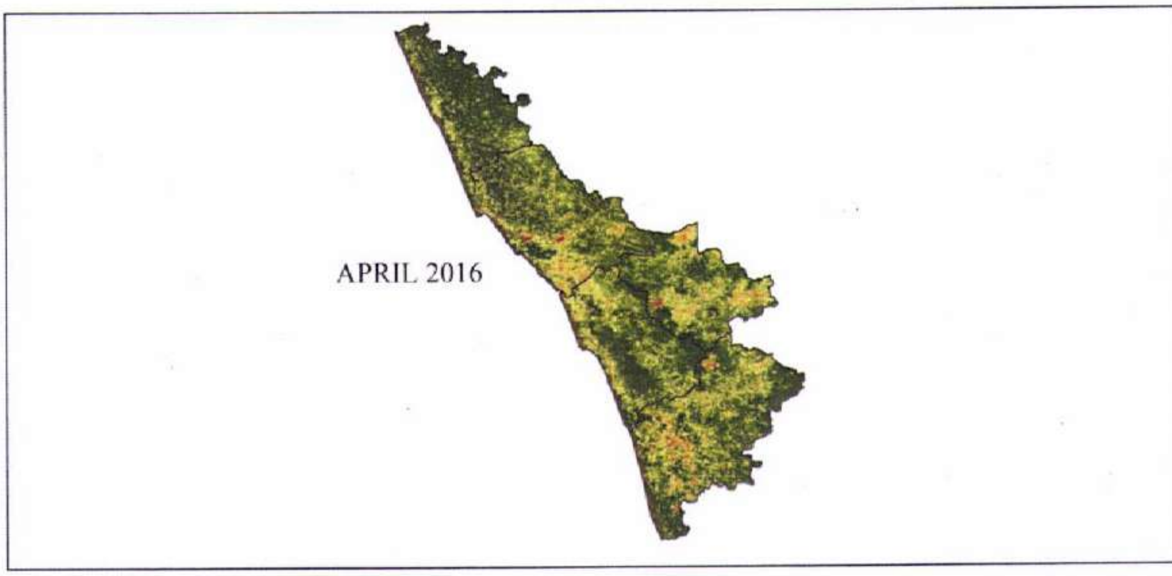
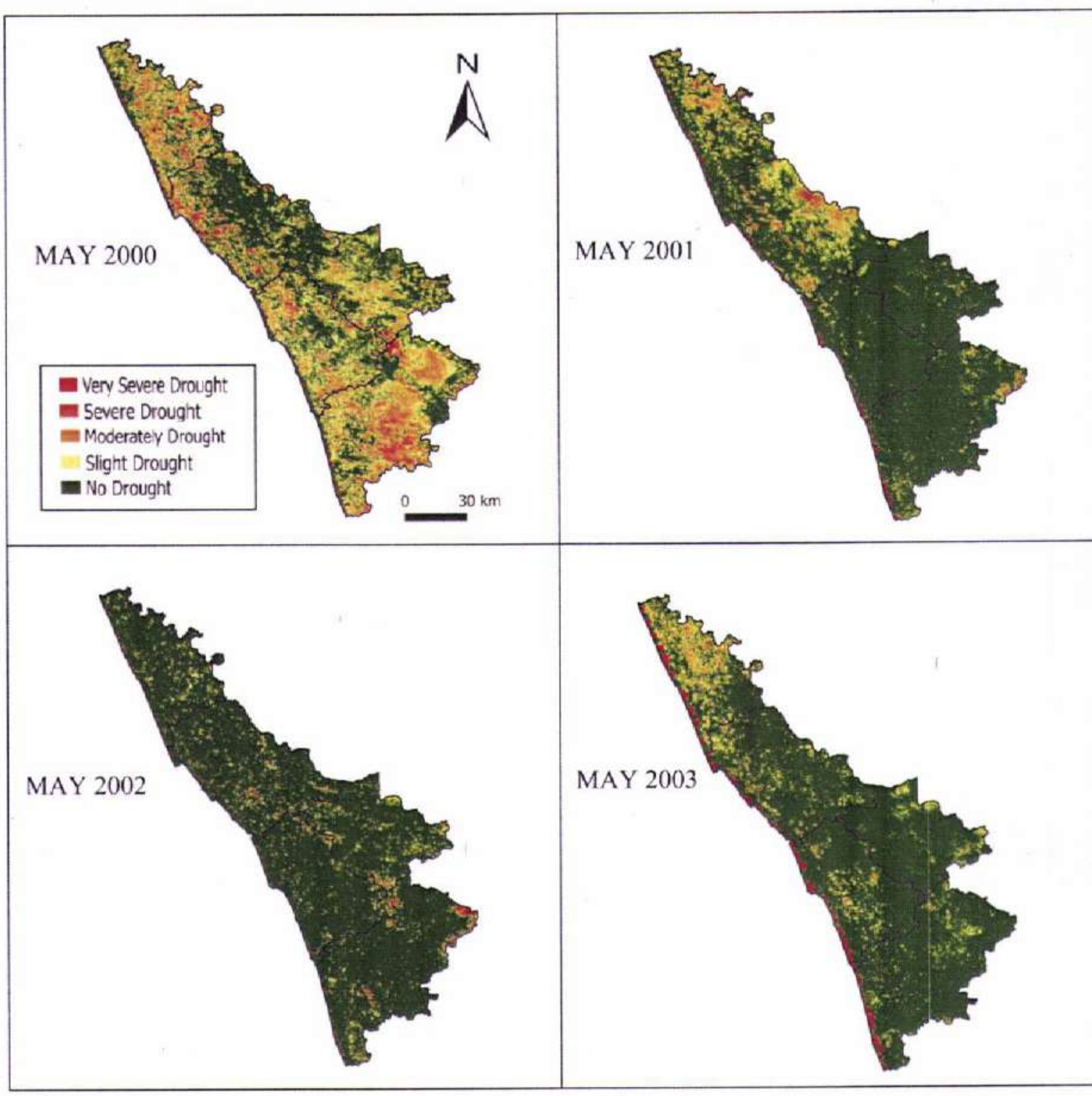
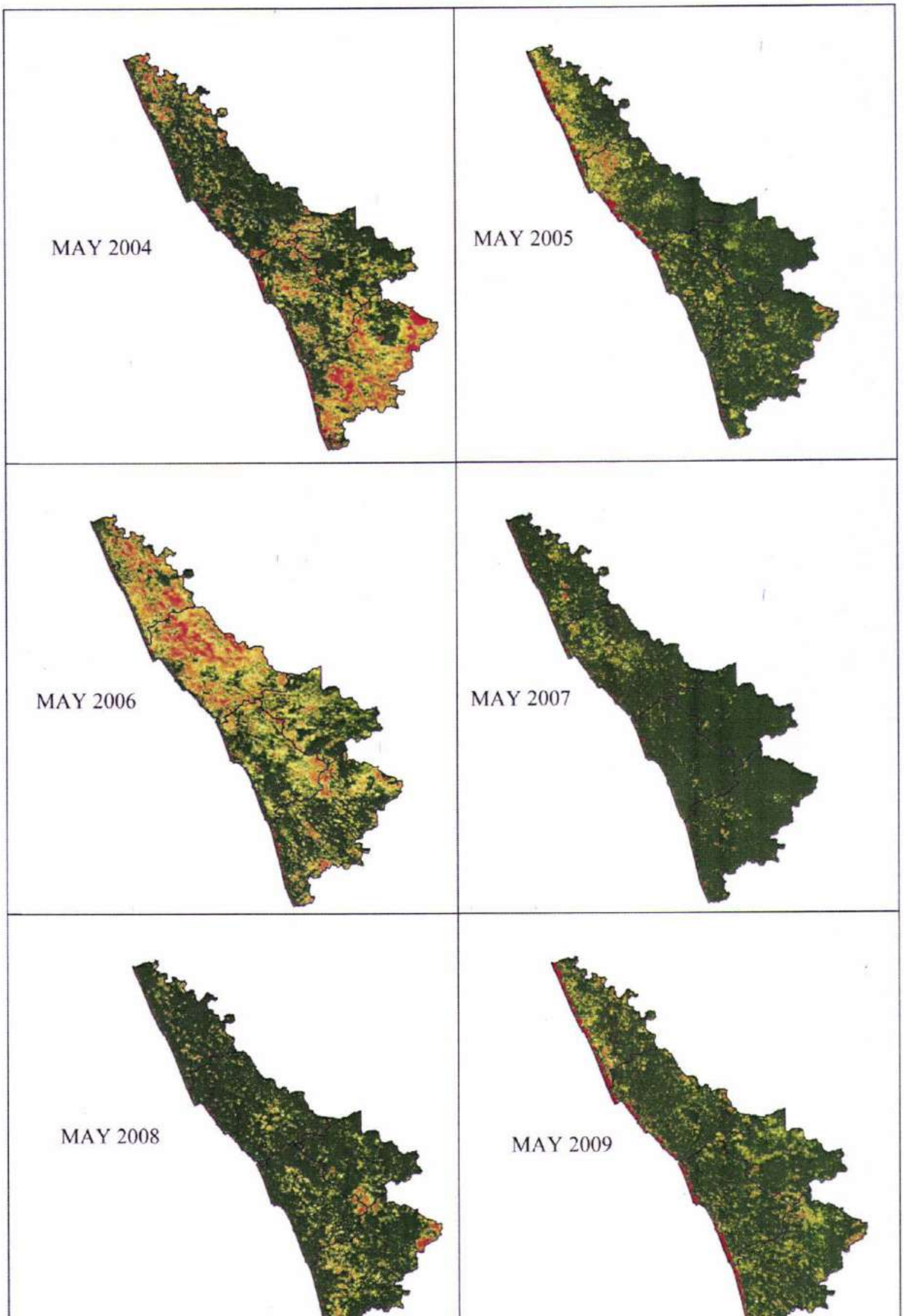


Figure 12: Spatial representation of NDVI Anomaly for the month of April (2000-16)




MAY 2004
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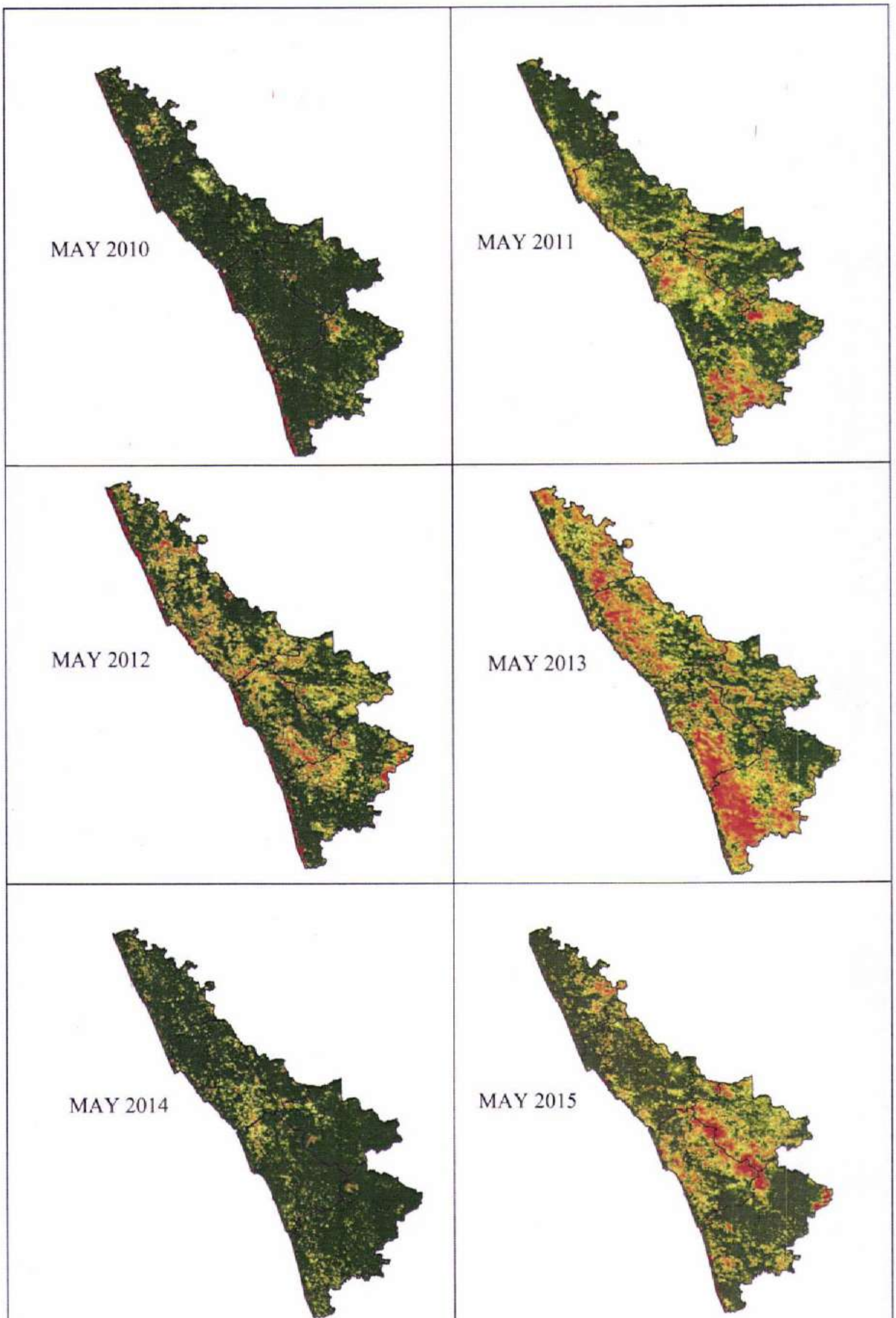
MAY 2010
MAY 2011
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MAY 2013
MAY 2014
MAY 2015

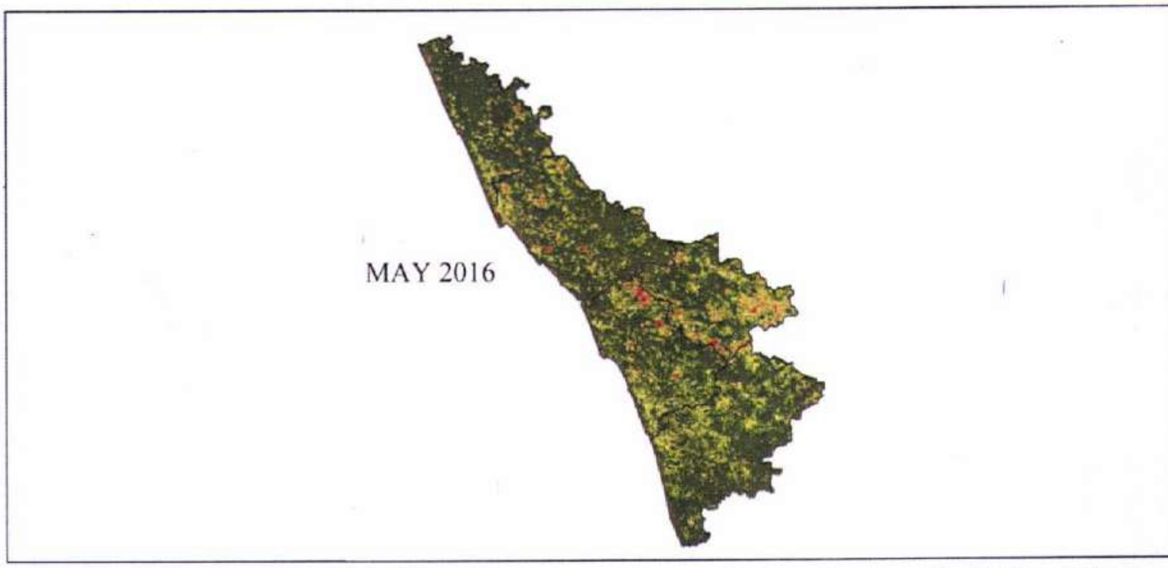
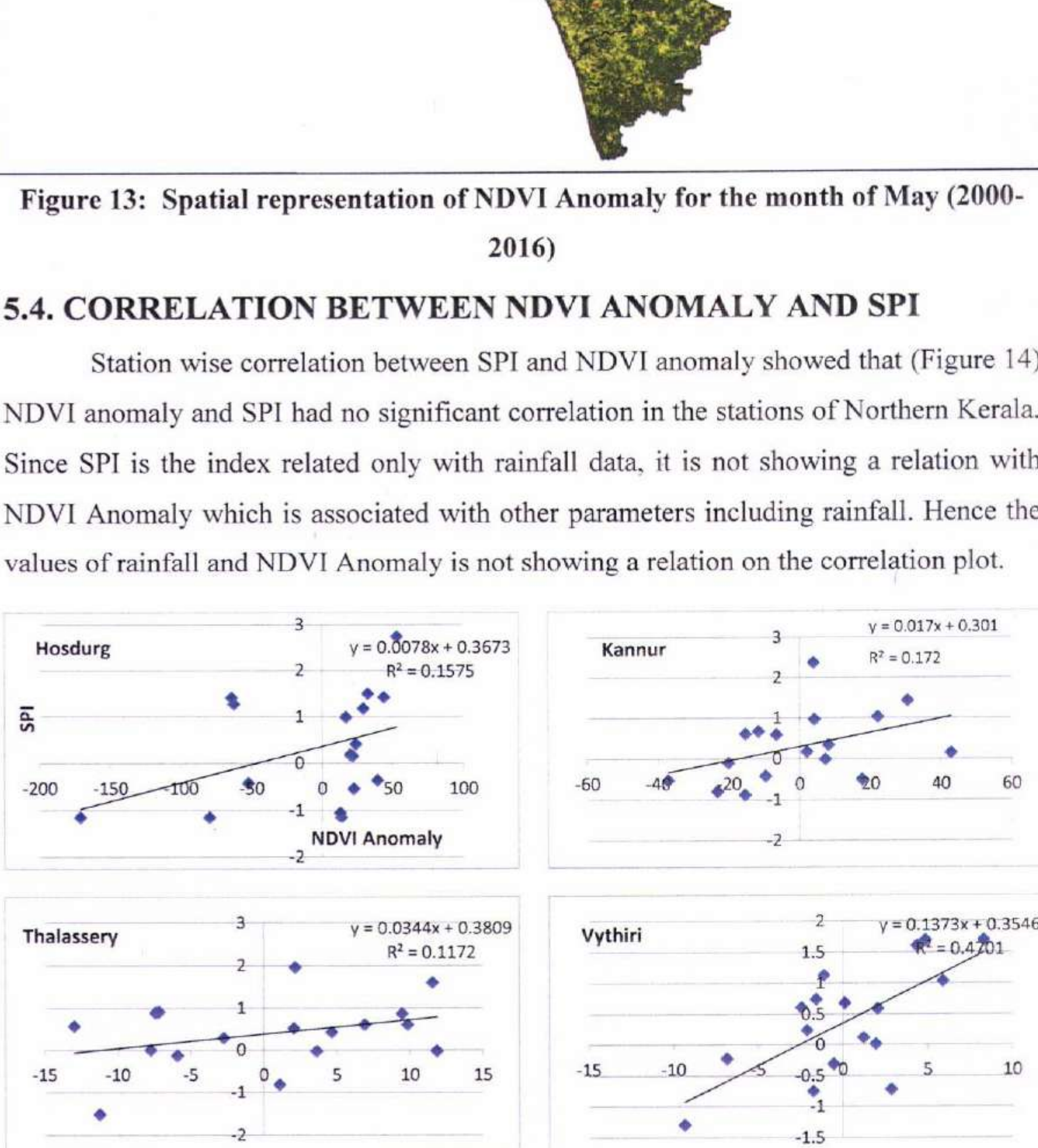


Figure 13: Spatial representation of NDVI Anomaly for the month of May (2000-2016)

5.4. CORRELATION BETWEEN NDVI ANOMALY AND SPI

Station wise correlation between SPI and NDVI anomaly showed that (Figure 14) NDVI anomaly and SPI had no significant correlation in the stations of Northern Kerala. Since SPI is the index related only with rainfall data, it is not showing a relation with NDVI Anomaly which is associated with other parameters including rainfall. Hence the values of rainfall and NDVI Anomaly is not showing a relation on the correlation plot.



