

**ESTIMATION OF NDVI VALUES FOR PARBHANI AND
HINGOLI DISTRICT OF MARATHWADA REGION**

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B. Sc. (Agriculture)

MASTER OF SCIENCE

IN

AGRICULTURE

(AGRICULTURAL METEOROLOGY)



DEPARTMENT OF AGRICULTURAL METEOROLOGY

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2021

**ESTIMATION OF NDVI VALUES FOR PARBHANI AND
HINGOLI DISTRICT OF MARATHWADA REGION**

BY

PATIL PRITAM PRAKASH

B. Sc. (Agriculture)

A Thesis submitted to

Vasant Rao Naik Marathwada Krishi Vidyapeeth, Parbhani

in partial fulfillment of the requirements for the award of the degree of

MASTER OF SCIENCE

IN

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2021

AFFECTIONALLY

DEDICATED

TO

MY BELOVED FAMILY,

RESPECTED RESEARCH GUIDE

AND FRIENDS

DECLARATION BY THE CANDIDATE

I hereby declare that the thesis entitled, “**ESTIMATION OF NDVI VALUES FOR PARBHANI AND HINGOLI DISTRICT OF MARATHWADA REGION**” submitted by me is based on the actual work carried out by me under the guidance and supervision of **Megha Pradip Jagtap**. The extent of information derived from the existing literature have been duly cited and referenced. The existing research work or its any part is not submitted anywhere else for the award of any degree or diploma.

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Place: **Parbhani**

Date: 13/08/2021



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Reg. No. 2019A/26M

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Document Information

Analyzed document	Pritam_Patil_2019A_26M_Agromet_MSc_Thesis.docx.pdf (D111004693)
Submitted	8/5/2021 11:34:00 AM
Submitted by	Megha P. Jagtap
Submitter email	meghap.jagtap@gmail.com
Similarity	5%
Analysis address	meghap.jagtap.vnmkv@analysis.arkund.com

Sources included in the report

W	URL: https://www.science.gov/topicpages/s/soil-adjusted%2Bvegetation%2Bindex.html Fetched: 6/26/2021 2:45:56 PM	 3
W	URL: https://www.researchgate.net/publication/251562129_Integrating_AVHRR_and_MODIS_data_to_monitor_NDVI_changes_and_their_Relationships_with_climatic_parameters_in_Northeast_China Fetched: 12/30/2019 2:07:11 AM	 5
W	URL: https://worldwidescience.org/topicpages/g/gimms+avhrr+ndvi.html Fetched: 6/28/2020 8:57:59 PM	 1
W	URL: https://www.researchgate.net/publication/331024469_Pattern_of_agricultural_drought_during_2000-2015_in_Marathwada_region_India Fetched: 8/5/2021 11:35:00 AM	 2
W	URL: https://www.researchgate.net/publication/257346522_Comparative_evaluation_of_the_Vegetation_Dryness_Index_VDI_the_Temperature_Vegetation_Dryness_Index_TVDI_and_the_improved_TVDI_TVDI_for_water_stress_detection_in_semi-arid_regions_of_Iran Fetched: 2/5/2020 7:28:41 AM	 2
J	The impact of seasonal rainfall variability on NDVI in the Tunga and Bhadra river basins, Karnataka, India URL: f4c63b8f-7527-473b-ac36-52f0ed2fd918 Fetched: 3/13/2019 8:38:44 AM	 2
W	URL: https://www.mdpi.com/2072-4292/11/6/724/pdf Fetched: 8/5/2021 11:35:00 AM	 1
W	URL: https://www.science.gov/topicpages/s/satellite%2Bvegetation%2Bindex Fetched: 1/22/2021 7:58:37 PM	 3
W	URL: https://www.researchgate.net/publication/258425317_Assessment_of_vulnerability_of_Indian_agriculture_to_rainfall_variability--Use_of_NOAA-AVHRR_8_km_and_MODIS_250_m_time-series_NDVI_data_products Fetched: 9/30/2019 8:19:17 AM	 3
W	URL: https://www.researchgate.net/publication/276885463_Agricultural_Drought_Analysis_Using_the_NDVI_and_Land_Surface_Temperature_Data_a_Case_Study_of_Raichur_District Fetched: 8/19/2020 10:25:40 AM	 1

ACKNOWLEDGEMENT

I would like to take this opportunity to thank many people who have helped me to complete this thesis.

*It is my proud privilege to express heart-felt indebtedness and deepest sense of gratitude to my research guide **Dr. M. P. Jagtap**, Assistant Professor, Department of Agronomy, V.N.M.K.V., Parbhani for her inspiring guidance, keen interest, her activeness and sharpness. I take this opportunity to express my deep and sincere feeling of gratitude to her for suggesting research topic, valuable guidance, constant inspiration, constructive criticism talented versatile advice and untiring efforts in preparation of the manuscript of this dissertation.*

*I express my sincere thanks to **Dr. A. S. Dhawan**, Vice Chancellor, VNMKV, Parbhani, **Dr. D. N. Gokhale**, Director of Instruction and Dean, Faculty of Agriculture, **Dr. Syed Ismail** Associate Dean and Principal, College of Agriculture, Parbhani for providing all the necessary facilities and his valuable contribution towards the completion of this investigation.*

*I take opportunity to express a heartfelt thanks to the member of Advisory committee, **Dr. M. G. Jadhav**, Professor and officer In-charge, Department Agriculture Meteorology, College of Agriculture, Parbhani; **Dr. K. K. Dakhore**, Assistant professor, Department of Agriculture Meteorology, College of Agriculture, Parbhani and **Dr. B. V. Asewar**, Head, Department of Agronomy, College of Agriculture, Parbhani.*

*My cordial thanks are to inspiring personality Associate Professor **Dr. P. R. Jayebhaye**; Assistant Professor **G. N. Gote**; SRF **Mr. Balaji Bobade**, **Mr. Yadav Kadam**, **Mr. Vijesh Jadhav**, **Mr. Hari Kerkar**, **Mr. Ramkrishna Mane**, **Rajubhau**, **Shinde Mavshi** and all staff members of Department of Agricultural meteorology, VNMKV, Parbhani may be regarded as the light hours for the ocean liners who have been kindly navigate my ship of academic pursuit and I would like to mention my gratitude to them.*

*I would like to take this opportunity to express my deepest and heartiest (no words to express) gratitude to my family, my beloved father **Shri. Prakash B. Patil**, my mother **Sau. Vaishali P. Patil**, my sister **Prachi P. Patil** and much more credit goes to my ideal uncle **Shri. Sagar J. Sambhushete** for continuous inspiration, constant encouragement, moral support, affection and guidance through my study period in building of my educational career. Also, my special thanks to my all relatives for their valuable support during M.Sc. (Agri.) course.*

*It is great pleasure to acknowledge the unfailing help rendered from my friends and my Agromet 2019 family, **Hrishikesh**, **Pavan**, **Sandip**, **Hameidalut**, **Snehal**, **Jayashree**, **Anjali** and **Pallavi** and especially heartiest thanks to **Pralay**, **Shaharukh**, **Satywan**, **Premkumar** and **Shubham***

for always being with me and all my P.G. batchmates along with the colleague of hostel and my seniors and juniors.

*I would like to express my gratitude to **Mr. Prasad Rankhambe**, IIRS, Dehradun for always advising me in the field of remote sensing.*

*I would like to express my special and sincere gratitude to **Dr. Kiran Majlekar** and **Mr. Harshal Jitkar**, Shivaji University, Kolhapur for their valuable advice and quick response towards my queries which helped me a lot of in my research work,*

*I would like to express my heartiest gratitude to **Prof. Pennan Chinnaswamy**, Ph.D., Assistant Professor, IIT, Bombay and **Mr. Shivanand Nalgire**, IIT, Bombay for solving my most of queries within short period of time and always properly advising me which results to successful completion of research.*

*I would like to express my thanks to **Dr. G. U. Shinde**, **Dr. A. U. Waikar** and **Team NAHEP DFSRDA VNMKV, Parbhani** for arranging various informative remote sensing and GIS training programs.*

Last but never the least my warm acknowledgements to farmers, soldiers, scientist and great Corona Worriers who have devoted their whole life for the country.

Place : Parbhani

Date : 13/08/2021


(Patil. P. P.)

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ABBREVIATIONS

ANPP	Above-ground Net Primary Productivity
AVHRR	Advanced Very-High-Resolution Radiometer
CRU	Climate Research Unit
DVI	Difference Vegetation Index
FWI	Fractional Water Index
GIMSS	Global Inventory Modelling and Mapping Studies
GIS	Geographic Information System
GPP	Gross Primary Productivity
IRS	Indian Remote Sensing Satellite System
ISDI	Integrated Surface Drought Index
LAI	Leaf Area Index
LiDAR	Light Detection And Ranging
LISS	Linear Imaging Self Scanning Sensor
LSP	Land Surface Phenology
LST	Land Surface Temperature
LULC	Land Use Land Cover
MODIS	Terra Moderate Resolution Imaging Spectroradiometer
MSS	Multi Spectral Scanners
NDDI	Normalized Difference Drought Index
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
NEB	Northeast Region of Brazil
NIR	Near-infrared
NOAA	National Oceanographic and Atmospheric Administration
NPP	Net Primary Productivity
NRB	Northeast Region of Brazil
OLI	Operational Land Imager
QGIS	Quantum GIS software
SAR	Synthetic Aperture Radar
SAVI	Soil Adjusted Vegetation Index
sNDVI	smoothed Normalized Difference Vegetation Index
SPI	Standardized Precipitation Index

SPOT	Satellite Pour l'Observation de la Terre (French word)
S-W	South-West
SWIR	Short Wave Infra-Red
TCI	Temperature Condition Index
TIRS	Thermal Infrared Sensor
TM	Thematic Mapper
TRMM	Tropical Rainfall Measuring Mission
UHI	Urban Heat Island
USDA	United States Department of Agriculture
VCi	Vegetation Condition Index
VegDRI	Vegetation Drought Response Index
VHI	Vegetation Health Index
VWC	Vegetation Water Content
WSVI	Water Supply Vegetation Index

THESIS ABSTRACT

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- 1) Title of the thesis : “Estimation of NDVI Values for Parbhani and Hingoli District of Marathwada Region”
- 2) Name of the Candidate : Patil Pritam Prakash
- 3) Name of the Research : Dr. M. P. Jagtap
Guide
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Marathwada Krishi Vidyapeeth, Parbhani
- 6) Degree to be Awarded : Master of Science in Agriculture (Agricultural
Meteorology)
-

ABSTRACT

Drought is consequence of a sudden break in monsoon and severe lack of precipitation, resulting in acute water scarcity, considerable soil moisture shortages, and lower agricultural yields. Droughts can not be prevented, but they can be forecasted and monitored in order to lessen their negative upshots. Droughts are divided into four categories as, meteorological, agricultural, hydrological, and socioeconomic.

Drought is depending upon climatic zone which include large area and variation in rainfall with time and space. In case of large area like districts, manual recording and monitoring drought is tedious work and it needs technology assistance. Now a days, various technologies like Remote sensing and GIS are available to solve such problems.

RS and GIS provides continuous and accurate data with large repetition without any interruptions. This type of reliable data helpful in monitoring drought with ease and in less period. Past study of drought is also possible with the help of satellite imageries captured at regular interval time. Drought can be interpreted or described on the basis of vegetation condition which is obtained from satellite image of particular time and area. The vegetation condition can be calculated and denoted in different terms like NDVI, NDWI and NDDI.

In the present study, remote sensing-based drought indices were utilised to classify agricultural droughts which is shown to vary spatially and temporally.

Drought severity maps were created in GIS for a better synoptic picture of drought conditions in the Parbhani and Hingoli districts of Marathwada region for year 2015 and 2020. The rainfall and dry spell data for the comparison were obtained from the Maharain portal, while the Landsat 8 satellite data was obtained from the USGS Earth Explorer portal for data analysis. The study area was divided into four drought classifications based on NDVI which were severe, moderate, mild, and no drought class and drought severity maps were created using QGIS software. Simultaneously, NDWI were estimated to obtain NDDI, which is drought indicating index. It expressed the severity of drought in study area.

It was found that, the yearly mean NDVI values for Parbhani and Hingoli districts for the normal year (2020) were 0.1925 and 0.1877, respectively. In both Parbhani and Hingoli districts, the area under Mild Drought Class was greatest in 2020, at 84.9 percent and 84.6 percent, respectively. NDVI readings for Parbhani and Hingoli districts during the 2015 drought year were 0.1580 and 0.1848, respectively. In Parbhani district, the area under Mild Drought Class was 90.9 percent; similarly, in Hingoli, the area under Mild Drought Class was 85.0 percent. It is concluded that, in both Parbhani and Hingoli districts, the area under Mild Drought Class increased during the drought year compared to the normal year which was resultant of rainfall pattern and dry spell occurrence during study period.

Similarly, the annual mean NDDI values for Parbhani and Hingoli districts for the typical year (2020) were -0.0771 and -0.0749, respectively. For the year 2020, the area covered by the No Drought Class was the greatest in both Parbhani and Hingoli districts, with 84.3 percent and 84.0 percent, respectively. The NDDI readings for Parbhani and Hingoli districts for the 2015 drought year were 0.04915 and 0.05265 respectively. In Parbhani district, the area under No Drought Class was 86.2 percent; similarly, in Hingoli, the area under No Drought Class was 89.1 percent.

After the study it was concluded that, change in NDVI was depends upon deviation of rainfall (percent increase / decrease) and distribution of rainfall (dry spells) during study period.

Keywords: Agricultural drought, Drought, Drought severity maps, Dry spell, NDDI, NDWI, NDVI, RS & GIS, Vegetation Indices

CHAPTER – I
INTRODUCTION

CHAPTER-I

INTRODUCTION

For getting information of earth's cover, remote sensing imaging is mostly used as one of the basic sources. Remote sensing is the innovative latest technique for obtaining various types of information relating vegetation condition. It is fact, it has wide coverage, regular periodicity coincident in time and is a low-cost technology. Its reliability is also increasing due to technological advances and instrumentation in the field. Remote sensing is widely used in detecting and monitoring vegetation changes and land use land cover (LULC) (Sahebjalal and Dashtekian, 2013). Remote sensing technology not only useful for acquiring information of large area within less period of time but also it is useful in acquiring information of remote area where continuous acquisition of data where other method is not possible.

Remote sensing has a wide range of applications in vegetation change detection in various manner such as, for vegetation area estimation, vegetation condition monitoring, drought management, stress determination in vegetation, water body detection, land use planning, etc. Vegetation change may be defined as the process of identifying variation in vegetation or land cover over time. Finding vegetation changes helps to identify why and where changes have occurred.

There are several methods used to detect vegetation changes, but vegetation index differencing is the most widely used (Sahebjalal and Dashtekian, 2013). There are large number of vegetation indices available ranging from very simple to very complex band combinations, in which the most widely-used vegetation index is Normalized Difference Vegetation Index (NDVI) (Sahebjalal and Dashtekian, 2013). Normalized Difference Vegetation Index (NDVI) was introduced by Deering in 1978 and Tucker in 1979.

The NDVI is calculated using visible and near-infrared (NIR) bands from Advanced Very-High-Resolution Radiometer (AVHRR), Terra Moderate Resolution Imaging Spectroradiometer (MODIS) and Landsat sensors. We derived NDVI data from Landsat 8 satellite data.

The NDVI is ratio of difference between near-infrared (NIR) and red (RED) reflectance and their sum. Where, NIR means near-infrared band (0.841–0.876

μm), and RED means band of Red (0.620–0.670 μm). NDVI varies between -1 and +1 during which the values below zero during the season indicate no vegetation cover, like desert, bare earth, cloud, snow, icepack, water body and glacier; while values quite zero within the growing season describe available vegetation cover. The NDVI data were rescaled to 0–255 to store the leads to unsigned 8-bit data.

NDVI minimizes the consequences of variations in background reflectance and emphasizes variations within the data that occur due to the density of green vegetation. NDVI allows global mapping of a greenness index for the earth's land surface and satellite measurements of greenness can provide estimates of net primary productivity (NPP), assuming that greenness is directly associated with leaf area which LAI may be a good predictor of NPP. NDVI is highly correlated with GPP and NPP. The relationship between NDVI and these two primary products is in strength line. Correlation between NDVI and both productivity measures was low for samples with bare ground and high for dense forest (Phillips *et al.*, 2008).

Two main reasons behind use of NDVI are,

- NDVI acts functionally, but not linearly, like the straightforward infrared/red ratio.
- The simple ratio (unlike NDVI) is usually positive, which can have practical advantages, but it also features a mathematically infinite range (0 to infinity), which may be a practical disadvantage as compared to NDVI.

Normalization is going to be,

- Dividing by (NIR+R) is normalizing.
- This normalization is employed to somewhat minimize the consequences of variable irradiance (illumination) level.

The healthy vegetation has low red-light reflectance and high near-infrared reflectance that produce high NDVI values. NDVI_i is one of the complex forms of NDVI means smoothed NDVI (sNDVI) observed at time step 'i' and their ratio gives a measure of photosynthetic activity. Less NDVI values indicate moisture-stressed vegetation and high values indicate a better density of green vegetation. NDVI has its further applications in complex indices such as Normalized Difference Drought Index (NDDI).

NDVI is used for drought monitoring and famine warning (Aswathy *et al.*, 2014). NDVI can also be a measure of surface reflectance and it provides a quantitative estimation of biomass and vegetation growth in combination with

physiological parameter of vegetation such as height of crop (Schaefer and Lamb, 2016).

NDWI is a Normalized Difference Water Index used for analysis of ground and plant water content. It is derived from the combination of NIR and SWIR bands. NDWI had similar range as like NDVI *i.e.*, -1 to +1 where, value below 0 indicates water scarcity and +1 value indicate highest water content in the body. In general, average NDWI values of an area remains consistently lower than 0.3 then this is considered as drought conditions and NDWI values higher than 0.4 then this is non-drought conditions (Gulácsi and Kovács, 2015). Also, this index used to derive NDDI.

Normalized Difference Drought Index (NDDI) is most widely used for calculating drought condition and monitoring drought of the study area. It is one of the supportive indices used for monitoring the vegetation. NDDI is most sensitive to drought than that of NDWI and NDVI. NDDI is a combined index derived from calculating two different indices *i.e.*, NDVI and NDWI. It also ranges between -1 to +1.

Parbhani and Hingoli districts are considered as dryland area due to the annual rainfall of Parbhani and Hingoli district are 903.2 mm and 923.6 mm respectively. But in past few decades, rainfall varied year by year, recording extreme drought events in both the district. In 2015, annual rainfall is reduced up to 417 mm and 640 mm in Parbhani and Hingoli district respectively. Which directly affected on vegetation cover and lead to drought condition.

Average temperature of Parbhani district is 21.2 °C with fluctuations ranging from 21°C in winter to 49 °C in summer. For Hingoli, annual temperature varies between 12.7 °C to 41.7 °C. The relative humidity for both the district are high during the south-west monsoon season ranging between 60 and 80 percent. After September, the humidity decreases gradually in the cold season and in summer the air is generally dry. In the summer which is the driest part of the year the relative humidity, especially in the afternoons, is less than 30 per cent. This whole change in weather conditions makes effect on vegetation cover.

The area of Parbhani and Hingoli district is 6511 sq km and 4827 sq km respectively, for which continue time repeated study for such large area is not possible. Hence, for this large area, it is necessary to use satellite image analysis for vegetation changes.

For current study, Landsat 8 satellite 16 days interval data were used to estimate vegetation indices and analyzed with the help of QGIS software for getting required imageries indices values.

Keeping in view the large geographical area of two districts under study, spatial and temporal weather variations in study area and applicability of remote sensing, this research problem was formulated to study the variations in NDVI values i.e., changes in vegetation cover during the two different situations round the year. This research included comparative study of NDVI values for two different years which are normal year and drought year.

Present study entitled “Estimation of NDVI values for Parbhani and Hingoli district of Marathwada region” was designed with following objectives.

1.1 OBJECTIVES

- 1.1.1 To estimate NDVI variations within normal year of the study area.
- 1.1.2 To estimate NDVI variations within drought year of the study area.
- 1.1.3 Comparative study of NDVI during normal and drought year for the study area.

CHAPTER – II
REVIEW OF LITERATURE

CHAPTER-II

REVIEW OF LITERATURE

Satellite data is increasingly being used to acquire information of vegetation change detection and estimation of drought severity from natural and agricultural surfaces hence, this technology was used to demonstrate this research. This study focuses on change in intensity and area of vegetation in our study region for evaluates drought severity, which is a demand for sustainable natural resource management these days.

The chapter is presented under the following objectives:

- 2.1 To estimate NDVI variations within normal year of the study area.
- 2.2 To estimate NDVI variations within drought year of the study area.
- 2.3 Comparative study of NDVI during normal and drought year for the study area.
- 2.4 Normalized Difference Water Index
- 2.5 Normalized Difference Drought Index

2.1. To estimate NDVI variations within normal year of the study area.

Deering (1978) was worked for measurement of rangeland reflectance characteristics using aircraft and spacecraft sensors. He used Landsat multi spectral scanners (MSS) and colour infrared aerial photographs for his study and data collected on six sample dates in three growing seasons from site in north central Texas. The result of this study suggested that normalized red/infrared difference parameter *i.e.*, NDVI $[(\text{Band } 6 - \text{Band } 5) / (\text{Band } 6 + \text{Band } 5)]$, was effective in adjusting for much of the variation in scene brightness. NDVI index was more sensitive to vegetation change compare to other parameters.

Tucker (1979) used red and photographic infrared linear combinations for monitoring vegetation on experimental plot biomass, Leaf water content, chlorophyll content for June, September and October months. He compared various linear combinations between IR and red with green and red. After analysis of above indices, it was observed that, the IR and red linear combinations were found to be more superior to the green/red ratio for vegetation change detection.

Wang *et al.* (2003) determined flood damage using NDVI estimation in China. The article used two NOAA-14 Advanced Very High-Resolution Radiometer (AVHRR) datasets to assess flood damage in the middle and lower reaches of China's

Changjiang River (Yangtze River) in 1998. In this study, many factors other than flooding (e.g., atmospheric conditions, different sun-target-satellite angles, and cloud) can change NDVI values, inundated areas can be distinguished from other types of ground cover by changes in the NDVI value before and after the flood after eliminating the effects of other factors on NDVI. The results showed a total of 3,58,867 ha with 2,07,556 ha of cultivated fields (paddy and non-irrigated field) inundated during the flood of 1998 in the middle and lower reaches of the Changjiang River Catchment; comparing with the reported total of 3,21,000 and 1,97,000 ha respectively. The results showed that 67.26% of the total area identified as inundated using the NOAA data.

Gallo *et al.* (2005) performed the multi-platform comparisons of MODIS and AVHRR NDVI data within the conterminous United States. NDVI data derived from RED and NIR data acquired by the AVHRR (NOAA-16 and NOAA-17) and MODIS sensors were compared over a variety of land cover classes for the same time periods. The results states that, the 16-day composite NDVI values showed similarity over the composite intervals of 2002 and 2003 and there was a linear relationship exist between the NDVI values from the various sensors.

Brown *et al.* (2006) evaluated that the consistency of the NDVI records derived from various satellite data including AVHRR, SPOT-Vegetation, SeaWiFS, Moderate Resolution Imaging Spectroradiometer and Landsat ETM+. They used independently derived NDVI at eight locations of drought and globally aggregated one-degree data from the four coarse resolution sensors to assess the NDVI records agreement. Result gives a similarity in their overall variance.

Sun and Kafatos (2007) worked on finding the NDVI-LST relationship and the use of temperature-related drought indices over North America. It is observed that the correlations between LST and Normalized Difference Vegetation Index (NDVI) depend on the season-of-year and time-of-day and it is positive for winter where strong negative for worm season. The result obtained that, the negative correlations between NDVI and LST are much stronger than those between NDVI and the brightness temperature.

Phillips *et al.* (2008) studied species energy relationship with the newest measures of ecosystem energy using NDVI derived from MODIS data in North America. In this study it was found that, NDVI was highly correlated with GPP and NPP in strength line relationship.

Quiring and Ganesh (2010) estimated NDVI values are spatially dependent on climate, soil, and topography and concluded that, more productive ecosystems have different radiometric properties than less productive ones.

An *et al.* (2013) worked on estimation of above-ground net primary productivity of the tallgrass prairie ecosystem of the Central Great Plains using AVHRR NDVI. This study was conducted to investigate the use of the normalized difference vegetation index (NDVI) to model ANPP of the tallgrass prairie. Many studies have established a positive relationship between the NDVI and ANPP but the strength of this relationship is influenced by vegetation types and can vary significantly from year to year depending on land use and climatic conditions. The creation of 1.0 km × 1.0 km resolution ANPP maps for a four-county (~7000 ha) area for years 1989-2007 showed considerable variation in annual and interannual ANPP spatial patterns, suggesting complex interactions among factors influencing ANPP spatially and temporally.

Jiang *et al.* (2013) studied on a comparative analysis between GIMSS NDVIg and NDVI3g for monitoring vegetation activity change in the northern hemisphere during 1982–2008. Their results indicated that, there were large differences between NDVIg and NDVI3g in the spatial patterns for both the overall changing trends and the timing of Turning Points in NDVI time series which spread over almost the entire study region.

Sahebjalal and Dashtekian (2013) worked for increase awareness for the LULC change in Ardakan, Iran, two Landsat ETM+ images of the years 1990 and 2006. For this purpose, they used the normalized difference vegetation index (NDVI) differencing method and its classification method for change detection and provided detailed information for detecting and monitoring changes in land use-land cover (LULC). This study resulted as, urban area of in study location was increased and agricultural land was decreased during study period.

