GEO-SPATIAL INVESTIGATION IN TO THE RECENTLY AGGRAVATED URBANIZATION AND DROUGHT SITUATION IN KERALA, INDIA

Anjali J., Soniyamol V. T. and John C. M.

Dr. R. Satheesh Centre for Remote Sensing and GIS, School of Environmental Sciences, Mahatma Gandhi University, Kottayam, Kerala, India
Email: rsgismgu@gmail.com

KEY WORDS: Climate change, Water Scarcity, Kattappana, NDVI, BT

ABSTRACT: Kerala State is recently experiencing extensive change in its climatic scenario in the form of less rainfall, its erratic pattern and high summer temperature as per various reports. This study investigated the phenomena trying to analyze its spatio-temporal trend for the last 30 years from 1986 using space-based satellite images and in-situ climate data. One of the recently elevated municipality in high-range mountainous Western Ghat district of the State - Idukki viz. Kattappana is taken as a specific case of investigation for the driving factors. Though post-monsoon and winter season rainfall shows increasing trend; monsoonal and summer rainfall shows highly decreasing trend. 2016 was the driest year with highest percentage departure from the normal rainfall and highest brightness temperature with extremely high intensity coinciding with considerable increase in the non-vegetation area as per the NDVI and the failure of both south-west and north-east monsoon**.** Wayanad district recorded the highest percentage departure of annual total rainfall from the normal consistently throughout the study period. As per the occurrence of deviation in Standard Precipitation Index, highest frequency of Extremely Dry Occurrence recorded at Kozhikode (10) and Palakkad (8) and Severely Dry Occurrence in Idukki (5) and Kottayam (5) districts. In Kattappana Municipality alone, the extent of core urban and semi urban built-up increased from 12% of the total area to 35% during 2001 to 2016 matching with increase in urban population and the number of built-ups Same may be the case with other municipalities and towns in the Ghat area of the State like Bathery in Wayanad, Nedumkandam in Idukki and Pala, Earattupetta in Kottayam districts. This has caused aggravated deviation from the long-term normal of the micro-climatic situation in terms of the total quantity and spatio-temporal distribution with serious socio-economic and environmental consequences.

1 INTRODUCTION

1.1 Drought and Urbanization

Drought is a creeping natural hazard that affects almost all regions of the world. It may be caused due to deficiency of rainfall or due to huge demand in water. Due to its complex nature and difficulty in prediction, study of drought is limited (Mishra and Desai, 2005). Indian Meteorological Department (IMD, 2016), defines drought as "the consequence of a natural reduction in the amount of precipitation over an extended period of time, usually a season or more in length, often associated with other climatic factors (viz. high temperatures, high winds and low relative humidity) that can aggravate the severity of the drought event". The occurrence of drought is governed by regional climatic parameters such as precipitation, temperature and evapotranspiration and hence drought is considered as regional event (Murad and Islam, 2011). So, better understanding of this hazard and its variation temporally and spatially helps to develop a comprehensive and integrated drought mitigation plan.

Urbanization refers to the concentration of human populations into discrete areas, leading to transformations of land for residential, commercial, and industrial and transportation purposes. United Nations projected that half of the world's population would live in urban areas at the end of 2008 (Pawan, 2016). This increase is projected to continue and will increase nearly 5 billion by 2030; but little is known about future locations, magnitudes and rates of urban expansion. If current trends in population density continue and all areas with high probabilities of urban expansion will undergo change, then by 2030, urban land will increase by 1.2 million km^2 (Karen et al., 2012). Urban growth is responsible for a variety of urban environmental issues like decreased air quality, increased runoff, and subsequent flooding, increased local temperature, deterioration of water quality. Land use and land cover changes as one of the main driving force of global environmental change (Ibrahim and Mosbeh, 2015)

1.2 Use of Remote Sensing and GIS

Several studies have attempted to utilize geospatial tools such as space based remote sensed earth observations (EOs), global navigational satellite systems (GNSSs), and geographic information system (GIS) in better understanding and monitoring of the hydrological hazards worldwide. These studies tried to develop and use various EO derived quantitative indices in the monitoring, assessment, mitigation and preparedness planning (Sandeep et al., 2015; Sruthi and Aslam, 2015; Suryabhagavan, 2016; WMO and GWP, 2016).

1.3 India and Kerala Context

The Kerala State located at the extreme southern tip of the Indian subcontinent is categorized as a multi hazard prone area (NDMA, 2010). In Kerala, about 86% of the annual rainfall is received during the monsoon period between June and December (70% during South west and 16% during the North east monsoon) and the remaining 14% during the non-monsoon period between January and May as summer showers. The occurrence and distribution of rainfall in the State also shows high spatial and temporal variations.

It has been observed that droughts and acute water scarcity have dramatically increased in number and intensity over the last three decades and affecting more people in Kerala than any other natural hazard for long periods of time. Drought is mainly manifested by the shrinking and drying up of rivers, ponds, lakes and the lowering of water table, and it adversely affects drinking water availability, agriculture production and power generation in the State. The gravity of the drought situation in Kerala is difficult to be understood because of the perennial greenery in the State. While the seasonal crops are damaged by drought, the perennial crops sustain because of their physiological and morphological adaptations 2001 (Kerala State IT Mission, 2016).