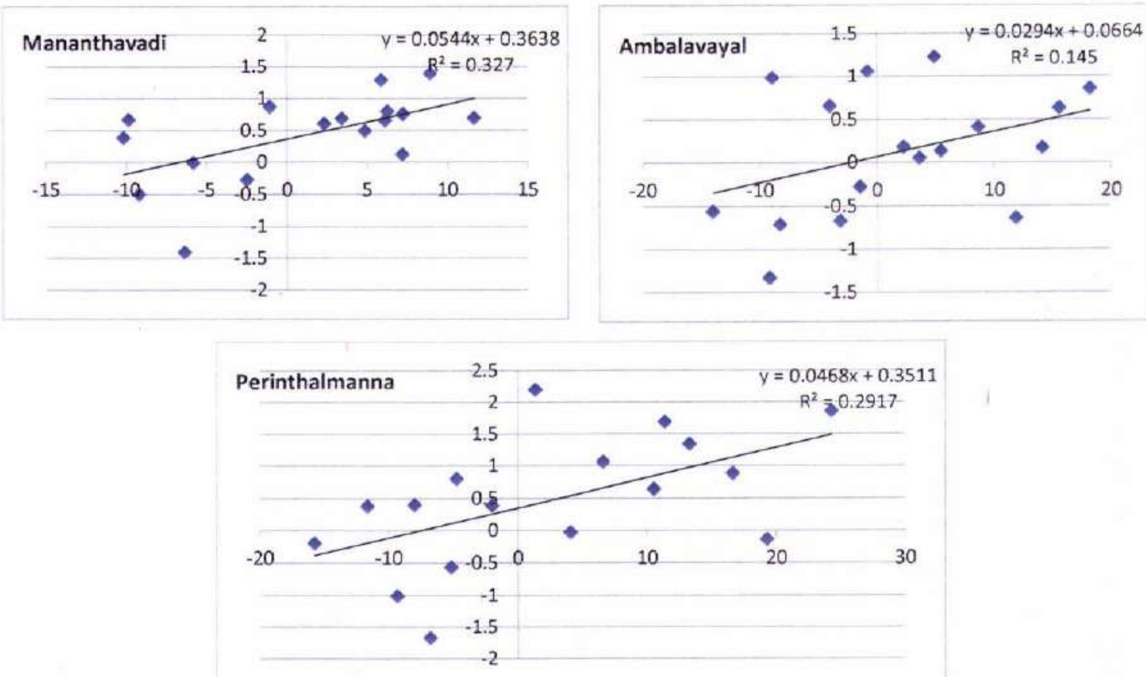


Figure 14: NDVI Anomaly- SPI Correlation of Hosdurg, Kannur, Thalassery, Vythiri, Mananthavadi, Ambalavayal and Perinthalmanna stations for April Month

5.5. DROUGHT SEVERITY CLASSIFICATION

Extent of drought affected areas over the year 2000 to 2016 during May for Northern Kerala is calculated and plotted in figure 15. From this figure, it is clear that year 2000 is a drought year with 43% of the area is drought affected. 2013 and 2016 are also drought years with a drought affected area of 55% and 50% respectively. For the year 2000, 3.7% area of Northern Kerala is under very severe drought, 3.4% area is severe, 26% area is under moderate and 10.3% area is under slight drought condition. In 2013, 2.7% area is under very severe, 10.1% area is under severe, 15.8% is moderate and 26.3% area is under slight drought condition. The intensity of drought is high in 2013. For the year 2016, 3% area is very severe, 2.8% severe, 9.3% moderate and 34.5% area is under slight drought conditions.

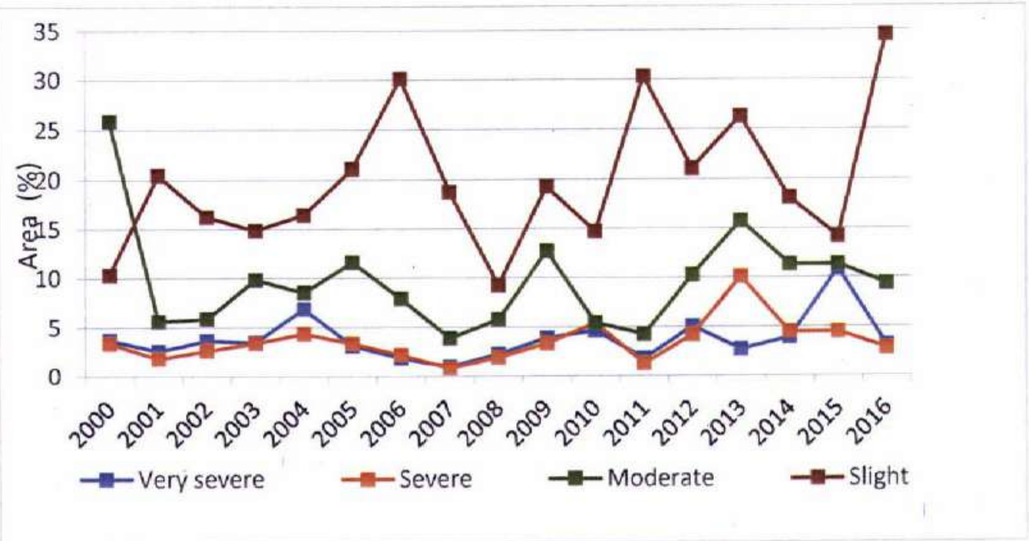


Figure 15: Percentage of geographic area suffering from different degrees of drought.

In figure 16, district wise drought details of Northern Kerala for March 2017 are calculated and plotted. From this, it is observed that the vegetation anomaly of first bi-week of March 2017 is equivalent to the Anomaly of May (hottest month) of 2016. In March 2017, 55.81% area of Wayanad district was drought affected which is a higher value compared to other districts of Northern kerala

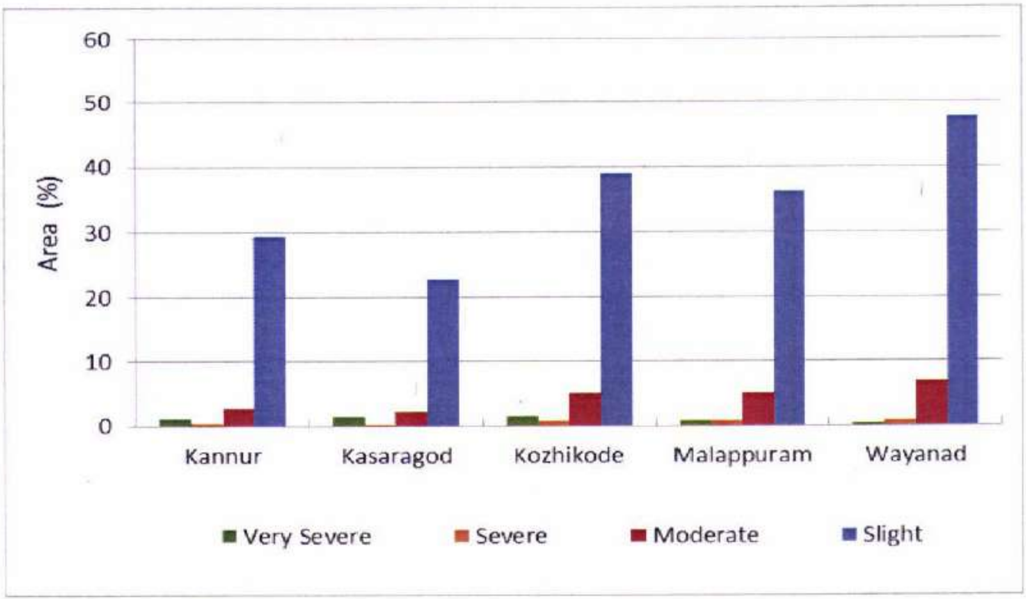


Figure 16: Drought percentage for first bi-week of March 2017

5.6. LAND USE PATTEN OF NORTHERN KERALA

The land use/ land cover map of Northern Kerala (2010) is classified using IRS-P6 LISS III data (Figure 17). Land use/land cover map reveals that coconut, rubber, arecanut, coffee, cashew, tea, teak, banana, pepper, tapioca and eucalyptus are some of the crops identified in this region. Major crops identified in Land use/Land cover map and its area in percentage is shown in Table 7. Overlaying the Land use/ Land cover map of Northern Kerala on Drought Risk map would help to identify drought affected crops.

Among these crops, Coffee is the highly exported crop in Northern Kerala which is found in Wayanad district for an area of 35.22%.