Zhou *et al.* (2013) was developed the Integrated Surface Drought Index (ISDI) as an indicator for agricultural drought monitoring in China. The Vegetation Drought Response Index (VegDRI) and an Integrated Surface Drought Index (ISDI) were developed in this work using data-mining technologies. The ISDI construction models for three periods of the growing season have very high regression accuracy according to the cross-validation data. Satellite-based drought indices have high spatial

resolution and it covers large area as compared to station-based meteorological drought indices and this is main advantage of satellite data.

Grover and Singh (2015) made analysis of Urban Heat Island (UHI) in relation to Normalized Difference Vegetation Index (NDVI): a comparative study of Delhi and Mumbai. The validation of the heat island is done in relation to the Normalized Difference Vegetation Index (NDVI) patterns. This is proven by the correlations of surface temperature with NDVI. South Delhi, New Delhi and areas close to river Yamuna have high NDVI and therefore, record low temperatures. There exists a strong negative correlation between NDVI and UHI of Mumbai owing to less coverage of green and vegetation areas.

Gulácsi and Kovács (2015) worked on drought monitoring with spectral indices calculated from MODIS satellite images in Hungary between 2000 and 2014. The major goal of this study was to define the biophysical status of vegetation by using vegetation and water indices to derive drought indicators. The Difference Vegetation Index (DVI), Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI) and Normalized Difference Drought Index (NDDI) were investigated. However, when compared to reference data NDWI outperformed the other indices investigated in this study. Water indices were also found to be more sensitive to changes in drought conditions than vegetation indices. They intend to use high temporal resolution MODIS data products to detect drought during the growing season in future.

Li *et al.* (2015) investigated spatial and temporal patterns of vegetation cover on the Loess Plateau's Shaanxi-Gansu-Ningxia region in central China using MODIS-NDVI data for 2000–2014. The roles of regional climate change and human activities in vegetation restoration particularly from 1999 when conversion of sloping farmland to forestland or grassland began under the national Grain-for-Green program were examined. Results indicated a general upward trend in average NDVI values in the study area. The green vegetation zone has been annually extending from the southeast toward the northwest with about 97.4% of the region evidencing an upward trend in vegetation cover.

Zhang *et al.* (2015) worked on spatial-temporal NDVI variation of different alpine grassland classes and groups in Northern Tibet from 2000 to 2013. They concluded that, the NDVI variations of alpine grassland generally increased slightly but

differed among different classes and groups. Although temperature and precipitation were the driving forces influencing the NDVI of the entire alpine grassland.

Schaefer and Lamb (2016) used a combination of plant NDVI and LiDAR Measurements to improve the estimation of Pasture Biomass in Tall Fescue. When estimating total biomass, a combination of NDVI and height data was shown to be more accurate than just the NDVI. The use of combined LiDAR and active optical reflectance sensors can assist uncover the complicated interplay between green percentage and biomass in swards comprising both green and senescent material according to the study's findings.

Leslie *et al.* (2017) explained uses of Landsat imagery for a field-level production management input in domestic agricultural applications. Landsat imageries have several agricultural applications such as vegetation change, estimation of crop production, monitoring consumptive water use and national agricultural statistics service etc. Landsat imageries have several agricultural applications such as vegetation change, estimation of crop production, monitoring consumptive water use and national agricultural statistics service etc.

Lumbierres *et al.* (2017) studied on modeling biomass production in seasonal wetlands using MODIS NDVI land surface phenology. In this study they proposed a method to estimate standing aboveground plant biomass using NDVI Land Surface Phenology (LSP) derived from MODIS, which we calibrate and validate in the Doñana National Park's marsh vegetation. Estimators based on a single MODIS NDVI image performed worse ($R^2 \leq 0.41$). The determination of plant biomass using remote-sensing techniques adequately supported by ground-truth data may represent a key tool for the long-term monitoring and management of seasonal marsh ecosystems.

Shrestha *et al.* (2017) studied regression model to estimate flood impact on corn yield using MODIS NDVI and USDA cropland data layer. This paper utilizes the moderate resolution imaging spectroradiometer (MODIS) weekly normalized difference vegetation index (NDVI) product to detect and further quantify flood damages on corn within the major corn producing states in the Midwest region of the US. Utilizing the linear regression approach, change in NDVI during the growing season of corn appeared to be a good indicator to quantify the yield loss due to flood. Additionally, with the 250 m MODIS-based NDVI, these yield losses can be estimated up to field level.

Zhang *et al.* (2017) worked on vegetation dynamics and their response to climatic variability in China. Based on Spot Vegetation data and meteorological data, NDVI (Normalized Difference Vegetation Index) and its response to temperature and precipitation in China and its different regions were investigated over the period 1998–2013 by using the maximum value composite and linear regression methods. The results showed that NDVI presented significant increase (0.0046/a) for all of China and all the regions over the last 16 years.

Waikar (2018) worked on drought characterization under climate change for sustainable crop planning in Marathwada region. Drought indices based on remote sensing can be used to classify agricultural drought because they provide a better synoptic view for understanding drought affected areas in the study region. Agricultural drought assessment was carried out using remote sensing-based drought indices such as NDVI to evaluate overall vegetation condition in the study area. Agricultural drought indicators and severity were shown to vary spatially and temporally. Drought severity maps showed that the Marathwada region is divided into four categories: extreme, severe, moderate, and mild drought. As a result, agricultural drought evaluation utilizing satellite data is becoming increasingly important for assessing previous and present agricultural drought conditions and generating baseline data.

Albarakat and Lakshmi (2019) studied the comparison of normalized difference vegetation index derived from Landsat, MODIS, and AVHRR for the Mesopotamian Marshes Between 2002 and 2018. The normalized difference vegetation index (NDVI) has been derived using observations from various satellite sensors, such as the Moderate Resolution Imaging Spectroradiometer (MODIS), Advanced Very-High-Resolution Radiometer (AVHRR), and Landsat over the Mesopotamian marshlands for the 17-year period between 2002 and 2018. The results illustrated a strong positive correlation between the NDVI derived from Landsat, MODIS, and AVHRR.

Maciel *et al.* (2020) took an effort to estimate leaf water potential of coffee using landsat-8 images in Minas Gerais-Brazil. The traditional method of water conditions monitoring of coffee areas are by measuring the leaf water potential throughout a pressure pump. But in this research, this is done using satellite data between September 2014 and July 2015. The main objective of this study was to estimate the leaf water potential by surface reflectance values and vegetation indices

obtained from the Landsat-8/OLI sensor. From the correlation analysis, a quadratic algorithm that uses the NDVI performed better with a correlation coefficient. From the proposed algorithm, drought monitoring in the coffee area leading to cost reduction to the producers.

2.2. To estimate NDVI variations within drought year of the study area.

Kogan (1995) analyzed droughts of the late 1980s in the US as derived from NOAA satellite data. NOAA developed a new AVHRR-based vegetation condition index (VCI) that showed good results for drought analysis. VCI is based on normalized difference vegetation index (NDVI). The NDVI values have range of -1 to +1 which is divided into four classes *i.e.*, (1) severe drought (-0.9 to -0.3), (ii) moderate drought (-0.3 to 0.0), (iii) mild drought (0.0 to +0.3) and (iv) no drought (+0.3 to +1). This provides accurate drought information for short-term and ill-defined droughts.

Jain *et al.* (2010) worked on application various vegetation indices for evaluation of drought impact within three districts of Rajasthan state. In this research they evaluated vegetation indices from satellite data quantifying drought conditions. Satellite indices includes normalized difference vegetation index (NDVI), water supply vegetation index (WSVI) and vegetation condition index (VCI) which were derived from AVHRR. Result obtained that, analysis of drought by SPI was strongly validated by satellite indices *i.e.*, NDVI, WSVI and VCI. With this study it was cleared that, integrated analysis of ground measured data and satellite data has a great potential in drought monitoring.

Kamble *et al.* (2010) studied on drought monitoring over India through Normalized Difference Vegetation Index (NDVI). Their attempt was made to find out the vegetation responses to rainfall through NDVI over the study area. Applicability of NDVI in drought monitoring is discussed using the NDVI and rainfall data for the period 1982-2003. The anomaly of NDVI is compared with the percentage departure of rainfall of corresponding years. Results showed a significant relation between the NDVI with the percentage departure of rainfall. Trend analysis of averaged NDVI over India showed that during last two decades the vegetation status had quite improved over the dry farming tracts of India.

Renza *et al.* (2010) successfully created drought estimation maps with the use of multirate Landsat fused images. They analysed the usefulness indices such as, NDVI and NDWI and NDDI using merged data for multiple dates with the main

aim of drought monitoring to facilitate the analysis for government premises. For this analysis they were used Landsat 7 ETM+ data for the month of June within nine-year period (2001-2009). Using these three indices they created the drought map which had ultimate aim to enhance the effectiveness of decision making.

Zhong *et al.* (2010) worked on vegetation change and their response to dynamics in precipitation and temperature in the Tibetan Plateau. They evaluated the climate change by relating it with vegetation dynamics. For that vegetation change detection, they analyse time series NDVI data derived from SPOT within period of 1998 and 2006. The results of this analysis showed that, the spatial distribution of NDVI values was directly correlated with the general climate pattern in the Tibetan Plateau. Asian monsoon influences the seasonal variation. Interannual analysis showed that vegetation density had increased. It was found that, there is a time lag response present between NDVI and climate variables. The NDVI of all selected sites showed strong correlation with air temperature and precipitation except in desert grassland.

Gupta *et al.* (2011) worked on problems facing during drought disaster and mitigation strategies at Indian continent. In this research, the methods of drought monitoring, data management, impacts of drought in India and mitigation approach are critically assessed in the Indian perspective. Also, integration of drought management with the framework on natural resources and climate-change adaptation at different levels have also been discussed.

Owraangi *et al.* (2011) worked on drought monitoring methodology using AVHRR images and SPOT vegetation maps. In this study, ten-day maximum Normalized Difference Vegetation Index (NDVI) maps were created. The results of this study indicated that the pro-posed method is a potentially promising method for early drought awareness which can be used for drought risk management in semi-arid climates such as in Fars, Iran.

Srinivas (2012) worked on identification of arid and drought prone areas from remote sensing-based land surface parameters – a study from a tropical region, Maharashtra, India. In this study Normalized Difference Vegetation Index (NDVI) were estimated using the NOAA-AVHRR data from a tropical region in central Maharashtra, India to identify the arid and drought regions. A comparative analysis of remote sensing-based land surface parameters with the climatic parameters revealed that the drought prone areas were associated with typic arid to dry semi-arid climate,

very low NDVI of 0.15 to 0.30, low span of growing season of 60 to 120 days, a high surface albedo of 16.7 to 23.5 per cent, dryness quotient 2.2 to 4.7 and high land surface temperature of 300 K in contrast to the high rainfall zones in the state. The study revealed that the remote sensing-based parameters were highly useful in the detection of arid and drought prone regions and can be operationally used for the purpose with a prior long-term analysis of the data.

Aswathy (2014) used remote sensing and GIS techniques for drought monitoring and assessment in Karur district of Tamil Nadu state during 2000 to 2009. For study, IRS P6 AWiFS satellite image and IRS 1D LISS III images used. Drought analysis was performed by calculating NDVI and other indices. After evaluation NDVI it was found that, NDVI values during the year 2009 was decreased, which correlates to negative deviation in rainfall quantity of the year. From the above result it was concluded that, Normalized Difference Vegetation Index (NDVI) can be used as the major indicator to evaluate drought.

Powell *et al.* (2014) deal with a question, can NDVI response indicate the effective flood extent in macrophyte dominated floodplain wetlands? In this study they cover the test whether NDVI can characterize ecologically effective flooding patterns. Vegetation response is used as a surrogate for open water flooding in floodplain wetlands. The results showed that, high NDVI response occurs following flooding in the floodplain and wetlands and was significantly correlated to 40-day inflow volumes.

Ghaleb *et al.* (2015) worked on monitoring the vegetation health in 2014 over Lebanon region using remote sensing techniques. They classified whole study area into 5 different drought classes which is based on different indices such as VCI (Vegetation Condition Index) and TCI (Temperature Condition Index). VCI is based on NDVI value. This analysis divides whole area into different classes according to their classes. This analysis helps to take decision for monitoring, investigate and resolve drought conditions more effectively.

Chandrasekaran *et al.* (2016) studies pattern of agricultural drought during 2000-2015 in Marathwada region of India using remote sensing. Fortnightly MODIS images were used to obtain NDVI (Normalized Vegetation Index) values. The NDVI images were stacked to include seasonal image data *i.e.*, *Kharif* (June-Sept), *Rabi* (Oct-Jan), *Zaid* (Feb-Mar) for the 2000- 2015 period. From the NDVI values the

deviation (anomaly) was calculated. This study indicates that the temperature has been increasing steadily over the past 50 years and there has been a decrease in rainfall in the past two decades. These have clearly is one of the drivers for the persisting drought.

Kulkarni *et al.* (2017) worked on assessment of impacts of agro-climatological droughts over Marathwada, India, using remote sensing technologies. The investigation of droughts includes use of remote sensing data acquired by Terra Moderate - Resolution Imaging Spectroradiometer (MODIS) MOD11A2 and MOD13A2. Standard algorithms for Land Surface Temperature (LST) and Normalize Deferential Vegetation Index (NDVI) were used to estimate TCI and VCI respectively. The results obtained for overall monsoon rainfall series indicated negative rainfall trends over almost all parts of Marathwada, in which significantly decreasing rainfall trend was noticed over the Latur district. The study indicates that, water scarcity and pertinent drought conditions may continue in coming years.

Bhanage and Gedam (2018) worked for modelling and analyse the seasonal variation of UHI over the nine cities of India. In this study, they evaluated the relationship between UHI and vegetation change with season. The value of UHI and vegetation change was measured from Terra-MODIS datasets using the method of fringe analysis. In this study the vegetation changes determined by NDVI variation. Result of this study gives that the summer means and the seasonal change of UHI value are mainly varied due to the changes in the vegetation gradient between urban rural areas. Contrast to this, temperature vegetation conditions over the rural zone effects on the intensity of UHI during the winter season.

Kulkarni *et al.* (2020) developed a remote sensing-based combined drought indicator approach for agricultural drought monitoring over Marathwada, India. In this study, satellite and model-based input parameters) were analysed at a monthly scale from 2001 to 2018. Satellite based analysis consist normalized difference vegetation index (NDVI). This study found a significant increase in drought intensities ($p \leq 0.05$) and drought frequency over the years 2001–2018, especially in the Latur, Jalna, and Parbhani districts.

Rousta *et al.* (2020) worked on impacts of drought on vegetation assessed by vegetation indices and meteorological factors in Afghanistan. They used data acquired by the Moderate Resolution Imaging Spectroradiometer (MODIS) and Tropical Rainfall Measuring Mission (TRMM) sensors to examine the drought effects on

vegetation in Afghanistan from 2001 to 2018. The MODIS data included the 16-day 250-m composites of the Normalized Difference Vegetation Index (NDVI) with 1 km resolution and the results showed that the vegetation coverage for the whole country, reaching the lowest levels of 6.2% and 5.5% were observed in drought years 2001 and 2008, respectively.

Wainwright *et al.* (2020) worked on satellite-derived foresummer drought sensitivity of plant productivity in Rocky Mountain headwater catchments between 1992 and 2010. Their study area (15 × 15 km) includes four drainages within the East Water watershed near Gothic, Colorado, USA. They classified fore summer drought sensitivity based on the regression slopes of the annual peak NDVI against the June Palmer Drought Severity Index. The Results obtained from this analysis as fore summer drought sensitivity was spatially heterogeneous and it was primarily dependent on the plant type and elevation of study area. They also found that peak NDVI becomes lowered due to earlier snowmelt and drier fore summer conditions; particularly in the low-elevation regions. This study can be useful for further drought monitoring situations.

2.3 Comparative study of NDVI during normal and drought year for the study area.

Goetz (1997) studied multi-sensor analysis of NDVI, surface temperature and biophysical variables at a mixed grassland site in the Central United States. The main goals of this study were to characterize temporal variability in the normalized difference vegetation index (NDVI), retrieved surface radiant temperature (T_s) and surface biophysical variables and to test the comparability of a set of satellite and aircraft sensors. Results suggested that data from different sensors when calibrated and corrected can be used to augment spatial and temporal characteristics of datasets. Such capability decreases the trade of spatial resolution at the expense of temporal resolution (and vice versa), thus allowing observation of short-term variations in biospheric processes.

Piao *et al.* (2003) in this paper, they analyzed interannual variations of normalized difference vegetation index (NDVI) and their relationships with climatic variables (temperature and precipitation) and human activity in China between 1982 and 1999. NDVI showed the largest increase (14.4% during the 18 years and a trend of 0.0018 year) over 85.9% of the total study area in spring and the smallest increase (5.2%

with a trend of 0.0012 year) over 72.2% of the area in summer. The NDVI trends showed a marked heterogeneity corresponding to regional and seasonal variations in climates. Rapid urbanization resulted in a sharp decrease in NDVI in the Yangtze River and Pearl River deltas, while irrigation and fertilization may have contributed to the increased NDVI in the North China plain.

Wang *et al.* (2004) studied the relations between NDVI and tree productivity in the central Great Plains. This research demonstrates strong relations between NDVI and ground-based measurements of productivity for forest trees in the central Great Plains. Standardized tree ring width, diameter increase and seed production all are strongly correlated with integrated NDVI of the same growing season. All tree productivity measures, except foliage production, are better related to NDVI averaged over an intermediate spatial scale (7×7 pixels, ~50 km) rather than just local NDVI (1 pixel, 1.2 km). Overall, NDVI is an excellent predictor of annual tree productivity.

Barbosa *et al.* (2006) analyzed a 20-year study of NDVI variability over the Northeast region of Brazil. In this study, they examined the spatial heterogeneity and temporal dynamics of the NEB using a 20-year time series of Normalized Difference Vegetation Index (NDVI) observations derived from the National Oceanographic and Atmospheric Administration (NOAA)-Advanced Very High-Resolution Radiometer (AVHRR) instrument. A set of 12000 spatially distributed NDVI values was analyzed to investigate significant deviations from the mean-monthly values of the base period (1982–2001) in the study area. The results of this study suggested that, patterns in NEB vegetation variability were a result of the impact of enhanced aridity occurring over the last decade of the 20th century.

Choudhary *et al.* (2012) mapped agricultural droughts using remote sensing technique for the period of 21 years (1991–2011). Variation in vegetation can be studied using remote sensing and GIS techniques to create spatial maps of vegetation indices. In this research, Landsat TM satellite data were used for change detection. Several indices were estimated such as SAVI, VCI and TCI etc. It was found that, the year 2000, 2002 and 2010 was classified under moderate drought class.

Jamali *et al.* (2012) worked on comparing parametric and non-parametric approaches for estimating trends in multi-year NDVI. The aim of this study was to systematically compare parametric and non-parametric techniques for analysing

trends in annual NDVI derived from NOAA AVHRR sensor in order to examine how trend type and departure from normality assumptions affect the accuracy of detecting long-term change.

Revadekar *et al.* (2012) deal with impact of climate variability on NDVI over the Indian region during 1981–2010. Climatic factors are well known to be associated with vegetation. Therefore, an attempt has also been made in this study to examine the impact of climate variability on NDVI over the Indian region. During hot weather, the all-India NDVI showed the lowest values; the values increase from the onset of the summer monsoon season (June–September) onwards over the Indian region. The NDVI attains its peak value in the month of October. During drought years, there is a decrease in all-India NDVI for all months. Opposite features were seen during flood years, with a substantial increase in all-India NDVI from the month of October onwards compared to normal years. This clearly indicates the impact of heavy summer monsoon rainfall over the country on NDVI during winter (October–December) and suggests that soil moisture gained by flood conditions helps the NDVI to increase. In contrast, drought conditions showed an immediate effect on NDVI but the incremental changes are of smaller magnitude. Spatial patterns also showed similar features, with negative anomalies in NDVI over large parts of the country during drought years and positive anomalies during flood years.

Thavorntam and Tantemsapya (2013) worked on Vegetation greenness modelling in response to climate change for North-East of Thailand using Multi-Temporal NDVI satellite imagery. The multi-temporal Terra MODIS Vegetation Indices Product was used for collection of NDVI data from 2001 to 2009 to evaluate the seasonal fluctuation of vegetation greenness in main land cover categories in the region. Both deciduous and evergreen forests had a declining trend in NDVI values, according to the findings. Utilizing linear regression, a vegetation greenness model was created using correlations between NDVI and meteorological data. They concluded that, the model may be used to detect changes in plant greenness and dynamics as a function of temperature and rainfall, according to the findings.

Guay *et al.* (2014) studied that vegetation productivity patterns at high northern latitudes: a multi-sensor satellite data assessment. They compared long-term changes in vegetation productivity at high northern latitudes ($>50^{\circ}\text{N}$), estimated as trends in growing season NDVI derived from the most widely used global NDVI data

sets. Their results highlight both critical uncertainties and areas of confidence in the assessment of ecosystem-response to climate change using satellite-derived indices of photosynthetic activity.

Kaushalya *et al.* (2014) studied assessing agricultural vulnerability in India using NDVI data products. Impact of climate change on Indian rainfed agriculture was assessed using temporal NDVI data products from AVHRR and MODIS. Methodology was developed to analyze NDVI variations with spatial pattern of rainfall using 10 X 10 girded data and spatially interpolating it to estimate Standard Precipitation Index. Study indicated large variations in vegetation dynamics across India owing to bio-climate and natural resource base. First ever estimates of agricultural vulnerability for India indicates 20.4 to 33.1% agricultural land under risk from climate change.

Gaikwad and Kale (2015) made assessment of agricultural drought during the post-monsoon season with Landsat 8 in Vaijapur taluka. The benefit of geospatial technology is that satellite photos may be used to understand drought-prone areas and their severity levels. Landsat 8 pictures from the years 2013 and 2014 were utilized in this study to measure drought in the post-monsoon season from October to December. The impact of post-monsoon rainfall on agriculture fields can be seen in the examination of vegetation cover using the NDVI, VCI, and SAVI indices. The year 2013 was influenced by agricultural drought, according to the research.

Sruthi *et al.* (2015) did analysis of agricultural drought using normalized difference vegetation index (NDVI) in Raichur district. The goal of this research was to use NDVI and land surface temperature (LST) calculations to assess vegetation stress in the Raichur district (LST). The MODIS data is utilised to calculate both the NDVI and the Land Surface Temperature. The combination of the normalised difference vegetation index (NDVI) and the long-term temperature (LST) gives extremely important data for agricultural drought monitoring and early warning system for the farmers. When the correlation between LST and NDVI is calculated, it is evident that they have a strong negative relationship. For the years 2002 and 2012, the correlation between LST and NDVI is -0.635 and -0.586, respectively.

Esau *et al.* (2016) studied on trends in normalized difference vegetation index (NDVI) associated with urban development in northern West Siberia. The study utilizes the normalized difference vegetation index (NDVI) from high resolution (250

m) MODIS data acquired for summer months (June through August) over 15 years (2000–2014). The results reveal the increase of NDVI (or “greening”) over the northern (tundra and tundra-forest) part of the region. Simultaneously, the southern forested part showed the widespread decrease of NDVI (or “browning”).

Ozelkan *et al.* (2016) worked with Landsat 8 OLI imagery for multiscale object-based drought monitoring and comparison in rainfed and irrigated agriculture during 2013-2014 within Turkey’s most important agricultural district - Southeast Anatolia. In this area, they evaluated NDVI data from Landsat 8 OLI to estimate meteorological drought. The results of this study showed that over the rainfed areas it is seen that, positive correlations between SPI and NDVI appear, whereas negative correlations were determined over the irrigated agricultural areas. Finally, it is concluded that there was a strong correlation between spring SPI and summer NDVI in both 2013 and 2014.

Sholihah *et al.* (2016) identified agricultural drought extent based on vegetation health indices of Landsat in Subang and Karawang, Indonesia (total study area was near about 184.486 ha) within long term sequence of 2000, 2005, 2010, and 2015 dry season. Vegetation Health Index (VHI) is used as a vegetative drought index using Landsat data. It helps to measure either moisture vegetation/vegetation condition (VCI) derived from NDVI. The results revealed that decrease in VHI decreased causes increase in severity of drought from mild drought in 2000 to severe drought in 2015. Also, due to decrease in NDVI values in recent years helps to leading agricultural fields more susceptible to drought.

Khosravi *et al.* (2017) studied the effect of drought on vegetation in desert area of Yazd - Ardakan plain, central Iran using Landsat data. In this study, they firstly calculated annual average for SPI index from 1996 to 2015, and then normalized difference vegetation index (NDVI) was calculated for May in 1998, 2000, 2009, 2010, 2011 and 2015. Where NDVI maps were classified into three groups such as no vegetation, poor vegetation and dense vegetation. It is noted that NDVI was a proper indicator of moisture condition and used as an important data source for detecting and monitoring drought in the arid and semiarid regions.

Huang *et al.* (2019) deal with dynamic changes of NDVI in the growing season of the Tibetan plateau during the past 17 years and its response to climate change. In this, the characteristics of temporal and spatial differences of NDVI to

different climate factors are summarized. The result indicates different trends of NDVI in the study area changes with time interval.

Kalisa *et al.* (2019) studied assessment of climate impact on vegetation dynamics over East Africa from 1982 to 2015. We have already known that Africa is known the severe vegetation degradation. Some known reasons are associated with the climate change events and unprofessional agricultural practices. For this purpose, the Advanced Very High-Resolution Radiometer (AVHRR) version 3 NDVI (NDVI3g) and Climate Research Unit (CRU) datasets for precipitation and temperature were used to assess the impact of climate factors on vegetation dynamics over East Africa from 1982 to 2015. Results reveal that the vegetation of the croplands (non-croplands) over East Africa changed insignificantly by $6.9 \times 10^{-5}/\text{yr}$. ($5.16 \times 10^{-4}/\text{yr}$.) suggesting that non-croplands are fast getting reduced Nonetheless, the NDVI growth responses to monthly and seasonal changes in climate were adjudged to be complex and dynamic.