Recently, all the 14 districts of Kerala have been declared drought hit by the government. It was due to the deficit of 34 percent rainfall during South-West monsoon and the state expects 69 percent deficient in North-East monsoon. The state reported 22 percent average reduction in the water storage in the dams, compared to that in September, last year. The Kerala State Disaster Management Authority (KSDMA) is planning to impose a water rationing system across households and industries in the state. Also the government is planning to rejuvenate at least 10,000 private temple ponds in the state out of the total 40,000 in the state. The drought of 2016 was reported to be the worst drought that affected Kerala in 115 years (The Hindu, 2016).

1.4 Present Study

In this background, the present study envisaged to study the spatio-temporal changes in climate scenario, urbanization and drought in Kerala over the last 30 years from 1986 to 2016 focusing on a) meteorological drought due to variation in monthly and annual rainfall; b) agricultural drought using Normalized Difference Vegetation Index (NDVI) and brightness temperature (BT) derived from the satellite images; c) region with high risk of drought using satellite data and other thematic information and d) urbanization in Kattappana municipality as a key indicator area.

2. MATERIALS AND METHODS

2.1 Study area – Kerala State and Kattappana Municipality

Kerala State of India is situated between the Arabian Sea on the west and the Western Ghats towering 500 to 2700 meters above Mean Sea Level (MSL) on the east. Located in the North latitude between 8˚18' and 12˚48' and East longitude between 74˚52' and 77˚24'; it occupies 38,863 sq.km (Fig. 1). The coastline is about 580 km in length while breadth varies from 32 to 121 km. It encompasses 1.18 per cent of the total area of India. For administrative purposes, Kerala is divided into fourteen districts. Kattappana Municipality in one of the districts viz., Idukki is taken as an area to study the recent urbanization (Fig.1). Kerala is located in the humid tropics characterized with high rainfall. South west monsoon (June to September) and North east monsoon (October to November) are the two monsoon seasons of the state. About 85% of the annual rainfall receives during South west (70%) and North east (15%) monsoon. The remaining 15% only during the non-monsoon period between December and May as summer shower (Table 1).

2.2 Materials Used

2.2.1 Data Sources:

1. Maps from District Town and Country Planning Office - Idukki
2. High resolution satellite images (of the years 2001, 2016): Landsat-7 ETM+ and Landsat-8 OLI of 30 m spatial resolution – for visual interpretation of land use/cover and generation of NDVI & BT (Table 2 and 3)
3. Historical records of monthly rainfall data for the time period 1986 to 2016 from the Indian Meteorological Department (IMD).

Table 1: Seasons in the Kerala State

Season	Average Temperature (˚C)		Average Rainfall (mm)
	Maximum	Minimum	
Winter season	28	18	25
Summer season	36	32	135
South West Monsoon	30	19	2250 - 2500
North East Monsoon	35	29	450 - 500

(Source: http://nidm.gov.in/pdf/dp/kerala.pdf)

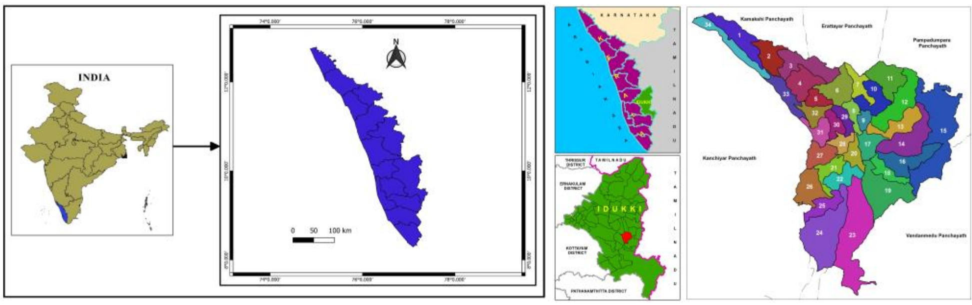

Figure 1: Study area - Location - Kerala State and Kattappana Municipality in Idukki District

Table 2: Characteristics of Landsat Thematic Mapper Plus (ETM+) sensor (Source: USGS, 2016)

Bands	Wavelength (micrometers)	Resolution (meters)
Band 1- Blue	0.45-0.52	30
Band 2- Green	0.52-0.60	30
Band 3- Red	0.63-0.69	30
Band 4- Near Infrared (NIR)	0.77-0.90	30
Band 5- Shortwave Infrared (SWIR) 1	1.55-1.75	30
Band 6- Thermal	10.40-12.50	60 * (30)
Band 7- Shortwave Infrared (SWIR) 2	2.09-2.35	30
Band 8- Panchromatic	0.52-0.90	15

*ETM+ Band 6 is acquired at 60-meter resolution, but products are resampled to 30-meter pixels

Table 3: Characteristics of Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)