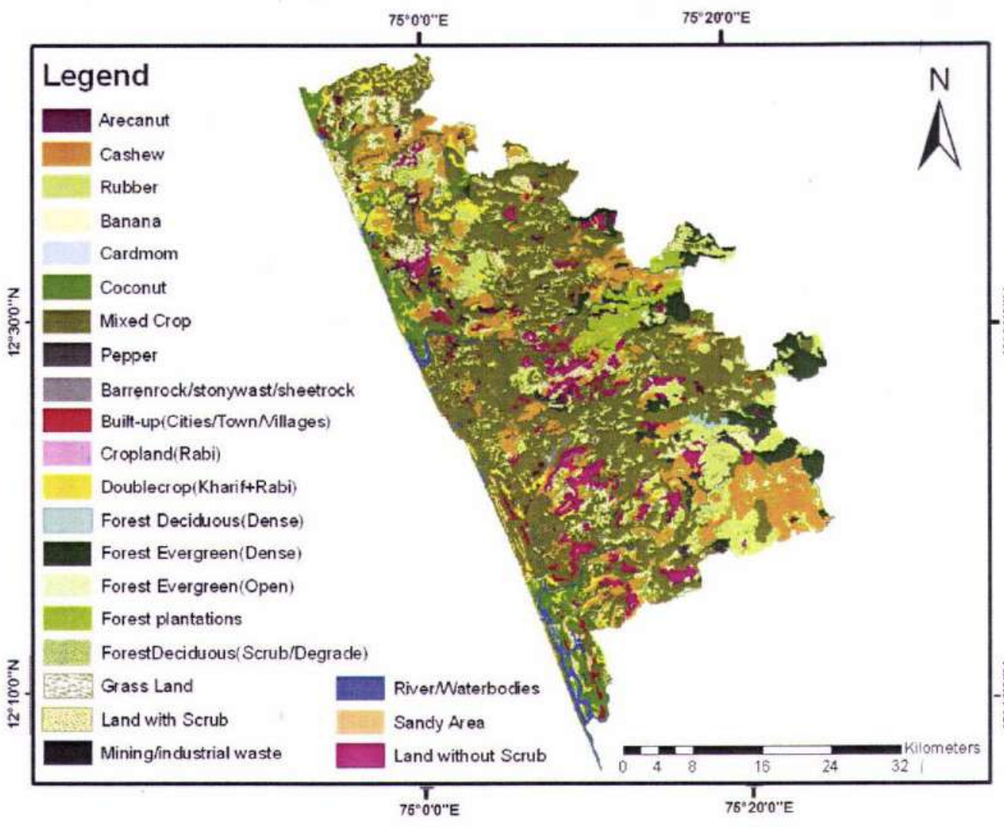


Figure 17. a. Land use/ land cover map of Kasaragod district

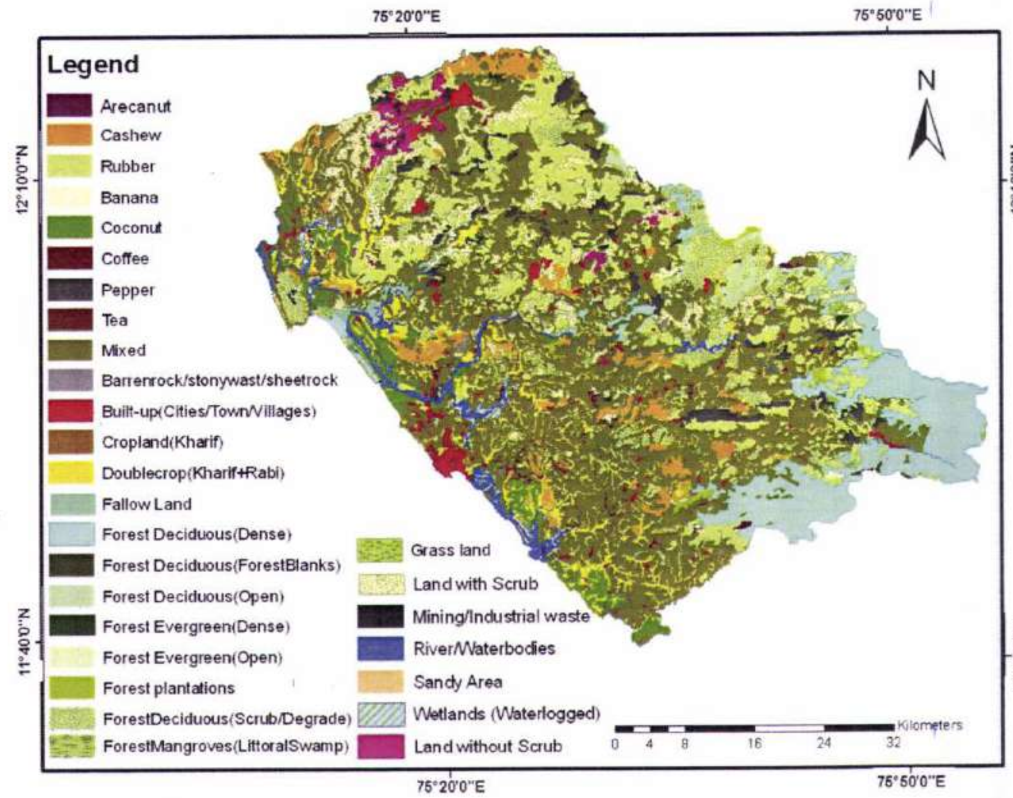


Figure 17. b. Land use/ land cover map of Kannur district

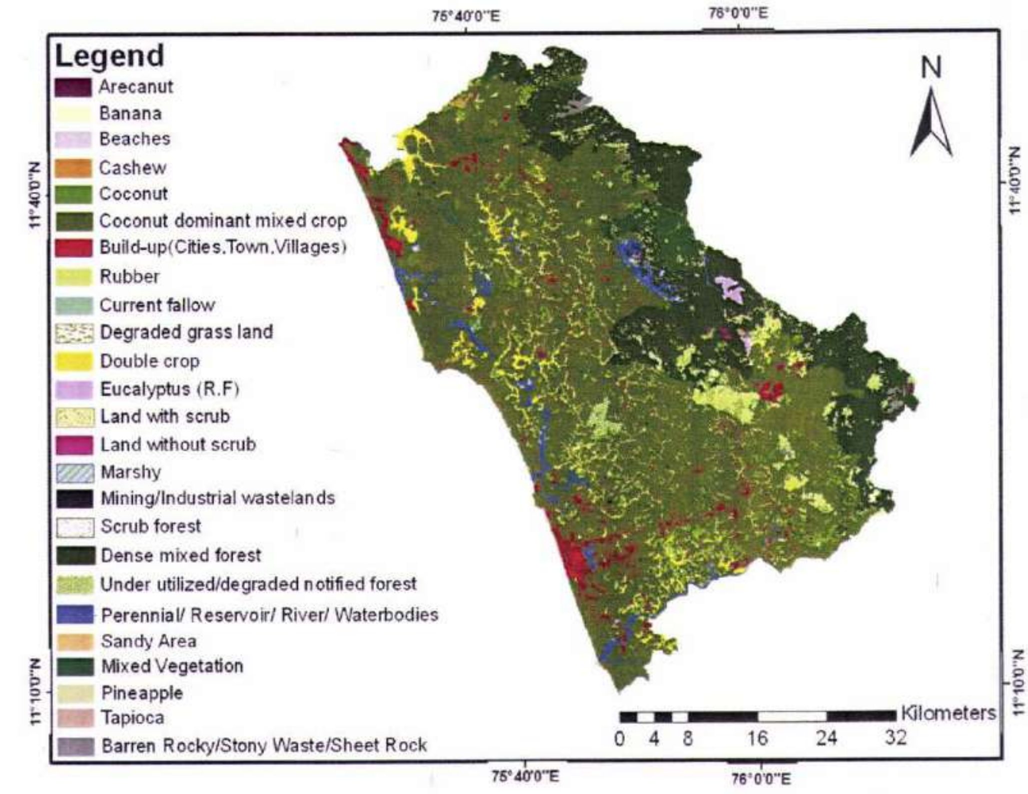


Figure 17. c. Land use/ land cover map of Kozhikode district

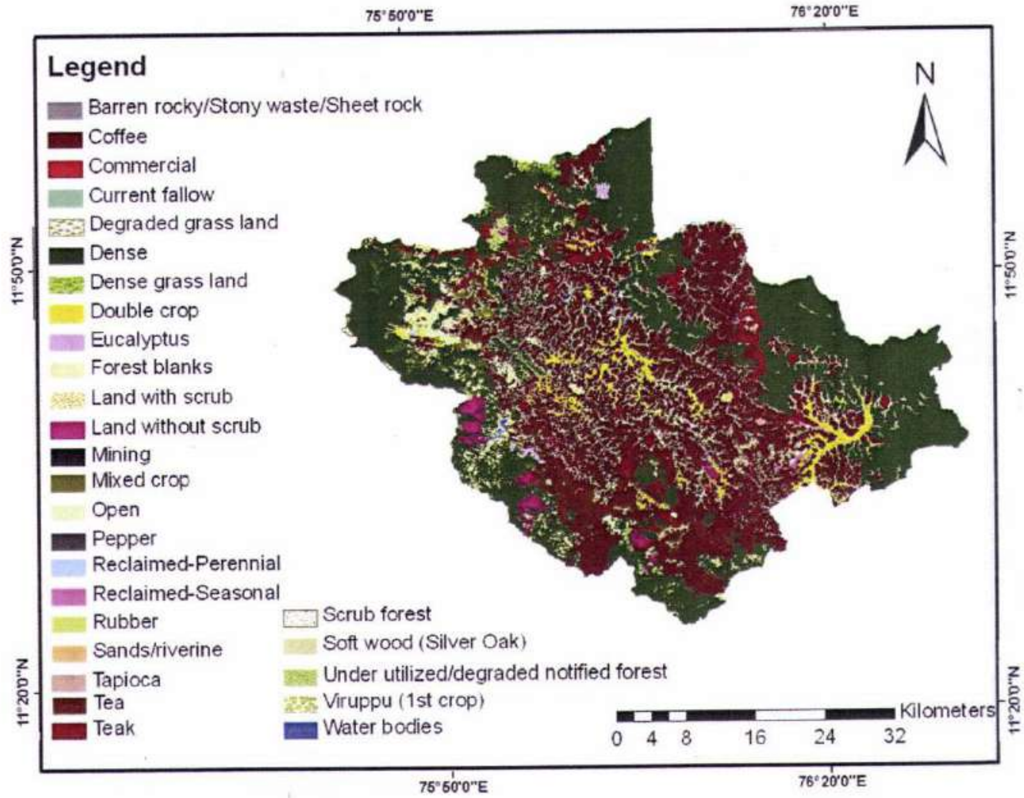


Figure 17. d. Land use/ land cover map of Wayanad district

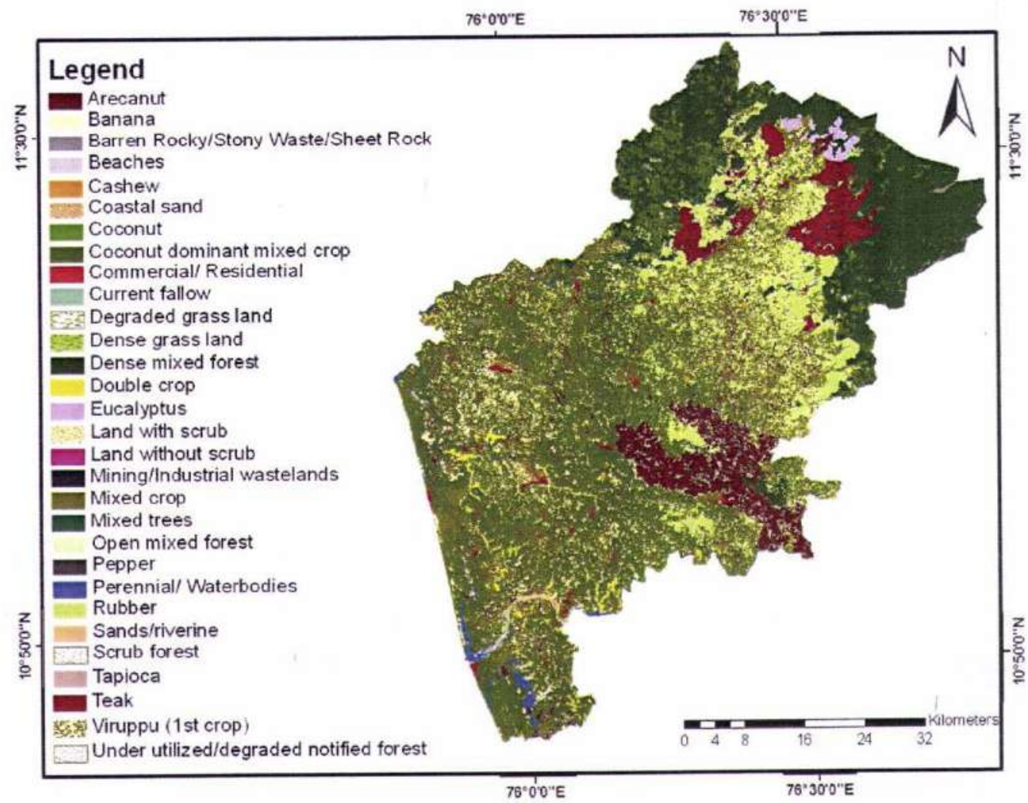


Figure 17. e. Land use/ land cover map of Malappuram district

Figure17: Land use/Land cover map of a)Kasaragod, b)Kannur, c) Kozhikode, d) Wayanad and e) Malappuram districts of study area.

Table 7: Major crops identified in Land use/Land cover map and its area in percentage

Major Crops	Kasaragod	Kannur	Kozhikode	Wayanad	Malappuram
Cashew	12%	3.6%	0.1%	-	0.06%
Coconut	4.1%	2.76%	53.51%	-	30.95%
Coffee	-	1.13%	-	35.22%	-
Double Crop	3.77%	6.14%	4.71%	3.79%	1.37%
Mixed crop	39.01%	39.17%	7.71%	0.29%	9.58%
Rubber	9.63%	11.44%	2.02%	0.65%	11.80%

5.7. LAND USE/ LAND COVER ANALYSIS OF WAYANAD DISTRICT

Wayanad district is perhaps one of the biggest foreign exchange earners of the State, with its production of cash crops like pepper, cardamom, coffee, tea, spices and other condiments. Hence our study is more focussed on Wayanad district.

The land use/ land cover map of Wayanad district (1967) prepared from the toposheet is showing that 42% of the land area is covered by dense forest and 33% of the area with coffee plantation. After four decades, the distribution in dense forest is found to be reduced by 5% and this area has been utilized by plantations like bamboo, pepper, cocoa, silver oak, eucalyptus etc. There is a marginal decrease in coffee plantation during these periods. The settlements in the study area got increased by about 2.5%, due to the migrants from the south Kerala. The population increased in the study area had exploited the plain regions for constructing their shelter, where the double crops are cultivated and thereby construction of roads got amplified for easy accessibility to the nearby main cities. Figure 18 below shows the bar chart showing the areal extent for each class in the map.

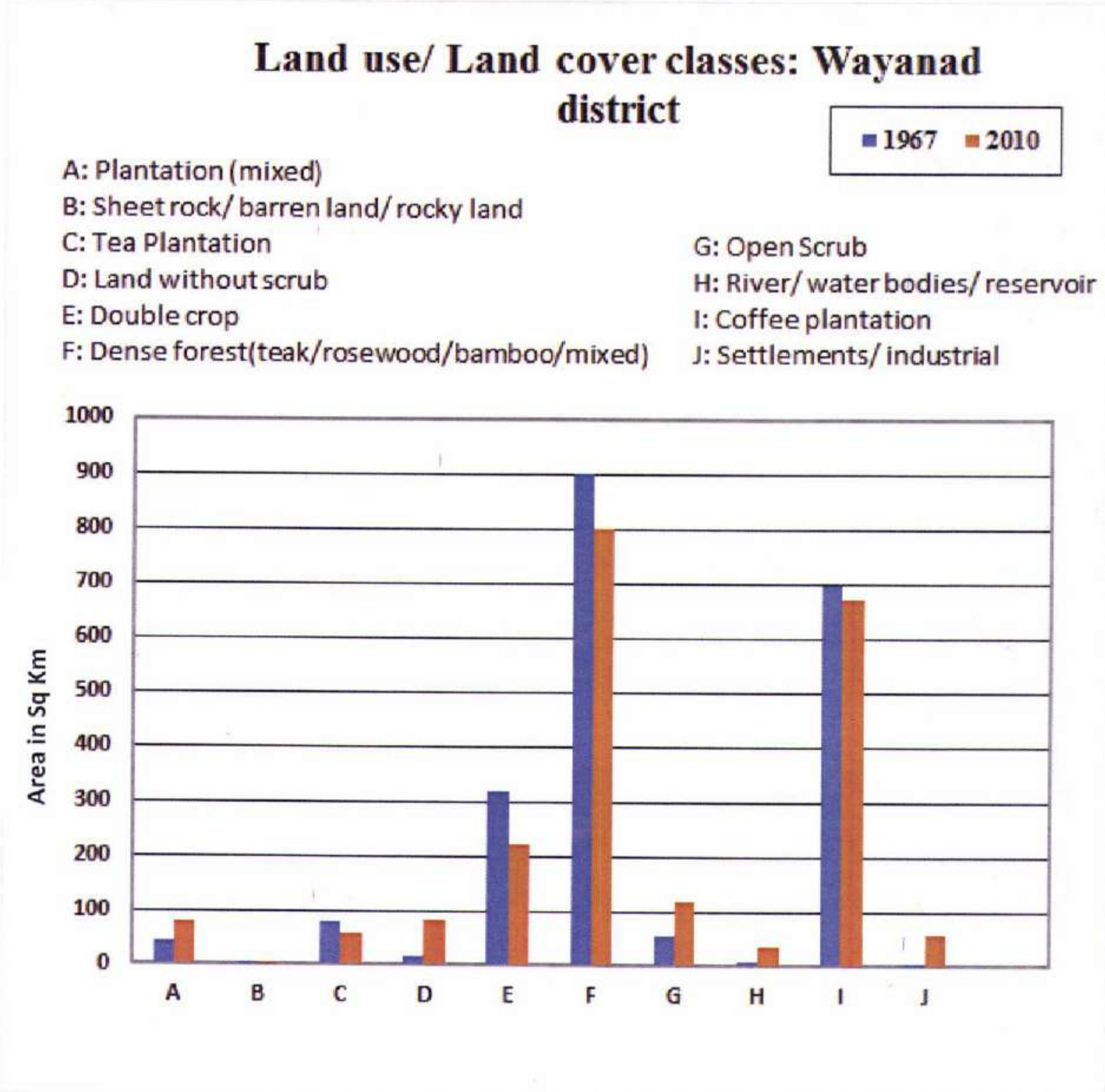


Figure 18: Bar chart showing Land use classification of Wayanad district and its aerial extent for the years 1967 and 2010

Table 8: Land Use/ Land Cover classes and its areal extent during the years 1967 and 2010

Classification	Area distribution 1967		Area distribution in 2010	
	sq. km	%	sq. km	%
Plantation(mixed)	43.82	2.06	77.85	3.65
Sheet rock/barren land/rocky land	0.12	0.01	3.86	0.18
Tea plantation	81.06	3.81	58.07	2.72

Land without scrub	17.90	0.84	82.15	3.85
Double crop	320.83	15.06	224.00	10.51
Dense forest(teak/rosewood/bamboo/mixed)	900.73	42.29	801.10	37.61
Open scrub	52.08	2.45	120.36	5.65
River/water bodies/reservoir	9.70	0.46	33.48	1.57
Coffee plantation	698.88	32.81	671.86	31.54
Settlements/industrial	4.87	0.23	57.28	2.68
Total area	**2130**	**100**	**2130**	**100**

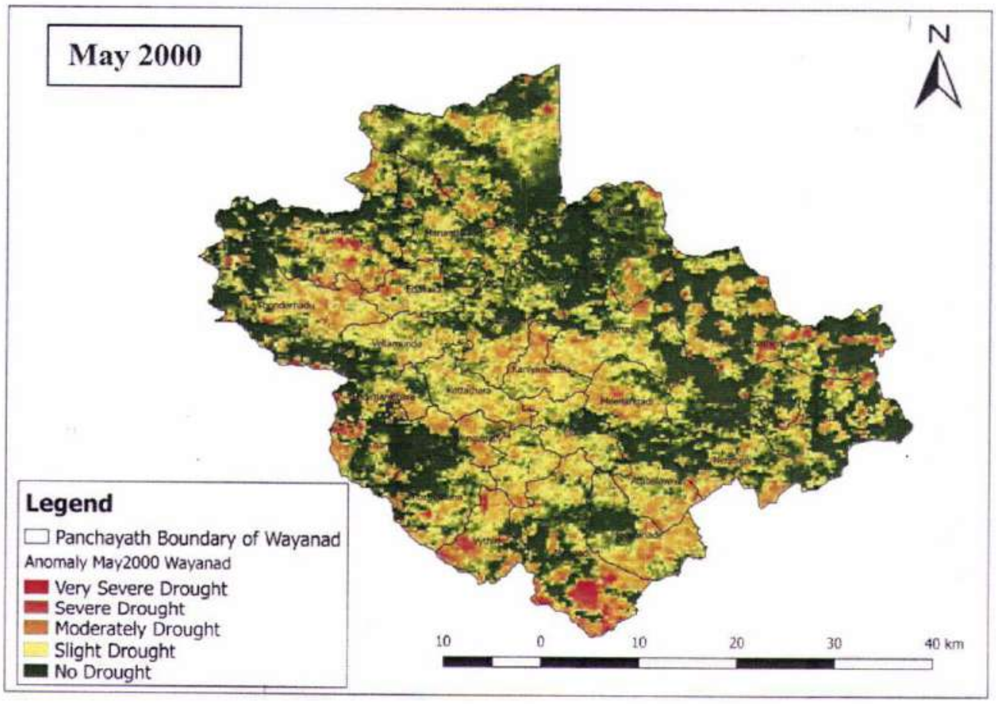
The dense forest in the study area has got cleared for connecting the main towns. As the irrigation practice increased, water availability became a major concern. To overcome this situation, Banasura Sagar Dam and canal system was constructed in 1979. And in 1977 Karapuzhadam, which started its construction in the east of Kalpetta to meet the demand for irrigation and drinking water in this region known to have water shortages in seasonal dry periods. Therefore, in the land use/land cover classification for 2010 shows an increase in the areal extent in water body. The open scrub in the area has increased by 3.25 % by the year 2010 compared to 1967. Sheet rock/barren land/rocky land is only covering a small area in the Wayanad district. The tea plantation in the study area is showing a marginal decrease in area during these four decades.

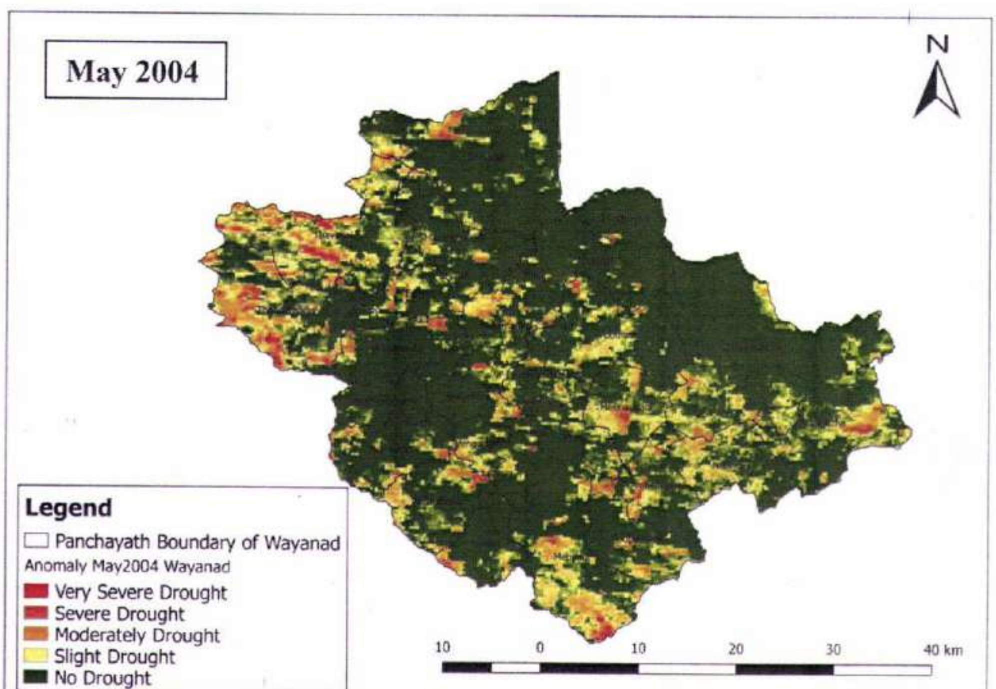
Table 8 shows the Land Use/ Land Cover classes and its areal extent between 1967 and 2010 years.

