ASSESSMENT OF LENGTH OF GROWING PERIOD USING METEOROLOGICAL AND REMOTE SENSING DATA OF NAGPUR DISTRICT, MAHARASHTRA

THESIS

Submitted to
Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola
in partial fulfilment of the requirements
for the Degree of

MASTER OF SCIENCE
IN
AGRICULTURE
(SOIL SCIENCE AND AGRICULTURAL CHEMISTRY)
(Land Resource Management)

By

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Enrolment Number-MM-1701 **2020**

DECLARATION OF STUDENT

I hereby declare that the experimental work and interpretation of the thesis entitled **“ASSESSMENT OF LENGTH OF GROWING PERIOD USING METEOROLOGICAL AND REMOTE SENSING DATA OF NAGPUR DISTRICT, MAHARASHTRA”** or part thereof has not been submitted for any other degree or diploma of any University, nor the data have been derived from any thesis/publication of any University or Scientific Organization. The source of materials used and all assistance received during the course of investigation have been duly acknowledged.

Place: Akola
Date: / /2020

PRIYANKA VILASRAO DESHMUKH
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CERTIFICATE

This is to certify that the thesis entitled **“ASSESSMENT OF LENGTH OF GROWING PERIOD USING METEOROLOGICAL AND REMOTE SENSING DATA OF NAGPUR DISTRICT, MAHARASHTRA”** submitted in partial fulfillment of the requirements for the degree of “**Master of Science in Agriculture (Soil Science and Agricultural Chemistry with specialization in Land Resource Management)”** of the Dr. Panjabrao Deshmukh Krishi Vidhyapeeth, Akola is a record of bonafide research work carried out by **Deshmukh Priyanka Vilasrao** under my guidance and supervision.

The subject of the thesis has been approved by the Student’s Advisory Committee.

Place: Nagpur
Date: / /2020

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AEZ	Agro Ecological Zoning
ALOS	Advanced Land Observing Satellite
AVHRR	Advanced Very High Resolution Radiometer
AWC	Available water Content
DEM	Digital elevation model
ET	Evapotranspiration
ET_o	Reference evapotranspiration
FAO	Food and Agricultural Organization
FCC	False colure composite
GIS	Geographic Information System
GVI	Global Vegetation Index
Ha	Hectare
IDW	Inverse Distance Weighing
IIASA	International Institute for Applied Systems Analysis
kPa	Kilopascal
LGP	Length of Growing Period
LULC	Land Use land Cover
M	Meter
Max.	Maximum
Min.	Minimum
mm	Millimeter
MODIS	Moderate Resolution Imaging Spectroradiometer
MSI	Multispectral Instrument
MSL	Mean sea level
NDVI	Normalized Difference Vegetation index

NIR	Near Infrared
nm	Nanometer
PALSAR	Phased Array type L-band Synthetic Aperture Radar
PET	Potential evapotranspiration
PRISM	Panchromatic Remote-sensing Instrument for Stereo Mapping
RBF	Radial Basis Functions
SGF	Savitzky-Golay filter
TGA	Total geographical area
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
VI	Vegetation index

(D) THESIS ABSTRACT

a)	Title of the thesis	**:**	“**ASSESSMENT OF LENGTH OF GROWING PERIOD USING METEOROLOGICAL AND REMOTE SENSING DATA OF NAGPUR DISTRICT, MAHARASHTRA**”
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ABSTRACT

The present investigation was carried out in Nagpur district, Maharashtra to assess the length of growing period using meteorological and remote sensing data. The meteorological data of different meteorological observatories located in Nagpur district was collected from the climatic database and potential evapotranspiration (PET) was computed using Penman-Monteith equation. Landforms and land use/land cover were characterized using ALOS-2 digital elevation model (DEM) and Sentinel-2 data. The existing soil database was upgraded using the landform and land use/land cover information. Length of growing period (LGP) was computed using rainfall, PET and soil attributes. Length of growing period (LGP) of the study area was also assessed using time-series NDVI-based MODIS data.