Bands	Wavelength (micrometers)	Resolution (meters)
Band 1- Ultra Blue (coastal/aerosol)	0.43-0.45	30
Band 2- Blue	0.45-0.51	30
Band 3- Green	0.53-0.59	30
Band 4- Red	0.64-0.67	30
Band 5- Near Infrared (NIR)	0.85-0.88	30
Band 6- - Shortwave Infrared (SWIR) 1	1.57-1.65	30
Band 7- Shortwave Infrared (SWIR) 2	2.11-2.29	30
Band 8- Panchromatic	0.50-0.68	15
Band 9- Cirrus	1.36-1.38	30
Band 10- Thermal Infrared (TIRS) 1	10.60-11.19	100* (30)
Band 11- Thermal Infrared (TIRS) 2	11.50-12.51	100* (30)

*TIRS bands are acquired at 100 meter resolution, but are resampled to 30 meter in the data product (Source: USGS, 2016)

2.2.2 Software Packages and Instruments Used:

1. ERDAS IMAGINE 2015 – for digital image processing
2. Quantum GIS 2.18.4 – for GIS thematic layer creation
3. ArcGIS 9.3 – for geospatial analysis
4. GPS Essentials (Android Smartphone Application) – for geospatial location and navigation during ground truth verification
5. Handheld GPS receiver (Garmin Oregon 650) – for geospatial location and navigation during ground truth verification

2.3 Data Processing and Analysis Methodology

2.3.1 Climate Change and Drought Assessment of Kerala State: The present study assessed the climate and drought situation in Kerala over a period of 30 years using remote sensed satellite images and the in-situ field meteorological/climatic data in GIS platform (Fig. 2)

The reflectance Digital Number (DN) value satellite images were converted to Radiance for NDVI and BT calculation using the equation 1 and 2 for Landsat-7 ETM+ and Landsat 8 OLI data respectively. This was done after layer stacking and mosaicking with colour correction and balancing between the seven image scenes to cover the entire Kerala State area in ERDAS Imagine.

$$L\lambda = ((LMAX\lambda - LMIN\lambda) / (QCALMAX - QCALMIN)) * (QCAL - QCALMIN) + LMIN\lambda \text{ ------ (Eq. 1)}$$

Where, $L\lambda$ = Spectral radiance at the sensor's aperture in W/m2 Srµm
QCAL = Quantized calibrated pixel value in DN
$LMAX\lambda$ = spectral radiance that is scaled to QCALMAX in W/m2 Srµm
$LMIN\lambda$ = spectral radiance that is scaled to QCALMIN in W/m2 Srµm
QCALMIN = minimum quantized calibrated pixel value (corresponding to $LMIN\lambda$) in DN
QCALMAX = maximum quantized calibrated pixel value (corresponding to $LMAX\lambda$) in DN

$$L\lambda = QCAL*ML + AL \text{ ------------ (Eq. 2)}$$

Where, $L\lambda$ = Spectral Radiance at the sensor's aperture in $W/m^2/Sr\mu m$
QCAL = Quantized calibrated pixel value in DN
ML = Radiance multiplicative scaling factor for the band (RADIANCE_MULT_BAND_n from the metadata).
AL = Radiance additive scaling factor for the band (RADIANCE_ADD_BAND_n from the metadata).

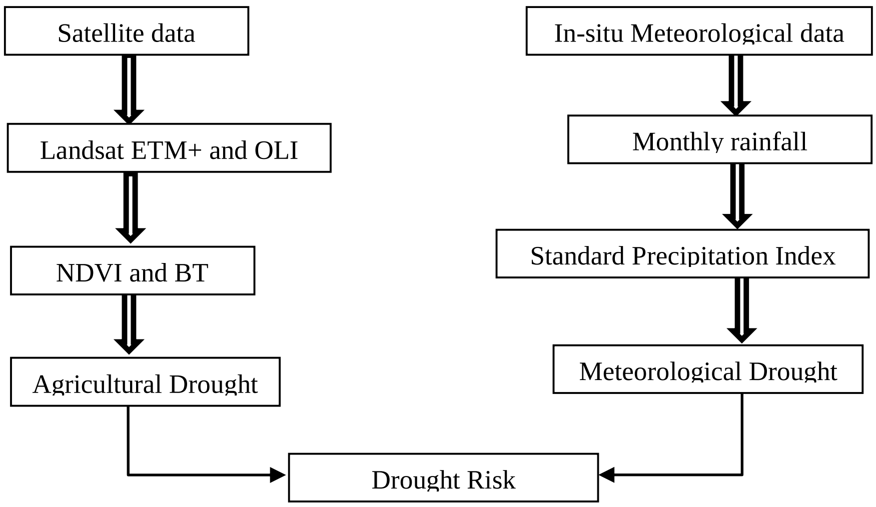

Figure 2: Methodological approach climate and drought assessment

Normalized Difference Vegetation Index (NDVI) is calculated using the equation 3 in the 'raster calculator' of QGIS software. NDVI was first suggested by Tucker (1979) as an index of vegetation health and density. It is an index which differentiates between the vegetative portion recorded by the satellite image with other observed objects including water bodies, buildings, bare lands and others. For healthy vegetation, reflected radiation in the near infrared wavelength is greater than visible wavelength. For unhealthy vegetation, there is very little difference between the amount of reflected radiation in the visible and infrared wavelength.

$$NDVI = (NIR - RED) / (NIR + RED) \text{ ---------------- (Eq. 3)}$$

Where NIR is reflectance in the near infrared and RED is reflectance in the visible (red) band.