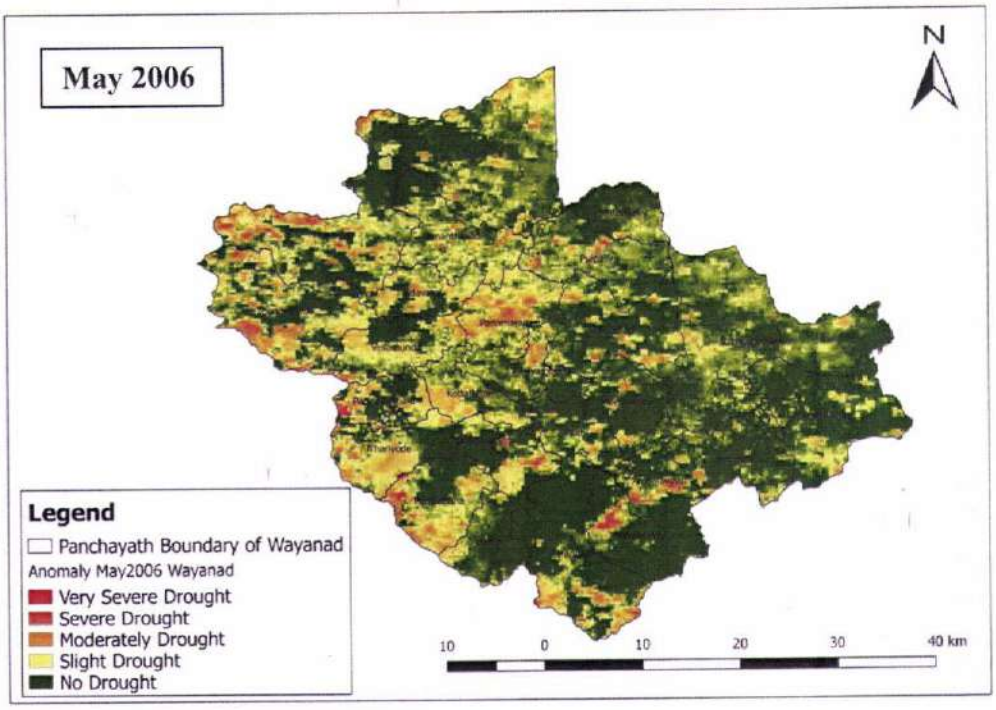
5.8. NDVI ANOMALY AND DROUGHT RISK ZONE MAPPING OF WAYANAD DISTRICT

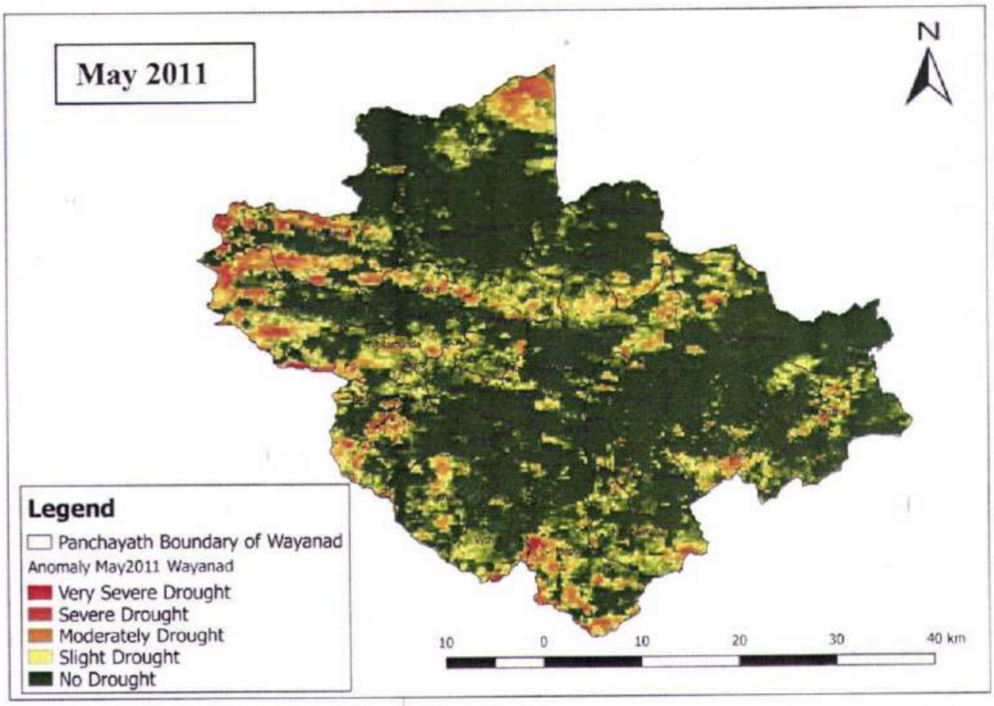
It is clear from the NDVI Anomaly maps that almost entire region of Northern Kerala is under drought risk, especially in Wayanad district, one of the major agriculture districts. Drought conditions of Wayanad district is shown in figure 19.

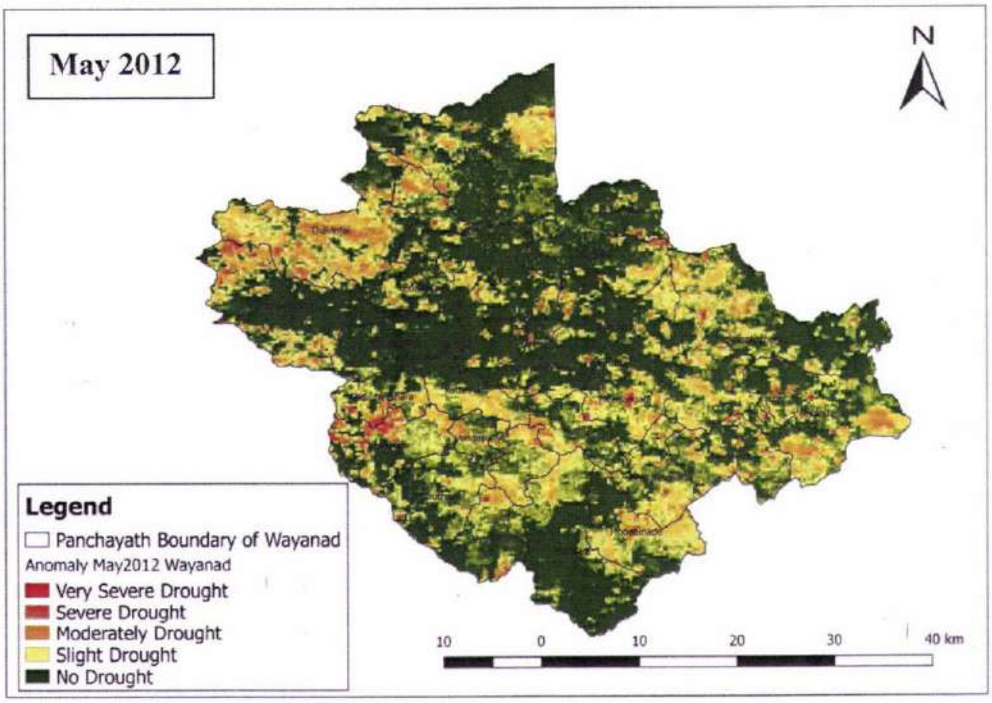
NDVI Anomaly is calculated for a period of 2000 to 2016 for the month of May. It is found that 2000, 2004, 2006, 2011, 2012, 2013, 2015, 2016 were drought years. NDVI Anomaly maps for these years were shown in figure 19. In 2000, drought was affected by almost every region of Wayanad district like Kottathara, Kaniyambetta, Meenangadi, Vengapally, Vythiri, Ambalavayal, Vellamunda etc. North-west region, centre and south-east of Wayanad were drought affected in 2004. In 2006, almost everywhere of the district is drought affected especially Panamaram, Pulpally and Thariyode. In 2011, north-east and south-west of wayanad was drought affected. In 2012, almost everywhere of district was drought affected. In 2013, severe drought exists at everywhere like Sulthan Bathery, Kottathara, Edavaka, Meenangadi panchayaths of Wayanad district. Also in 2015, almost everywhere is drought affected especially in Thondernadu, Padinjarethara, Thariyode, Pozhuthana, Meppadi, Vythiri etc. In 2016, Sulthan Bathery, Noolpuzha, Muttil, Vythiri and Pulpally are drought affected areas.






May 2006
N
Legend
Panchayath Boundary of Wayanad
Anomaly May2006 Wayanad
Very Severe Drought
Severe Drought
Moderately Drought
Slight Drought
No Drought
10 0 10 20 30 40 km


May 2011
N
Legend
Panchayath Boundary of Wayanad
Anomaly May2011 Wayanad
Very Severe Drought
Severe Drought
Moderately Drought
Slight Drought
No Drought
10 0 10 20 30 40 km


May 2012
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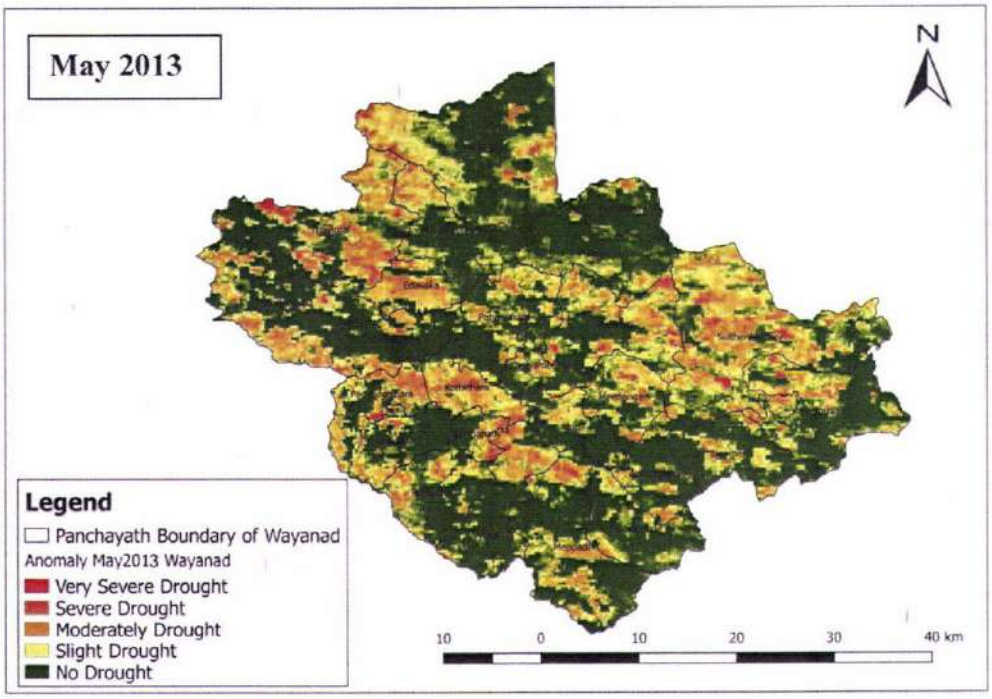
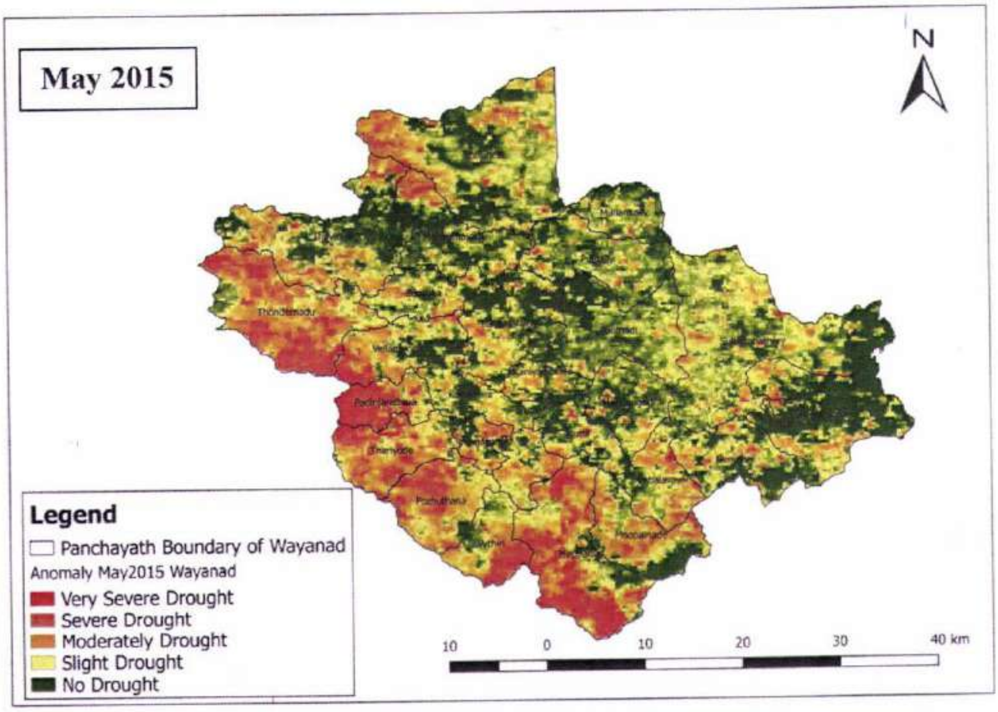
Legend
Panchayath Boundary of Wayanad
Anomaly May2012 Wayanad
Very Severe Drought
Severe Drought
Moderately Drought
Slight Drought
No Drought
10 0 10 20 30 40 km


May 2013
N
Legend
Panchayath Boundary of Wayanad
Anomaly May2013 Wayanad
Very Severe Drought
Severe Drought
Moderately Drought
Slight Drought
No Drought
10 0 10 20 30 40 km



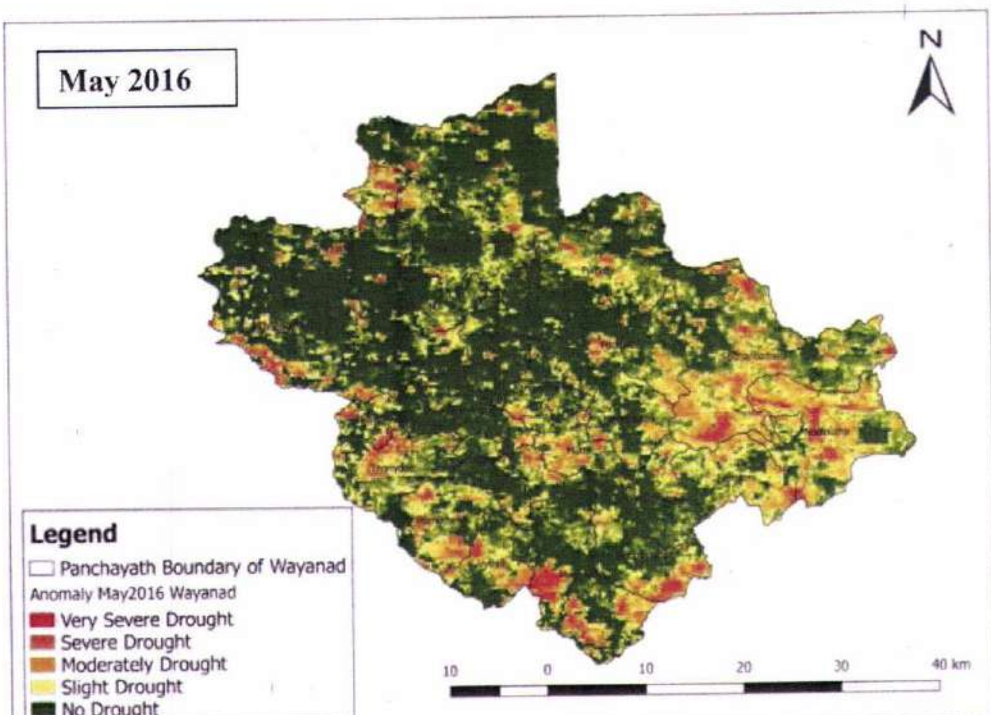


Figure 19: NDVI Anomaly of Wayanad district for the year 2000, 2004, 2006, 2011, 2012, 2013, 2015, 2016 of May month

5.9. DROUGHT SEVERITY ON COFFEE IN WAYANAD DISTRICT

This study is mainly focusing on drought analysis of the Coffee plantation, the major crop grown in Wayanad district, using the index NDVI. Wayanad is a district in the north east of Kerala State which produces cash crops like pepper, cardamom, coffee, tea, spices and other sediments. Among these Coffee is the major cash crop produced in Wayanad. Even though Wayanad district experiences high rainfall in areas such as Lakkidi, Vythiri and Meppady and also is covered with forest and thousands of streams and springs, it is faced by occasional drought events. This is mainly due to change in rainfall pattern, unchecked deforestation and large-scale conversion of paddy fields into plantations.

From the NDVI Anomaly maps for February 2016 and 2017, it is observed that February 2017 is experiencing more drought than February 2016 especially in the eastern part of Wayanad district. Overlaying the Land Use/ Land Cover maps on the Anomaly maps the drought severity of Coffee for the particular period was observed. It is seen that 28.11% of Coffee was under drought in February 2016. Among these 11.96% is moderate and 16.1% is slight drought. But during 2017, drought affected area under coffee increased to 48.07% with 25.41% moderately affected and 22.4% under slight drought. 19.96% increase in drought is found in February 2017 compared to February 2016. The drought severity of Coffee for February 2016 and 2017 is shown in figure 20.