Ten major landforms *i.e.*hills, plateau, scarp, pediments, pediplain, valley, gullied land, butte/mesa/ridge, mining area and waterbodies have been identified. The pediplains were further divided in to pediplains (hillside), upper pediplains and lower pediplains. There were six major land use/land cover classes namely agriculture, forest, scrubland, built up area, mining and waterbodies. Highest rainfall was observed in Nagpur-Rural tehsil (1569 mm) and the lowest rainfall was recorded in Narkhed tehsil (982 mm). Highest PET was observed in Hingna tehsil (1758 mm) and the lowest PET was recorded in Nagpur-Rural tehsil (1656 mm). The surface mapof LGP prepared from point data (krigged) indicate that LGP ranged from 138 to 155 days. The pixel-wise LGP data computed using MODIS-NDVI-time-series data has been reclassified in to 5 classes *viz.*, 90-120, 120-150, 150-180, 180-210 and 210-240 days. The surface map of LGP indicate that LGP class150-180 days occupied maximum area (40.7%) followed by LGP class 210-240days (17.7%), LGP class 180-210 days (15.4%), LGP class 120-150 days (14.8%), whereas, LGP class 90-120 days has least area (11.8%). LGP in different landforms indicated that maximum LGP was in lower pediplains (46.3%) followed by pediments (21.7%)

and plateau (11.1%). Lower LGP was observed in upper pediplains (7.1%), hills (5.4%), pediplain (hillside) (2.5%), scarp slope (1.9%), valley (1.6%) and gully land (0.8%). LGP in different land use/land cover indicate that maximum LGP was under agriculture (69.5%) followed by forest (23.3%) and scrubland (7.1%). Out of the 5 classes of LGP, 93.7 per cent of total agricultural area has LGP from 120-240 days. Based on length of growing period and soil characteristics, a tehsil-wise land use plan has been prepared for intensive cultivation, agri-horticulture, agroforestry, silvipasture, vegetable cultivation, floriculture and afforestation.

Chapter - I

INTRODUCTION

Importance of study:

Agricultural crops grow in favourable weather conditions for their emergence, vegetative growth and ripening. India is predominantly under rainfed farming with 55% of net sown area being rainfed (NRAA, 2012), which depends on timely onset and well distribution of rainfall. Rainfall determines the potential of any region in terms of crops to be grown, farming system to be adopted, the nature and sequence of farming operations to be followed and to achieve higher agricultural productivity (Singh and Dhillon, 1994; Chaudhary*et al.* 2003). Rainfall particularly south-west monsoon, its amount and distribution, plays a vital role in Indian agriculture, especially, in rainfed area which impacts the nation’s economy in various ways. Occurrence of long dry spells and droughts once in every five years negatively influencing crop yields, livestock production and national economy is common in India (Sudhishri *et al.*2007a). Thus, knowledge of weekly, monthly and annual rainfall pattern with onset and withdrawal of monsoon is the key factor for overall planning of agricultural activities. Analysis of daily, weekly, monthly and annual rainfall data are essential for planning and design of soil and water conservation measures, irrigation, drainage, command area development, water resource development and overall management of agricultural situation of the region (Sudhishri *et al.* 2007b).

The most important problems associated with rainfall variability on moisture availability are: (a) the high variability in onset of monsoon from one station to another; (b) the temporal (monthly and annual) distribution of the rainfall at each station or over a certain area; (c) the cessation and length of the rainy season. Hence, it is necessary to explore the rainfall and its spatial variability over a space along with its length of growing period (LGP) to make crop based decisions (Sathyamoorthy *et al.*2017).