Brightness Temperature (BT) was computed from the thermal bands of the images (Band-6 of ETM+ and Band-10 of OLI) using the equation 4.

$$T = K2 / \ln (K1 / L\lambda) + 1) \text{ ------------------------ (Eq. 4)}$$

Where, K1=Thermal conversion constant for the band (K1_CONSTANT_BAND_n K1 from the metadata)
K2=Thermal conversion constant for the band (K2_CONSTANT_BAND_n K2 from the metadata)
$L\lambda$=Spectral Radiance at the sensor's aperture in W/m2/Sr/µm of the thermal band

Standardized Precipitation Index (SPI) is a tool which measures meteorological drought. The drought can be analysed using the available data collected by India Meteorological Department. Mathematically SPI is calculated using the equation 5:

$$\text{SPI} = Xi - Xm / \sigma \text{ -------------- (Eq. 5)}$$

Where, Xi: Monthly rainfall record of the station
Xm: Rainfall mean
σ: Standard deviation

Monthly rainfall data of the available stations within the study area was used as an input to calculate SPI using a computer software downloaded from http://droughtunl.edu/monitor/spi/program/spiprogram.htm#program. The classification of meteorological drought risk using SPI values are given in Table 4 (WMO and GWP, 2016).

Table 4: SPI value ranges and drought classes

SPI value ranges	Class
2.0 or more	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2 and less	Extremely dry

(Source: WMO and GWP, 2016)

2.3.2 Urbanization in Kattappana Municipality: The land use land cover (lulc) was classified into 17 categories (Table 4). Urban built-up included educational institutions, hospitals, banks and other commercial built-ups. After visually interpreting the lulc, the core urban and semi urban categories were extracted from both the years 2001 and 2016. The area summarization was done using the 'summarize' tool in ArcGIS. The change analysis was done after overlaying the lulc layers of the 2 years using the 'union' overlay function and the area of change category was then summarized.

3 RESULTS

3.1 Climate Change and Meteorological Drought Assessment

The monsoons in Kerala have been highly erratic for the past 30 years, i.e., 1986-2016. The state is divided into four seasons for climatological purpose, i.e., pre-monsoon (March-May), monsoon (June-September), post-monsoon (October-December) and winter (January-February) season. As per India Meteorological Department (IMD), the average normal rainfall to be received in Kerala during the above four seasons is given in Table 5.

Table 5: Average normal rainfall in Kerala

Season	Month	Average normal rainfall (mm)
Pre-monsoon	March - May	379.7
Monsoon	June - September	2039.6
Post-monsoon	October - December	480.7
Winter	January - February	24.3

(Source: IMD, 2016)

3.1.1 Deviation of rainfall from normal during the pre-monsoon season: The greatest departure of pre-monsoon rainfall occurred during the year 1987 with a deviation of -209.9 mm from the average normal rainfall. It is then followed by the year 1986 where deviation from the average normal rainfall is -178.7 mm. The years with highest departure in pre-monsoon deviation is shown in Table 6 in the descending order (Fig. 3).

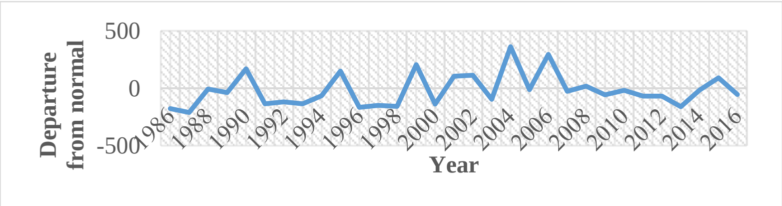

Figure 3: Pre-monsoon departure of rainfall in Kerala from 1986 to 2016

Table 6: Years with maximum departure of pre-monsoon rainfall in Kerala

Sl. No.	Year	Departure from normal (mm)
1	1987	-209.9

2	1986	-178.7
3	1996	-166.7
4	2013	-161.2
5	1998	-158.9

3.1.2 Departure of monsoon rainfall from the average normal for the years 1986 to 2016: The greatest departure of monsoon rainfall occurred during the year 2002 with departure of -717.7 mm from the average normal. This is followed by the years 1987 (-692.4 mm), 2016 (-687.22 mm) and 2003 (-583.7) (Fig. 4) (Table 7).