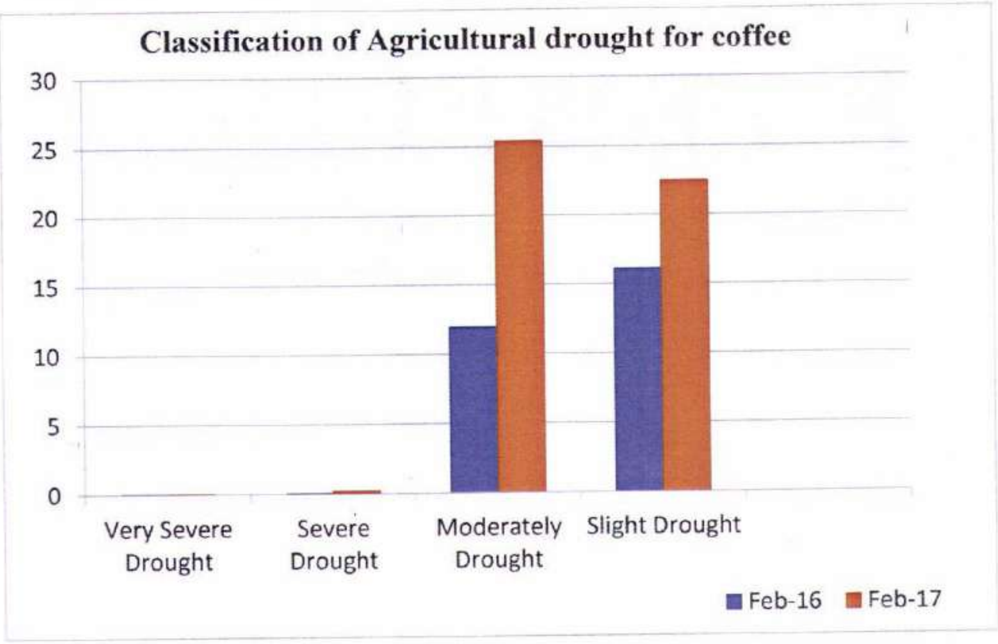


Figure 20: Agricultural drought for Coffee

5.10. WEB BASED DROUGHT RISK MAPPING AND ANALYSIS

The web tool allows users to view drought severity at various spatial scales. Whenever a new satellite image is automatically downloaded, the NDVI (daily and 16-day composite) and NDVI Anomaly maps are generated and these maps are updated in the Web Server. The latest NDVI image map thus generated can be viewed through web browser (Shery et al., 2012). Search option based on date is also available. Figure 21 shows the web page of NDVI Anomaly map generated from satellite data. From the NDVI Anomaly map it is possible to identify the severity of drought. Based on NDVI anomaly, drought severity is classified and displayed as shown in the figure. Each colour in the map indicates different drought intensity levels. This near real time NDVI Anomaly map (drought classification map) that is automatically displayed on the web page can be used by common people to understand severity of drought. Zoom functionality of this map will help to identify the severity of drought in the panchayath (lowest administrative unit) level. In addition, a pan tool is also provided to adjust the view by moving either horizontally or vertically. Currently, the overlaying of land use maps on NDVI anomaly maps is done.

The web-page is also provided with various menus such as Drought, Monitoring tools and Downloads (Figure 22). Drought menu gives general information on drought, its classification, the drought scenario in the country and for the state. Monitoring tools provide information on various indices that are used in drought monitoring. Downloads menu gives the option for viewing the drought risk maps generated and for downloading them. NDVI maps and SPI maps are available for downloads in the dropdown list. Currently, drought classification and risk mapping is done based on NDVI anomaly only. The NDVI menu gives the option for viewing daily NDVI, 16-day composite NDVI (MOD13Q1), NDVI Anomaly maps derived from NDVI and drought affected area in percentage is also shown.

To understand the crop specific drought risk in the area, the NDVI anomaly map generated was overlaid with land use/land cover map. Overlaying of Normalized Vegetation Supply Water Index maps, developed from NDVI and Land Surface temperature, with land cover map to study the duration of drought was done by Abbas *et al.* (2014). Agriculture, Built-up (Cities/Town/Villages), Forest, Wasteland and Water bodies are the land use types identified in Northern Kerala. Coconut, Rubber, Arecanut, Coffee, Cashew, Tea, Teak, Banana, Pepper, Tapioca, Eucalyptus etc are the crops identified in the Agriculture type, dominant land use type in Northern Kerala.

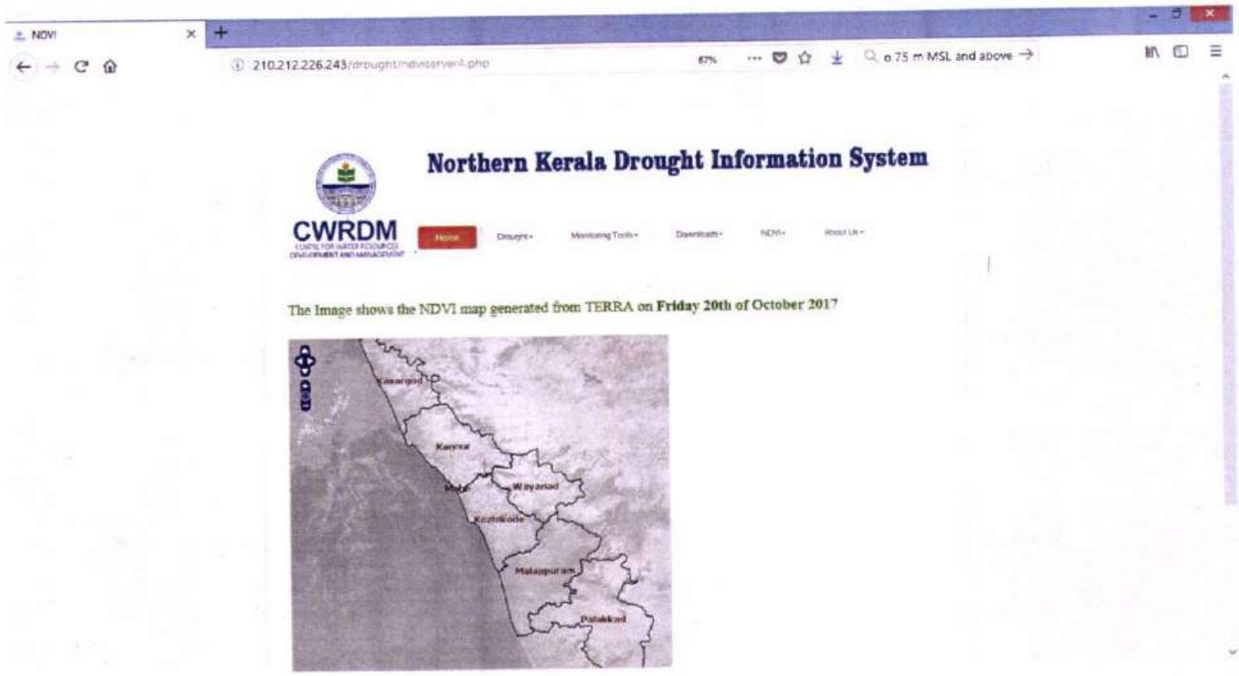


Figure 21. Screenshot of the recent NDVI map (MOD13Q1) displayed on the Web page.

Figure 22: Screenshot of the recent NDVI Anomaly map displayed on the Web page.

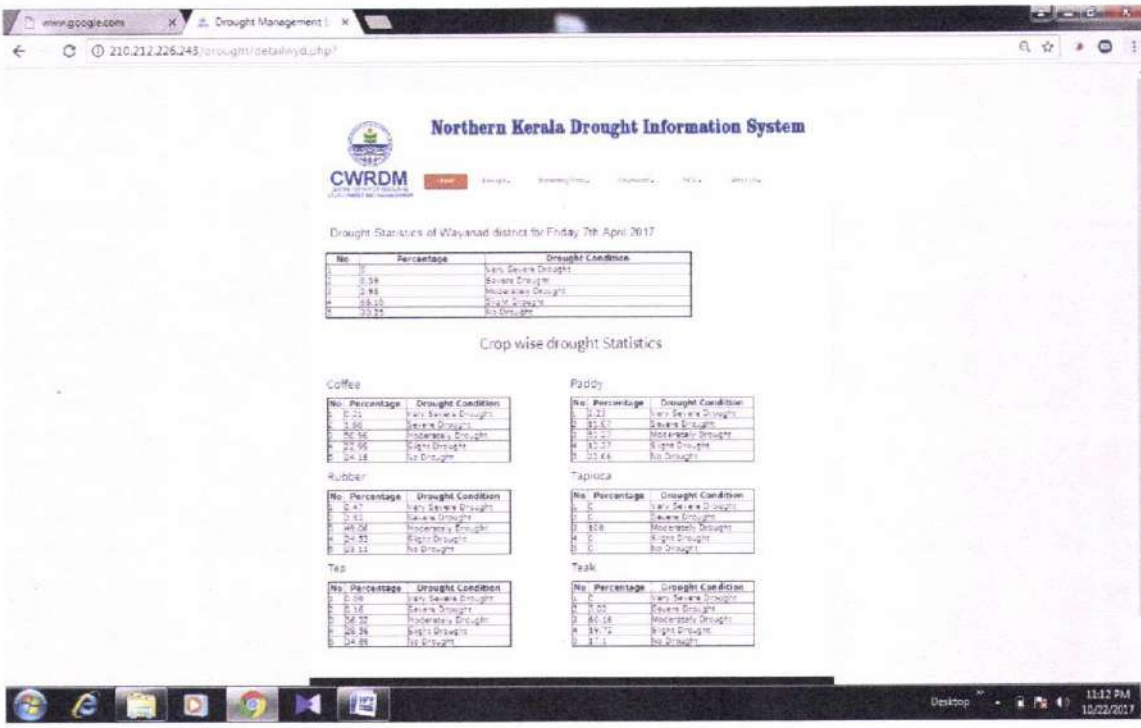


Figure 23: Screenshot of the recent drought information displayed on the Web page.

5.11. DISSEMINATION OF RESULTS THROUGH CWRDM WEB

The application is available at **http://210.212.226.243/** for everyone without any prior installation of add-on software's for supporting the browser. The open source tools such as Python, PHP, GDAL, NumPy, Open Layers and Map Server are used for the development of Drought information table and drought maps which are published to understand the intensity of drought through web page. By using this web application, policy makers can easily monitor and identify the drought prone areas, and take necessary measures by providing local level support so that the local bodies will be better-equipped to help especially the rural farmers and the agricultural sector at grass-root level.

Table 9: Technical characteristics of the Northern Kerala Drought Information System

Name of software/ data set	Northern Kerala Drought Information System
Developer Contact address, telephone, fax and email numbers	Centre for Water Resources Development and Management, Kunnamangalam, Kozhikode-673 571 Kerala, India Phone: (91) 495 2351800

	Fax: (91) 495 2351808, gg@cwrdm.org
Year first available	2013
Hardware required - software required	A web-browser by using normal PC, laptop, tablet of smartphone (network connection required)
Availability	http://210.212.226.243/
Program language	PHP, Python
Program size	13MB
Form of repository (database, files, spreadsheet)	files
Size of archive	750MB/month
Access form	Through web browser

Figure 24: Screen short of Northern Kerala Drought Information system home page

6. SUMMARY AND CONCLUSION

The main objective of the study was to develop a space enabled drought management support system for the five drought prone districts of Northern Kerala using satellite data, meteorological and other ancillary data.

Though many studies have dealt with establishing relation between rainfall/NDVI, showing that NDVI is a good indicator of vegetation vigour, yet efforts towards a union of different factors to define risk areas was still to be attempted for better describing an area at risk.

The first chapter gives an overview of the problem under study, the different definitions, concept describing drought types and impacts and need for risk evaluation and the objectives of the study.

The second chapter deals with the previous drought related studies, different methods used to study, monitor and assess drought. It was seen that most of the studies has studied about relating either of the satellite derived parameters as NDVI, VCI, TCI with each other and other meteorological parameters to assess drought conditions but inclusion of agricultural drought from the point of agricultural production and its linkage with the satellite parameters could not be found in the literature referred.

The third chapter gives a brief description of the study area. The fourth chapter discusses about the methodology followed to achieve the framed research questions and objectives. Correlation regression relation has been worked out between different factors such as: NDVI anomaly and SPI.

The fifth chapter deals with the results obtained after the entire processing of the data and preparation of final risk map. In accordance with the station wise annual rainfall data of 15 stations over the year 1900 to 2016, mean annual rainfall of each station is calculated and its trend is calculated. For the whole 106 years the annual rainfall showed a declining trend.

NDVI Anomaly is calculated using MODIS NDVI Images. From this anomaly map it is concluded that 2000, 2013 and 2016 severe drought was found. In year 2016, for Kasaragod district Cheruvathur, Neeleswaram, Thikkarippur, Padanna were some of the drought affected panchayaths. In Kannur district, Thrikkarippur, Cherupuzha, Alacode are drought faffected panchayaths. In Kozhikode Atholi, Kakkur, Kavilumpara, Perumanna panchayaths were drought affected. SulthanBathery, Muttil, Noolpuzha, Neenmeni are some of the drought affected panchayaths of Wayanad district. For malappuram district Kuzhimanna, Kondotty, Areekode, Pulppatta are drought affected panchayaths.

The land use/ land cover map of Northern Kerala (2010) is classified using IRS-P6 LISS III data. Land use/land cover map reveals that coconut, rubber, arecanut, coffee, cashew, tea, teak, banana, pepper, tapioca and eucalyptus are some of the crops identified in this region.

Among the districts of Northern Kerala Wayanad is highly drought affected and this district is one of the biggest foreign exchange earners of the State, with its production of cash crops like pepper, cardamom, coffee, tea, spices and other condiments. Though our study is more focussed on Wayanad district.

It is identified that 28.11% of Coffee was under drought in February 2016. Among these 11.96% is moderate and 16.1% is slight drought. But when 2017 is concerned 48.07% of the Coffee is drought affected and among this 25.41% is moderate and 22.4% is slight drought. 19.96% increase in drought is found in February 2017 compared to February 2016.

An application is developed and available at **http://210.212.226.243/** for everyone without any prior installation of add-on software's for supporting the browser. This web tool allows users to view drought severity at various spatial scales. Whenever a new satellite image is automatically downloaded, the NDVI (daily and 16day composite) and NDVI Anomaly maps are generated and update these maps in the Web Server. The latest NDVI image map thus generated can be viewed through web browser. Search option based on date is also available. Drought information table calculated from NDVI Anomaly map is also available through this application. This web-based platform serves as a powerful tool on which decisions could be made based on the extent and severity of drought as well as its impact on various crops. By using this application, policy makers can easily monitor and identify the drought prone areas, and take necessary measures by providing local level support so that the local bodies will be better-equipped to help especially the rural farmers and the agricultural sector at grass-root level. The use of Remote sensing and GIS technology has helped mankind in monitoring near real time drought-risk areas, which further helped to understand its severity and act accordingly to reduce its impactsIt is also possible to make informed decisions on water resources allocations during drought conditions based on this tool.

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Appendix

Publication of papers in Journals

1. Girish Gopinath, Ambily G K, Shery Joseph Gregory and Anusha C K (2015) Drought Risk Mapping of South-Western State in the Indian Peninsula - A Web based Application, Journal of Environmental Management, Vol.161, pp 453-459, Elsevier DOI: 10.1016/j.jenvman.2014.12.040
2. Girish Gopinath (2015), Free data and Open Source Concept for Near Real Time Monitoring of Vegetation Health of Northern Kerala, India, International Conference on Water Resources, Coastal and Ocean Engineering (ICWRCOE 2015), pp 1461-1468. DOI: 10.1016/j.aqpro.2015.02.189

International and National Proceedings/conferences/Seminars

1. Shery Joseph Gregory, Anusha C K and Girish Gopinath (2012) Geospatial Technology for Drought Monitoring in Panchayaths with Special Reference to Kasaragod District, Kerala Environment Congress, 16-18th August 2012 at Thiruvanthapuram, pp461-464
2. Shery Joseph Gregory, Anusha C K and Girish Gopinath (2013) Near real time monitoring of vegetation health of Malabar districts in Kerala state through efficient use of free data and open source concept 25th Kerala Science Congress - 29th Janury to 1st February 2013 at Trivandrum, pp 368-370, ISBN 81-86366-83-0
3. Anusha C K, Shery Joseph Gregory, Girish Gopinath and Roopa Ramakrishna (2013). Application of Geospatial Technology for Drought Monitoring in Northern Malabar District, Kerala, India', Proceedings of International Meet on Impact of Climate Change on Water Resources Development and Management, Karunya University, on 17th to 18th August 2012, pp 97-101.
4. Anusha C.K. and Girish Gopinath (2014) Assessment and Near Real Time Monitoring of Water Stress Condition of Vegetation using Geospatial Technology in Northern Region of Kerala State, 26th Kerala Science Congress - 28th to 31st January 2014 at Kerala Veterinary & Animal Sciences University, Pookode, pp 1716-1723

5. Anusha C K and Girish Gopinath (2014). Monitoring of Water Stress using MODIS derived Normallized Difference Vegetation Index, Proceedings of International Symposium on Integrated Water Resources Management (IWRM-2014), February 19-21,2014, Vol.2, pp 1272-1279. ISBN:978-81-8424-907-1

6. Anusha C K, Renjith K and Girish Gopinath (2017) Drought Monitoring of Wayanad district using Geospatial Techniques with special reference to Coffee, National Seminar on "Natural Resources Management for Horticultural Crops under Changing Climatic Conditions- (NRMHCCC-2007) - (with special reference to Drought Management of Plantation Crops and Spices) at CWRDM, Kozhikode on March 16-17, 2017, p 87-88.

7. Girish Gopinath (2017), Geospatial technology for monitoring of vegetation health using FOSS and free data, Proceedings of the 3rd Disaster, Risk and Vulnerability Conference (DRVC2017) 29–31 March 2017, Dept of Geology, University of Kerala, India, p143, ISBN:9788192344980.