Dagnachew *et al.* (2020) studied effects of climate variability on Normalized Difference Vegetation Index (NDVI) in the Gojeb river catchment, Omo-Gibe Basin, Ethiopia. This study was conducted to examine the effects of climatic variability (rainfall) on NDVI for the periods 1982–2015 in the Gojeb river catchment and they concluded that the Sen's slope trend analysis and MK significant test indicated that the magnitude of annual NDVI and rainfall showed significant decrement and/or increment in various portions of the Gojeb river catchment.

2.4 Normalized Difference Water Index (NDWI)

Gao (1996) proposed the new indices *i.e.*, NDWI—A normalized difference water index in his article used for estimation of vegetation liquid water using satellite data. He experienced that, NDWI is sensitive to change of water content in leaves of plants whereas, NDWI is less sensitive to atmospheric changes. NDWI is between NDVI and NDWI for an individual index which is alternative to NDVI. he did the comparison over Jasper ridge in California and High plains in Northern Colorado.

McFeeters (1996) focused on the identification of open water features using the Normalized Difference Water Index (NDWI). The Normalized Difference Water Index (NDWI) is a new method for identifying open water features in remotely sensed digital photography and enhancing their visibility.

Jackson *et al.* (2004) worked for evaluation of NDWI using Landsat data Vegetation water content mapping for corn and soybean crop. In this experiment two indices studied, these were the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Water Index (NDWI). They observed that, NDVI saturated during the study period while the NDWI continued to reflect changes in vegetation water content. They used NDWI to map daily VWC for the watershed over the 1-month and found that, NDWI was performed superior for quantitative analysis of bias and standard error.

Chen *et al.* (2005) estimated VWC using MODIS near- and short-wave infrared bands for corn and soybeans in Iowa, USA as part of the Soil Moisture Experiments. In this experiment, all possible combinations were derived from 7 different MODIS bands were used to construct vegetation indices. After evaluating the performance of all derived combinations, it is concluded that, NDVI and NDWI indices performs best with respect to other.

Gu *et al.* (2007) studied for 5 years on NDVI and NDWI indices using MODIS data for grassland drought assessment over the central Great Plains of the US. Initially they observed that, these are strong relationship between NDVI, NDWI, and drought conditions. They observed that, NDWI values revealed a quicker response to drought conditions than NDVI. They concluded that, combination of NIR and SWIR is very sensitive to drought. Combination of both NDVI and NDWI results NDDI gives more accuracy in drought monitoring than NDVI alone.

Gu *et al.* (2008) evaluated NDVI and NDWI using MODIS data for vegetation drought monitoring with the use of Oklahoma Mesonet soil moisture data over the 2002–2006 growing seasons. They found that the correlation between NDVI and NDWI indices and the fractional water index (FWI) was highly dependent on soil type and land cover heterogeneity. The result showed that, there is strong correlation between NDVI and NDWI indices and the fractional water index (FWI) in homogeneous vegetation cover while low relation at heterogeneous vegetation cover on soil.

Ji *et al.* (2011) worked on normalized difference water index using near-infrared (NIR) and shortwave-infrared (SWIR) reflectance used to indicate vegetation moisture condition. They studied several definitions, associated sensors and channel

specifications; they observed three variants of SWIR region (1.2–1.3, 1.55–1.75 or 2.05–2.45 μm).

2.5 Normalized Difference Drought Index (NDDI)

Cheng-lin and Jian-jun (2008) derived NDWI using MODIS data for drought monitoring in Jiangxi province of mid-territory in China. They also used land use map and soil humidity of crop as a supportive data for the growing season and structured a simple model of Jiangxi province for crop drought monitoring. Using NDDI indices they analysed crop drought condition of the study area and developed operational crop drought monitoring system.

Bai *et al.* (2012) worked on NDDI using MODIS data with aim to analysis of spatio-temporal characteristics of drought in Southwest China in 2010. Firstly, they prepared NDVI and NDWI indices using MODIS data and then by combination of these two indices they evaluated NDDI. During evaluating NDDI process, pixel reliability data acquired from MODIS product was introduced. The main aim of this data was to eliminate noise such as clouds and ice or snow in NDDI calculation. Then, the correlation between NDDI and ground-based soil moisture and vegetation condition index (VCI) was analysed. The result obtained that NDDI was sensitive to ground soil moisture to shallow surface drought severity than that of VCI. The result showed that the period of severe drought conditions lasted from January to April in 2010 occupied more than 75% of the total area of Guizhou Province. Meanwhile, area suffered with "heavy drought" occupied more than 50% of the total area of study area.

Khampeera *et al.* (2018) evaluated drought indices in Kuan Kreng Peat Swamp (KKPS) during 1984 to 2013 for study special characteristic of drought. They classified NDDI into 5 classes. The NDDI showed that vegetation of study area was affected due to this being the summer season with high temperatures and less moisture in the air by the drought between February and September.

Tavazohi and Ahmadi (2018) worked on assessment of drought using NDDI indices. This study was conducted in the Zayandehroud basin during 2000-2015. For this study Landsat images was used during 2000 to 2015. NDVI, NDWI and NDDI was estimated using Idrisi Taiga software. The result of this study showed that, NDDI index indicated an ascending trend in the drought within the 2000 to 2015. The result of the study helps in drought monitoring in study area.

Guha *et al.* (2019) analysed seasonal variability in normalized difference vegetation index, normalized difference water index, in Raipur City. The study was carried out using four seasonal Landsat 8 data.

Dobri *et al.* (2021) worked evolution and severity of drought on Arable Lands in Romania Derived from Normalized Difference Drought Index (NDWI) during 2001 to 2020. NDDI was obtained using MODIS sensor of the Terra satellite. According to Normalized Difference Drought index, the driest year was 2003 and wettest year was 2016. Simultaneously, the correlation between NDDI and precipitation amount was investigated and its results reveals that the annual regional mean NDDI is overall negatively correlated with annual rainfall. And hence they concluded that NDDI is most suitable and effective indices for drought monitoring in study area.

CHAPTER – III
MATERIALS AND METHODS

CHAPTER-III

MATERIALS AND METHODS

This chapter includes information about location of study area, datasets which were used to fulfil the objectives and methods of analysis adopted to achieve the objectives of the research.

3.1 Location of Study Area

Study area comprise of middle part of Marathwada region of Maharashtra. The study area includes two districts namely Parbhani and Hingoli for research study. The information regarding geographical, location, meteorological details along with land use is given in Table 3.1 (Waghmare, 2013a and 2013b).

Table 3.1: Information of Study Area

Content	Districts	
	Parbhani	Hingoli
Area (Sq. Km.)	6511	4827
Latitude	76° 13'E to 77° 26' E	76° 16' E and 77° 28' E
Longitude	18° 45'N to 20° 01'N	19° 14'N to 20° 01' N
Altitude (m) above sea level	407	547
Agro-Climatic Region (Planning Commission)	Western Plateau and Hills Region (IX)	Western Plateau and Hills Region (IX)
Agro Ecological Sub Region (ICAR)	Deccan Plateau, Hot Semi- Arid Eco-Region (6.2)	Deccan Plateau, Hot Semi- Arid Eco-Region (6.2)
Agro Climatic Zone (NARP)	Central Maharashtra plateau Zone (MH-7)	Central Maharashtra Plateau Zone (MH-7) & Central Vidarbha Zone (MH-8)
Annual rainfall (mm)	903.2	923.6
Normal rainy days	44	45
Soil type	Black cotton soils	Black cotton soils
Major Drainage	One;	Three;

	Godavari	Penganga, Purna, Kayadu
Talukas	Nine; Parbhani, Jintur, Gangakhed, Pathri, Purna, Palam, Selu, Sonpeth and Manwat	Five; Hingoli, Sengaon, Aundha Nagnath, Kalamnuri and Vasmat.
Principal crops	Cotton, Cereals, Pulses, Jowar, Wheat	Cotton, Cereals, Pulses, Jowar, Wheat
Land use (Sq. Km) and Percent area (%)		
1. Forest Area	278.08 (4.26%)	275 (5.69%)
2. Net Area Sown	4859.53 (74.63%)	4451.36 (92.21%)
3. Cultivable Area	3610.62 (55.45%)	4509.42 (93.42%)
Irrigation Area ('000 ha) and Percent area (%)		
Net Irrigated area	131.77 (2.02%)	80.42 (1.67%)
Gross irrigated area	182.27 (2.8%)	204.3 (4.23%)
Rainfed area	387.01(5.94%)	293.2 (6.07%)

3.1.1 Location

Parbhani district lies between 18° 45' N and 20° 01' N latitude and 76° 13' E and 77° 26' E longitude. Which has the total geographic area of about 6511 sq km. The elevation above the mean sea level is 407 m. The area comes under Deccan Plateau, Hot Semi-Arid Eco-Region.

Whereas, the Hingoli district locate between 19°14' N to 20°01' N Latitude and 76°16' E and 77° 28' E Longitude with 547 m elevation from mean sea level. The total geographic area of Hingoli district is about 4827 sq km.

3.1.2 Geography

Parbhani district is located towards eastern part of Maharashtra and it is one of the eight districts of Marathwada division. The population of Parbhani district is 15.27 lakhs and it ranks 8th in the Maharashtra State. Near about 68.24% population is rural. It includes nine talukas Parbhani, Jintur, Gangakhed, Pathri, Purna, Palam, Selu, Sonpeth and Manwat with two sub-divisions which together have 841 villages and 9 towns. Mainly the population of Parbhani district is depends upon agriculture, industry, commerce and transport claiming only a small share of it.

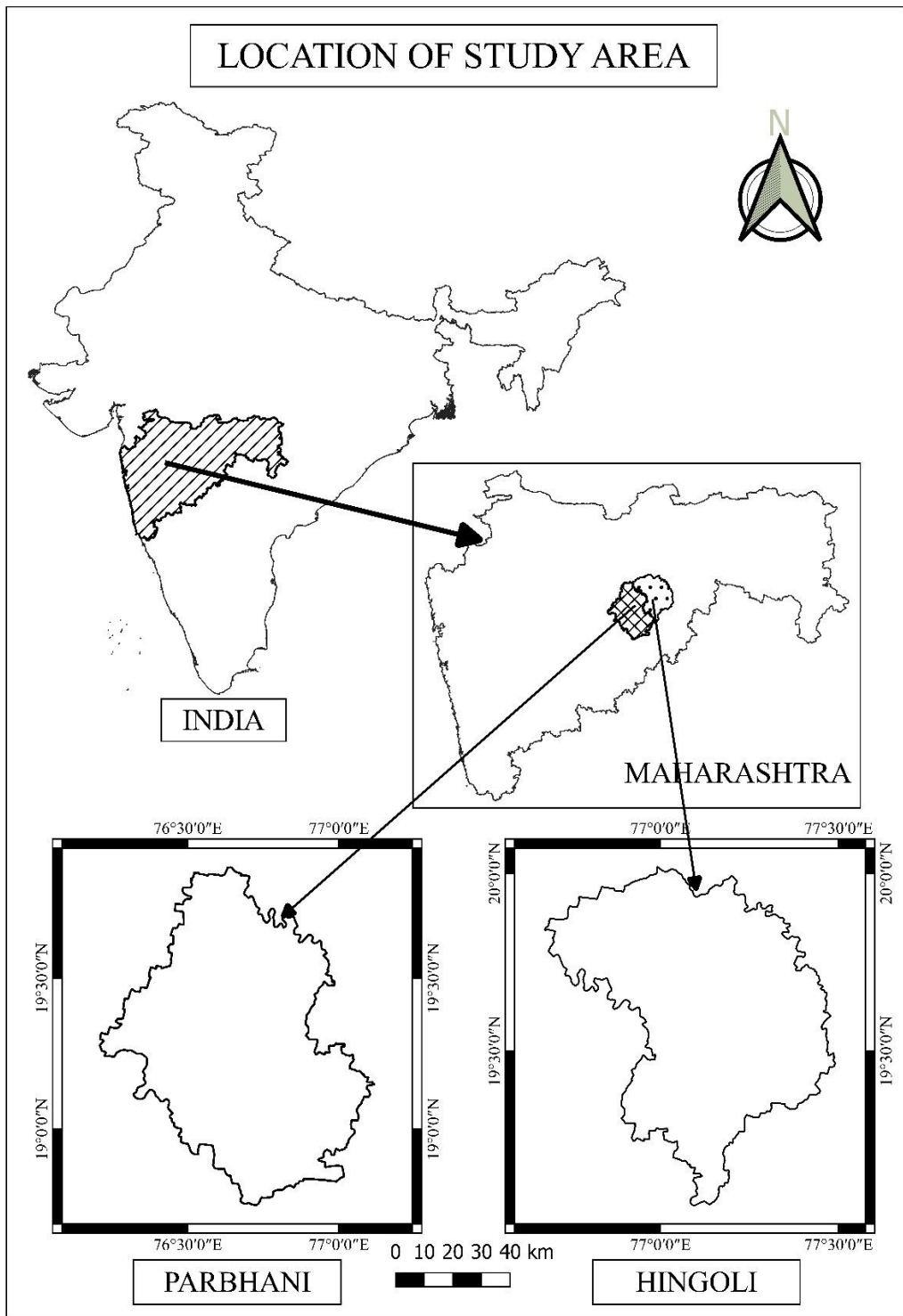


Figure 3.1: Location of Study Area

The Hingoli district comprises of 5 talukas viz: Hingoli, Sengaon, Kalamnuri, Aundha Nagnath and Vasmal. The district forms the part of Marathwada region of Maharashtra and is bordered by Parbhani district in the west, Buldhana district in the north, Yavatmal and Washim districts in the east and Nanded district in the south.

Parbhani district bounded by Hingoli in North East, Nanded in South East, Latur in South, Beed in South West and Jalana in North East. Similarly, Hingoli is bounded by Washim, Yavatmal, Nanded, Parbhani and small share with Buldhana in clockwise direction starting from North side. Both the districts come under Deccan Plateau, Hot Semi-Arid Agro Ecological Region and in the Western Plateau and Hills Agro Climatic Region.

As a part of the Deccan Plateau, the land of Parbhani and Hingoli districts has a general elevation of about 407 m and 547 m above the sea level respectively. The Godavari River crosses over the district boundary. Topography of Pathri, Partur (except its northern part), Gangakhed and Parbhani talukas have plain surface. But Jintur, Hingoli, Kalamnuri and the northern and eastern parts of Partur and Basmath talukas are hilly and mountainous in nature. The Hingoli district as a whole belongs to the Godavari peninsular drainage, but the area of the district mainly belongs to two river systems, one in the north and north-east: the Penganga and other is the Marathwada Purna and other immediate tributaries of the Godavari flowing in this district.

The Parbhani district belongs to the Godavari peninsular drainage, but the area distributes under two river systems, one in the north the Penganga and the other in the north-east the Marathwada Purna and other immediate tributaries of the Godavari flowing in this district. On the other hand, Hingoli district is covered by three main drainage systems viz: (1) Penganga River and (2) the Purna and (3) Kayadu rivers.

Both the districts mainly rich in Black Cotton or Regure type soil. But in Northern and southern part of Parbhani district contain light and medium black cotton soil whereas central part is rich in heavy black cotton soil. In Hingoli district, due to higher ground elevation the thickness of the soil cover is less in northern and western parts consequently soil regur, gravels, *murum* are transported down to lower regions through gravity, water or winds. This soil is suitable for cultivation of Cotton, Cereals, Pulses, Jowar and Wheat. Also, in river basin region Sugarcane is grown using

irrigation facilities. This soil contains high Nitrogen, Medium Phosphorus and Low amount of Potassium.

3.1.3 Climate

The climate of the Parbhani district is generally hot and dry except during the S-W monsoon season. The average annual rainfall recorded in Parbhani district is 903.2 mm which decreases from the east to the west. The meteorological data is collected in VNMKV, Parbhani as a representative of whole district. The cold weather starts from the end of November when the temperatures commence to fall. December is the coldest month with the mean temperature range lies between 12.6 °C to 29.3 °C.

The highest relative humidity observed during the south-west monsoon season (June to September) ranging between 60 and 80 percent. After SW monsoon, the humidity decreases gradually; cold and dry air observed during Winter season (October to February) whereas, hot and dry air appears in summer (March to May) *i.e.*, less than 30 per cent humidity.

Hingoli is dry and tropical region having hot summer and mild winter season. Humidity higher during S-W monsoon. The temperature range of the district is varying between 12.70° C to 41.70° C. The average annual rainfall of the Hingoli district is 923.6 mm. the humidity of this district is lower than 30 per cent in dry season and higher only during S-W monsoon. The Length of Growing Period is lies between 90 to 150 days.

3.1.4 Cropping Pattern

In the study area, during *kharif* (S-W monsoon) season Soybean, Cotton, Sorghum and Green gram were cultivated in most of the parts and Rabi Sorghum, Wheat, Gram, Sunflower and Safflower were cultivated during post monsoon season. In river basin of both the districts during *rabi* season Sugarcane crop were sown. In summer season, Groundnut production under irrigated condition is taken in some part of study area. If sufficient irrigation facility available then Mango and Banana fruit cropping is done in both districts. Seasonal crops like Soybean, Cotton, Sorghum and Green gram have full vegetation coverage in June, July, while annual crops like Sugarcane, Banana and Turmeric covers land completely in month of October-November.

3.2 Dataset used

Now a days, remote sensing and GIS techniques widely used well enough for assessment of Agricultural drought. Several types of satellite sensors like Landsat, MODIS, ASTER, AVHRR, AWiFS and ETM+ are present from which we can acquire required data which is used as the input for various methods throughout the electromagnetic spectrum and are capable for the identification, location and severity of the agricultural drought. In the present study, Landsat 8 data having eleven bands out of which one in visible range and two in infra-red range were used for estimation of vegetation indices for drought classification.

3.2.1 Satellite Used

Landsat 8 images with a resolution of 30 m were selected to extract NDVI. Landsat 8 is an American earth observation satellite launched on 11th February, 2013. It comprises passive type sensors containing the camera of the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS) which can be used to study earth surface temperature, to study global warming and also for find out some important indices such as NDVI. For calculation of NDVI we used band 4 and band 5 *i.e.*, visible red and near infrared respectively. Collecting data at the temporal and geographic scales necessary to capture agricultural activities is a significant endeavor. By the use of remote sensing technology, satellite imagery captured by Landsat, offers one of the most effective and efficient means of collecting temporal and spatial data on agricultural activities (Leslie *et al.*, 2017). The Landsat 8 Level-1 data was downloaded from USGS Earth Explorer (NASA LPDAAC Collection) (open-source data) for two years 2015 and 2020 as per the availability of data except data having large cloud cover. For the month of August, which have cloud cover, Oceansat-2 satellite filtered ORD sensor NDVI data was used. The details are given in Table.3.2.

3.2.2 Instrument used

- **Computer:** Used to run the image processing and other software.
- **Software used: A. Microsoft office 2019**
B. MS-Excel used for numerical data arrangement, analysis and graphs creation.
C. QGIS 3.16.4 used for database collection, data analysis and maps creation.

QGIS gives a world of different options for special processing required for this research. QGIS provides different tools required for data analysis. QGIS is very fast processing and freely available. It uses a small

amount of time to carry out task this is because of the intern structure. Hence, in this research QGIS is selected.

Table 3.2: Satellite data information

1.	Satellite	Landsat-8		Oceansat-2	
2.	Data portal	Earth Explorer – USGS		Bhuvan platform of ISRO	
3.	Data type	Landsat collection Level-1		Filtered – Ortho Rectified Data	
4.	Spatial Resolution	30 m		0.01017 Degree (1080 m)	
5.	Temporal Resolution	16 days		-	
6.	Row and path	a. Path: 145, Row: 46 b. Path: 145, Row: 47		Path: 09, 10, 11 Row:12, 13, 14	
7.	Bands used	a. Band-4 (Red) b. Band-5 (NIR) c. Band-7 (SWIR)		OCM 2 sensor	
8.	Date of Data acquisition	2015	2020	2015	2020
		2015/01/20	2020/01/18	01 to 15	01 to 15
		2015/02/05	2020/02/03	August, 2015	August, 2020
		2015/02/21	2020/02/19	16 to 31	16 to 31
		2015/03/09	2020/03/06	August, 2015	August, 2020
		2015/03/25	2020/03/22		
		2015/04/10	2020/04/07		
		2015/04/26	2020/04/23		
		2015/05/28	2020/05/09		
		2015/06/29	2020/05/25		
		2015/07/15	2020/06/26		
		2015/09/01	2020/07/12		
		2015/10/03	2020/09/30		
		2015/10/19	2020/10/16		
		2015/11/04	2020/11/17		
		2015/11/20	2020/12/03		
		2015/12/22	2020/12/19		

3.2.3 Estimation of Normalized Difference Vegetation Index

In the present study, Landsat-8 data having eleven bands out of which band-4 (Red) and band-5 (NIR) were used for estimation of NDVI (Normalized Difference Vegetation Index) based agricultural drought indices at the same time, band-4 (Red) and band-7 (SWIR) were used to estimate NDWI (Normalized Difference Water Index). And using NDVI and NDDI, NDDI (Normalized Difference Drought Index) were estimated.

A. Normalized Difference Vegetation Index

Normalized Difference Vegetation Index (NDVI) is based on the concept that amount of vegetation and it indicates availability of water or its stress and is a measure of the “greenness” or amount of vegetation. It is based on the known radiational properties of plants, using visible (red) and near-infrared (NIR) radiation. NDVI is the ratio of difference between NIR and Red to the sum of NIR and Red bands, it expressed as:

$$NDVI = \frac{NIR-RED}{NIR+RED} \quad \dots\dots\dots[Deering (1978), Tucker (1979)]$$

Where, NIR and RED are the reflectance in the near infrared and red bands.

$$\text{For Landsat 8, } NDVI = (\text{Band 5} - \text{Band 4}) / (\text{Band 5} + \text{Band 4})$$

Chlorophyll present in leaves absorb more red radiation which is the visible part of solar spectrum where as it reflects more NIR radiation. Hence, NDVI is used as best index to identify and estimate vegetation covered area. Good vegetation reflects maximum NIR radiation and absorb much of the red light. If there is maximum difference between reflected NIR and red radiation, NDVI value becomes high. Then, this higher NDVI value indicates good healthy vegetation. Whereas, difference between NIR and red radiation reflection is little then minimum NDVI value indicates unhealthy vegetation or partially or non-vegetative surface.

NDVI values range between -1 to +1. In which +1 value indicates highest possible density of vegetation, zero and below zero NDVI value indicating low or no green vegetation. Areas of barren rock, sand, and snow produce NDVI values of 0.1 or less, while shrub and grassland typically produce NDVI values of 0.2-0.3, and temperate and tropical rainforests produce values in the 0.6-0.8 range. NDVI values are spatially dependent on climate, soil, and topography and hence, more productive

ecosystems have different radiometric properties than less productive ones (Quiring and Ganesh, 2010).

The temporal change in NDVI based drought indices were obtained using satellite images and GIS tool which were further used for assessing drought severity for Study area.

The NDVI values have range of -1 to +1, which is divided into four classes (Kogan, 1995 and Waikar, 2018) such as,

Severe drought	:	-1.0 < NDVI < -0.3
Moderate drought	:	-0.3 < NDVI < 0
Mild Drought	:	0 < NDVI < 0.3
No Drought	:	0.3 < NDVI < 1.0

B. Normalized Difference Water Index

Normalized Difference Water Index (NDWI) is Remote sensing-based indicator used to detect change in water content in leaves (Gao,1996). NDWI was introduced by McFeeters [1996]. NDWI is the ratio of difference between NIR and SWIR to the sum of NIR and SWIR bands, it expressed as:

$$NDWI = \frac{\rho_{858} - \rho_{2130}}{\rho_{858} + \rho_{2130}} \quad \dots\dots\dots (Ji \text{ et al. } 2011)$$

Where, NIR and SWIR are the reflectance in the near infrared and short-wave infrared bands.

For Landsat 8, NDVI = (Band 5 – Band 7) / (Band 5 + Band 7)

Similar to NDVI, the NDWI value also ranged between -1 to +1, where, maximum water content in leaves. When drought or scarcity of water occurs in leaves then NDWI value will reduces.

C. Normalized Difference Drought Index

Normalized Difference Drought Index (NDDI) is used drought monitoring. This index is the combination of above two NDVI and NDWI indices. NDDI is the ratio of difference between NDVI and NDWI to the sum of NDVI and NDWI bands, it expressed as:

$$NDDI = \frac{NDVI - NDWI}{NDVI + NDWI}$$

Also, the NDDI varies between -1 to +1. This is the more sensitive indicator than above two indicators *i.e.*, NDVI and NDWI for drought. Where, maximum value of NDDI indicates drought condition at the same time NDVI and

NDWI becomes low. While minimum NDDI value indicate no drought or non-water scarcity condition. When NDDI becomes low, NDVI and NDWI values becomes higher indicating high vegetation with sufficient water.

The Normalized Difference Drought Index (NDDI) was in mainly divided into five classes and two extra supplementary classes for out-of-range values (Khampeera *et al.* 2018). These classes are-

Class		NDDI Values
Water Body	:	$\text{NDDI} < -1.0$
No Drought	:	$-1 < \text{NDDI} < 0.2$
Mild Drought	:	$0.2 < \text{NDDI} < 0.3$
Moderate Drought	:	$0.3 < \text{NDDI} < 0.4$
Severe Drought	:	$0.4 < \text{NDDI} < 0.5$
Extreme Drought	:	$0.5 < \text{NDDI} < 1.0$
Unclassified	:	$1.0 < \text{NDDI}$

The flow chart of methodology used to achieve the objectives of present study is as shown as below in Fig 3.2.