Table 7: Years with maximum departure of monsoon rainfall in Kerala

Sl. No.	Year	Departure from normal (mm)
1	2002	-717.7
2	1987	-692.4
3	2016	-687.2
4	2003	-583.7
5	1986	-541.2
4	2015	-530.9

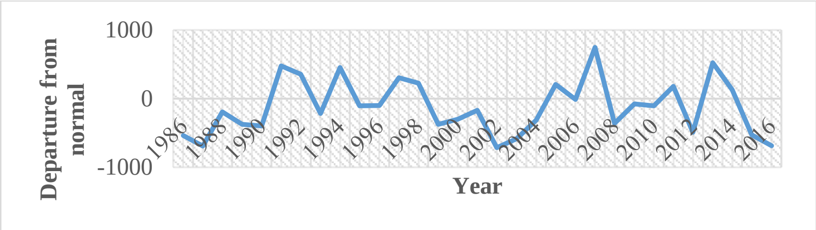

Figure 4: Monsoon departure of rainfall (mm) in Kerala from 1986 to 2016

3.1.3 Departure of post-monsoon rainfall from the average normal for the years 1986 to 2016: Northeast monsoon rainfall is the next principal rain season in which the Kerala State depends for the cultivation of paddy and cash crops. The greatest departure of rainfall occurred during 2016 with departure of -393.73 mm from the normal average. This is followed by the years 1988 (-314.1), 2012 (-167.9), 2000 (-119.3), 1986 (-111) and 1995 (-99.7). There is not much departure of rainfall during the post-monsoon season for the last 30 years even though the year 2016 showed an excess dip in rainfall. Most of the years showed a positive trend. The year 2010 showed an excess of +348.7 mm rainfall than the normal average during the post-monsoon season. The years with highest positive trend in post-monsoon rainfall is shown in Table 8 in descending order (Fig. 5).

Table 8: Years with maximum departure of post-monsoon rainfall in Kerala

Sl. No.	Year	Excess rainfall from the normal average (mm)
1	2010	+348.7
2	1988	+314.1
3	1997	+195.0
4	1998	+178.5
5	1999	+160.2
6	1993	+150.5

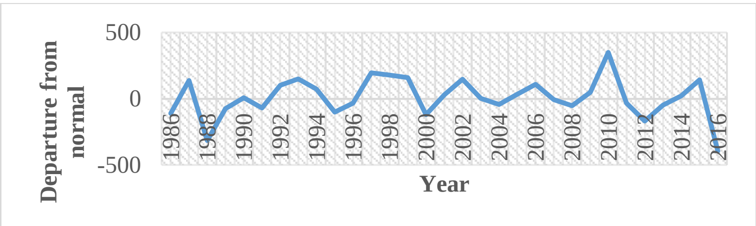

Figure 5: Post-monsoon departure of rainfall (mm) in Kerala from 1986 to 2016

3.1.4 Deviation of winter (January-February) rainfall from the average normal during 1986 to 2016: Winter season in Kerala receives 24.3 mm average rainfall. The greatest departure of rainfall occurred during the year 1987 with a departure of -22.9 mm from the normal average. This is followed by the years 1992 (-21), 1997 (-20.7), 2009 (-19.8) and 2007 (-18.3). It is vivid that after 1999, there is more positive trends in winter rainfall than before 1999 The years with highest positive trend in winter rainfall is given in Table 9 in descending order (Fig. 6).

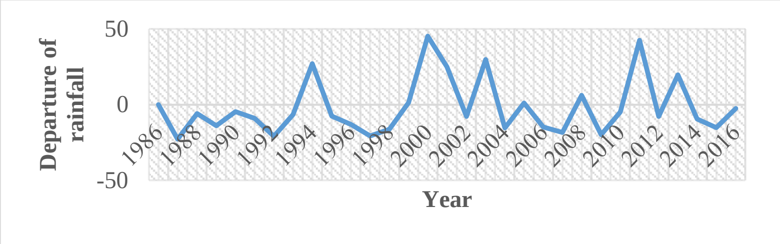

Figure 6: Winter departure of rainfall (mm) in Kerala from 1986 to 2016

Table 9: Years with maximum positive deviation of winter rainfall in Kerala

Sl. No.	Year	Excess rainfall from the normal average (mm)
1	2000	+45.2
2	2011	+42.4
3	2003	+29.8
4	1994	+27.1
5	2001	+24.9

3.1.5 Deviation of annual rainfall from the normal: As per IMD's classification of rainfall distribution, if the amount of rainfall received over a region [expressed as percentage departure from normal (PDN)] is between -19% and +19%, it is termed as *normal*. If PDN is between -20% and -59%, the region comes under *deficient* category, if PDN is less than -60%, the region falls under *scanty* category and PDN of ≥20% indicates *excess* rainfall category (Table 10).

Table 10: Percentage departure of rainfall and its respective drought class (Source: IMD, 2016)

Sl. No.	Class	Percent departure of rainfall from the normal value
1	Excess	+20% and more
2	Normal	-19% to +19%
3	Deficient	-20% to -59%
4	Scanty	-60% to -99%

The period from the year 1990 to 2016, Wayanad district has the highest number of rainfall deviation from normal, i.e., -25%. All the 14 districts of Kerala showed negative deviation of rainfall for the years 2012 and 2016 (Table 11). 2016 is the year with highest annual percent departure of rainfall from the normal (-35.52 %). The year 2007 is the only year where rainfall is +23.77 percent more than the normal and it falls under the rainfall class of excess rainfall (Table 12) (Fig. 7).