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Drought risk mapping of south-western state in the Indian peninsula – A web based application

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ABSTRACT

Application of geospatial technology is very shimmering in drought monitoring. Drought severity in crops for six northern districts of Kerala has been attempted using Geospatial Techniques. Normalized Difference Vegetation Index (NDVI) is the major parameter used to measure vegetation health obtained from MODIS, Terra satellite products MOD13Q1, MOD02QKM. The mean Normalized Difference Vegetation Index (NDVI) of Kerala state over 13 years was calculated. The daily anomalies of NDVI from its long term mean NDVI over the same period was determined based on which drought risk classification was done. High negative NDVI anomaly areas are susceptible to drought and the severity of drought risk on each crop can be identified using Land Use/Land Cover data. Overlaying daily NDVI Anomaly based drought risk map on land use/land cover map gives the drought risk for different crops. Based on this, a web application has been developed for Northern districts of Kerala state in India. This web application can be used to plan for drought management measures and can also serve as a database for drought analysis.

1. Introduction

Drought is considered by many to be the most complex but least understood of all natural hazards, affecting more people than any other hazard (Hagman, 1984; Wilhite, 2000). Drought is defined as a prolonged abnormally dry period when there is not enough water for user's normal needs, resulting in extensive damage to crops and a loss of yields (Wilhite, 2005). It should be considered relative to some long term average condition rather than absolute condition (Wilhite and Svoboda, 2000). An extreme climatic condition like drought poses severe damage to crops, livestock and humans and the associated economic repercussions are huge (Al-Riffai and Breisinger, 2012; Gupta et al., 2014; Lin et al., 2013). Unlike other natural disasters, drought impacts large areas and for extended periods of time. Hence it is important to monitor the duration, frequency and spatial extent of drought using relevant indices to provide planners with useful information required to plan for disaster response measures (WMO, 2006). Since drought as a condition of precipitation deficit start as a reduction in soil moisture, agriculture is the sector that is affected first (WMO, 2006). 68% of the net sown area in India is vulnerable to drought conditions. A decrease in 17.9% of food grain production during the drought of 1987, has led to a 3.2% decline in agricultural GDP of the country (Murthy and Sesha Sai, 2010).

India Meteorological Department (IMD) defines meteorological drought as a situation when the seasonal rainfall over the area is less than 75% of its long term average. Rainfall deficits between 26% and 50% is classified as moderate drought, and that more than 50% is classified as severe drought (India Meteorological Department, n.d). On an average, 28% of the geographical area in India is considered to be vulnerable to drought (Samra, 2004). The country has witnessed worst droughts in the years 1918, 1972, 1987, 2002 and 2009 (Indian Agricultural Statistics Research Institute, 2014). There has been an increase in the area affected by moderate droughts in the country, since 1951 (Kumar et al., 2013). Even with an average annual rainfall of about 3000 mm, the state of Kerala is affected by occasional localized drought events. The state has experienced drought conditions in the years 1982–83, 1983–84, 1986–87, 1987–88, 2000–01and 2008–09 (Dinesan, 2013). A total of 693 villages in the state were affected by drought in the last ten years (Government of Kerala (2012)).

Drought monitoring and its assessment are carried out using various indices; Standardized Precipitation Index (SPI), Palmer Drought Severity Index (PDSI), Surface Water Supply Index (SWSI)

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and Bhame and Mooley Drought Index (BMDI) are the ones extensively used. BMDI is drought index used in drought intensity assessment of Northern Nigeria (Francis and Kayode, 2013) and the indices SPI and PDSI is used in U.S Drought Monitoring System. Remote sensing is far superior to conventional methods (Jain et al., 2009) for drought monitoring and early warning applications. Remote sensing data, or data from satellite sensors, can provide continuous datasets that can be used to detect the onset of drought as well as its duration and magnitude (Chopra, 2006; Mu et al., 2013; Thiruvengadachari and Gopalkrishna, 1993). Normalized Difference Vegetation Index (NDVI), Vegetation Condition Index (VCI), and Temperature Condition Index (TCI) are some of the extensively used vegetation based drought indices. Among this, Normalized Difference Vegetation Index (NDVI) is the most popular satellite based vegetation index used to measure vegetation health. . Web-based drought monitoring system has been developed by many international agencies. The Global Drought Monitoring Portal (GDMP), created in April 2011 serves as a global drought information system, through which users can access interactive maps on both global and regional drought conditions (http://www.drought.gov/gdm). International Water Management Institute (IWMI) has developed a regional drought monitoring system for South West Asia, which provides information on drought onset, progression and areal extent for Afghanistan, Pakistan and Western India (http://dms.iwmi.org/). A near real time global drought monitoring based on Standardized Precipitation Evapotranspiration (SPEI) index, the SPEI Global Drought Monitor, provides drought information at 0.5^0 spatial resolution and monthly time resolution. The present study was done with an objective to develop a regional drought monitoring system for Northern Kerala. This paper explains how the drought monitoring system was developed, utilizing open source components based on the NDVI anomaly, for the near real time drought monitoring of Northern Kerala in India.

2. Material and methods

2.1. Study area

Northern Kerala encompassing the districts of Kasaragod, Kannur, Kozhikode, Malappuram, and Wayanad located between 10° 20′ and 12° 47′ North latitudes and 74° 51′ and 76° 54′ East longitudes were selected for the study (Fig. 1). Palakkad, one of the driest districts of Kerala, was also included in the study. The entire region covers an area of 17,465 km^2. Northern Kerala receives an average annual rainfall of 3379 mm (Kandiannan et al., 2008). Long-term (1871–2005) trend analysis has shown a decreasing trend (−1.7 mm/year) in Southwest monsoon and an increasing trend (+0.7 mm/year) in post monsoon rainfall over the entire state (Krishnakumar et al., 2009). Analysis of one and half century of data from 1870 to 2006 has revealed that for 21.2% of years, the onset of monsoon in Kerala was between 4th and 8th of June (Prasada Rao, 2008).

The topographical conditions marked by steep slope facilitate the fast runoff of rainwater to the Arabian Sea. Other than the natural peculiarities, anthropogenic activities like decreasing forest area/land cover due to urbanization have also contributed to this rapid runoff. Relative humidity is in general high over the state. During monsoon, the relative humidity rises to about 85%for the state. The annual range of temperature is comparatively low in Kerala. The coastal areas record a maximum temperature of 32 °C and minimum of 22 °C. The midland area records a maximum of 37 °C during summer. In the coastal area it is hot and humid during April–May while cool during December–January (Dinesan, 2013). Climate in Kerala can be divided in to four season winter, Summer, South – West monsoon, North – East monsoon.

2.2. Materials and methodology

The study area was delineated from georeferenced toposheets in Quantum GIS. Details of toposheets used are given in Table 1. The satellite data used in this study are the freely downloadable MODIS Terra Satellite products MOD13Q1 and MOD02QKM. MODIS images are used since it provides continuous daily coverage and has been widely used in drought studies. Use of MODIS images facilitate near real time monitoring of drought. Images from other sensors are not used as there might be conflicts with the pixel resolution. The monitoring period of drought for the present investigation from the year 2000–2012. In Kerala, the summer season corresponds to the months of March–May, and is severe in the month of May. Hence images for May are used for this study. The open source tools, Map Server and Open Layers are used to publish the spatial maps in the web. IRS-P6 data was collected for Land Use/Land Cover classification.

Drought monitoring using remote sensing is based on three approaches: determining drought based on a relationship between drought and soil moisture, which is obtained from remote sensing observations; vegetation index calculated from satellite images and related to drought condition; using Land Surface Temperature derived from satellite images to detect drought (Cai et al., 2011). The 16 day composite 250 m resolution Terra MODIS data [MOD13Q1] from the year 2000–2012 were downloaded and re-projected using NASA's free MRT swath Reprojection tool. The NDVI of the study area were extracted from the re-projected data. Composite value of latest 16 day MOD02QKM product is used to remove cloud from daily image. From the difference of this latest 16 day composite NDVI and the long term NDVI mean for the same period NDVI anomaly is calculated. The mean NDVI of the area over the years 2000–2012 for each 16-day period was calculated and used as reference.

NDVI is associated with various biophysical properties of crops such as its biomass, canopy cover, leaf area index etc. and hence can represent agricultural drought effectively. Tucker first suggested NDVI in 1979 as an index of vegetation health and density (Thenkabail et al., 2004). The vegetation absorbs a great part of incoming radiation in the visible portion of the electro-magnetic spectrum (VIS: 380–730 nm) and reaches maximum reflectance in the near-infrared channel (NIR: 730–1100 nm) (Propastin et al., 2008). The NDVI, defined as ratio (NIR-VIS)/(NIR + VIS), represents the absorption of photosynthetic active radiation and hence is a measurement of photosynthetic capacity of the canopy. Negative NDVI values indicate non-vegetated areas such as snow, ice and water. Positive NDVI values indicate green vegetated surfaces, and higher values indicate increase in green vegetation. NDVI itself does not reflect drought or non drought conditions (Owrangi et al., 2011). But Anomaly of NDVI from the mean values was classified to determine the agricultural drought risk (Hasan Murad and Saiful

Table 1
Toposheets used for delineating the study area.

SL. no	Districts	Toposheet No:
1	KASARAGOD	48 L/14,48 P/2,48 P/6,48 L/15,48 P/3,48 P/7,48 P/4, 48 P/8
2	KANNUR	48 P/4,48 P/7,48 P/11,48 P/8,48 P/12,48 P/16,49 M/5,49 M/ 9, 49 M/13,48 M/10
3	KOZHIKODE	48 M/10,49 M/9,49 M/13,49 M/14,49 M/11,49 M/15,58 A/2, 58 A/3,49 M/16
4	WAYANAD	49 M/13,58 A/1,58 A/5,49 M/14,58 A/2,58 A/6, 58 A/3
5	MALAPPURAM	58 A/2,49 M/15,58 A/3,58 A/7,58 A/11,49 M/16,58 A/ 4,58 B/8, 49 N/13,58 B/1,58 B/5,49 N/14,58 B/2
6	PALAKKAD	58 B/8,58 A/12,58 A/16,58 B/1,58 B/5,58 B/9,58 B/13,58 B/2, 58 B/6,58 B/10,58 B/14,58 B/7,58 B/11,58 B/15

Islam, 2011; Muhaimeed and Al-HednySuhad, 2013; Song et al., 2004). The NDVI Anomaly is calculated as the difference between the NDVI of the same time period and the long term mean NDVI of the same period for each pixel. The negative anomaly indicates the below normal vegetation condition which would indicate a drought situation.

The equations used for calculation of mean NDVI and NDVI anomaly are as follows

$$\text{Mean NDVI} = (\text{NDVI}_i + \text{NDVI}_{i+1} + \text{NDVI}_{i+2} + \text{NDVI}_{i+3} \ldots\ldots + \text{NDVI}_{i+n-1})/n$$

where, NDVI_i is the NDVI of the same16-day period in year 'i'.

The daily NDVI anomaly is calculated using the equation

$$\text{Daily NDVI Anomaly} = \text{Daily NDVI} - (\text{Long term average NDVI over the same period})$$

The daily NDVI and Anomaly maps generated is published to the Web using a Web server (Fig. 2). The process repeated every ten minutes daily for processing Satellite data is as follows.

The satellite images may be present in multiple frames or in a single image. If the image of the study area is present in multiple images, the images are merged and the study area is extracted using GDAL packages and Python using the shape file created using Quantum GIS.

Daily/Latest NDVI Anomaly is calculated by using the product MOD02QKM.

$$\text{Anomaly NDVI}_i = (\text{NDVI}_i - \text{mean NDVI})/(\text{mean NDVI})*100$$

where, Anomaly NDVI_i is the NDVI Anomaly in ith day. NDVI_i is the ith NDVI and mean NDVI is the average of NDVI during the period of study.

The threshold values used to classify drought risk using NDVI anomalies, based on Murad and Islam (2011) is given in Table 2.

The derived maps were cross-checked for drought conditions in the seven districts covering the study area, using meteorological data from India Meteorological Department, from 01st March to 31st May 2013.

IRS-P6 data was collected for Land Use/Land Cover classification. IRS images were classified using supervised classification tool of ERDAS software. Field Trips were conducted for ground truthing and correction. The Kappa coefficient accuracy assessment (Hudson and Ram, 1987; Nishi and Tanaka, 1999) was adopted in the study and approximately 100 training sites were selected for each district for which the study was done.

3. Results and discussion

The web tool allows users to view drought severity at various spatial scales. Whenever a new satellite image is downloaded, the NDVI and NDVI Anomaly maps are generated by the algorithm mentioned in the above section. The application automatically updates the recent NDVI and NDVI Anomaly maps in the Web Server. The latest NDVI image map thus generated can be viewed through web browser (Shery et al., 2012). Fig. 3 shows the web page of NDVI Anomaly map generated from satellite data. From the NDVI Anomaly map it is possible to identify the severity of drought. Based on NDVI anomaly, drought severity is classified and displayed as shown in the figure. Each color in the map indicates different drought intensity levels. This near real time NDVI Anomaly map (drought classification map) that is automatically displayed on the web page can be used by common people to understand severity of drought. Zoom functionality in of this map will help identify the severity of drought in the *panchayat* (lowest administrative unit) level. In addition a pan tool is also provided to adjust the view by moving either horizontally or vertically.

Table 2
Drought Risk Classification using NDVI anomalies (Murad and Islam, 2011).

Percent of NDVI anomalies	Class
0% to −10%	Slight drought
−10% to −20%	Moderately drought
−20% to −30%	Severe drought
Above −30%	Very severe drought

Pre-monsoon rainfall that has occurred in the study area from 01st March 2013 to 31st March 2013 is given in Table 3. It can be seen that except for Wayanad, the rainfall was deficient during the season for all the districts. North-east monsoon rainfall received in the study area during 2012–13 (Table 4) also shows a deficit condition. As per the definition of IMD, the districts of Malappuram and Palakkad has experienced severe drought, whereas moderate drought conditions existed in Kannur, Kasaragod and Kozhikode districts. Accordingly, drought was declared in all 14 districts of Kerala during May, 2013 (www.ndtv.com, 02 May 2013).

The web-page is also provided with various menus such as Drought, Monitoring tools and Downloads (Fig. 3). Drought menu gives general information on drought, its classification, the drought scenario in the country and for the state. Monitoring tools provide information on various indices that are used in drought monitoring. Downloads menu gives the option for viewing the drought risk maps generated and for downloading them. NDVI maps and SPI maps are available for downloads in the dropdown list. Currently, drought classification and risk mapping is done based on NDVI anomaly only. This will further be refined by incorporating SPI maps also. The correlation between NDVI anomaly and SPI will be calculated and drought risk classification will be done based on the correlation coefficient (r^2). This step is under progress.

To understand the crop specific drought risk in the area, the NDVI anomaly map generated was overlaid with land use/land cover map. Overlaying of Normalized Vegetation Supply Water Index maps, developed from NDVI and Land Surface temperature, with land cover map to study the duration of drought was done by Abbas et al. (2014). Fig. 4a to f shows the Land Use/Land Cover map of six Northern Kerala districts classified using IRS-P6 data. Agriculture, Built-up (Cities/Town/Villages), Forest, Wasteland and Water bodies are the land use types identified in Northern Kerala. Coconut, Rubber, Arecanut, Coffee, Cashew, Tea, Teak, Banana, Pepper, Tapioca, Eucalyptus etc are the crops identified in the Agriculture type, dominant land use type in Northern Kerala. Table 5 shows the crops identified and its district wise area in percentage.

The progress of rains is of special significance for each crop during particular times in the year. For e.g., February rains are of high significance for plantation crops in Kerala (Government of India (2012)). Land-use based analysis has shown that mixed crops in western parts and rubber grown in north-western parts of Kannur are under severe risk of drought. Similarly in Kozhikode district, coconut grown in midland region shows severe drought risk. Rubber and cashew grown in South-east part of Kasaragod district have only slight risk due to drought. Percentage of area under each land-use type susceptible to drought is given in Table 6. More area under forest plantation and bamboo in Palakkad as well as mixed vegetation in Kozhikode districts are comparatively at a higher risk of drought. Teak, one of the major trees in forest plantations, when exposed to drought stress shows a significant reduction in chlorophyll content, seedling height, collar diameter, number of leaves, total dry weight and relative growth rate (Sneha

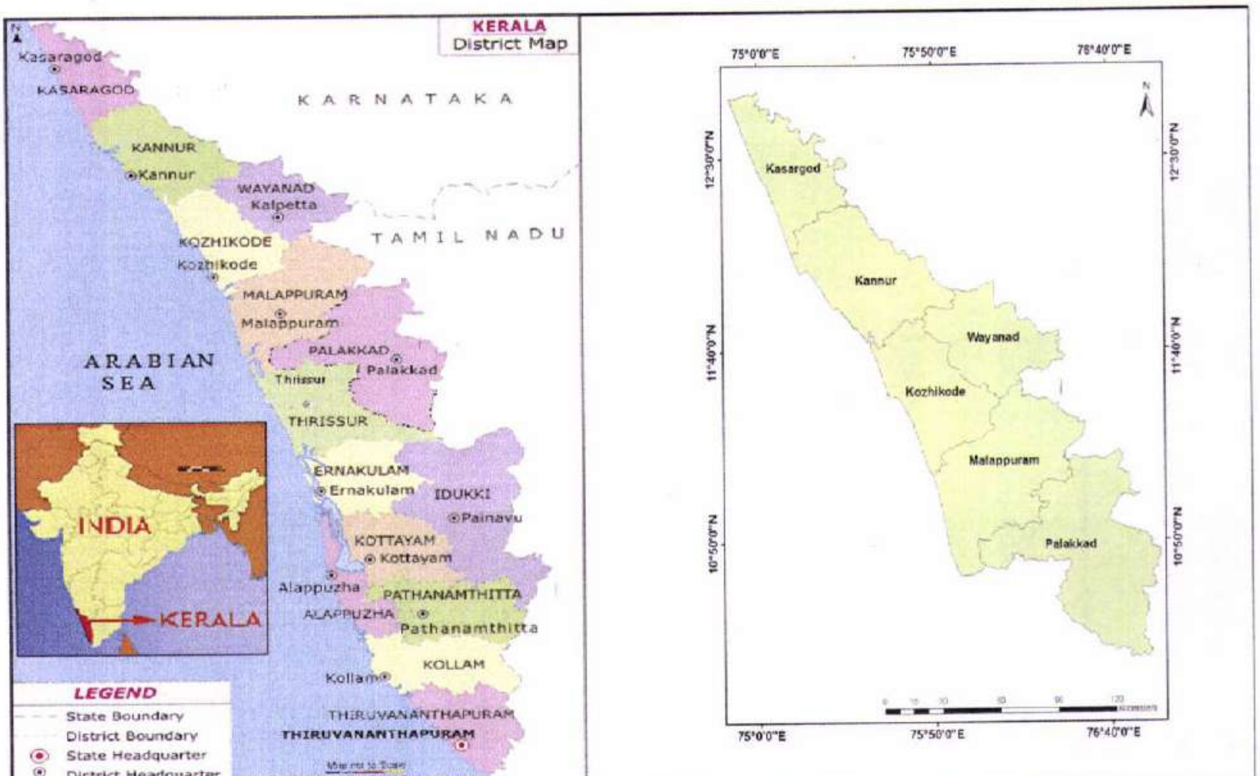

Fig. 1. Figure showing district boundaries of Kerala and study area.

et al., 2012). Drought risk of coconut dominant mixed crop is found to be relatively small.