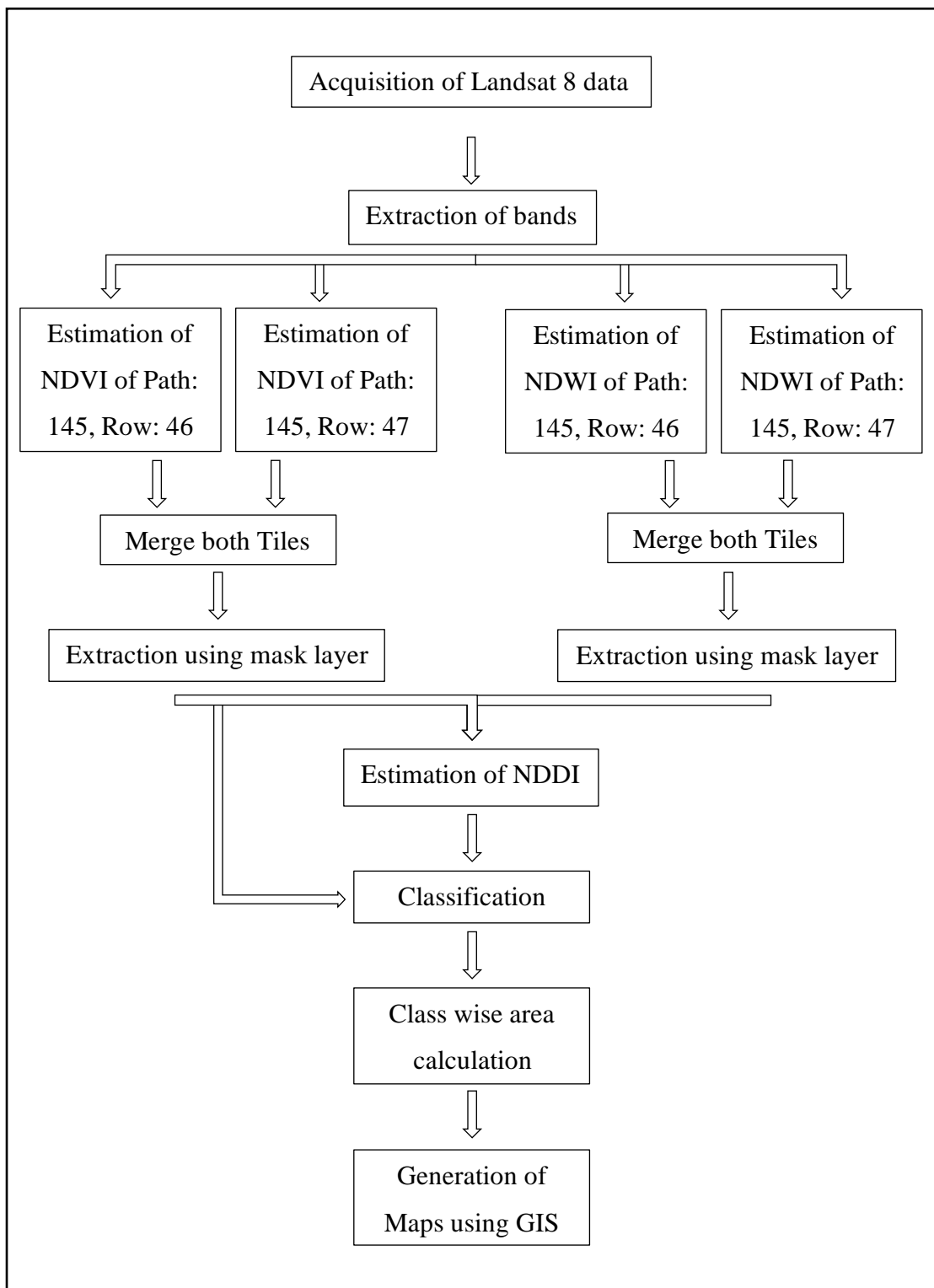


Fig. 3.2: Flow chart of research methodology used in present study

CHAPTER – IV
RESULTS AND DISCUSSION

CHAPTER-IV

RESULTS AND DISCUSSION

The study has been undertaken with the objectives of estimation of NDVI variation within normal and drought year in Parbhani and Hingoli district of Marathwada region. Study regarding temporal trend estimation of various agricultural drought indices in Parbhani and Hingoli district was done using remote sensing data. The obtained results are discussed in this chapter. For this study, Landsat 8 Level-1 data of 16 days temporal resolution were acquired and analyzed. The attempts have been made to analyze these indices on monthly basis. For the better understanding and identification of drought, another drought indices *i.e.*, NDDI (Normalized Difference Drought Index) were used for analyzing agricultural drought in Parbhani and Hingoli district for the study period.

In this chapter, after data analysis results are proposed under the following heads,

4.1 Rainfall and rainy days of study area during study period

4.2 NDVI variations within normal year (2020) of the study area

4.3 NDVI variations within drought year (2015) of the study area

4.4 NDDI variations within normal year (2020) of the study area

4.5 NDDI variations within drought year (2015) of the study area

4.6 NDVI and NDDI comparison between normal and drought year of the study area

4.1 Rainfall and rainy days of study area during study period

The rainfall and rainy days occurred during the study period *i.e.*, 2015 and 2020 are presented in Table 4.1 and the data were plotted graphically in Fig. 4.1. and Fig, 4.2 for Parbhani and Hingoli districts respectively. The weather data and dry spell data for the corresponding period of experiment were collected from official website Department of Agriculture, Maharashtra State. For Parbhani district, in year 2015 the annual rainfall was 417.8 mm which was (-53.7%) deviated from normal rainfall, where as in case Hingoli, the deviation of rainfall was -22.2 % of normal. Year 2015 was come under drought condition for Parbhani and Hingoli districts (Kulkarni *et al.*, 2017; Kulkarni *et al.*, 2020 and report on the spot study of water situation in drought affected areas of the country 2015-16).

Table 4.1: Monthly rainfall (mm) and rainy days (day) in study area

Year	Parbhani					Hingoli				
	Avg.	2015		2020		Avg.	2015		2020	
	RF	RF	RD	RF	RD	RF	RF	RD	RF	RD
January	6.3	10.6	2	3.1	1	5.1	22.6	2	5.9	1
February	3.0	0.1	0	2	0	3.5	6.3	1	0.7	0
March	8.7	23.8	2	4.8	0	7.2	75.9	6	14.4	2
April	6.0	39	6	0	0	6.3	38.4	6	1.7	0
May	14.2	6.2	1	3.7	0	11.7	7.6	1	6.5	1
June	145.3	79.9	10	196.8	16	169.2	157.2	13	235.4	16
July	219.2	23.5	4	229.3	20	230.2	44	4	276.6	20
August	227.8	85.3	10	133.9	17	241.2	165.9	10	192.4	16
September	169.0	138.2	11	261.2	18	154.7	192.7	12	256.3	17
October	77.6	9.8	2	104	9	64.3	8.3	2	110.4	9
November	17.5	1.4	0	0.9	0	17.9	0	0	1.4	0
December	8.6	0	0	0.1	0	12.3	0	0	0.4	0
Total	903.2	417.8	48	939.8	81	923.6	718.9	57	1102.1	82
Deviation	-	-53.7	-	+4.1	-	-	-22.2	-	+19.3	-

*RF – Rainfall in mm, *RD - Rainy Days (Source: <https://maharain.maharashtra.gov.in>)

The data regarding occurrence of dry spell during the study years (2015 and 2020) of both the districts (Parbhani and Hingoli) is given Table 4.2. For Parbhani district, the frequency of dry spell was 6 times with duration of 88 days in 2015 whereas, in 2020 the frequency of dry spell occurrence was 5 times with duration of 32 days. In case of Hingoli district in 2015, the dry spell was recorded 6 times with 84 days duration and in 2020 it was 3 dry spells for 34 days.

Satellite-based drought indices have high spatial resolution and it covers large area as compared to station-based meteorological drought indices and this is main advantage of satellite data (Zhou *et al.* 2013). Variation in vegetation can be observed by spatial maps of vegetation indices prepared by using remote sensing and GIS techniques (Owringi *et al.*, 2011; Choudhary *et al.*, 2012; Thavorntam & Tantemsapya 2013; Aswathy *et al.*, 2014; Gaikwad and Kale, 2015 and Sruthi *et al.*, 2015).

The NDVI and NDDI maps of the years 2015 and 2020 were generated for each month of study year using Landsat data. In case of August month, images of Oceansat-2 were used instead of Landsat 8. The NDVI values were classified into four classes and area under each class was estimated using ‘raster layer unique value report’ tool.

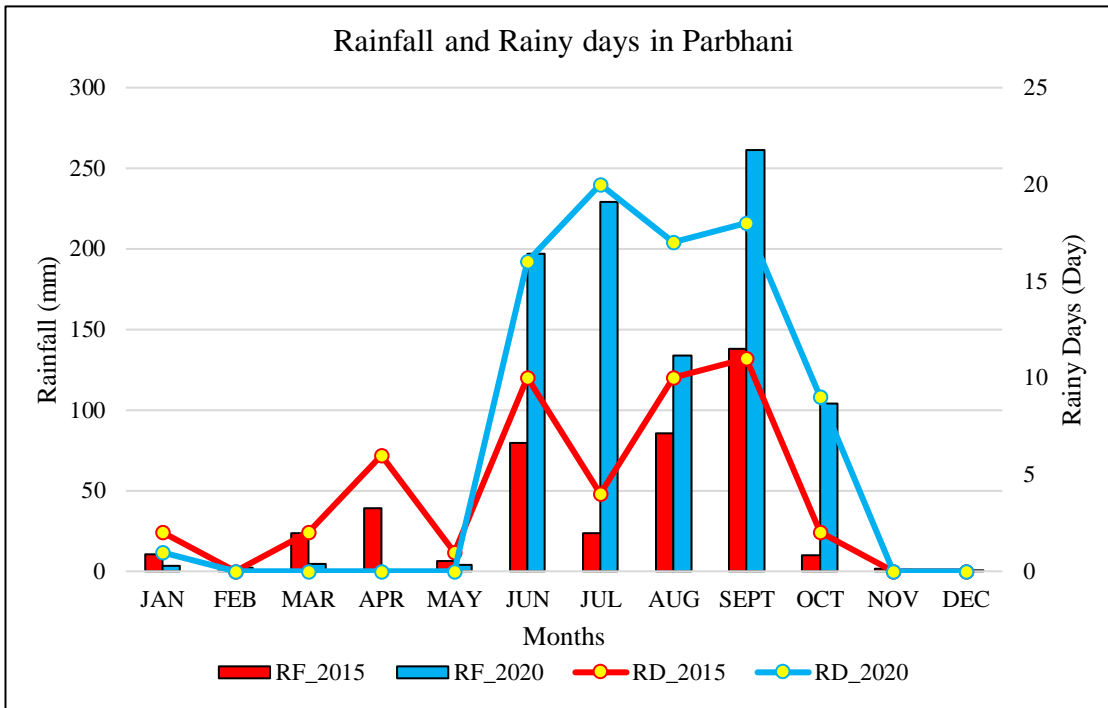


Fig. 4.1 Monthly rainfall and rainy days for Parbhani

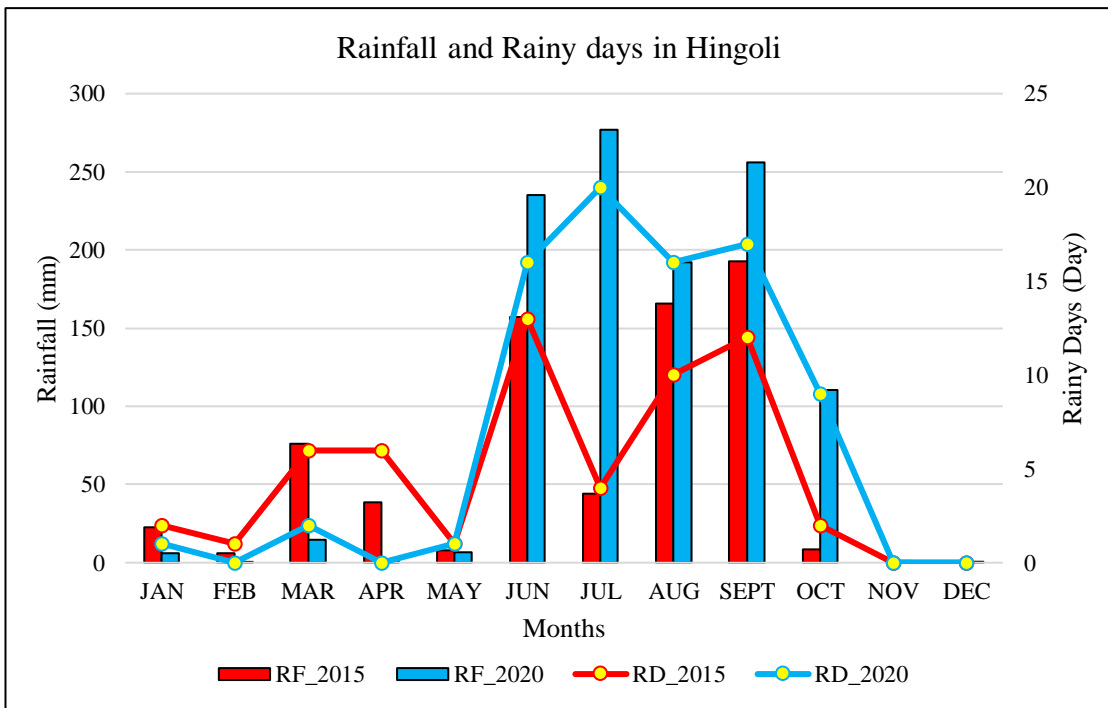


Fig. 4.2 Monthly rainfall and rainy days for Hingoli

Table 4.2 Dry spell and its duration in study area

Months	District	Parbhani				Hingoli			
	Year	2015		2020		2015		2020	
		Dry spell	Days	Dry spell	Days	Dry spell	Days	Dry spell	Days
June	From	01/06/2015	8	04/06/2020	7	24/06/2015	7	-	-
	To	08/06/2015		10/06/2020		30/06/2015		-	
	From	20/06/2015	11	-	-	-	-	-	-
	To	30/06/2015		-		-			
July	From	03/07/2015	19	-	-	03/07/2015	19	-	-
	To	21/07/2015		-		21/07/2015		-	
	From	26/07/2015	10	-	-	26/07/2015	10	-	-
	To	04/08/2015		-		04/08/2015		-	
August	From	-	-	28/08/2020	10	21/08/2015	10	23/08/2020	15
	To	-		06/09/2020		30/08/2015		06/09/2020	
September	From	20/09/2015	13	-	-	22/09/2015	11	-	-
	To	02/10/2015		-		02/10/2015		-	
October	From	05/10/2015	27	03/10/2020	7	05/10/2015	27	02/10/2020	9
	To	31/10/2015		09/10/2020		31/10/2015		10/10/2020	
	From	-	-	16/10/2020	7	-	-	20/10/2020	12
	To	-		22/10/2020		-		31/10/2020	
	From	-	-	24/10/2020	8	-	-	-	-
	To	-		31/10/2020		-		-	
Total		6	88	5	32	6	84	3	34

(Source: <https://maharain.maharashtra.gov.in/>)

4.2 NDVI variations within normal year (2020) of the study area

Monthly NDVI map of Parbhani district was developed using fortnight images for the normal year of 2020 and is shown in Fig.4.3 (a) and 4.3(b). and Hingoli district maps are given in Fig. 4.4(a) and 4.4(b).

4.2.1 NDVI variation within normal year (2020)

Table 4.3: Monthly minimum, mean and maximum NDVI of Parbhani in 2020

Months	Min. NDVI	Mean NDVI	Max. NDVI
January	-0.0778	0.207	0.4703
February	-0.0851	0.1959	0.4924
March	-0.1033	0.1837	0.495
April	-0.109	0.1519	0.5361
May	-0.1001	0.1231	0.4965
June	-0.0226	0.1238	0.4946
July	-0.1482	0.2011	0.5931
August	0.1225	0.6403	1
September	-0.0649	0.2165	0.5816
October	-0.2107	0.2396	0.595
November	-0.1172	0.2564	0.5383
December	-0.1162	0.2198	0.4823
Mean	-0.105	0.1926	0.5250
Annual	-0.0533	0.1925	0.4032

In Table 4.3, monthly minimum, mean and maximum NDVI values for Parbhani of year 2020 are given. It is observed that, in the year of 2020 the minimum mean NDVI value was 0.1231 in May month and the maximum mean value was 0.6403 in August month for Parbhani district. The same relation was observed between NDVI and rainfall by Zhang *et al.*, (2015). In case of Hingoli district monthly NDVI values given in Table 4.4, NDVI value 0.1063 and 0.597 are minimum and maximum monthly mean NDVI in June and August month respectively. Similar trends of NDVI values were in found in Kamble *et al.*, (2010).

Mean NDVI values denotes the vegetation in both the district. Based on the above values it is very clear that in the year May - June months there was minimum

vegetation occurred whereas, August month had maximum vegetation compared to other Months of year 2020. The respective greenness of vegetation is visible in maps.

Table 4.4: Monthly minimum, mean and maximum NDVI of Hingoli in 2020

Months	Min. NDVI	Mean NDVI	Max. NDVI
January	-0.0639	0.2105	0.4872
February	-0.0748	0.1881	0.4967
March	-0.0941	0.1599	0.5427
April	-0.1148	0.136	0.539
May	-0.0987	0.1139	0.5267
June	-0.0434	0.1063	0.4588
July	-0.1589	0.2646	0.6032
August	0.0625	0.597	1
September	-0.0065	0.1953	0.4954
October	-0.1345	0.2385	0.628
November	-0.0857	0.239	0.5434
December	-0.0774	0.2127	0.4824
Mean	-0.0866	0.1877	0.5275
Annual	-0.0521	0.1877	0.3810

4.2.2 Area estimation of classified image within normal year (2020)

According to Kogan (1995) classification, the study area was classified and their area distribution was estimated. For year 2020 classified area distribution given in Table 4.5 and Table 4.6 for Parbhani and Hingoli district respectively.

The estimated value indicates that, whole year except August, October and November months maximum area *i.e.*, above 80% area comes under Mild Drought Class. Whereas, in August, October and November months area of No Drought Class were increased for Parbhani district due to sufficient rainfall in year 2020. Similar method uses by Kogan (1995) to classify NDVI values.

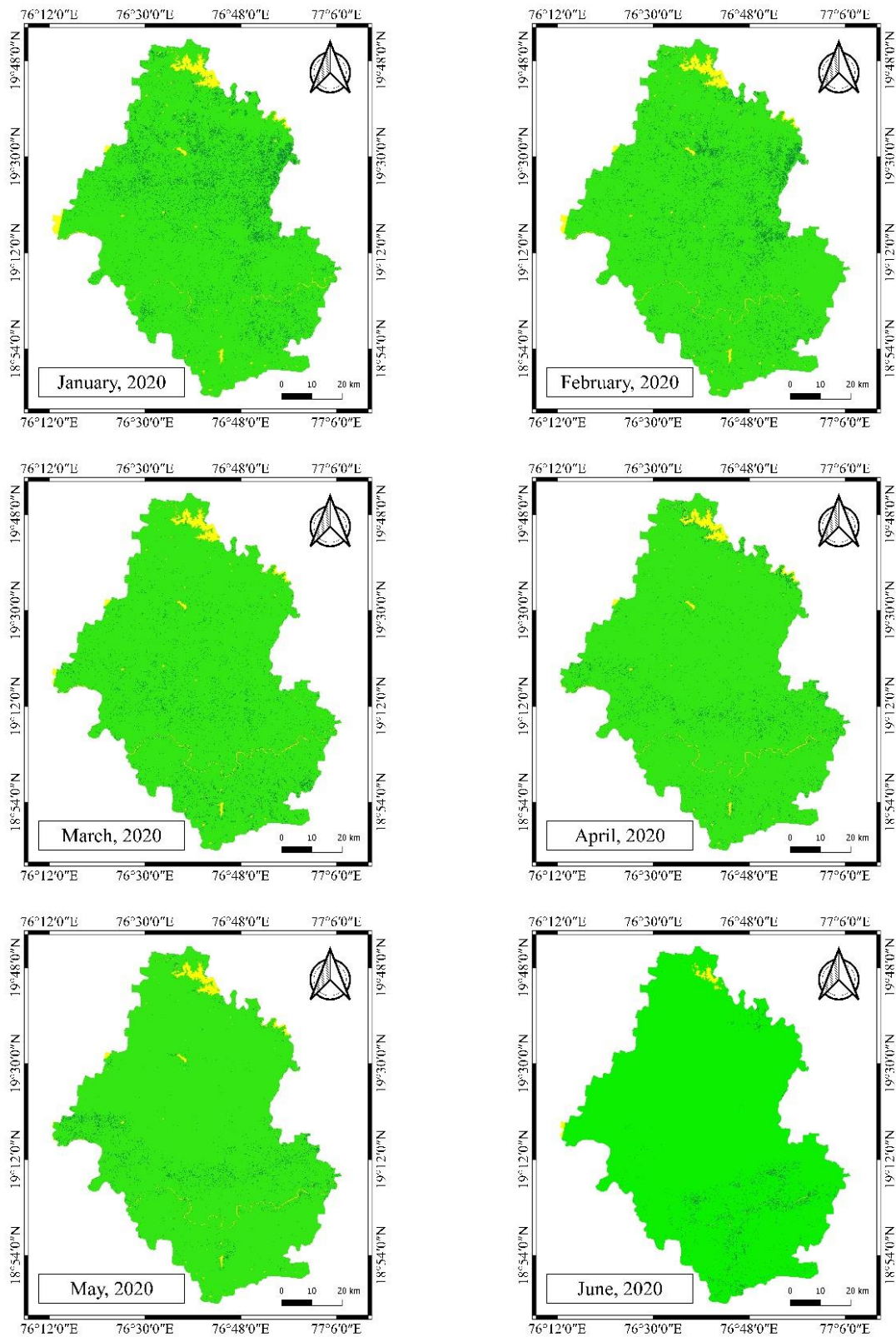
Similarly, in Hingoli district the area classified in July, August, October and November have more vegetation as compared to other months in which, August month contains 98.9 % area under No drought class and remaining three months, area under No Drought Class was more than 28 %. Piao *et al.*, (2003) found similar variation in classified NDVI area with respect to change in seasonal pattern.