Table 11: Average normal rainfall and deviation of rainfall for the years 2003, 2012 and 2016

District	Average Normal	Departure from normal (2003)	Departure from normal (2012)	Departure from normal (2016)
Kasargod	3494.1	-468.2	-448.3	-1028.1
Kannur	3220.4	-388	-553.5	-1004.8
Wayanad	3280.8	-1426.4	-1440.9	-1953.0
Kozhikode	3264.0	-1037.8	-334.2	-1003.9
Malappuram	2719.0	-587.7	-733.0	-1186.0
Palakkad	2091.2	-405.7	-393.3	-741.3
Thrissur	2863.2	-662.9	-501.8	-1175.8
Ernakulam	2877.9	-381.9	-267.7	-551.6
Idukki	2807.9	261.0	-206.4	-695.9
Kottayam	2794.3	-192.7	-495.6	-708.3
Alappuzha	2536.6	-354.7	-690.9	-765.3
Pathanamthitta	2576.2	-115.4	-758.3	-429.2
Kollam	2182.5	-310	-526.9	-266.5
Thiruvananthapuram	1685.5	-75.6	-531.1	-487.7

(Source: IMD, 2016)

Table 12: Years with highest percentage departure of rainfall

Sl. No.	Year	Annual percent departure from normal	Class
1	2016	-35.52	Deficient
2	1986	-28.41	Deficient

3	1987	-26.90	Deficient
4	2012	-25.19	Deficient
5	2003	-22.17	Deficient

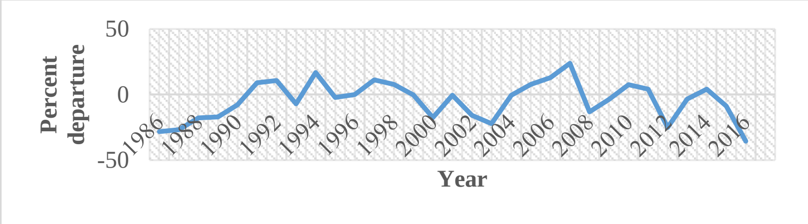

Figure 7: Annual percent departure of rainfall from normal in Kerala from 1986 to 2016

3.1.6 Deviation as per the SPI: Assessment of meteorological drought condition is done using the SPI values. SPI value ≤-1 denote dry condition; the range from -1 to -1.49 refers to moderately dry condition; value -1.5 to -1.99 refers to severely dry condition and value -2 and less refers to extremely dry condition. Maximum extremely dry occurrence (EDO) is reported from Kozhikode district (10 times) - 3 in June, 2 in July, 2 in August and 3 times in October followed by Palakkad with 8 occurrences - 2 in June, 2 in July, 2 in August and 2 in October. Maximum severely dry occurrence (SDO) is reported from Ernakulam (7) district followed by Pathanamthitta (6). Maximum moderately dry occurrence (MDO) is reported from Kottayam district (39) followed by Kollam (38), Thrissur (35) and Wayanad (34) districts.

3.2 Agricultural Drought Assessment

3.2.1 Normalized Difference Vegetation Index: The range of NDVI is -0.57 to 0.75 in 2001 and -0.155 to 0.65 in 2016. From the NDVI images, it was observed that the lowest NDVI value exists at non-vegetation area such as urban area, water body and highest NDVI exists at Vegetative areas such as plantation area, forest land and agricultural land. NDVI images were then reclassified based on the values ranges into 6 NDVI categories. The classification scheme adopted for NDVI reclassification is given below (Table 13) (Fig. 8).

Table 13: Classification scheme adopted for NDVI reclassification

NDVI class and value range	2001		2016	
	Area (hectare)	Area (%)	Area (hectare)	Area (%)
Non-vegetation (≤ 0.1)	98,379	2.93	195,004.35	13.27
Very low density (0.1 to 0.2)	795,271.23	23.76	361,412.46	24.61
Low density (0.2 to 0.3)	653,071.14	19.51	378,175.68	25.75
Medium density (0.3 to 0.4)	893,845.26	26.71	229,129.38	15.6
High density (0.4 to 0.5)	174,135.24	5.2	146,482.47	9.97
Very high density (0.5 to 0.9)	732,367.44	21.88	158,436.72	10.78

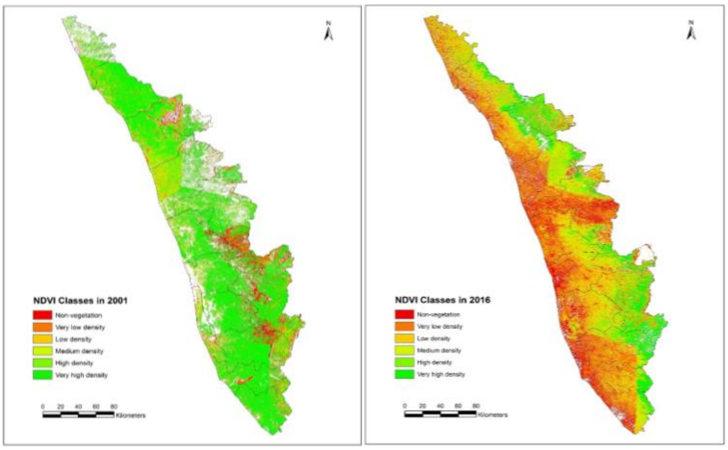

Figure 8: Distribution of the NDVI classes in Kerala State in 2001 and 2016

3.2.2 Brightness Temperature (BT): In the year 2001, the range of brightness temperature is 14.79 to 17.09 and in 2016, it is between the ranges 16.34 to 27.91. Brightness temperature were then reclassified based on the values ranges into 6 categories. The classification scheme adopted for brightness temperature reclassification is given below (Table 14) (Fig. 9).