Currently, the overlaying of land use maps on NDVI anomaly maps is done. However, as a better indicator of agricultural drought, we plan to develop crop soil moisture index maps and classify short term droughts based on them. This would give an accurate measure of drought stress of individual crops grown in the region.

Web monitoring of drought conditions certainly has an edge over traditional methods as it enables local people even to identify and mitigate isolated drought events. Low NDVI does not always correspond to drought condition in much vegetation. The physiology of the crop comes into play in these circumstances. Hence drought verses Crop/Land use is significant in understanding drought induced crop losses.

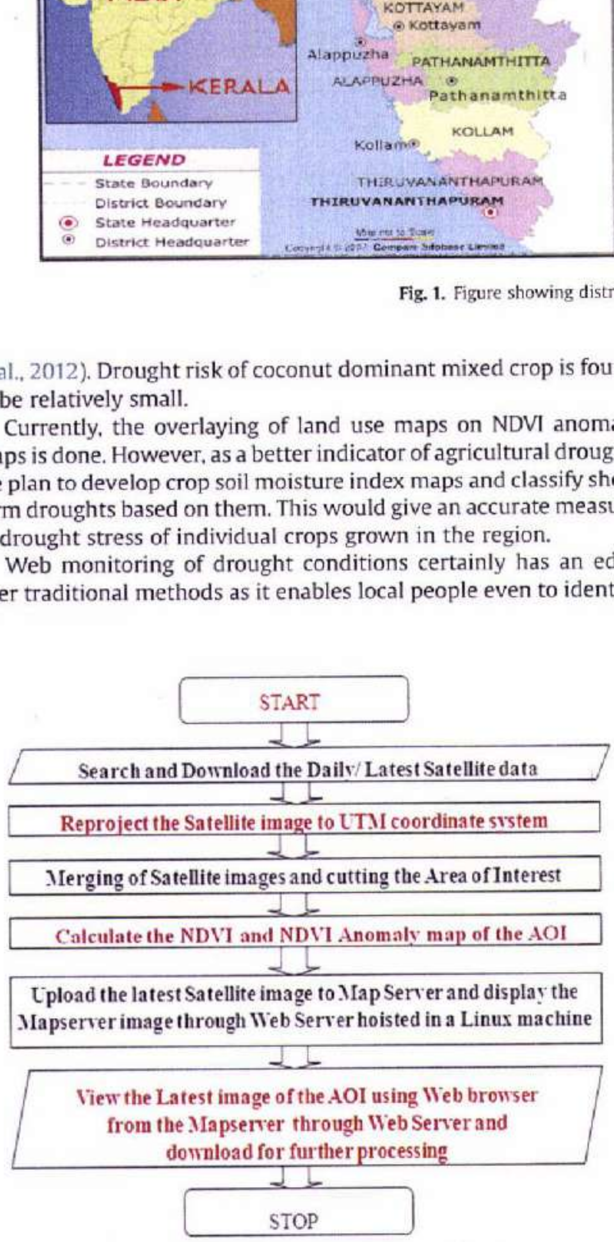

Fig. 2. Flow chart showing sequence of steps followed for Satellite data processing.

4. Conclusion

Geospatial technology is used for near real time drought monitoring of Northern Kerala using the web application. Open source GIS tools and free satellite data services from Terra Satellite were utilized in this study. Daily NDVI Anomaly based drought risk of Northern Kerala can be viewed by this web application. This web-based tool serves as an information source for decision makers and public to plan for drought response activities as well as for its mitigation. Maximum negative NDVI Anomaly areas are affected by severe drought. Since NDVI Anomaly values affect the land use, Overlaying Land Use/Land Cover map on NDVI Anomaly map helps to identify the severity of drought risk on each crop. The finer spatial resolution and drought condition upto panchayat level provided through this web interface is helpful in devising drought response strategies locally.

Acknowledgements

Author is very thankful to the Executive Director, Centre for Water Resources Development and Management (CWRDM), Kozhikode, Kerala, India for providing the facilities to develop this application. We are grateful towards Ministry of Water Resource (MoWR), Govt. of India, for providing the financial assistance for this study (Project No.23/INCOH-65/2010-R&D/3040-3050).

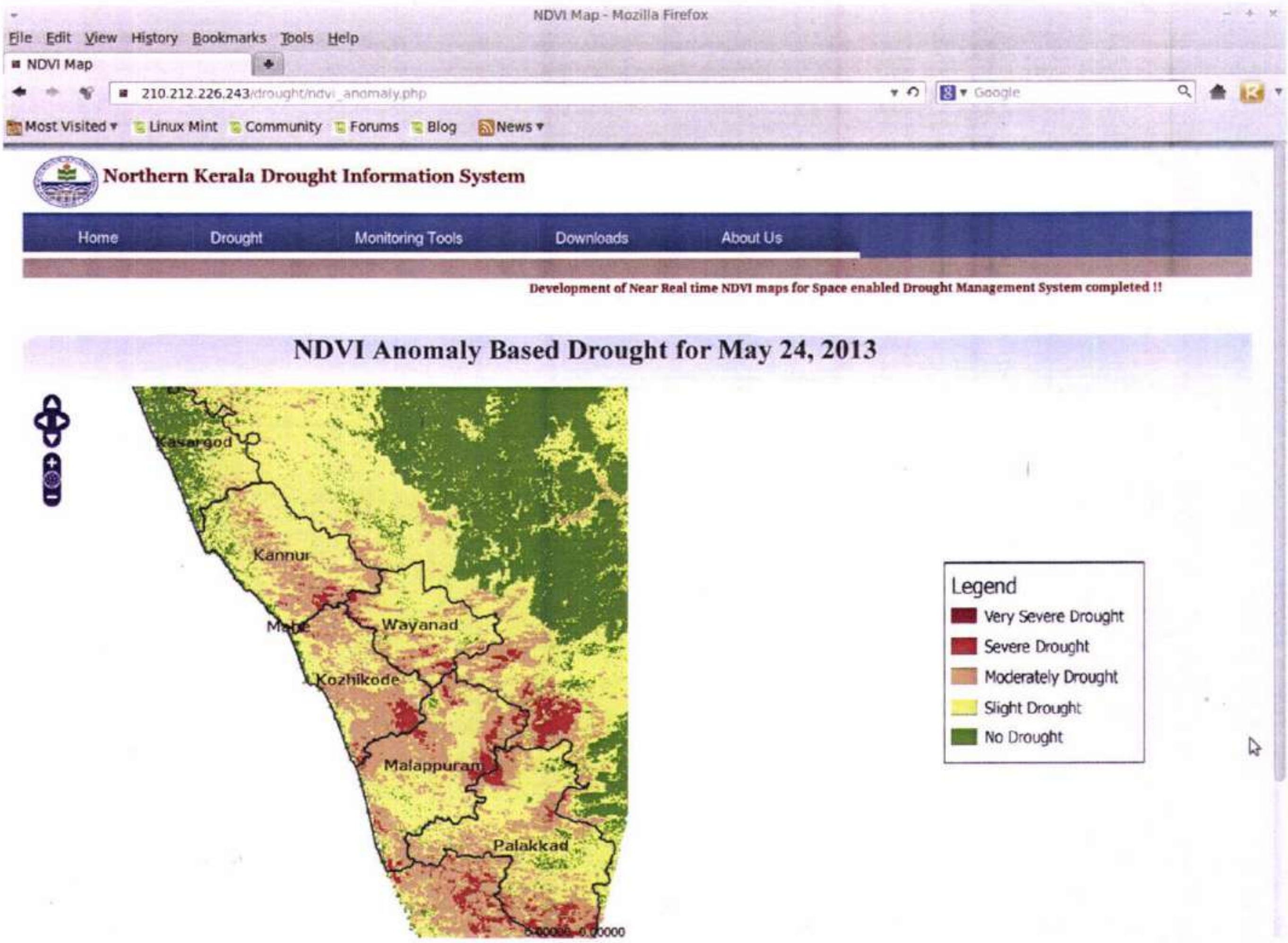

Fig. 3. Screenshot of the recent NDVI Anomaly map displayed on the Web page.

Table 3
Pre-monsoon rainfall in the study area, from 01st March 2013 to 31st May 2013.

Sub Division/ Districts	Actual rainfall (mm)	Normal rainfall (mm)	Percentage departure (%)
Kerala	218.9	379.7	−42 Deficient
Kannur	164.6	300.4	−45 Deficient
Kasaragod	180.5	272.5	−34 Deficient
Kozhikode	254.5	352.9	−28 Deficient
Malappuram	141.5	320.6	−56 Deficient
Palakkad	124.1	279.5	−56 Deficient
Wayanad	238.5	275.1	−13 Normal

Source: Indian Meteorological Department.

Table 4
Deficit in North-east monsoon rainfall in study area during 2012–13.

Sub Division/Districts	Percentage deficit
Kannur	28
Kasaragod	48
Kozhikode	27
Malappuram	52
Palakkad	39
Wayanad	22

Source: Dinesan (2013).

Table 5
Major crops identified in Landuse/Landcover map and its area in percentage.

Major crops	Kasaragod	Kannur	Kozhikode	Wayanad	Malappuram	Palakkad
Cashew	12%	3.6%	0.1%	–	0.06%	0.3%
Coconut	4.1%	2.76%	53.51%	–	30.95%	15.91%
Coffee	–	1.13%	–	35.22%	–	0.26%
Double Crop	3.77%	6.14%	4.71%	3.79%	1.37%	13.84%
Mixed crop	39.01%	39.17%	7.71%	0.29%	9.58%	15.84%
Rubber	9.63%	11.44%	2.02%	0.65%	11.80%	8.62%

Table 6
Percentage of area under each landuse type susceptible to drought.

District name	LULC type	Percentage area at risk
Kannur	Forest Decedious(Dense)	16.85
Wayanad	Double Crop(Kharif + Rabi)	11.13
	Dense deciduous forest and evergreen forest	3.02
Kozhikode	Coconut Dominant Mixed Crop	7.3
	Mixed vegetation	36.95
Malappuram	Coconut Dominant Mixed Crop	2.72
	Rubber and arecanut	29.11
Palghat	Dense Mixed Forest	13.82
	Forest Plantation and Bamboo	38.65

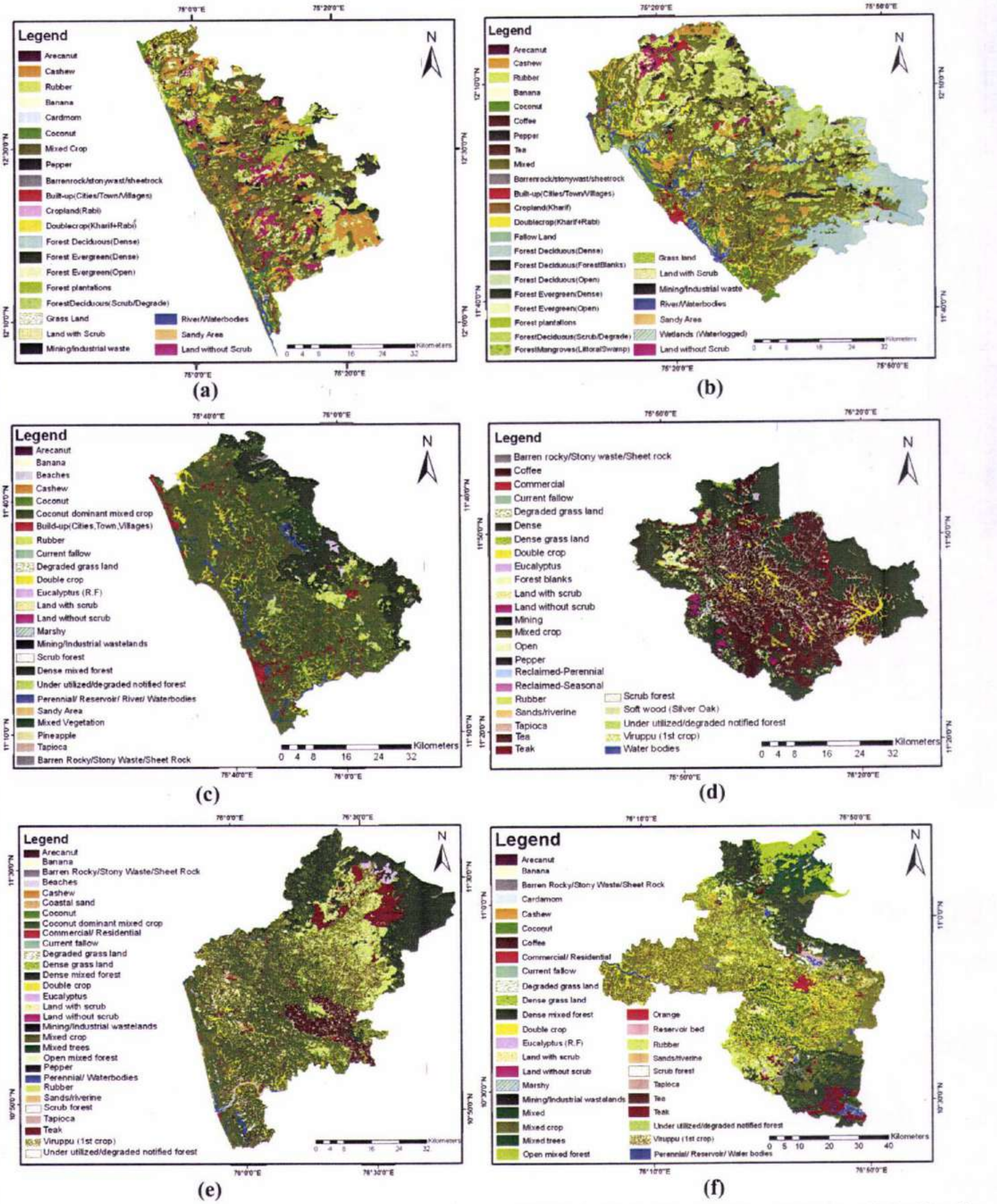

Fig. 4. Land Use/Land Cover Map of Northern Kerala. a. Land Use/Land Cover Map of Kasaragod District. b. Land Use/Land Cover Map of Kannur District. c. Land Use/Land Cover Map of Kozhikode district. d. Land Use/Land Cover Map of Wayand district. e. Land Use/Land Cover Map of Malappuram district. f. Land Use/Land Cover Map of Palakkad district.

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Free data and Open Source Concept for Near Real Time Monitoring of Vegetation Health of Northern Kerala, India

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Abstract

The paper focuses on a method of detecting and monitoring vegetation health in near-real time using freely available remote sensed satellite data and open source tools. Unhealthy vegetation condition can be interpreted as a signal to indicate the onset of drought. Recently Northern Kerala has been experiencing an increasing number of drought incidents due to weather anomalies and developmental pressures resulting in economic losses. Early detection of drought and dissemination of this information can help the State machinery to take necessary steps to mitigate drought impacts. The NDVI (Normalized Difference Vegetation Index) image is generated from the AOI (Area of Interest) satellite images obtained in the NIR and Red band. Satellite images captured by Terra satellite were uploaded in the internet ftp server within 24 hours. The uploaded satellite data is searched and automatically downloaded using web services by the software application developed and processed, within 10-30 minutes. The process include generation of NDVI by an algorithm and the application automatically updates the recent NDVI map in the Web Server and is uploaded in the Intranet Web Server using open source software. The latest NDVI image map thus generated can be viewed through web browser in the organization intranet. Thus the Vegetation Health status of a day can be monitored the following day. Since the vegetation health do not change significantly overnight this can be considered as Near Real Time Monitoring with respect to Vegetation health. This map can be downloaded by potential users and analyzed according to the spatial area of interest.

Peer-review under responsibility of organizing committee of ICWRCOE 2015

Keywords: Terra satellite data, NDVI, Near Real Time, Open Source software

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1. Introduction

Drought is a normal, recurring feature of climate; it occurs in virtually all climatic regimes (Wilhite 1992). According to (WMO 2006), drought occurs in both dry and humid regions. It must be considered relative, rather than absolute condition that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalance that adversely affect land resource production systems. Drought is often perceived as a creeping hazard as it develops slowly and has a prolonged duration (Smith 2000). Drought is a regional phenomenon and its characteristics differ from one climate regime to other (Iglesias et al. 2009). In many countries such as Australia, China, India and the United States of America, drought occurs over a portion of the country each year.