Table 4.5: Percentage Area of classified NDVI for Parbhani district in 2020

Months	Severe drought	Moderate drought	Mild drought	No drought	Total
January	0	2.01	89.2	8.77	100
February	0	1.85	91.8	6.31	100
March	0	1.78	94.3	3.93	100
April	0	1.58	95.3	3.07	100
May	0	1.43	96.2	2.42	100
June	0	0.41	97.6	2	100
July	0	0.71	82.2	17.1	100
August	0	0	0.69	99	100
September	0	0.09	82.6	17.3	100
October	0	1.6	63.3	35.1	100
November	0	2.13	59.9	38	100
December	0	2.08	82.3	15.6	100
Mean	0	1.31	77.9	20.7	100
Annual	0	1.30	77.94	20.71	0

Table 4.6: Percentage Area of classified NDVI of Hingoli district in 2020

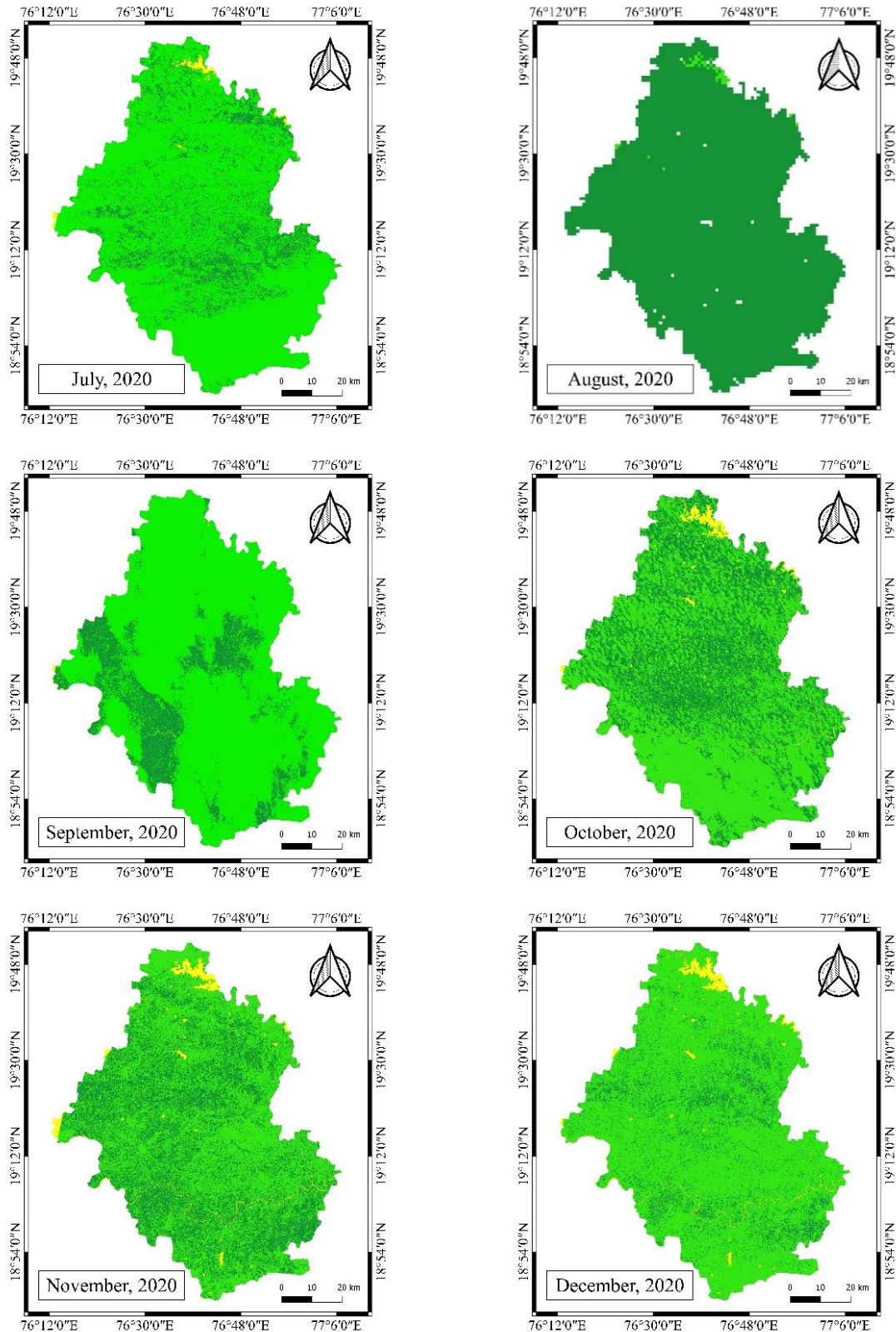
Months	Severe drought	Moderate drought	Mild drought	No drought	Total
January	0	2.25	81.7	16.1	100
February	0	2.05	88.8	9.1	100
March	0	2.09	95.8	2.11	100
April	0	1.97	94.6	3.4	100
May	0	1.8	95.6	2.59	100
June	0	0.09	99.3	0.62	100
July	0	1.04	64.8	34.1	100
August	0	0	1.09	98.9	100
September	0	0.03	90.3	9.72	100
October	0	1.18	65.5	33.3	100
November	0	2.45	68.9	28.7	100
December	0	2.6	85.9	11.5	100
Mean	0	1.46	77.7	20.9	100
Annual	0	1.30	77.94	20.72	0



Legend - NDVI values

-1.0 to -0.3	-0.3 to 0	0 to 0.3	0.3 to 1.0
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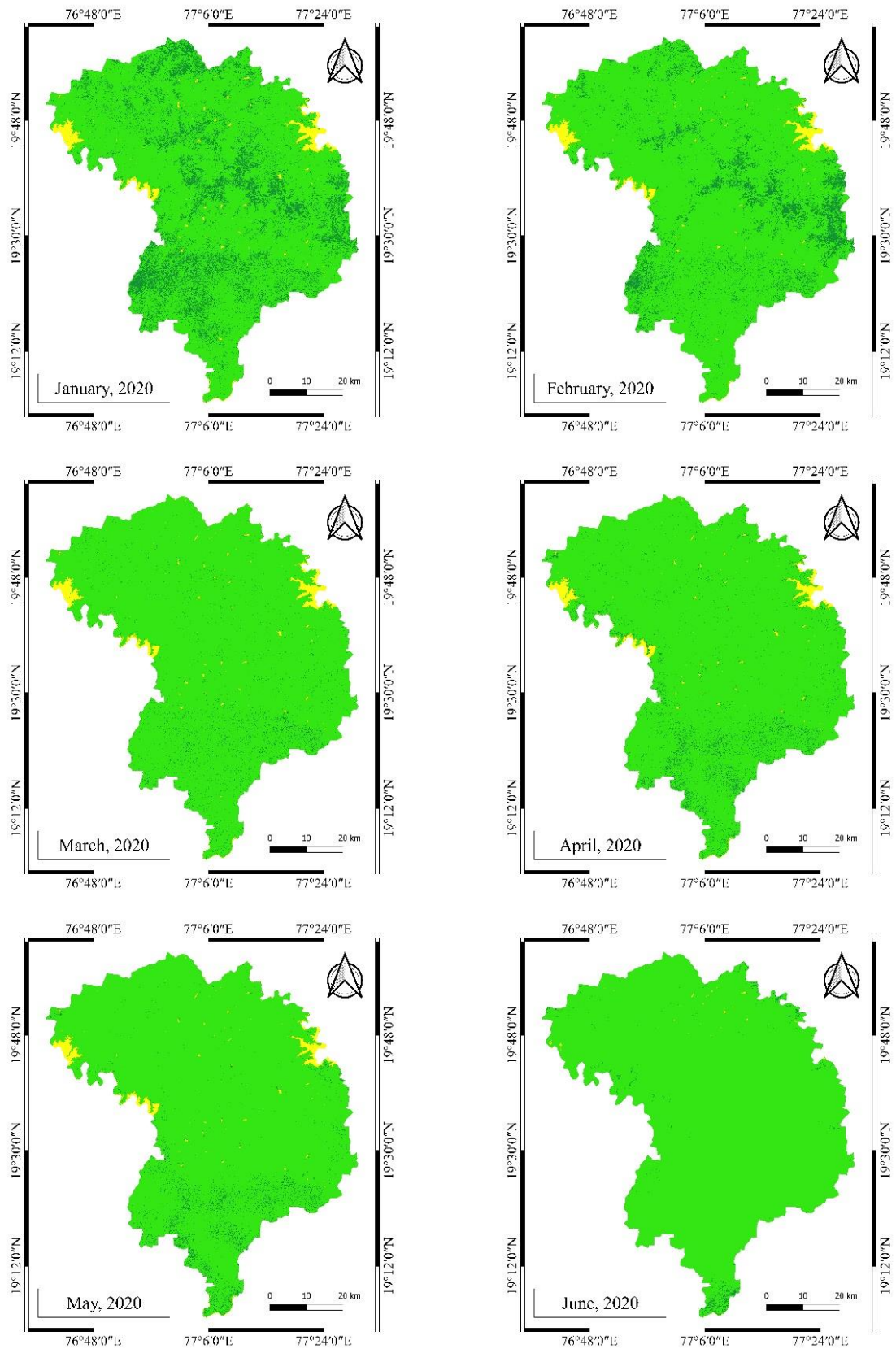
Fig 4.3(a): NDVI variations within normal year (2020) of the Parbhani



Legend - NDVI values

■ -1.0 to -0.3	■ -0.3 to 0	■ 0 to 0.3	■ 0.3 to 1.0
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Fig 4.3(b): NDVI variations within normal year (2020) of the Parbhani



Legend - NDVI values

■ -1.0 to -0.3	■ -0.3 to 0	■ 0 to 0.3	■ 0.3 to 1.0
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Fig 4.4(a): NDVI variations within normal year (2020) of the Hingoli

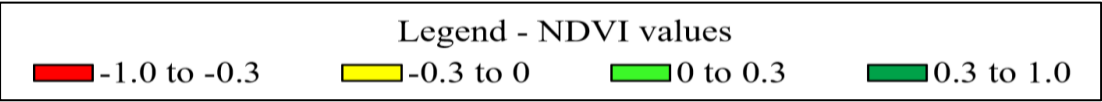
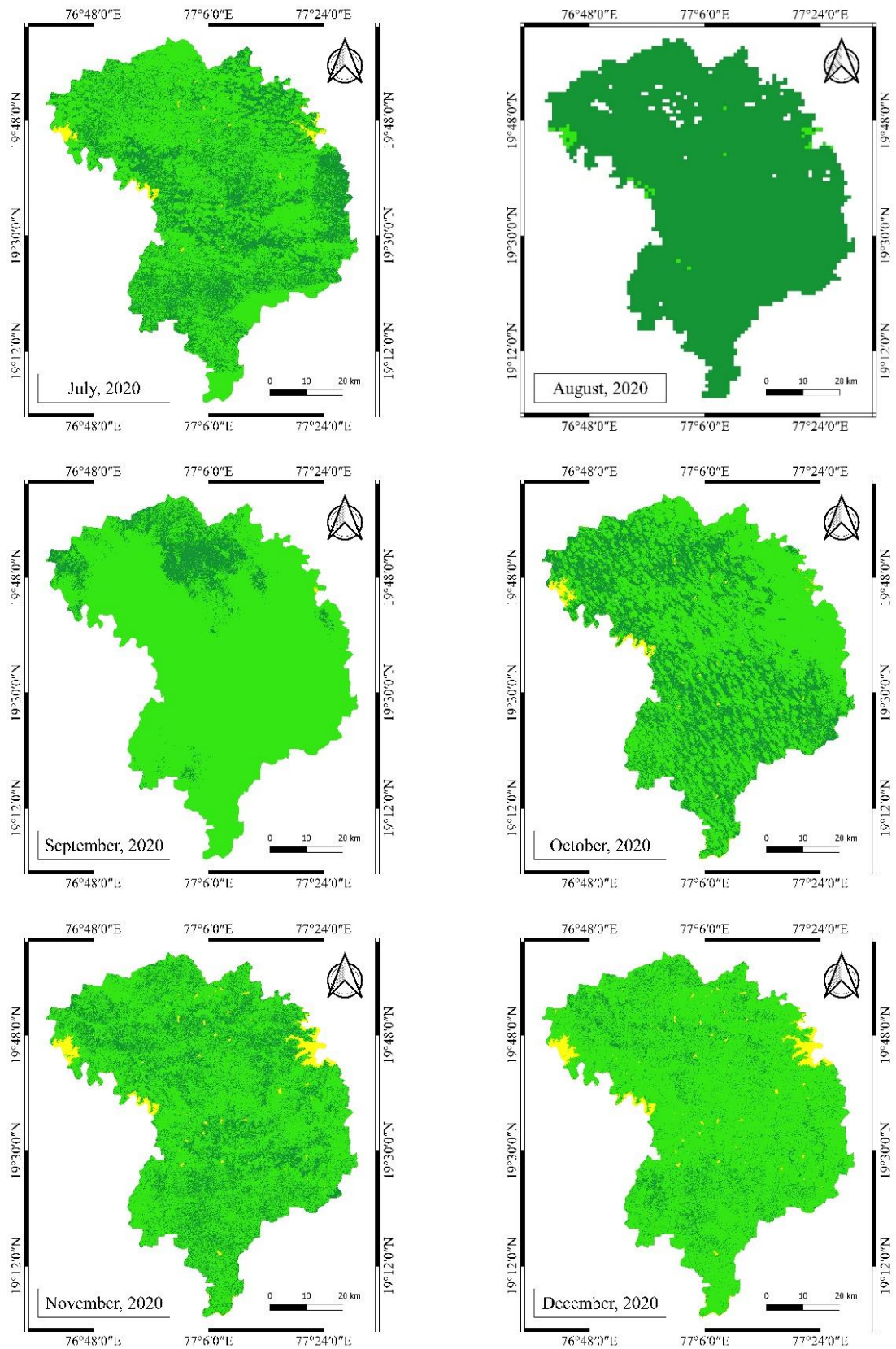


Fig 4.4(b): NDVI variations within normal year (2020) of the Hingoli

4.3 NDVI variations within drought year (2015) of the study area

In Fig.4.5 (a) and 4.5(b) monthly NDVI map of Parbhani district were arranged. While Hingoli district maps were given in Fig.4.6(a) and 4.6(b) for the drought year 2015. Renza *et al.* (2010) successfully created drought estimation maps with the use of Landsat 7 ETM+ data for the month of June from 2001 to 2009 for nine-year period.

4.3.1 NDVI variation within drought year (2015)

The monthly minimum, mean and maximum NDVI values of drought year 2015 were given in Table 4.7 for Parbhani districts. In month of January, there was lowest mean NDVI for Parbhani district was observed and 0.5841 was the highest mean NDVI values observed in August month as compared to other months in year 2015. Similar findings were found in Revadekar *et al.*, (2012), that NDVI values of the study area were decreased in summer season where in month of October NDVI attends peak point value.

Table 4.7: Monthly minimum, mean and maximum NDVI of Parbhani in 2015

MONTH	Min. NDVI	Mean NDVI	Max. NDVI
January	-0.0394	0.0892	0.3026
February	-0.107	0.136	0.4815
March	-0.1387	0.1396	0.505
April	-0.1052	0.1209	0.4852
May	-0.0915	0.1029	0.4256
June	-0.0453	0.1056	0.4303
July	-0.0248	0.1229	0.3904
August	0.0474	0.5841	1
September	-0.1154	0.3021	0.6106
October	-0.0774	0.2403	0.4868
November	-0.1352	0.2046	0.5134
December	-0.1157	0.174	0.4869
Mean	-0.0905	0.1580	0.4653
Annual	-0.0607	0.1580	0.3647

In Table 4.8, the monthly minimum, mean and maximum NDVI values of drought year 2015 was given for Hingoli district. The lowest mean NDVI for Hingoli

district was 0.1048 in May and 0.6796 is the highest mean NDVI values observed in August month. Similar method was used in Sahebjalal and Dashtekian (2013) to estimate of NDVI for year 1990 to 2006.

Table 4.8: Monthly minimum, mean and maximum NDVI of Hingoli in 2015

MONTH	Min. NDVI	Mean NDVI	Max. NDVI
January	-0.0449	0.1169	0.3836
February	-0.0964	0.1559	0.5092
March	-0.126	0.1462	0.531
April	-0.1007	0.1302	0.5294
May	-0.0813	0.1048	0.4843
June	-0.0245	0.1335	0.391
July	-0.0256	0.1708	0.415
August	0.2025	0.6796	1
September	-0.0965	0.4047	0.62
October	-0.0556	0.2636	0.4927
November	-0.1318	0.2235	0.5362
December	-0.1046	0.1826	0.4594
Mean	-0.0807	0.1847	0.4865
Annual	-0.0571	0.1848	0.3696

It can be noted that in Parbhani, drought existed in months of January to June while in other months of July to December vegetation condition starts to improve with rainfall in study area. Similarly, for Hingoli district severity of drought condition was appears from January to June then starts to decalin.

4.3.2 Area estimation of classified image within drought year (2015)

In case of drought year 2015, in Parbhani district area under Mild Drought Class was always more than 95 % except 4 months from August to November. In which August month had only 9.05 % area come under Mild Drought Class which was again increased in successive months. The percentage area distribution of classified NDVI of Parbhani district in year 2015 is given in Table 4.9. Similar method was used by Waikar (2018) to classify the area according to NDVI values for Marathwada region.

Table 4.9: Percentage Area of classified NDVI of Parbhani district in 2015

Months	Severe drought	Moderate drought	Mild drought	No drought	Total
January	0	0.68	99.3	0	100
February	0	0.88	96.9	2.19	100
March	0	0.83	96.9	2.25	100
April	0	0.62	98.5	0.86	100
May	0	0.65	98.8	0.55	100
June	0	0.25	99.5	0.25	100
July	0	0.06	99.9	0.04	100
August	0	0	9.05	87.2	96.2
September	0	0.61	46.6	52.8	100
October	0	0.64	80	19.4	100
November	0	0.75	88.6	10.6	100
December	0	0.64	95.4	3.96	100
Mean	0	0.55	84.1	15	99.7
Annual	0	0.55109	84.12	15.00	0

Table 4.10: Percentage Area of classified NDVI of Hingoli district in 2015

Months	Severe drought	Moderate drought	Mild drought	No drought	Total
January	0	1.12	98.4	0.44	100
February	0	1.57	92.9	5.55	100
March	0	1.48	95.7	2.79	100
April	0	1.29	97	1.75	100
May	0	1.08	97.7	1.2	100
June	0	0.03	99.2	0.77	100
July	0	0.02	98.6	1.36	100
August	0	0	1.11	96	97.1
September	0	0.78	14.4	84.8	100
October	0	1	66.7	32.3	100
November	0	1.44	81.8	16.7	100
December	0	1.33	93.3	5.38	100
Mean	0	0.93	78.1	20.8	99.8
Annual	0	0.92	78.07	20.75	0

Table 4.10 gives the percentage area distribution for Hingoli. In Hingoli district, the area of classified NDVI is changes according to rainfall. In subsequent months August and September, rainfall is high 165.9 and 192.7 mm respectively, it results into area with high NDVI values increases for both August and September months while other months had shown Mild Drought in Hingoli district.

According to above study, we analyzed the change in vegetation condition in both districts using remote sensing and GIS. Hence, remote sensing and GIS are the most efficient tools for temporal and quantitative analysis of the drought severity in the region. With the help of NDVI, we can evaluate the vegetation change and using another complementary index like NDDI we can analyze drought condition easily. Hence, NDVI coupled with other indices may be used for assessing drought condition in the study area.

Comparative study of NDVI and rainfall in study area indicated the decline in vegetation cover is due to change in rainfall pattern and appearance of dry spell. Similar results were found in Thavorntam & Tantemsapya (2013) that, there was significant correlation between NDVI and rainfall was observed in Thailand which could be used for identify drought events in the region. Fig. 4.7 and Fig. 4.8 shows monthly mean NDVI for Parbhani and Hingoli district respectively.

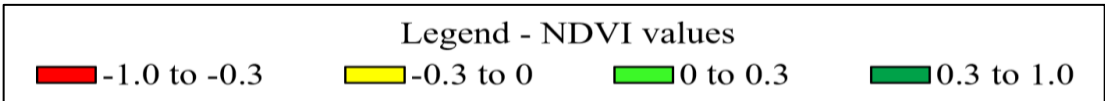
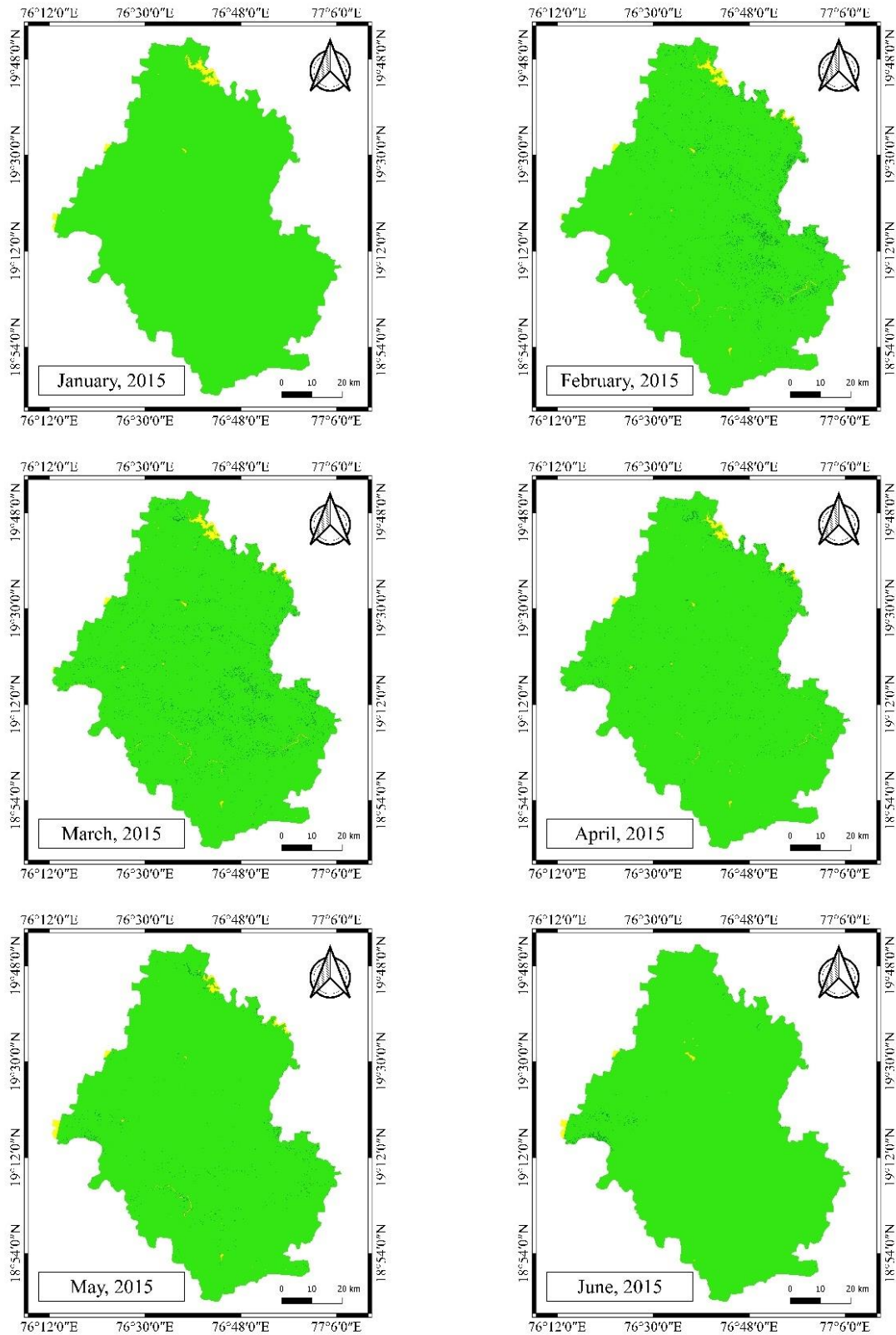
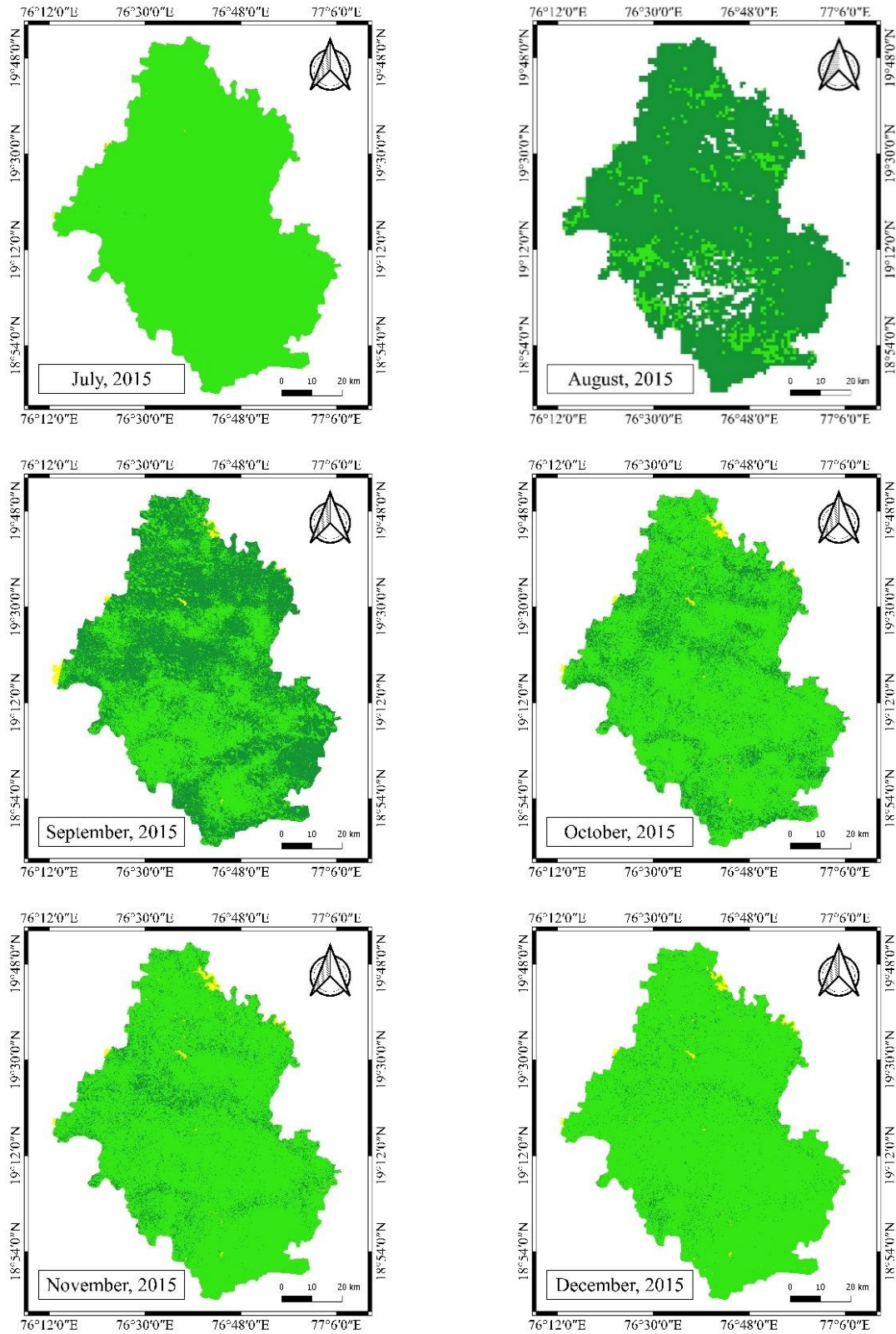