Table 14: Classification scheme adopted for brightness temperature reclassification

Brightness temperature class and value range	2001		2016	
	Area (hectare)	Area (%)	Area (hectare)	Area (%)
Very low intensity (7 to 10)	26249.31	0.16	3455.19	0.02
Low intensity (10 to 13)	10864.71	0.07	2617.38	0.02
Medium intensity (13 to 15)	1437509.97	9.10	2709.99	0.02
High intensity (15 to 16)	6588044.28	41.75	85522.05	0.54
Very high intensity (16 to 17)	7028394.66	44.54	443221.74	2.83
Extremely high intensity (17 to 31)	688590.63	4.36	15083049.60	96.55

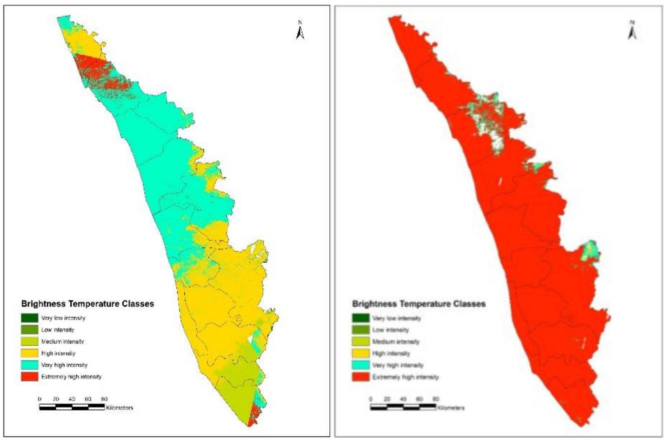

Figure 9: Distribution of brightness temperature classes in Kerala State in 2001 and 2016

3.2 Urbanization in Kattappana Municipality

Urban built up (core urban) occupied 164.2 ha in 2001 which increased to 722.94 ha in 2016. The increase is 558.74 ha (9.7 %); which includes the conversion from urban built-up with thin vegetation, less settlement with mixed crop land, grass-land, cardamom plantation, mixed cultivation, thick vegetation and thick vegetation. Urban built up with thin vegetation (semi-urban) occupied 44.83 ha in 2001 increased to 514.88 ha in 2016. The area percentage increase is 8.4 %; which include the conversion from mixed cultivation, thick vegetation, thin vegetation, thick settlement with thin-vegetation, less settlement with mixed crop and thin vegetation, grass-land, cardamom plantation, and urban built up with mixed crop. This means after few years this area (urban built-up with thin vegetation) became urban built-up. The extent of core urban and semi urban built-up together increased from 11 to 35% of the total area during 2001 to 2016 matching with increase in urban population and the number of built-ups such as educational institutions, hospitals and commercial centers (Fig. 10).

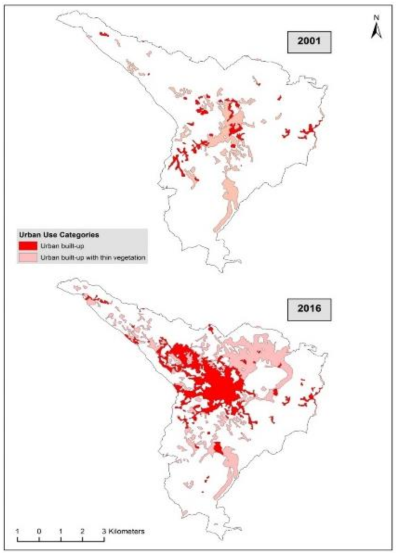

Figure 10: Distribution of increase urban built-up extent in Kattappana Municipality from 2001 to 2016

4. DISCUSSION

There is no trend in the pattern of pre-monsoon, monsoon, post-monsoon and winter rainfall in Kerala. This is supported by the study "Analysis of long-term rainfall trends in India" by Kumar et al. (2010), where the trend analysis of rainfall data of 135 years (1871-2005) indicated no significant trend for annual, seasonal and monthly rainfall on an all-India basis. The analysis of annual percent departure of rainfall from normal reveals that the year 2016 is the driest year during the last 30 years (1986-2016) with a departure of -35.52 percent from the normal average. This is because of the failure of both south-west and north-east monsoon during 2016. The changes in the rainfall pattern in Kerala may be due to the El-Nino effect (IMD, 2016), global warming, and increase in temperature and changes in the strength of the Pacific walker circulation in spring (Schewe and Levermann, 2012). Annual and monsoon rainfall decreased whereas that of pre-monsoon, post-monsoon and winter rainfall increased over the years (Kumar et al., 2010; Pal and Al-Tabbaa, 2009). There exists a cyclic trend in annual rainfall with a declining trend and south-west monsoon rainfall and an increasing trend in post-monsoon and winter rainfall since last few decades (Prasada Rao et al., 2009). The sharp increase in the intensity of brightness temperature and decrease in NDVI from 2001 to 2016 is supported by the result of meteorological drought in Kerala (1986 to 2016) which finds that 2016 is the driest year during the last 30 years. This finding is also supported by the fact that the year 2016 was declared as drought hit by the government of Kerala (The Hindu, 2016).