The major drought years in India were 1877, 1899, 1918, 1972, 1987 and 2002(Shewale and Kumar 2005). Large parts of the country perennially reel under reoccurring drought. Over 68% of India is vulnerable to drought. The chronically drought prone areas around 33% receive less than 750 mm of rainfall, while 35%, classified as "drought prone" receive rainfall of 750-1125 mm. The drought prone areas of the country are confined to Peninsular and Western India. Major drought prone states are Rajasthan, Gujarat, Orissa, Andhra Pradesh, and Northern Karnataka. In North Kerala, North-East monsoon rainfall shows a decreasing trend and contributes about 15% of the annual rainfall. This may adversely affect the second rice crop in the area. South-West monsoon rain, which contributes 82% of the area's total rainfall, does not show any increase in trend. Similarly, in South Kerala, South-West and North-East monsoon rains have decreased by 5% and 8.3%, respectively. Mean annual rainfall is also decreasing in South Kerala. The decreasing rainfall over the region, late onset of the monsoon, failure of the monsoon and break in the monsoon in the state lead to many drought situations. Kerala had severe dry spells and drought in 1983, 1985, 1986 and 1987, even though the state has wet climate. There were dry spells of 5 and 4 weeks in 1985 and 1986, respectively, during the SW monsoon period. Damage due to drought was particularly significant in Kerala in 1987.

Remote sensing data, or data from satellite sensors, can provide continuous datasets that can be used to detect the onset of a drought as well as its duration and magnitude (Thiruvengadachari and Gopalkrishana, 1993). Previous studies are the evidence for geo - infomatics as an effective tool for drought analysis (Chopra (2006), Park, et al (2004), Partheepan and Dayawansa (2008), Moktari (2005), Hasan Murad and Saiful Islam (2011), Asthma Shaheen and Muhammad Anwar Baig (2011), Aweda and Adeyewa (2011).For this study Normalized Difference Vegetation Index (NDVI), which is the normalized reflectance difference between the near infrared and visible bands (Tucker 1979) is collected from MODIS Terra satellite and is used for measuring vegetation health. NDVI itself does not reflect drought or non drought conditions (Owrangi et al. 2011).

Drought is expensive causing loss to both human and environment. If detected early, impacts due to drought can be mitigated through necessary measures. Drought can be detected by monitoring the Vegetation health status of a region and comparing it with the health of the same region for the same season in previous years. Remote Sensing Technology can be used to study large areas and predict drought by monitoring the temporal and spatial variation in the vegetation health. NDVI is one of the indices used for measuring Vegetation health generated from satellite imagery. Daily monitoring of generated NDVI maps gives an idea of the trend of Vegetation health in the absence of precipitation and possible scenario of drought. NOAA and TERRA satellites provide moderate resolution daily satellite image to generate NDVI maps. In this paper, an application developed for the automatic generation of NDVI maps of the Area of Interest (AOI), daily using free Satellite Data, open source software and dissemination of this information through Web Server is presented.

2. Study area

Northern Kerala comprising of Kasaragod, Kannur, Kozhikode, Malappuram, and Wayanad districts of Kerala State lies along the south western coast of Indian Peninsula. Palakkad has also been included in the study area. This region is geographically situated in between 10° 20' and 12° 47' North latitudes and 74° 51' and 76° 54' East longitudes (Fig.1) and covers an area of 17,465 Km2. The State receives an average annual rainfall of about 3000 mm but is affected by occasional localized drought events. Ground water flow, surface flow owning to high slope of the terrain facilitates the fast runoff of rainwater to the Arabian Sea. Decreasing forest area/land cover owing to urbanization can be attributed to be the main cause for surface runoff. As the state stretches from north to south with the Arabian Sea in its west, relative humidity is in general high over the state. In the period January to March afternoon humidity reduce to 60-63%, during this period is maximum and ranges from 4 – 16%, depending upon the proximity of the sea. The relative humidity in the monsoon period rises to about 85%for the state. The wind is mainly governed by differential heating of land and water mass together with mountain winds. Winds have westerly components during the night through the year. In general winds are quite strong during afternoons when the thermal circulation is best developed and weak during night. The presence of Western Ghats on the eastern side of the state and across the path of the south-west Monsoon creates an important climatic zone with copious rainfall on the windward side and a dry belt on the leeward eastern side. The annual range of temperature is comparatively low in Kerala. The coastal areas record a maximum temperature of 32°C and minimum of 22°C. The midland area records a maximum of 37°C during summer. In the coastal area it is hot and humid during April - May while cool during December - January. Climate in Kerala can be divided in to four season winter, summer, South - West monsoon, North - East monsoon. The Table 1 below shows the details about the seasons in Kerala.

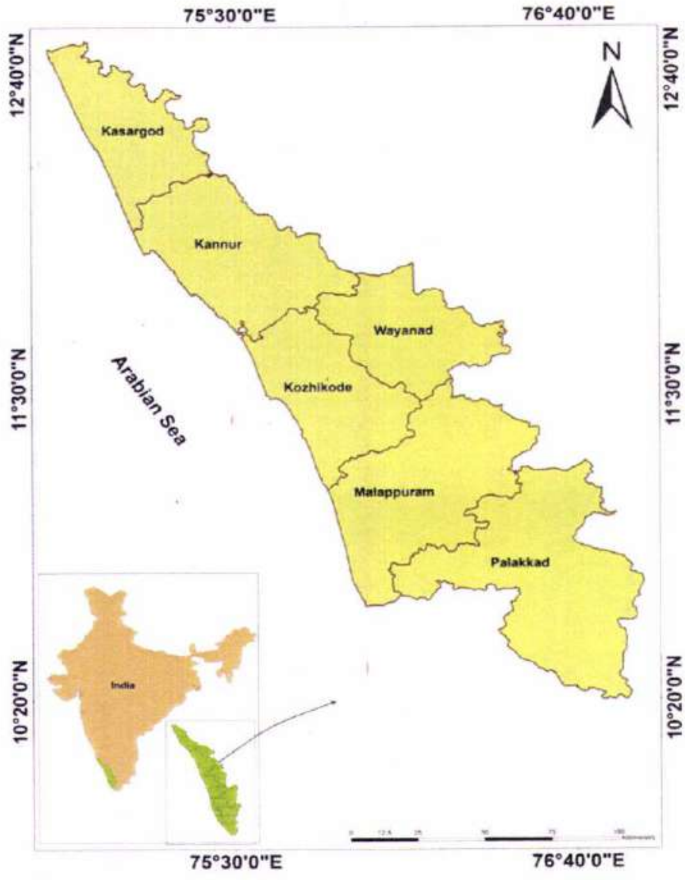

Fig. 1. Study area map with district boundary

3. Materials and methods

The vector shape file enclosing the Area of Interest (AOI) is first created using free Quantum GIS software. This is a onetime process and is used to extract the AOI from the daily satellite images. The primary data used in this study are the daily satellite images from TERRA MODIS sensor which is freely downloadable. The Satellite data is reprojected to UTM coordinate system using NASA's free MRT swath Reprojection tool. NDVI index is an indicator of vegetation health and is based on the principle of band ratioing. Since Healthy Vegetation has high spectral reflectance in the NIR region and low reflectance in the visible region, NDVI maps shows healthy vegetation as bright and less healthy ones as darker shades in a grayscale image. By just looking at the daily NDVI map, areas having healthy vegetation and vegetations areas turning out unhealthy with time can be identified. Drought can be indirectly detected by using the vegetation health of an area as an indicator. If the health of vegetation goes down below a threshold level, it indicates the onset of drought. The NDVI map of the AOI is generated from the NIR and Red bands of MODIS sensor using the equation.

$$NDVI = (NIR - Red) / (NIR + Red)$$

Where NIR refers to the data from Near Infrared Region channel and Red refers to data from Red channel of the MODIS sensor. The image processing operations for NDVI is computed making use of open source GDAL Libraries and languages Python and PHP. The following series of steps (Fig.2) are repeated every ten minutes for processing Satellite Data.

1. Search and Download the Daily/ Latest Satellite data of the AOI

   The daily/latest images of the Terra Satellite in the AOI is searched using automated Web Services requests to the ftp site offering the Satellite data through a PHP web software application developed. Error control is implemented in the software such that if the image file size is less than the actual size or if the file information cannot be extracted, the file is downloaded again. If the file fails to download correctly within the maximum number of allotted attempts, the downloaded is attempted in the next time slot.

2. Reproject the Satellite image to UTM coordinate system

   The Satellite image from TERRA satellite is reprojected to UTM coordinate system using NASA's MRT swath Reprojection tool and the necessary bands i.e. NIR and Red bands are saved as separate images.

3. Merging of Satellite images and cutting the Area of Interest

   The satellite images may be present in multiple frames or in a single image. If the image of the AOI is present in multiple images, the images are merged and the AOI is cut using GDAL libraries and Python using the one time Shape file created using Quantum GIS.

4. Calculate the NDVI map of the AOI from the NIR and Red Band Images

5. Convert latest NDVI image of AOI to Portable Network Graphics format and upload to Web Server hoisted in the intranet Linux Server machine.

6. View the Latest image of the AOI through Internet browser from the web server and download for further processing.

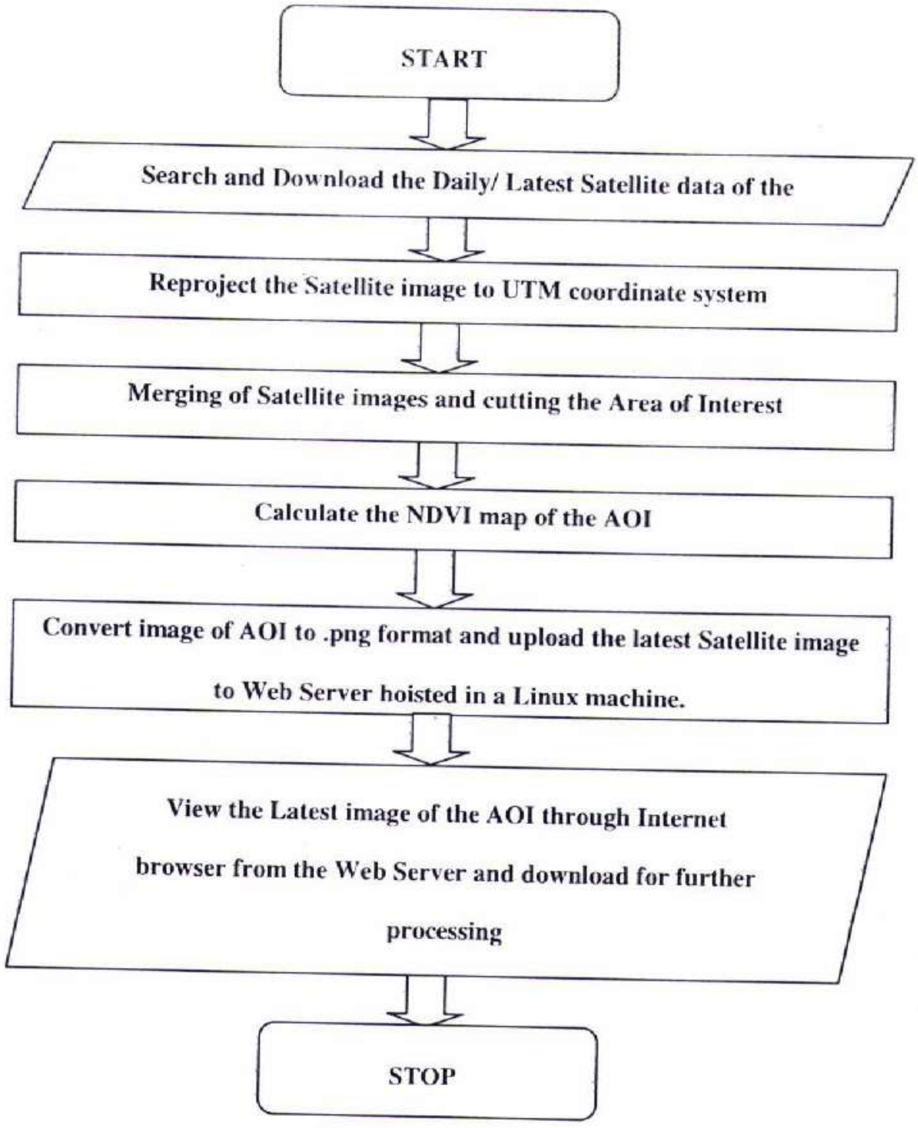

Fig. 2. Flow chart showing various steps involved for processing Satellite Data.

4. Results

The shape file enclosing Malabar region was created using Quantum GIS software and NDVI image calculated for the entire AOI. In certain days, the area under the AOI was captured piecewise by TERRA in multiple Frames. In this scenario, the application identifies the frames on the same date and merges them into a single image and then the AOI region cut from it. The NDVI image is then generated from the AOI Satellite images obtained in the NIR and Red band. Whenever a new satellite image is downloaded, the NDVI map is generated by the algorithm mentioned above and the application automatically updates the recent NDVI map in the Web Server (Fig.3). The latest NDVI image map thus generated can be viewed through web browser in the organization intranet as shown in

Figure 4. This map can be downloaded by potential users and analyzed according to the spatial area of interest of the user. It was found that the Satellite images captured by TERRA were uploaded in the internet ftp server within 24 hours. The uploaded satellite data is searched and automatically downloaded using web services by the software application developed and processed within 10-30 minutes and uploaded in the Intranet Web Server. Thus the Vegetation Health status of the previous day can be seen this day. Since the vegetation health do not change significantly overnight this can be considered as Near Real Time Monitoring with respect to Vegetation health.

This technique makes efficient use of free satellite data and Open Source software platform to monitor vegetation health. Further plans involve automating the identification and classification of drought risk areas on a day to day basis and providing this information to the public through the Web server. To spatially locate the drought prone area, the daily images need to be displayed through a map server with district and panchayath boundaries added as layers. Discussions are also underway to share this information with the Government Disaster Management Cell in each District through a WAN network established with the Web Server.

Fig. 3. Figure shows AOI and NDVI image obtained for the Malabar Districts and displayed using Mapserver

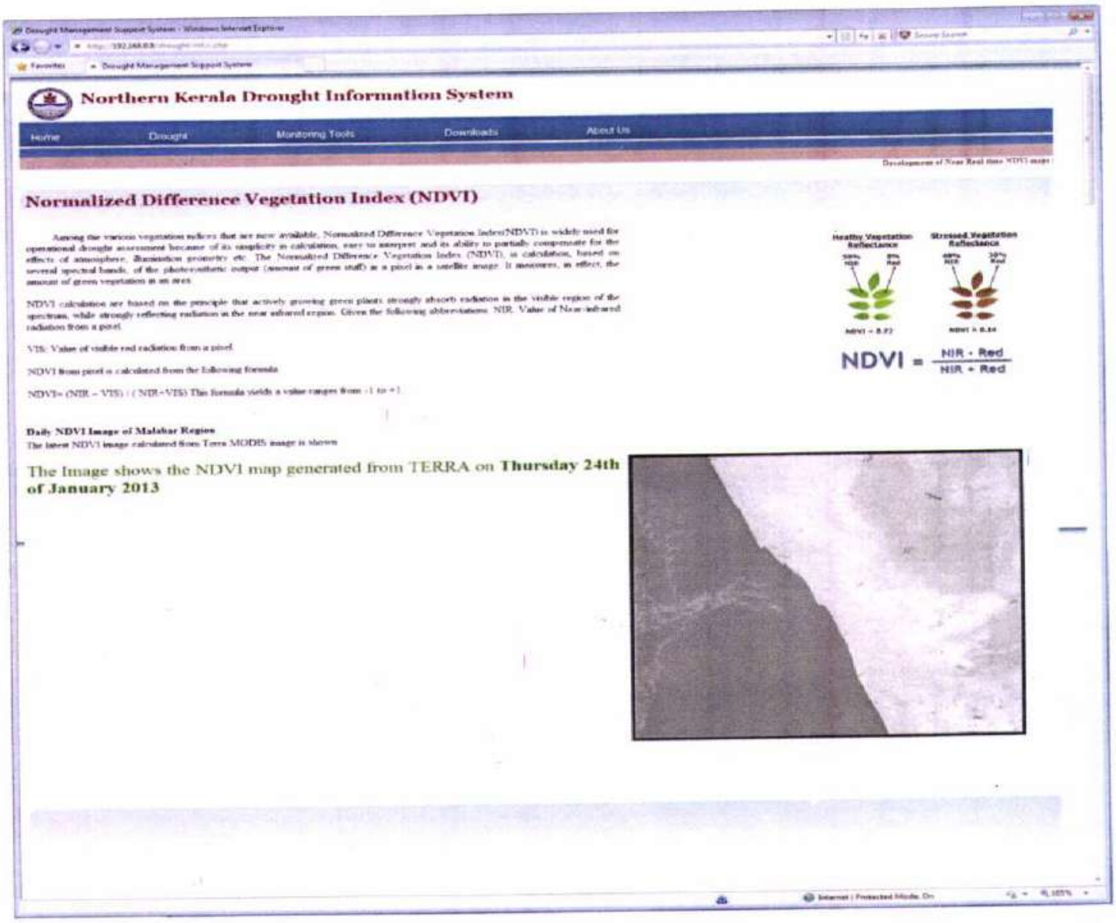

Fig. 4. Screenshot of the recent NDVI map being viewed through the internet browser in the Organization intranet.

5. Conclusion

Drought incidence can be detected by monitoring Vegetation Health in Near-Real time. Vegetation health can be found by generating NDVI maps of the region of Interest using satellite remote sensed images. Unhealthy status of Vegetation can be interpreted as a signal to indicate the onset of Drought. A technique for monitoring Vegetation Health using freely available remote sensed satellite data, processing images using FOSS and dissemination of this information using a Map server is discussed. Satellite data from NOAA and TERRA are freely available in the internet. Recently Kerala has been experiencing an increasing number of localized drought incidents. This is mainly due to weather anomalies and developmental pressures and has resulted in severe economic losses. To understand localized incidence of drought, panchayath level maps of each district were overlaid on the daily Vegetation health maps. Early detection of localized Drought incidence and dissemination of this information can help the State machinery to take necessary steps to mitigate drought impacts.

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