Fig 4.5(a): NDVI variations within drought year (2015) of the Parbhani



Legend - NDVI values

Fig 4.5(b): NDVI variations within drought year (2015) of the Parbhani

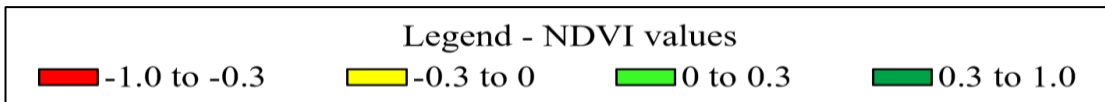
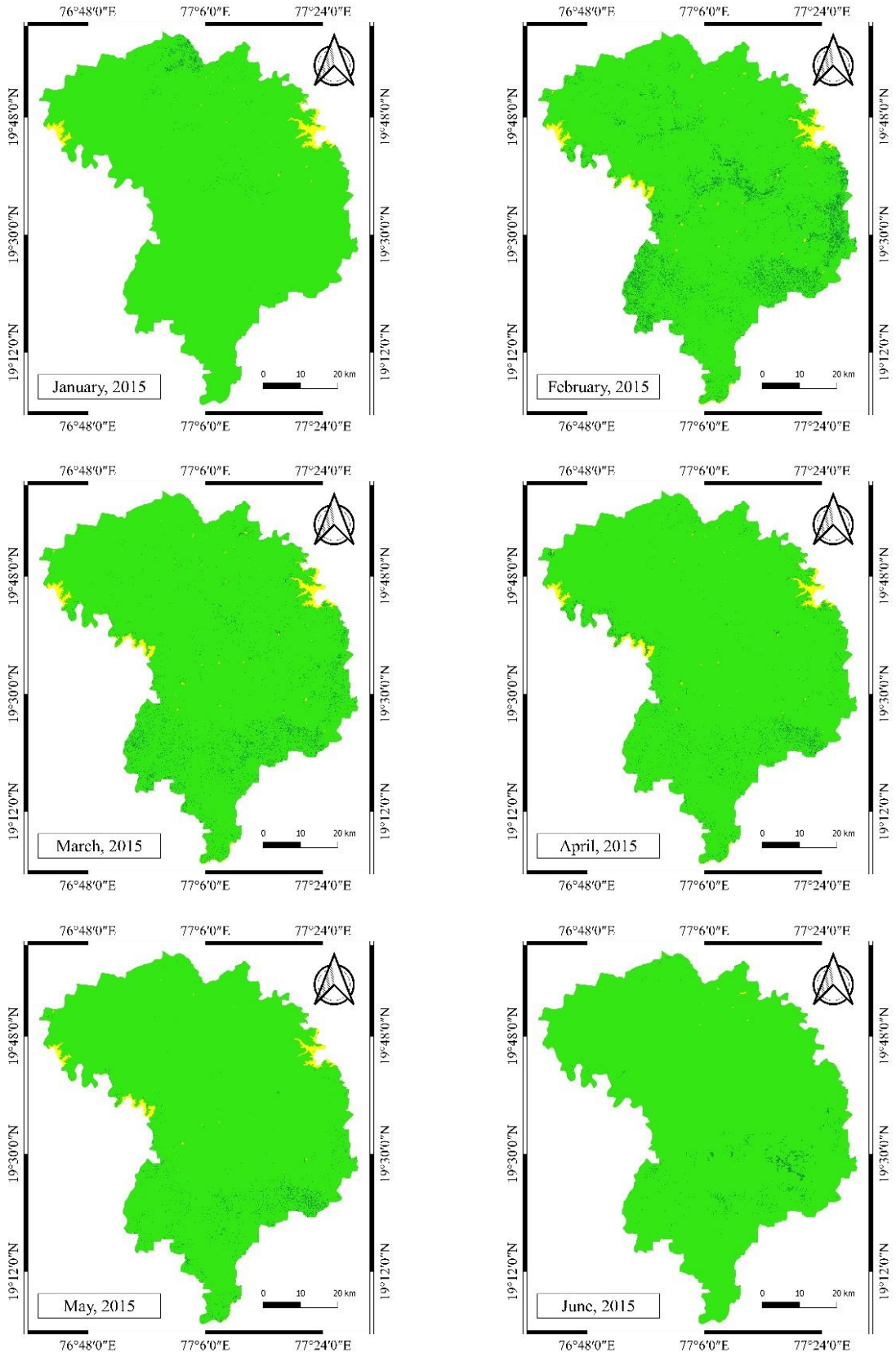


Fig 4.6(a): NDVI variations within drought year (2015) of the Hingoli

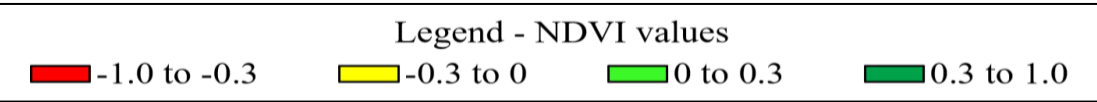
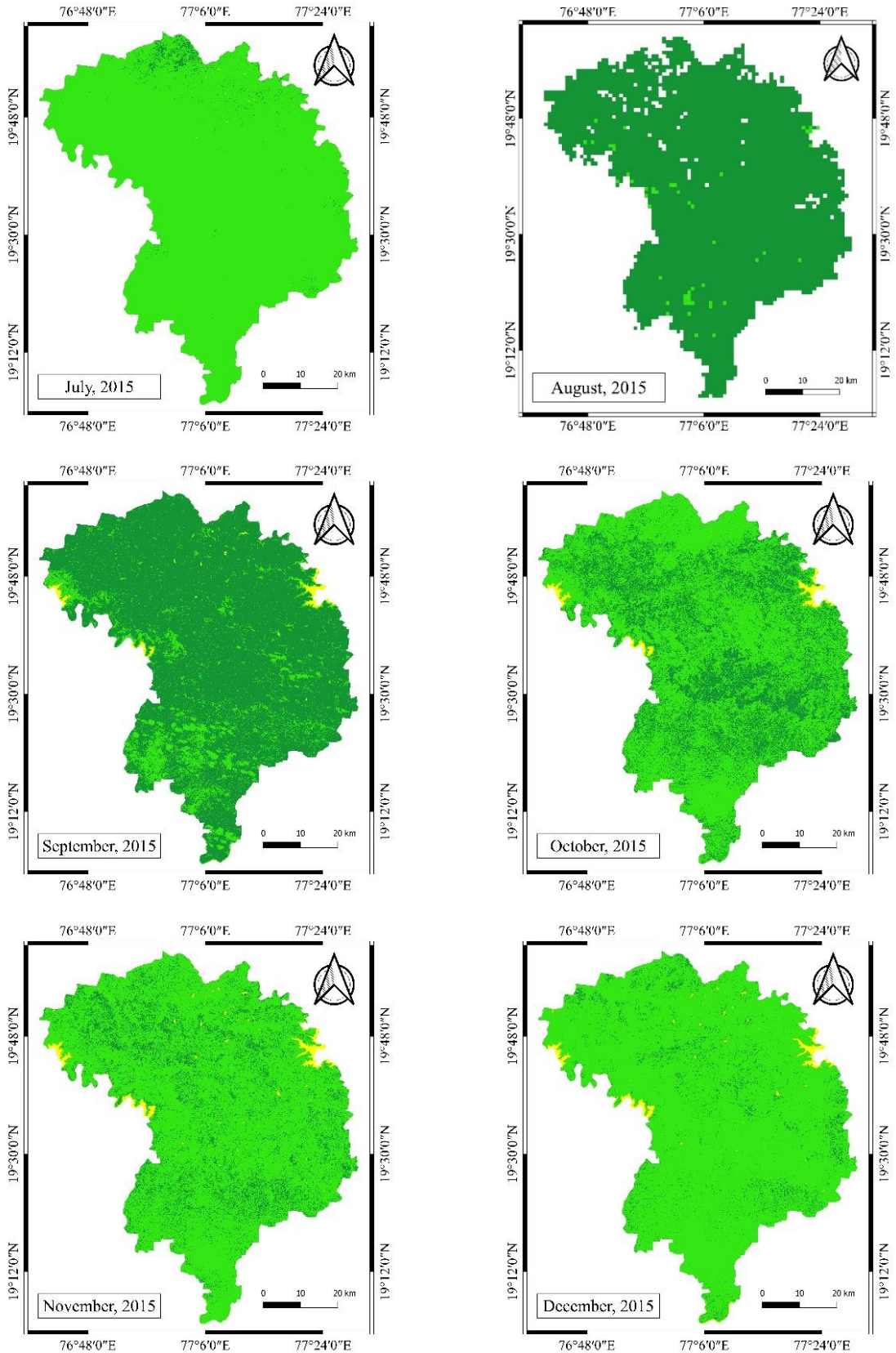


Fig 4.6(b): NDVI variations within drought year (2015) of the Hingoli

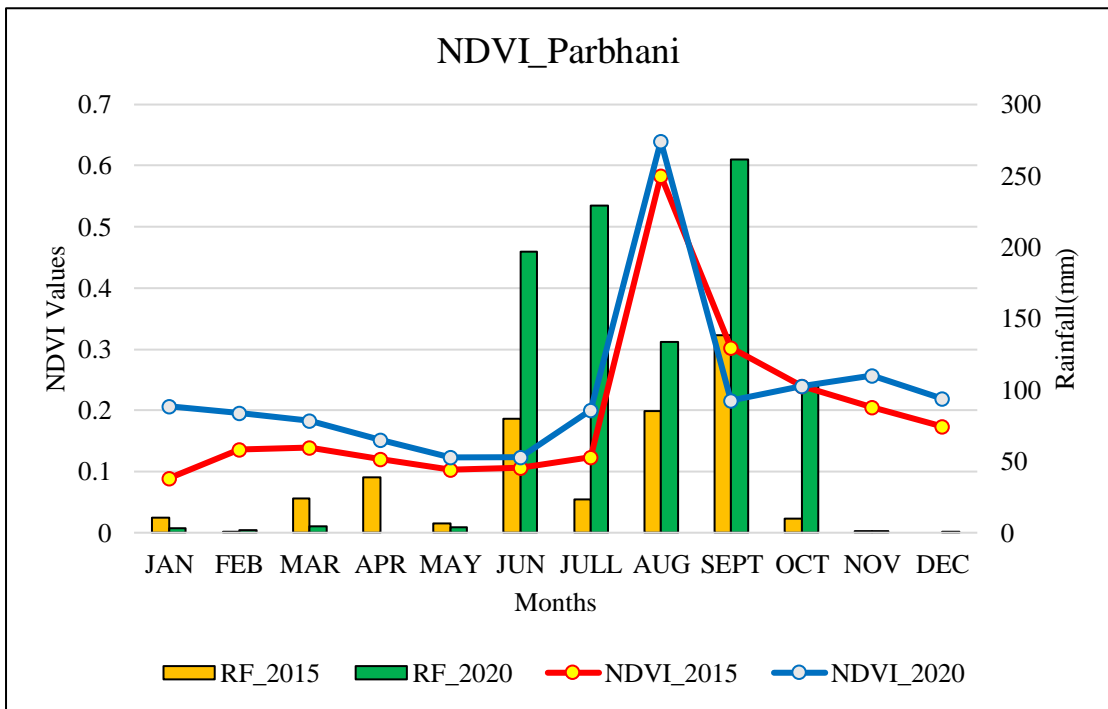


Fig. 4.7 Monthly mean NDVI for Parbhani district

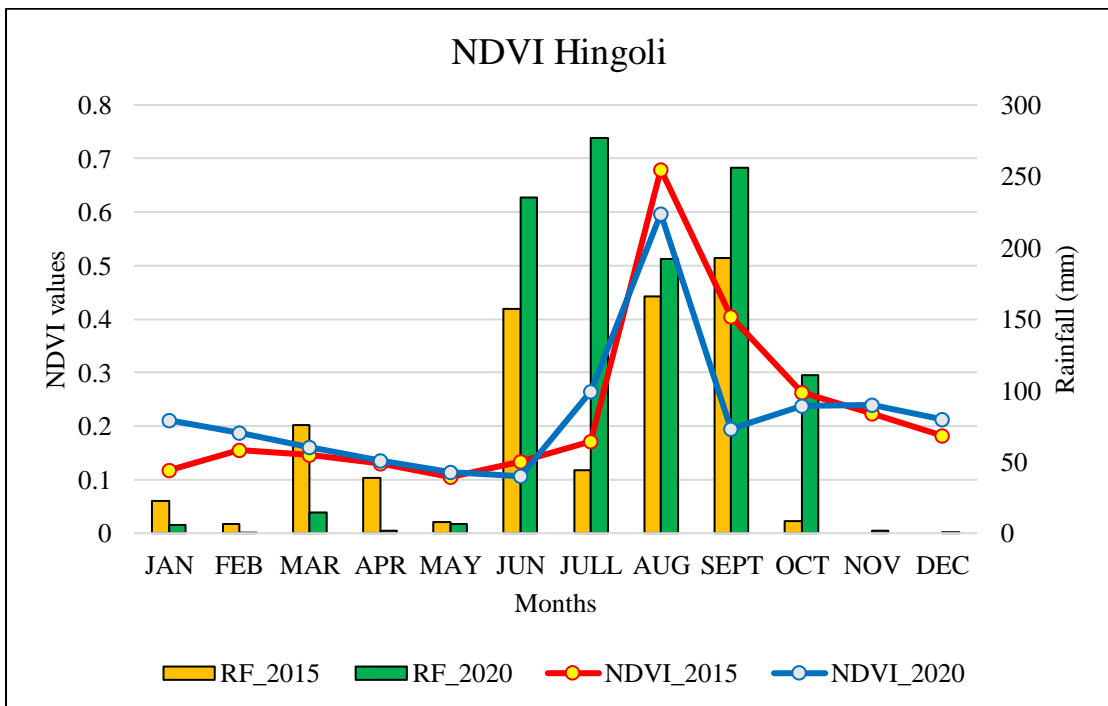


Fig. 4.8 Monthly mean NDVI for Hingoli district

4.4 NDDI variations within normal year (2020) of the study area

In Fig.4.9(a) and 4.9(b) monthly NDDI map of Parbhani district arranged. While Hingoli district monthly NDDI maps is given in Fig.4.10(a) and 4.10(b) for the normal year 2020.

4.4.1 NDDI variation within normal year (2020)

The mean monthly NDDI values of year 2020 for Parbhani district is given in Table 4.11. Minimum NDDI value was observed in March of 2020 for Parbhani was estimated -0.4099. On the other hand, the maximum NDDI value was 0.1388 in April and May month. Similarly, Guha *et al.* (2019) estimated NDDI using Landsat data for drought analysis within study area.

Table 4.11: Monthly mean NDDI of Parbhani in 2020

Months	JAN	FEB	MAR	APR	MAY	JUN	JUL
Mean NDDI	-0.0177	-0.0019	-0.4099	0.1388	0.1388	-0.2839	-0.1774
Months	AUG	SEPT	OCT	NOV	DEC	Mean	Annual
Mean NDDI	-	-0.0494	-0.1127	-0.0243	-0.0483	-0.0771	-0.0809

The mean monthly NDDI values of year 2020 for Hingoli district is given in Table 4.12. Minimum NDDI value was observed in March of 2020 was -0.4906. On the other hand, the maximum NDDI value was 0.2507 for Hingoli district. Bai *et al.* (2012) and Khampeera *et al.* (2018) used NDDI for drought analysis in Southwest China and Kuan Kreng Peat Swamp (KKPS) respectively.

Table 4.12: Monthly mean NDDI of Hingoli in 2020

Months	JAN	FEB	MAR	APR	MAY	JUN	JUL
Mean NDDI	-0.0077	-0.0204	-0.4906	0.1204	0.0795	-0.3702	-0.0717
Months	AUG	SEPT	OCT	NOV	DEC	Mean	Annual
Mean NDDI	-	-0.0695	-0.1657	0.2507	-0.0782	-0.0749	0.0748

4.4.2 Area estimation of classified image within normal year (2020)

The Normalized Difference Drought Index (NDDI) was totally classified into seven classes in which two were extra supplementary classes included for out-of-range values. For year 2020, monthly NDDI percentage area distribution of Parbhani and Hingoli is given in Table 4.13 and Table 4.14 respectively. In both the districts, March, April and May of 2020 were three months of drought condition in which area of No Drought Class declines below 65 % of total areas. Where, in remaining months No Drought Class area is more than 90 % for Parbhani and more

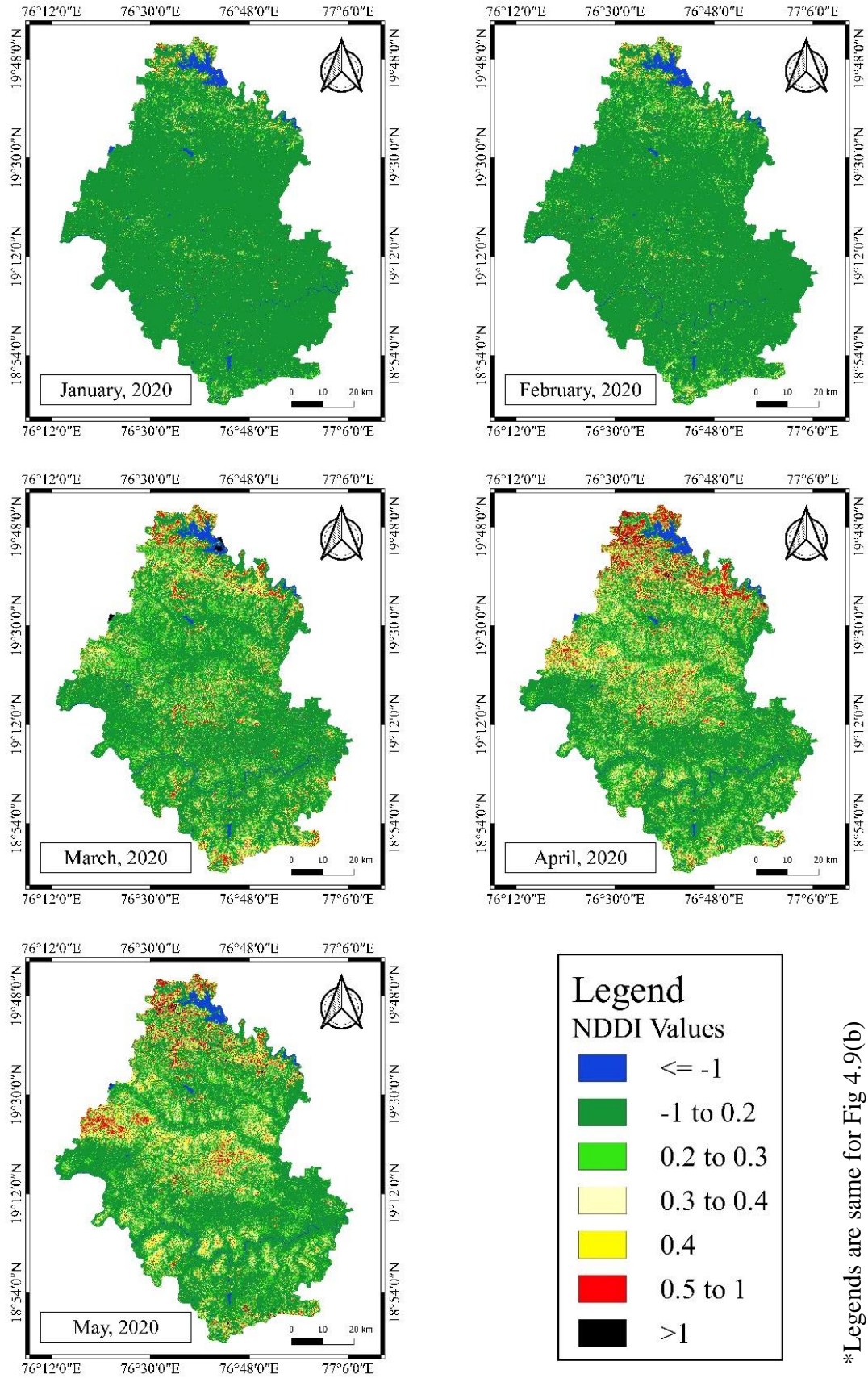
than 80% for Hingoli district. Similarly, Khampeera *et al.* 2018 classified NDDI into 5 different classes according NDDI range.

Table 4.13: Percentage Area of classified NDDI for Parbhani district in 2020

Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	SEPT	OCT	NOV	DEC	Mean
Water Body	1.76	1.7	1.57	1.6	1.43	0.34	0.62	0.05	1.36	1.88	2.05	1.3
No Drought	90.2	86.8	61.6	49.5	53.6	99.6	99.2	99.7	97.2	96.3	94.3	84.3
Mild Drought	4.3	6.65	18.2	20.7	19.7	0.01	0.04	0.18	0.87	1.23	2.51	6.7
Moderate Drought	2.03	2.99	10.1	13.9	12.9	0	0.01	0.03	0.26	0.2	0.74	3.9
Severe Drought	0.89	1.14	4.88	7.35	6.76	0	0	0.01	0.08	0.05	0.21	1.9
Extreme Drought	0.53	0.53	3.42	6.51	5.03	0	0	0	0.03	0.04	0.13	1.4
Unclassified	0.27	0.17	0.3	0.48	0.55	0.07	0.09	0.04	0.25	0.27	0.06	0.2
Total	100	100	100	100	100	100	100	100	100	100	100	100

Table 4.14: Percentage Area of classified NDDI of Hingoli district in 2020

Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	SEPT	OCT	NOV	DEC	Mean
Water Body	2.25	2.06	1.92	1.98	1.81	0.09	1.04	0.03	1.17	2.02	2.6	1.54
No Drought	84.1	85	58.7	49	63.7	99.9	98.9	99.8	98.2	96.6	91	84.0
Mild Drought	7.21	7.31	14.6	16.5	14.4	0	0.03	0.17	0.48	0.82	4.56	6.01
Moderate Drought	3.83	3.58	10.4	11.8	8.87	0	0.01	0.03	0.13	0.11	1.41	3.65
Severe Drought	1.74	1.45	6.95	8.29	5.31	0	0	0	0.03	0.03	0.33	2.19
Extreme Drought	0.88	0.64	7.1	11.9	5.5	0	0	0	0.01	0.02	0.12	2.3
Unclassified	0.01	0.01	0.31	0.56	0.34	0	0	0	0.01	0.44	0.02	0.15
Total	100	100	100	100	100	100	100	100	100	100	100	100



*Legends are same for Fig 4.9(b)

Fig 4.9(a): NDDI variations within normal year (2020) of the Parbhani

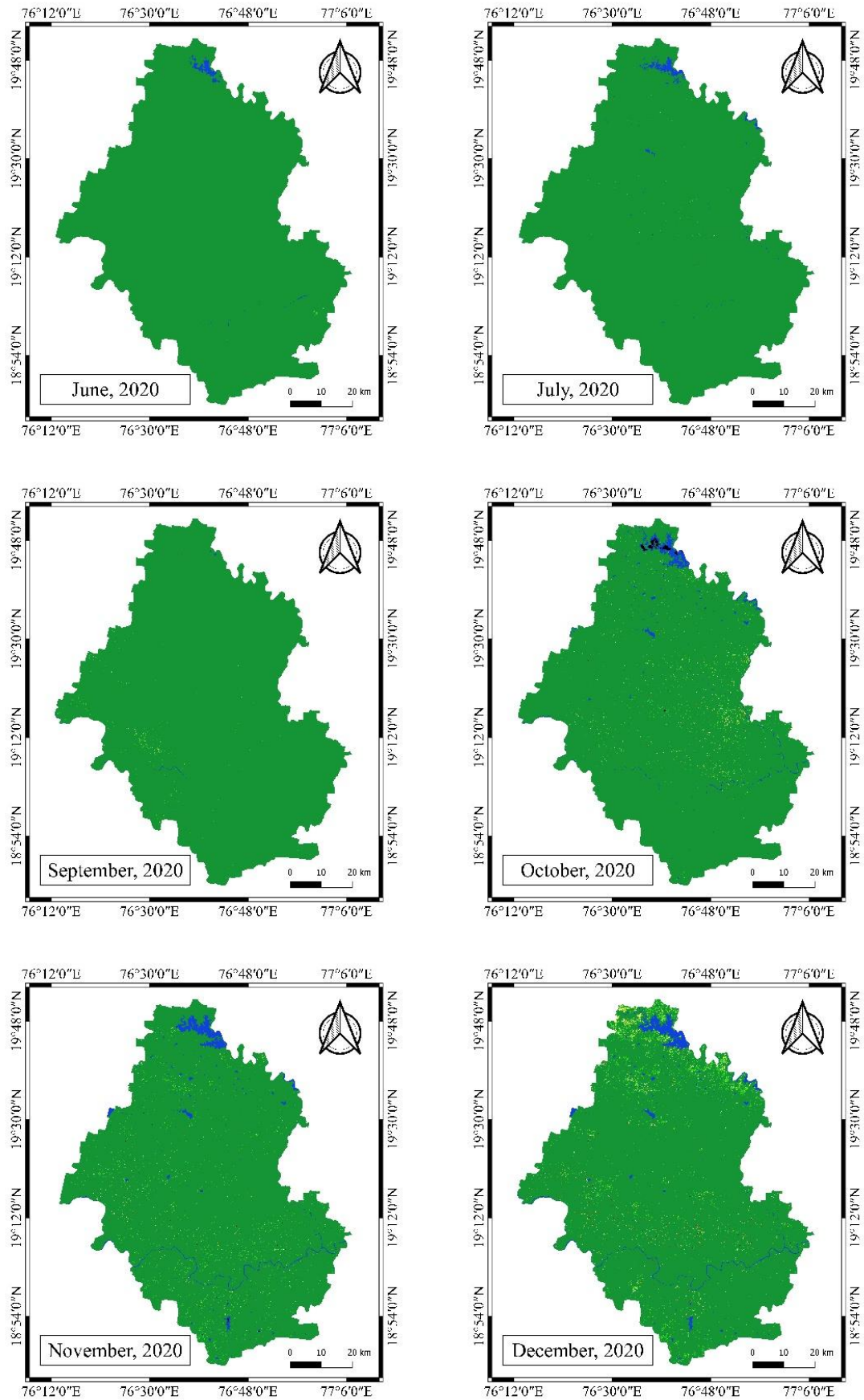
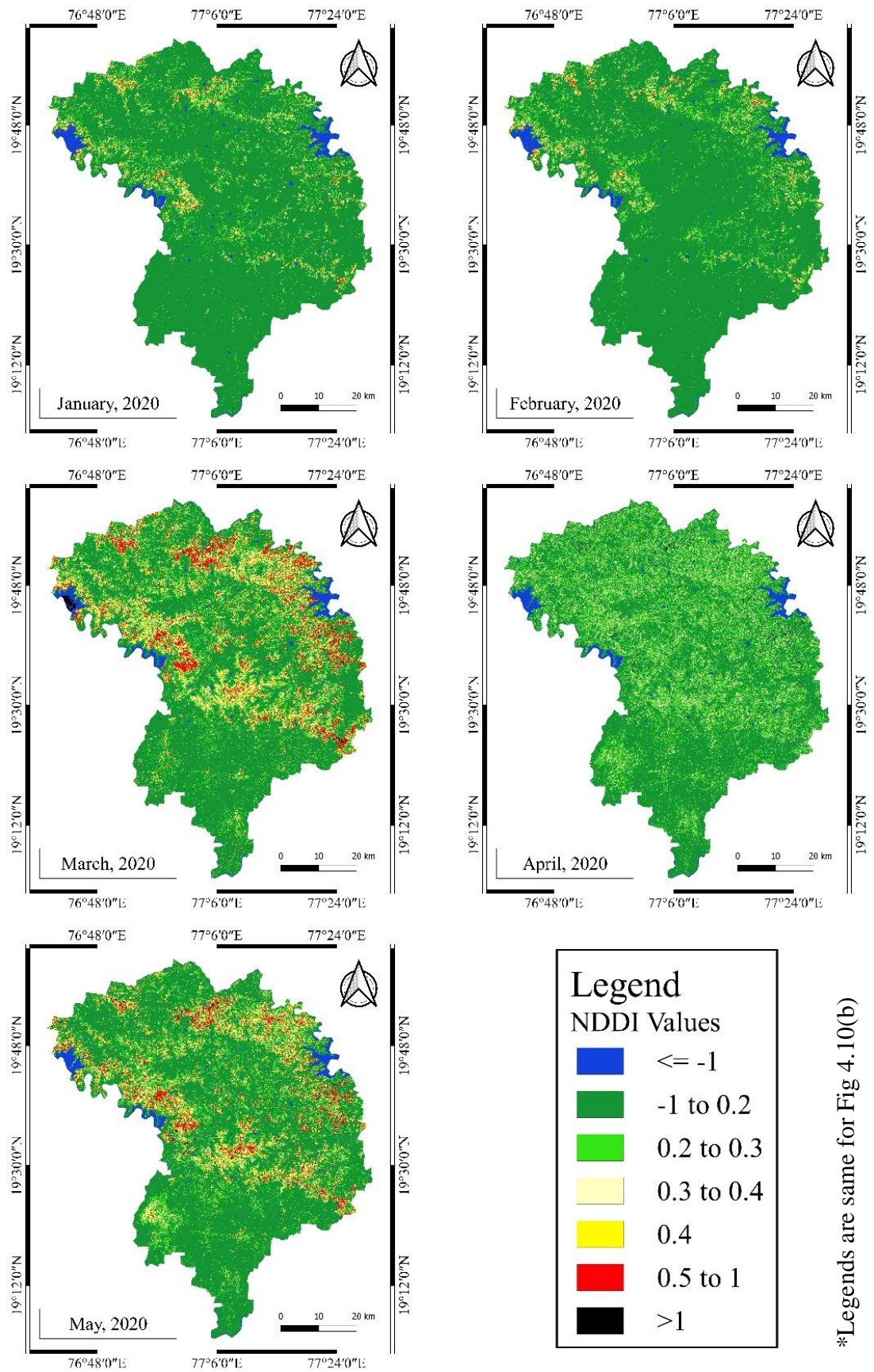