5. CONCLUSION

During the last 30 years, 2016 was the driest year with an increase in the non-vegetation area, brightness temperature and failure of both south-west and north-east monsoon. Wayanad district recorded considerable negative departure from annual normal rainfall consistently through the study period. In Kattappana Municipality alone, the extent of core urban and semi urban built-up increased drastically in the study period matching with increase in urban population and the number of built-ups Same may be the case with other municipalities and towns in the Ghat area of the State like Bathery in Wayanad, Nedumkandam in Idukki and Pala, Earattupetta in Kottayam districts. This has caused aggravated deviation from the long-term normal of the micro-climatic situation in terms of the total quantity and spatio-temporal distribution with serious socio-economic and environmental consequences. The study finds that remote sensing and GIS is an unavoidable toolset to assess climate changes in terms of meteorological and agricultural drought and urbanization in Kerala or elsewhere.

REFERENCES

Ibrahim Rizk Hegazy and Mosbesh Kaloop, 2015. Monitoring Urban growth and land use change detection with GIS and Remote sensing techniques in Daqahila governorate Egypt. International Journal of Sustainable Built Environment, 4, pp. 117-124.

IMD, 2016. The drought (Online). Indian Meteorological Department. Retrieved February 12, 2017, from http://imd.gov.in/section/nhac/wxfaq.pdf.

Karen C. Seto, B. Gueneralp, and L R Hutyra, 2012. Global forecast of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. Proceeding of the National academy of science of the United States of America, 40, pp. 7687-7692.

Kerala State IT Mission. (2016). Kerala calling. Retrieved April 10, 2017 from https://kerala.gov.in/documents/10180/9ac98952-d68a-4a98-a406-92c6c4f6469c.

Kumar, V., Jain, S. K and Singh, Y., 2010. Analysis of long-term rainfall trends in India. Hydrological Science Journal, 55, pp. 484-496.

Mishra, A, K. and Desai, V. R., 2005. Spatial and temporal drought analysis in the Kansabati River Basin, India. International River Basin Management, 3(1), pp. 31-41.

Murad Hasan and Saiful Islam, A.K.M, 2011). Drought assessment using remote sensing and GIS in North-west region of Bangladesh. 3rd International Conference on Water and Flood Management, Bangladesh (Dhaka), on 8-10 January, 2011.

NDMA, 2010. National Disaster Management Guidelines: Management of drought. National Disaster Management Authority, Government of India. ISBN 978-93-80440-08-8, September 2010, New Delhi.

Pal, I and Al-Tabbaa, A., 2009. Trends in seasonal precipitation extremes-an indicator of climate change in Kerala, India. Journal of Hydrology, 367, pp. 62-69.

Pawan, 2016. Urbanization and its cause effects: A review. International Journal of Research and Scientific Innovation (IJRSI), 3(9), pp. 2321-2705.

Prasada Rao, G.S.L.H.V., Kesava Rao, A.V.R., Krishnakumar, K.N and Gupakumar, C.S., 2009. Impact of climate change on food and plantation crops in the Humid Tropics of India. In: Impact of climate change on Agriculture, Panigrahy, S., Ray, S.S and Parihar, J.S (Eds.). ISPRS Archives, Ahmedabad, India, pp. 127-130.

Sandeep, V, Gaikwad., Karbhari, V, Kale., Sonali, B, Kulkarni., Amarsingh, B, Varpe and Ganesh, N, Pathare, 2015. Agricultural drought severity assessment using remote sensed data: A Review. International Journal of Advanced Remote Sensing and GIS, 4(1), pp. 1195-1203.

Schewe Jacob and Anders Levermann, 2012. A statistically predictive model for future monsoon failure in India. Enviromental Research Letters, 7(4), pp. 12-20.

Sruthi, S and Mohammed Aslam, M, A., 2015. Agricultural drought analysis using the NDVI and land surface temperature data; a case study of Raichur district. Presented at International Conference on Water Resources, Coastal and Ocean Engineering (ICWRCOE 2015). Aquatic Proceedia, 4(2015), pp. 1258-1264.

The Hindu, 2016. Drought in Kerala. Retrieved April 22, 2017 from www.thehindu.com/news/national/kerala/kerala-declared-drought-hit/articles16086701.ece#.

USGS, 2016. Band designation for Landsat satellites. Retrieved March 4, 2017 from https://landsat.usgs.gov/what-are-band-designations-landsat-satellites.

WMO and GWP, 2016. Handbook of drought indicators and indices. World Meteorological Organization - Global Water Partnership: Integrated Drought Management Programme (IDMP), Integrated Drought Management Tools and Guidelines Series 2: Geneva.