Knowledge of water budget elements in space and time is essential not only for the crop schedule but also to determine the crop growing period. Soil moisture is the key parameter in the physiological processes of the soil-crop-atmosphere system and also plays a vital role in agro-ecological systems and this approach defines LGP as the number of days when soil moisture and temperature permit crop growth (Fischer *et al.* 2002) or more specifically, the period during the year when actual evapotranspiration exceeds half of the potential evapotranspiration (Fischer *et al.* 2012). The 'length of the rainy season' is the duration between the onset and end of agriculturally significant rains. This includes the period of soil moisture storage at the end of the rainy season, the post rainy season and winter rainfall, which can all meet the crop water needs. Therefore, the LGP depends not only on the climatic conditions but also on the type of soil, soil depth, water retention and release characteristics of the soil, air temperatures and daylight hours. LGP for most crops continues beyond rainy season with varying duration depending upon the soil moisture holding capacity and rooting depth of soils. Thus, the nature of soil modulates the growing season through available water content (AWC). LGP is also an important input to the Agro-Ecological Zoning (AEZ) approach of the International Institute for Applied Systems Analysis (IIASA) and the Food and Agricultural Organization (FAO) [2012]. Therefore, spatial assessment of LGP helps in land preparation, crop planning, agricultural operations and water management. Kruska *et al.* (2003) used LGP thresholds to distinguish between arid, semi-arid, sub-humid and humid livestock production systems.

Quantification of growing period is crucial for understanding seasonality in land resource appraisal and is a vital criterion for delineating ecosystem (FAO, 1996). Generally, yields may suffer significantly with the length of the growing season, as well as with a high frequency of damaging dry spells within the growing season. The amount of soil water available to crops depends on variability of rainfall and length of growing period, which influence the success/failure of a cropping season (Ngetich *et al.* 2014) and the variability in onset of monsoon and cessation could pose socio-economic and developmental challenges as they threaten food security and induce poverty (Cooper *et al.* 2008; Lacombe *et al.* 2012). The ability to estimate effectively the length of the growing period, therefore, becomes fundamental. Information on LGP of a particular region helps in selection of cultivar (short/medium/long duration) of a particular crop. Therefore, farmers can select their crops carefully based on LGP by reducing the risks of not meeting the crop demands in specific years.

Several methods have been used to estimate the LGP using rainfall (IMD, 1991; Sivakumar *et al.*1993), rainfall and Potential Evapotranspiration (Velayutham *et al.*1999). An alternative approach to estimate LGP is through the direct use of multi-temporal remote sensing MODIS data in which Normalized Difference Vegetation Index (NDVI) reflects the growing status of green vegetation (Thirupathi *et al*. 2015). Crop monitoring could be realized by using remote sensing technique on the basis of time series NDVI data together with agriculture calendars (Dong *et al.* 2003). NDVI is calculated as the near infrared minus red reflection, divided by the sum of the two (Tucker, 1979). Sabins *et al.* (1996) reported that phenological changes in the crop during the growing season can be studied by examining changes in remote sensing-based NDVI.

To capture the vegetation development and reduce atmospheric effects, we need sensors that provide near-daily image acquisition. These include the Advanced Very High Resolution Radiometer (AVHRR) and the Moderate Resolution Imaging Spectroradiometer (MODIS). The AVHRR normalized difference vegetation index (NDVI) is the basic Global Vegetation Index (GVI) product and has been routinely used to monitor vegetation growth at global scale (Burgess *et al.* 1995). Many authors have performed phenological analysis on vegetation index time series from these sensors (Boschetti *et al.* 2009; Brown *et al.* 2010; Kaushalya *et al.* 2014).

Geostatistics tools in Geographic Information System (GIS) generate continuous surfaces from point data (Burrough, 1986). Mathematical functions of various interpolation types and complexity are used to fit surfaces through the points.

The Nagpur district of Maharashtra is experiencing frequent erratic rainfall with continuous depletion of vegetative cover and increase in soil erosion with low crop productivity. Spatial information in terms of length of growing period is very important for crop planning and various agricultural operations to prevent crop failure due to erratic rainfall. Therefore, the present investigation has been planned to compute the length of growing period using various methods with the following objectives.