Fig 4.9(b): NDDI variations within normal year (2020) of the Parbhani



*Legends are same for Fig 4.10(b)

Fig 4.10(a): NDDI variations within normal year (2020) of the Hingoli

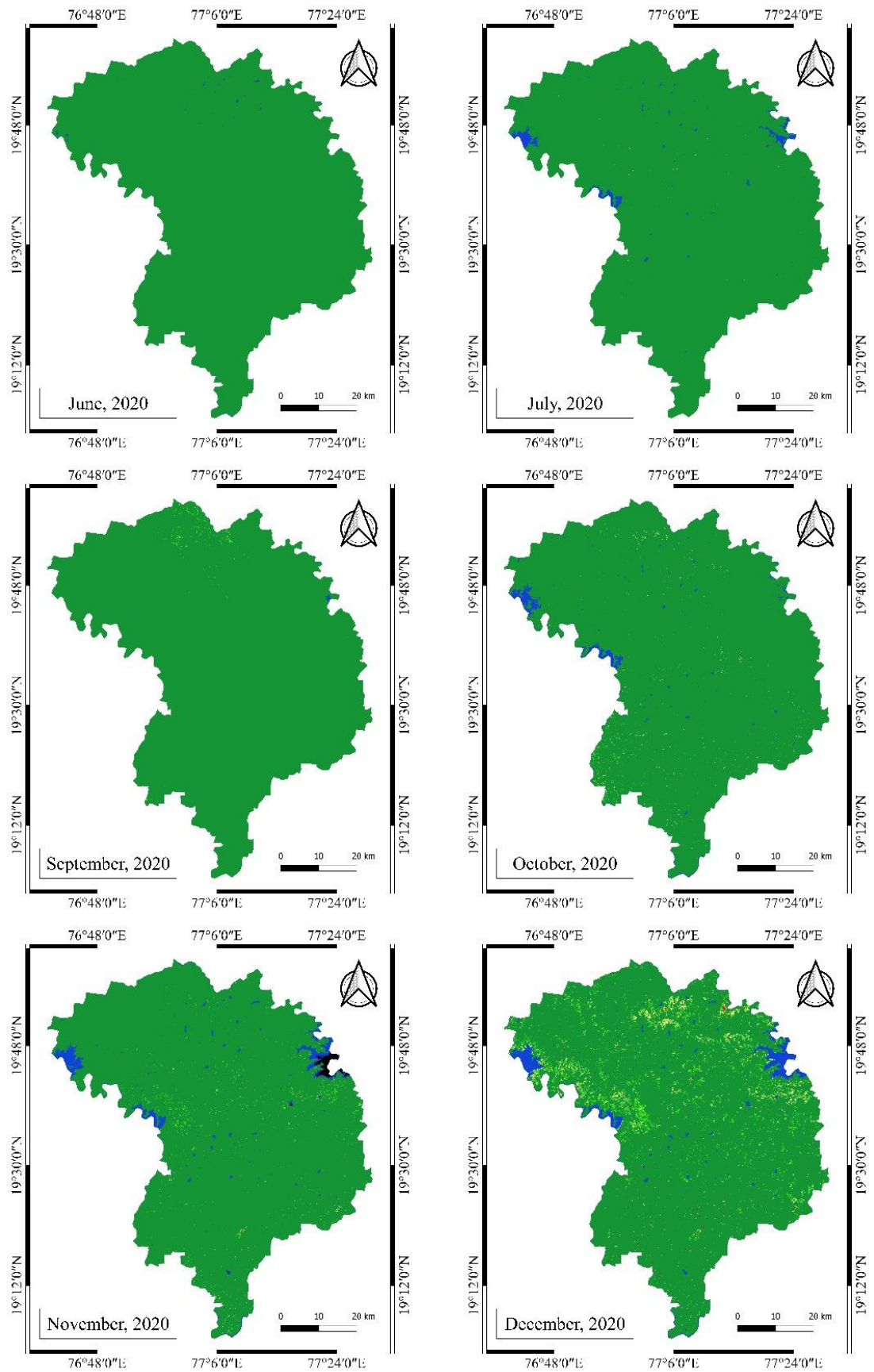


Fig 4.10(b): NDDI variations within normal year (2020) of the Hingoli

4.5 NDDI variations within drought year (2015) of the study area

Monthly NDDI map of Parbhani district was developed using Landsat 8 images for the drought year of 2015 and is shown in Fig.4.11(a) and 4.11(b) and Hingoli district NDDI maps are given in Fig. 4.12(a) and 4.12(b).

4.5.1 NDDI variation within drought year (2015)

Table 4.15 showed monthly mean NDDI values for year 2015 of Parbhani district. In which it was observed that, there are subsequent four months having NDDI values above 0.1 indicates more drought condition as compared to same months of year 2020. Similarly, negative anomalies found during drought year in Revadekar *et al.* (2012) where area under more NDVI was reduced.

Table 4.15: Monthly mean NDDI of Parbhani in 2015

Months	JAN	FEB	MAR	APR	MAY	JUN	JUL
Mean NDDI	-0.2464	0.179	0.1846	0.1451	0.1227	-0.2247	0.1668
Months	AUG	SEPT	OCT	NOV	DEC	Mean	Annual
Mean NDDI	-	0.0241	0.0037	0.158	0.0278	0.0492	0.0188

On the other hand, Table 4.16 indicates monthly mean NDDI values for year 2015 of Hingoli district. In which, June and July were two rainy season months had more drought condition in Hingoli district. It indicates low vegetation and indirectly denotes insufficient rainfall in regarding months. Cheng-lin and Jian-jun (2008) used similar index *i.e.*, NDDI for analysis of crop drought condition of study area and developed operational crop drought monitoring system.

Table 4.16: Monthly mean NDDI of Hingoli in 2015

Months	JAN	FEB	MAR	APR	MAY	JUN	JUL
Mean NDDI	0.1642	0.0059	0.0611	0.0849	0.0454	0.2317	0.1627
Months	AUG	SEPT	OCT	NOV	DEC	Mean	Annual
Mean NDDI	-	0.0103	0.0049	-0.1222	-0.0698	0.0527	-0.0489

4.5.2 Area estimation of classified image within drought year (2015)

The NDDI percentage area distribution of year 2015 for both the districts is presented in Table 4.17 and Table 4.18. In which drought severity high in March, April and May for Parbhani on the other hand February to May are drought months of Hingoli district. In this analysis, we were observed that, June and July of year 2015

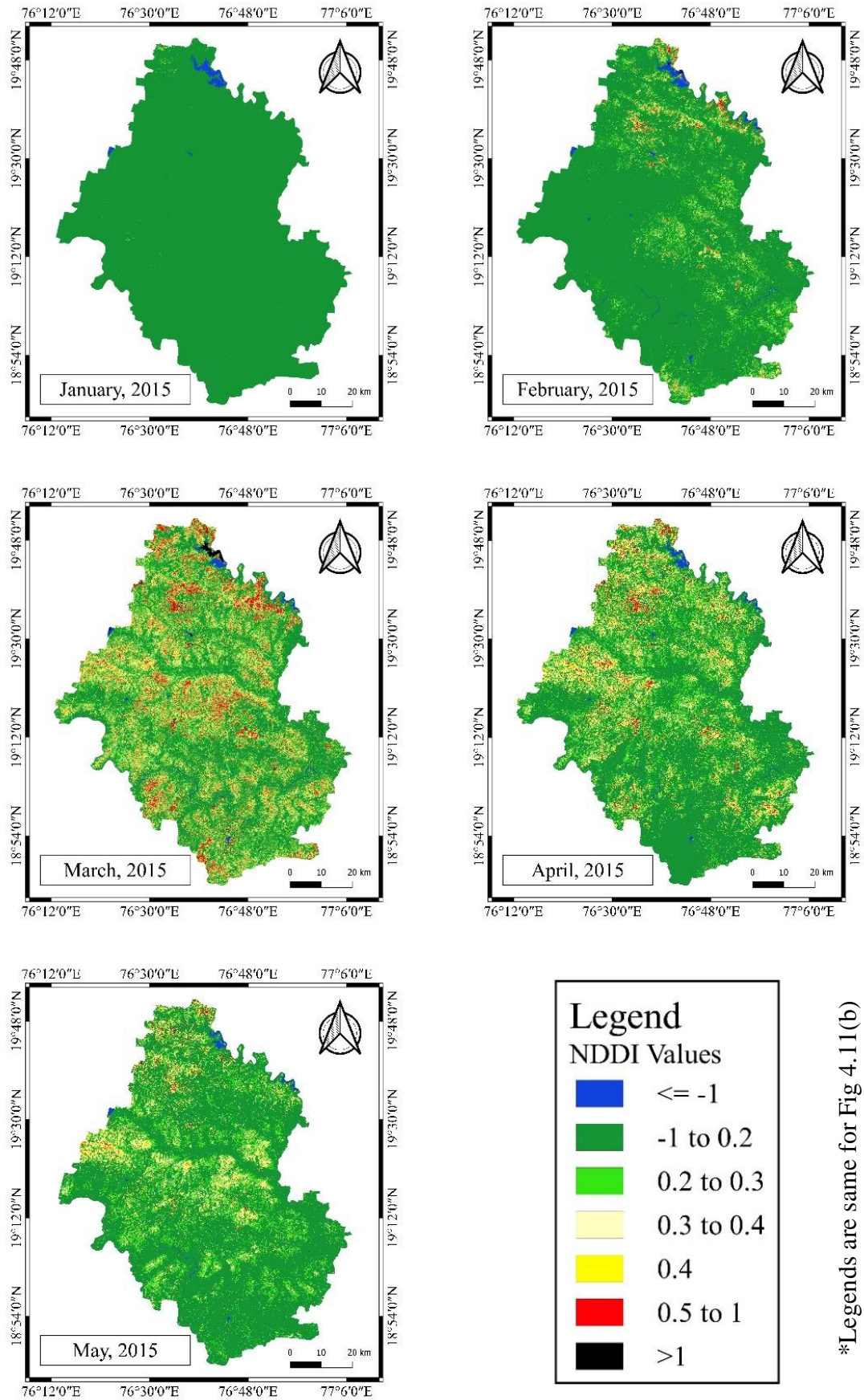
were almost 100 % classified in to no drought class. This is miracle resulted in drought year.

Table 4.17: Percentage Area of classified NDDI of Parbhani district in 2015

Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	SEPT	OCT	NOV	DEC	Mean
Water Body	0.6	0.84	0.6	0.62	0.49	0.11	0.04	0.37	0.57	0.68	0.51	0.4
No Drought	99.1	85.7	44.3	59.3	69.5	99.7	99.9	98	98.4	97.7	97.1	86.2
Mild Drought	0.13	8.17	20.3	19.3	17.5	0.01	0	1.16	0.81	1.21	1.67	6.3
Moderate Drought	0.04	3.14	16.1	11.7	8.1	0	0	0.18	0.15	0.22	0.35	3.6
Severe Drought	0.01	1.2	9.9	5.5	2.8	0	0	0.02	0.03	0.06	0.11	1.7
Extreme Drought	0	0.85	8.3	3.48	1.34	0	0	0.01	0.01	0.04	0.12	1.2
Unclassified	0.09	0.07	0.61	0.15	0.28	0.14	0.03	0.24	0.07	0.08	0.18	0.1
Total	100	100	100	100	100	100	100	100	100	100	100	100

Table 4.18: Percentage Area of classified NDDI of Hingoli district in 2015

Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	SEPT	OCT	NOV	DEC	Mean
Water Body	1.12	1.53	1.46	1.3	1.09	0.03	0.02	0.78	1	1.41	1.33	1.0
No Drought	97.9	79.6	60.9	71.2	81.5	100	100	99.1	96.7	96.4	97.3	89.1
Mild Drought	0.73	9.47	14.4	14.5	10.4	0	0	0.1	1.81	1.76	0.98	4.9
Moderate Drought	0.2	4.83	9.84	7.28	4.32	0	0	0.02	0.37	0.28	0.19	2.4
Severe Drought	0.06	2.36	6.15	3.21	1.64	0	0	0.01	0.06	0.08	0.06	1.2
Extreme Drought	0.03	2.05	6.9	2.39	0.97	0	0	0	0.01	0.05	0.07	1.1
Unclassified	0	0.11	0.32	0.07	0.05	0	0	0	0	0.03	0.03	0.05
Total	100	100	100	100	100	100	100	100	100	100	100	100



*Legends are same for Fig 4.11(b)

Fig 4.11(a): NDVI variations within drought year (2015) of the Parbhani

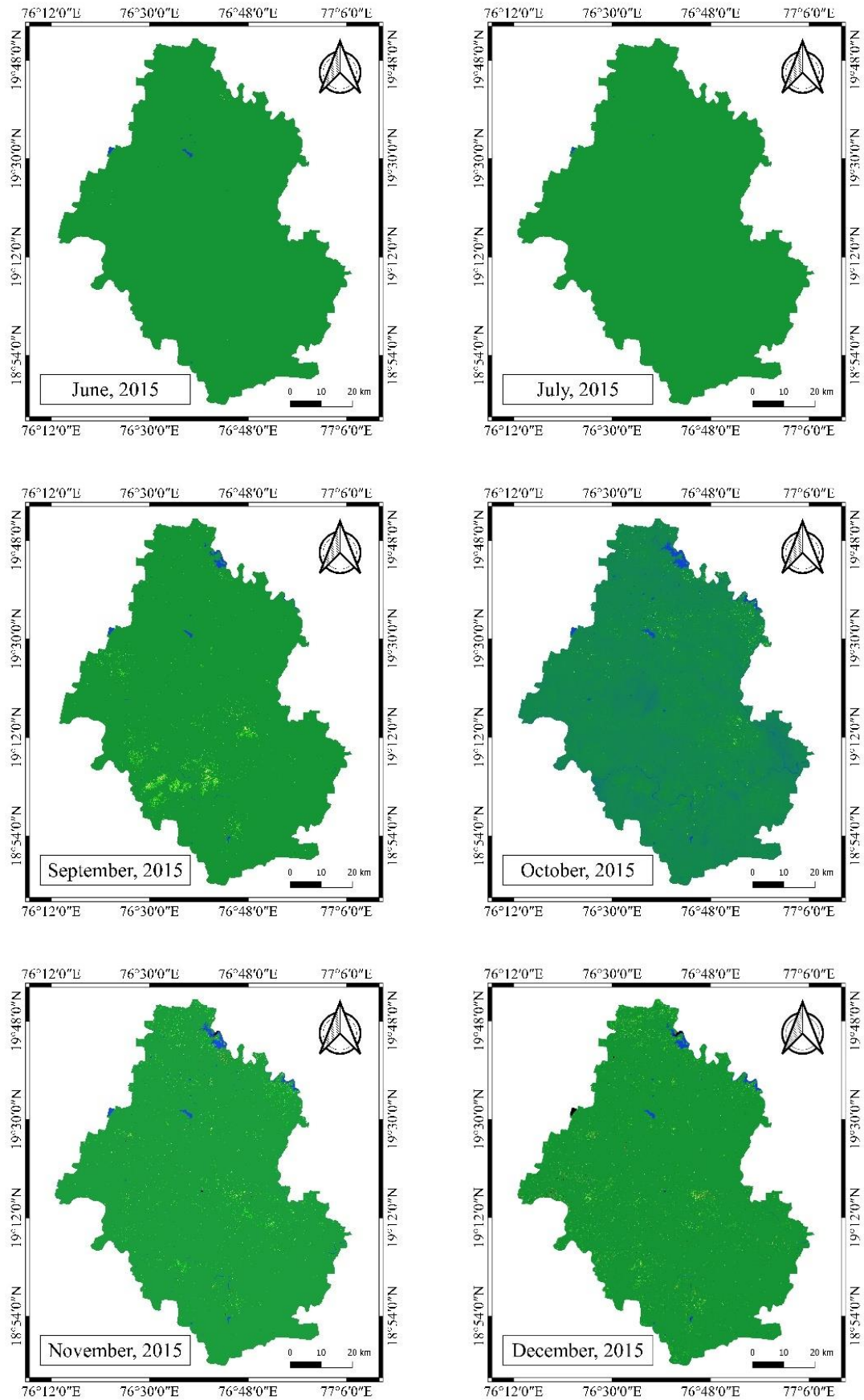
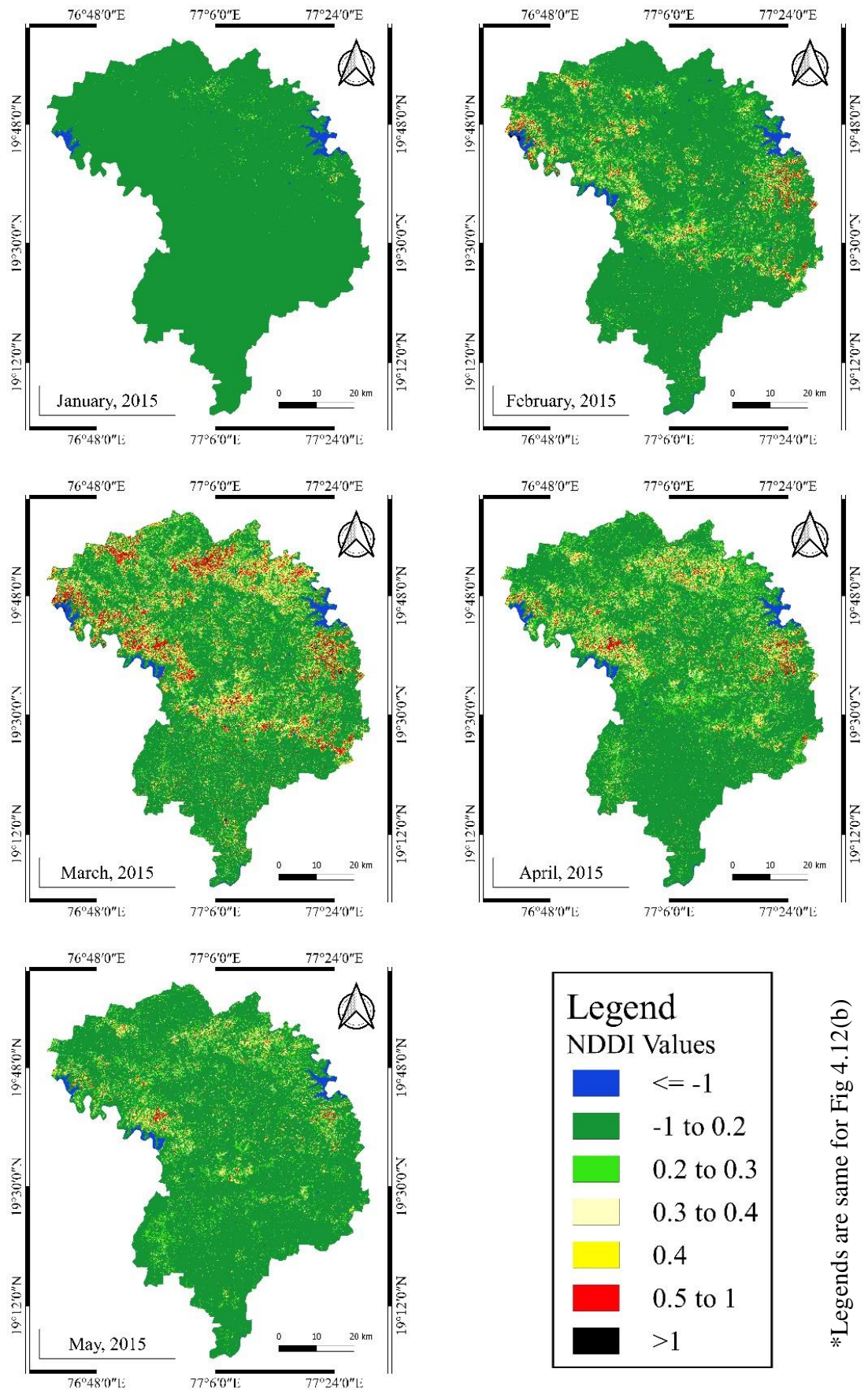


Fig 4.11(b): NDDI variations within drought year (2015) of the Parbhani



*Legends are same for Fig 4.12(b)

Fig 4.12(a): NDDI variations within drought year (2015) of the Hingoli

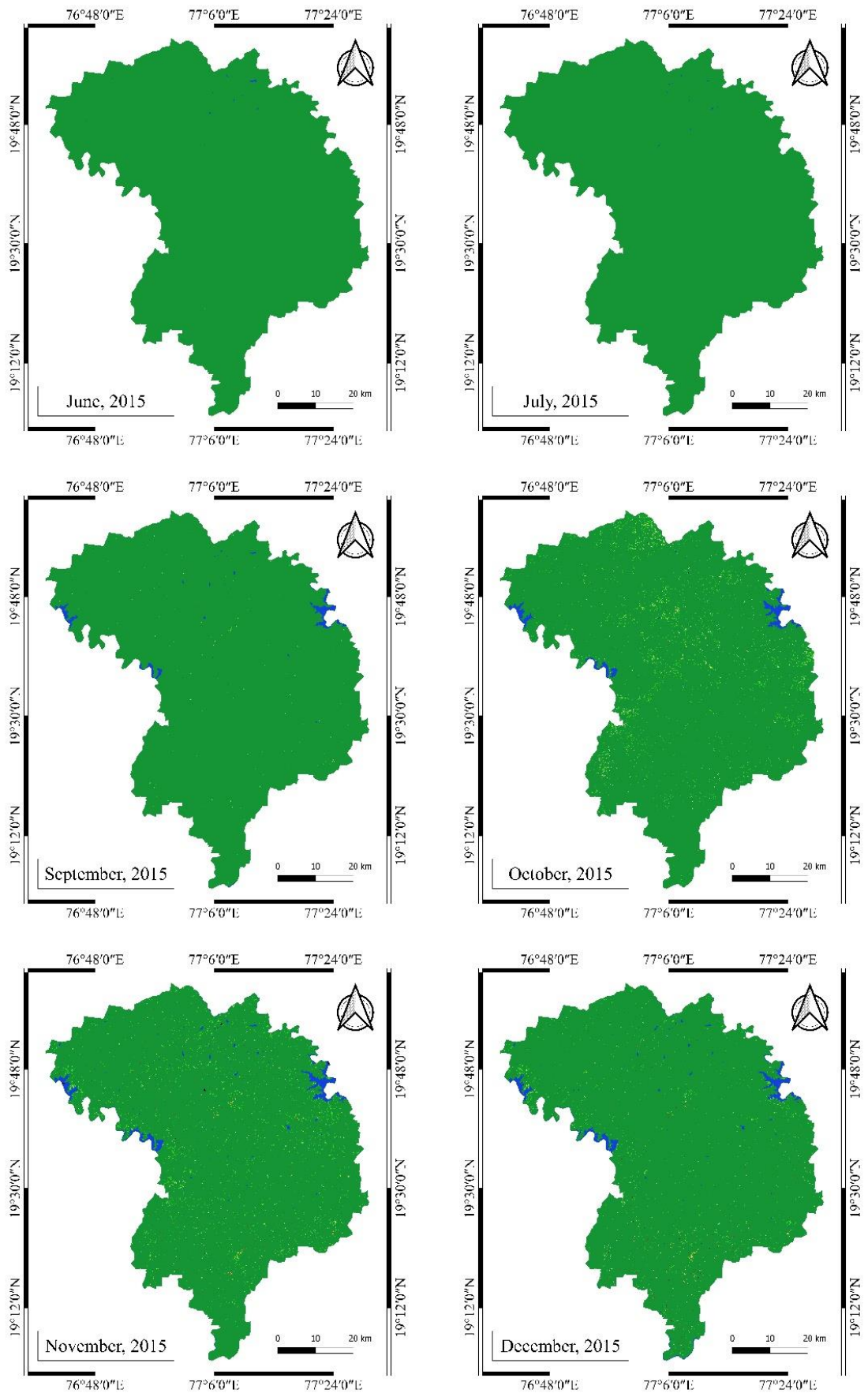


Fig 4.12(b): NDDI variations within drought year (2015) of the Hingoli

4.6 NDVI comparison between normal and drought year of the study area

The comparison between satellite images of two years having different weather condition gives the actual idea about intensity of vegetation change. Similarly, in current study, area for each district was classified on monthly basis into 4 different NDVI classes for both the year. The annual percentage area for whole year was estimated. Then estimated percentage area for normal and drought year was compared and the difference obtained from comparison was expressed into two different tables.

4.6.1 Monthly Comparison of percent area classified NDVI of the study area

Table 4.19 and Table 4.20 indicate the monthly based comparison of percent area classified NDVI for Parbhani and Hingoli districts respectively. After comparing Table 4.19 it was found that, for the summer months (March to May) in drought year (2015) area of Mild Drought Class was more as compare to summer months in normal year (2020). On the other hand, this trend was changed in rainy season (June to September).

In rainy season, the area of Mild Drought Class was higher in year 2015 than year 2020 with its increase up to 17.7 % and 8.7 % in July and August months respectively. In September month drastic decrease of 35.4 % area in No Drought Class which get converted into Mild Drought Class. It may be due to dry spell at the end of August month (28/08/2020 to 06/09/2020) of 10 days duration, affected on vegetation in succeeding month.

In the winter season, again area of Mild Drought Class was increased in 2015 compared to 2020 with 16.7 %, 28.7 % and 31.1 % for October, November and December months respectively. Grover and Singh (2015) also used NDVI to analyze urban heat island (UHI) for comparative study of Mumbai and Delhi.

In case of Hingoli district (Table 4.20) it was observed that, in summer season there was increase in Mild Drought Class in year 2015 than year 2020 except March month because, in March month 75.9 mm rainfall was recorded in Hingoli district, which caused 0.7 % area increased in No Drought Class in 2015 compared to 2020.

In rainy season, large change in Mild Drought Class with 33.8 % decrease in vegetation was observed in July month of drought year (2015) than normal year (2020). There was successive 19 days dry spell was observed in July, 2015

(03/07/2021 to 21/07/2021). In September, 2020 contrast with July,2020 it was observed that, dry spell from 23/08/2020 to 06/09/2020 (15 days duration) was observed, causes decrease in No Drought Class in September, 2020 than year 2015.

In November month of winter season, highest (12 %) increase in Mild Drought Class was observed in drought year (2015) compared to month October and December. Zhong *et al.* (2010) concluded that, the spatial distribution of NDVI values was directly correlated with the general climate pattern in their study area.

The severity of drought caused due to deficient rainfall is more prominently evidenced during summer season rather than rainy season. During the rainy season, the weather factors like temperature, humidity, evapotranspiration, wind velocity and bright sunshine hours are ranging at lower to middle scale of annual normal values whereas, during summer season all the weather parameters are at its maximum range. Therefore, the effect of deficient rainfall in *monsoon* will have its severe noticeable effect on vegetation in the consequent summer season. Fig. 13 and Fig. 14 shows comparison of percent area classified NDVI for Parbhani and Hingoli districts respectively.

Table 4.19: Comparison of percent area classified NDVI for Parbhani district

MONTH		Severe drought	Moderate drought	Mild drought	No drought
January	2020	0.0	2.0	89.2	8.8
	2015	0.0	0.7	99.3	0.0
Difference		0.0	1.3	-10.1	8.8
February	2020	0.0	1.8	91.8	6.3
	2015	0.0	0.9	96.9	2.2
Difference		0.0	1.0	-5.1	4.1
March	2020	0.0	1.8	94.3	3.9
	2015	0.0	0.8	96.9	2.2
Difference		0.0	0.9	-2.6	1.7
April	2020	0.0	1.6	95.3	3.1
	2015	0.0	0.6	98.5	0.9
Difference		0.0	1.0	-3.2	2.2
May	2020	0.0	1.4	96.2	2.4
	2015	0.0	0.7	98.8	0.5
Difference		0.0	0.8	-2.6	1.9
June	2020	0.0	0.4	97.6	2.0
	2015	0.0	0.2	99.5	0.3
Difference		0.0	0.2	-1.9	1.7
July	2020	0.0	0.7	82.2	17.1
	2015	0.0	0.1	99.9	0.0
Difference		0.0	0.6	-17.7	17.1
August	2020	0.0	0.0	0.7	99.0
	2015	0.0	0.0	9.0	87.2
Difference		0.0	0.0	-8.4	11.8
September	2020	0.0	0.1	82.6	17.3
	2015	0.0	0.6	46.6	52.8
Difference		0.0	-0.5	36.0	-35.4
October	2020	0.0	1.6	63.3	35.1
	2015	0.0	0.6	80.0	19.4
Difference		0.0	1.0	-16.7	15.7
November	2020	0.0	2.1	59.9	38.0
	2015	0.0	0.7	88.6	10.6
Difference		0.0	1.4	-28.7	27.4
December	2020	0.0	2.1	82.3	15.6
	2015	0.0	0.6	95.4	4.0
Difference		0.0	1.4	-13.1	11.7

Table 4.20: Comparison of percent area classified NDVI for Hingoli district

Month	Year	Severe drought	Moderate drought	Mild drought	No drought
January	2020	0.0	2.3	81.7	16.1
	2015	0.0	1.1	98.4	0.4
Difference		0.0	1.1	-16.8	15.6
February	2020	0.0	2.1	88.8	9.1
	2015	0.0	1.6	92.9	5.6
Difference		0.0	0.5	-4.0	3.5
March	2020	0.0	2.1	95.8	2.1
	2015	0.0	1.5	95.7	2.8
Difference		0.0	0.6	0.1	-0.7
April	2020	0.0	2.0	94.6	3.4
	2015	0.0	1.3	97.0	1.7
Difference		0.0	0.7	-2.3	1.6
May	2020	0.0	1.8	95.6	2.6
	2015	0.0	1.1	97.7	1.2
Difference		0.0	0.7	-2.1	1.4
June	2020	0.0	0.1	99.3	0.6
	2015	0.0	0.0	99.2	0.8
Difference		0.0	0.1	0.1	-0.2
July	2020	0.0	1.0	64.8	34.1
	2015	0.0	0.0	98.6	1.4
Difference		0.0	1.0	-33.8	32.8
August	2020	0.0	0.0	1.1	98.9
	2015	0.0	0.0	1.1	96.0
Difference		0.0	0.0	0.0	2.9
September	2020	0.0	0.0	90.3	9.7
	2015	0.0	0.8	14.4	84.8
Difference		0.0	-0.7	75.8	-75.1
October	2020	0.0	1.2	65.5	33.3
	2015	0.0	1.0	66.7	32.3
Difference		0.0	0.2	-1.3	1.1
November	2020	0.0	2.4	68.9	28.7
	2015	0.0	1.4	81.8	16.7
Difference		0.0	1.0	-13.0	12.0
December	2020	0.0	2.6	85.9	11.5
	2015	0.0	1.3	93.3	5.4
Difference		0.0	1.3	-7.4	6.1

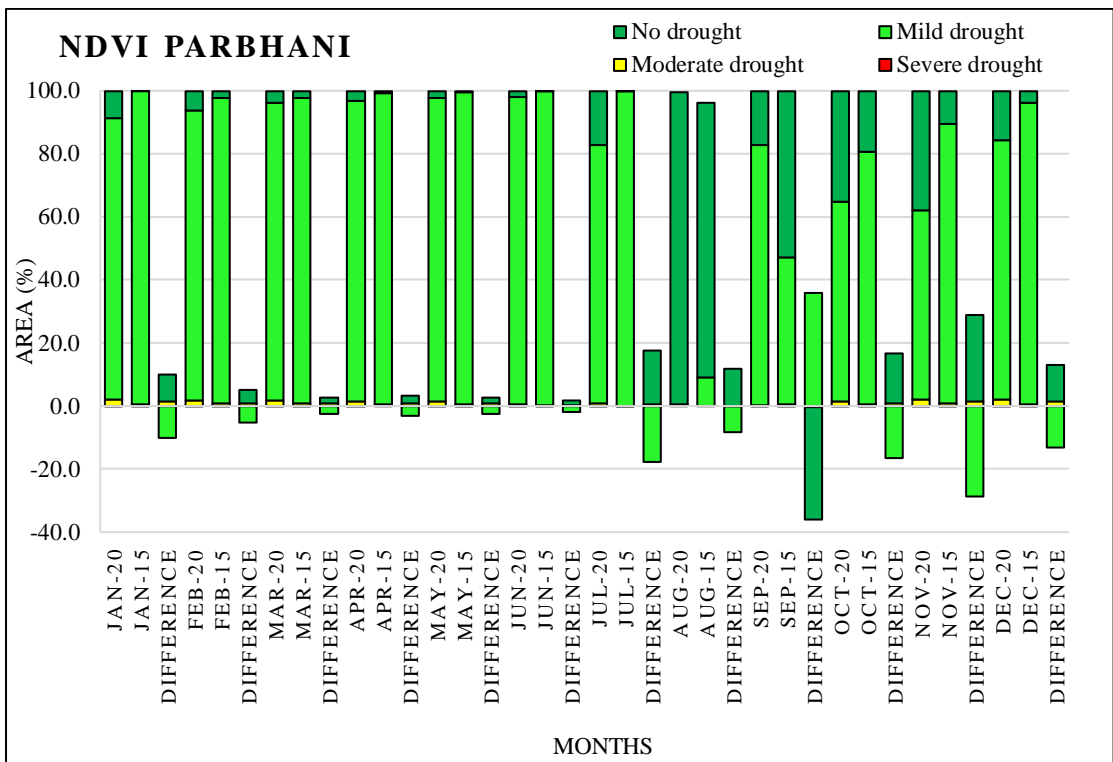


Fig. 4.13 Comparison of percent area classified NDVI for Parbhani district

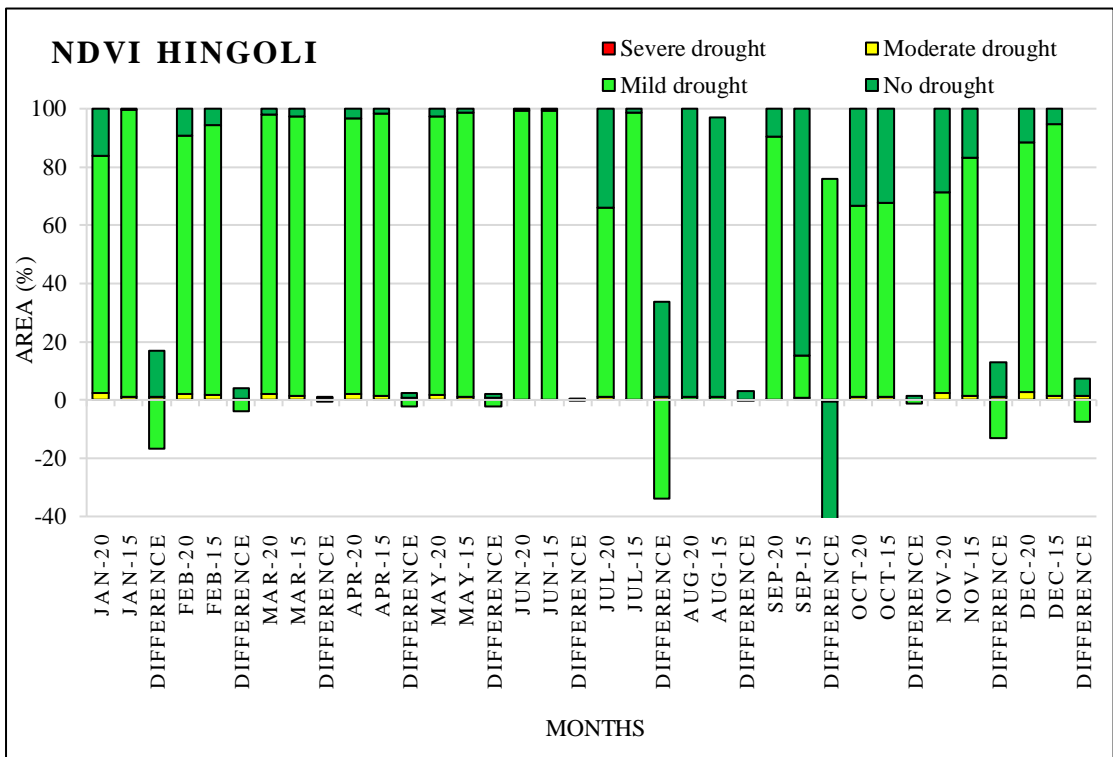


Fig. 4.14 Comparison of percent area classified NDVI for Hingoli district

4.6.2 Monthly Comparison of percent area classified NDVI for Hingoli district

In Table 4.21 indicates the comparison of percent area classified annual NDVI for Parbhani district. From this table, it was resulted that, area of No Drought Class was decreased by 0.42 % in drought year (2015) indicates reduction in vegetation cover due to decline in rainfall, similarly in Moderate Drought Class 0.75 % area was decreased. On the other hand, in Mild Drought Class there was increase in area by 1.17 % more than normal year 2020. Fig. 15 and Fig. 16 shows percent area classified annual NDVI for Parbhani and Hingoli districts respectively.

Table 4.21: Comparison of percent area classified annual NDVI for Parbhani district

NDVI classes	2020	2015	Difference
Severe drought	0	0	0
Moderate drought	1.14	0.39	0.75
Mild drought	98.38	99.55	-1.17
No drought	0.47	0.05	0.42

In Table 4.22, comparison of percent area classified annual NDVI for Hingoli district was given. It was found that, area of No Drought Class and Moderate Drought Class was decreased by 0.03 % and 0.57 % respectively in drought year (2015) whereas; in Mild Drought Class there was increase in area by 0.6 % more than normal year 2020.

Table 4.22: Comparison of percent area classified annual NDVI for Hingoli district

NDVI classes	2020	2015	Difference
Severe drought	0	0	0
Moderate drought	1.56	0.99	0.57
Mild drought	98.19	98.79	-0.6
No drought	0.23	0.2	0.03

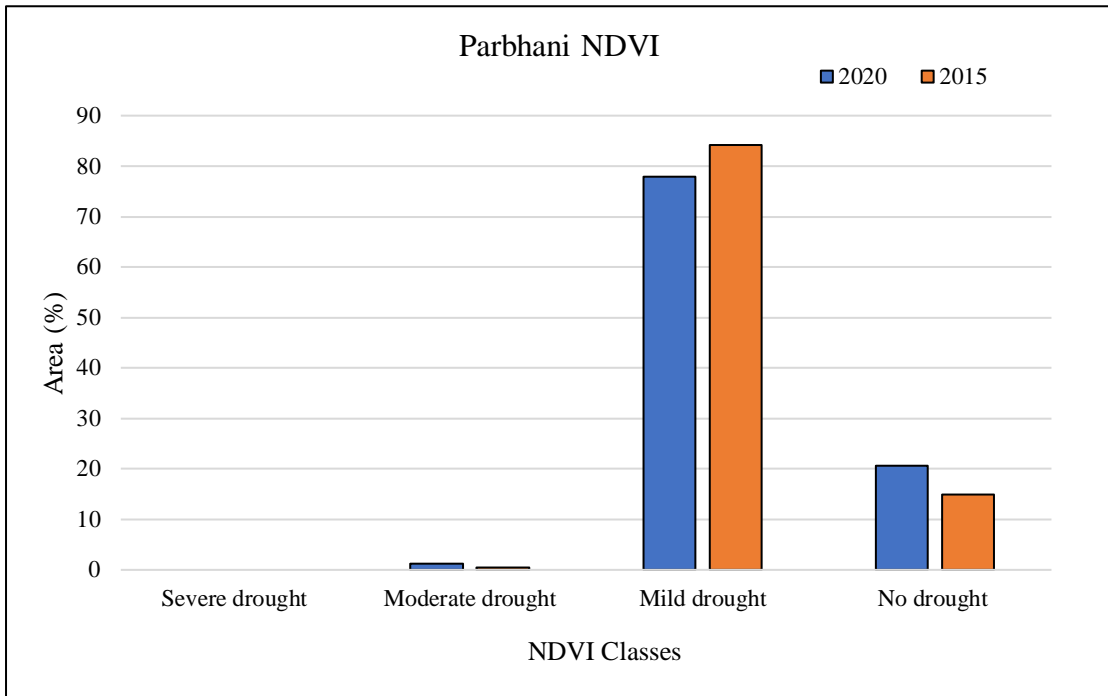


Fig. 4.15 Percent area classified annual NDVI for Parbhani district

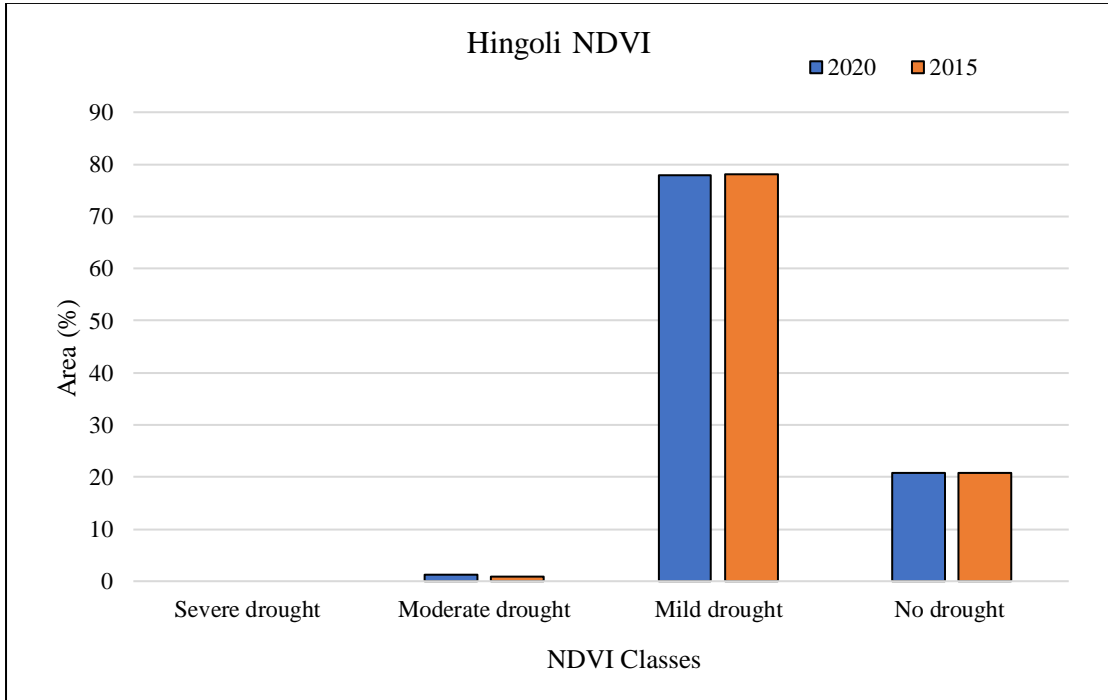


Fig. 4.16 Percent area classified annual NDVI for Hingoli district

CHAPTER – V
SUMMERY AND CONCLUSIONS

CHAPTER-V

SUMMARY AND CONCLUSIONS

Drought is caused by a sudden and large deviation in precipitation, resulting in acute water scarcity, significant soil moisture shortages and lower crop yields. Droughts cannot be prevented, but they can be forecast and monitored in order to lessen their negative consequences. Droughts are divided into four categories: meteorological, agricultural, hydrological, and socioeconomic. Severity, duration and spatial extent of agricultural droughts vary from place to place and time to time depending on several other factors such as late arrival and/or early retreat of the monsoon, duration of dry spell and lack of irrigation water. A comprehensive analysis of the spatial and temporal extension of droughts can help to develop drought monitoring signals based on relevant drought indices. The analysis of distribution and variability of rainfall is important to improve water management in agricultural sector.

Therefore, the study was undertaken with the objectives of characterization of droughts in Marathwada region for sustainable crop planning under climate change scenario. Rainfall is one of the important climatic variables that largely determine the occurrence of drought and also influences the growth and development of vegetation which is reflected in NDVI.

Rainfall is one of the most critical parameters that affects vegetation area and intensity, resulting in drought-like circumstances in disadvantaged areas such as the Marathwada region's Parbhani and Hingoli districts. In the same way, meteorological and agricultural drought indexes are complementary. As a result, modern tools such as GIS and remote sensing were used to conduct a temporal and spatial analysis of agricultural drought. Drought in the Marathwada region was assessed using remote sensing-based agricultural drought indices such as NDVI, NDWI, and NDDI. For that the Landsat 8 images having 3 bands for the year 2015 and 2020 with pixel size of 30m x 30m were used. For a better synoptic perspective of the drought condition in the region, the drought severity maps were created using the IDW interpolation technique in GIS.

The experiment was carried out by using the 2 years having different weather condition of weather (2015 and 2020) and rainfall data. Data analysis was carried out by using QGIS 3.16.4 software. Obtained results are discussed below.

Conclusion

1. From the present study it was observed that, maximum mean NDVI was highest in August month for both Parbhani and Hingoli districts (0.6403 % & 0.597 % respectively) where as minimum mean NDVI was observed in May (0.1231) and June (0.1063) months in Parbhani and Hingoli districts respectively. In case of classified area for Parbhani and Hingoli, August month contribute highest area under No Drought Class (99 % & 98.9 % respectively) due to highest rainfall on successive month of July and August.
2. In case of drought year, it was observed that, maximum mean NDVI was highest (0.5841 & 0.6796 respectively) in August month for both Parbhani and Hingoli districts followed by September, October and November months whereas minimum mean NDVI was observed in January (0.0892) for Parbhani and May (0.1048) month for Hingoli district. In case of classified area for Parbhani district, all month had Mild drought except August and september months more than 80 % whereas for Hingoli district area under Mild Drought Class were more than 78 % due to dry spell occurrence except August, September October due to sufficient rainfall.
3. After comparison of NDVI during normal and drought year; in case of Parbhani, it was observed that, Mild drought area was observed more in 2015 compared to 2020 due to maximum dry spell duration and minimum rainfall except August month. In August 2020, due to large dry spell reduces vegetation coverage compared to 2015. Similarly, for Hingoli district, due to 19 days dry spell July affected on vegetation in year 2020. Otherwise, whole 2020 year has more vegetation than 2015 was observed.
4. Only April and May months had a positive value of NDDI, whereas other months had negative. In the case of the Hingoli district, a maximum of 0.2507 NDDI was observed in November. In year 2020, throughout a year except March, April and May had maximum area comes under No Drought Class for both Parbhani and Hingoli districts.
5. In drought year, monthly mean NDDI values throughout a year were positive except January and June for Parbhani and November and December for Hingoli which indicates maximum drought occurrence during 2015. In case of area

distribution during March, April and May month in year 2015 area under Mild Drought Class was increased compare to other months for both the districts.

From the present study of Parbhani and Hingoli districts of Marathwada region it is concluded that,

1. The annual mean NDVI values during the normal year (2020) for Parbhani and Hingoli districts was 0.1925 and 0.1877 respectively. For year 2020, area under Mild Drought Class for both Parbhani and Hingoli district was highest 84.9 % and 84.6 % respectively.
2. During the drought year (2015) NDVI values for Parbhani and Hingoli districts were 0.1580 and 0.1848 respectively. The area under Mild Drought Class was 90.9 % in Parbhani district; similarly, in Hingoli 85.0 % area was highest under Mild Drought Class.
3. During the drought year area under Mild Drought Class was increased as compare to the normal year in both Parbhani and Hingoli district.
4. The annual mean NDDI values during the normal year (2020) for Parbhani and Hingoli districts was -0.0771 and -0.0749 respectively. For year 2020, area under No Drought Class for both Parbhani and Hingoli district was highest 84.3 % and 84.0 % respectively.
5. During the drought year (2015) NDDI values for Parbhani and Hingoli districts were 0.04915 and 0.05265 respectively. The area under No Drought Class was 86.2 % in Parbhani district; similarly, in Hingoli 89.1 % area was highest under No Drought Class.

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