Objectives:

- To refine and develop database on broad landforms, land use and soils of Nagpur district using legacy data and remote sensing and GIS.
- To compute LGP using meteorological and remote sensing data (MODIS) of Nagpur district in GIS environment.
- To compare the spatial variability of LGP computed by meteorological and remote sensing data.

Scope and limitations:

Spatial assessment of length of growing period helps in land preparation, crop planning, agricultural operations and water management. There are limitations in climate-based LGP approach as the weather stations located in the region are limited and also do not have sufficient ground-based resources in terms of infrastructure and automation in collecting and processing the weather data. The use of multi-temporal remote sensing MODIS data helps in spatial analysis of many parameters including Normalized Difference Vegetation Index (NDVI) and length of growing period and helps us in land preparation, crop planning, intercultural operations and water management.

Chapter - II

REVIEW OF LITERATURE

A brief review of literature related to the study has been grouped under following heads and sub-heads.

2.1 Characterization and mapping of land resources

2.1.1 Land Use/Land Cover mapping

2.1.2 Physiography-soil mapping

2.2 Length of growing period using meteorological data

2.3 Length of growing period using remote sensing data

2.1 Characterization and mapping of land resources

2.1.1 Land use/ land cover

Ardak *et al.* (2010) characterized the land resources of Khapri village of Nagpur district, Maharashtra on 1:12500 scale using IRS-P6 LISS-IV and IRS-1D PAN merged LISS-III data. They delineated and mapped land use/land cover classes as agriculture (single and double crop), wasteland with scrub and degraded forest.

Patil *et al.* (2010) studied the Longadga watershed of Chandrapur district of Maharashtra using IRS-1D LISS-III and Landsat-7 TM data. They identified and prepared the land use, land cover map comprising cultivated land, wasteland with scrub, water body and habitation.

Patil *et al.* (2010) studied the land resources of Lendi Watershed, Chandrapur district, Maharashtra using IRS-1D LISS-III. They identified five major land use/land cover classes as cultivated land (62.8 %), wasteland with scrub (18.9 %), forest (14.9 %), rock out crop comprising quarry (0.7 %) and water body (2.0 %). The cultivated area was further delineated into single (43.3 %) and double cropped (19.5 %) areas.

Wadodkar and Ravisankar (2011) characterized the land resources of Mohammadabad village in Nalgonda district, Andhra Pradesh on scale 1:10000 scale using Resourcesat-1 LISS-IV + Cartosat-1 merged data. They delineated and mapped land use/land cover as agriculture land, fallows, forest, wastelands and barren/rocky.

Pachpor *et al.* (2012) visually interpreted the IRS-P6 LISS-IV data of Savli micro-watershed, Nagpur district, Maharashtra and prepared land use/land cover map comprising single crop, double crop, wasteland, water body and habitation.

Deshmukh *et al.* (2012) prepared the land use/land cover map of Tandulwadi watershed of Nagpur district, Maharashtra using Geocoded FCC of IRS-P6 LISS-IV imagery and SOI toposheet (1: 50,000) they reported that nearly 42.8 % of the area is crop land, 37.5 % notified forest, 19.4 % wasteland and the remaining 0.3 % is under habitation.

Bante *et al.* (2012) prepared land use land cover of Taroda watershed of Vidarbha region of Maharashtra usingIRS-1D LISS-IV data and revealed that 54.8 per cent of TGA was under cultivation, 22.7 percent under wasteland with scrub and 21.1 percent under degraded forest.

Das *et al.* (2013) studied nine villages of Doomdoma subdivision of Tinsukia district of Assam using IRS-P6 LISS-IV, Cartosat-1 and LISS-IV +Cartosat -1 merged and LISS-III image and prepared land use/land cover showing agriculture (field crops and tea garden), wasteland (scrublands), built up forest plantations and water body. They reported that 81% area was under agriculture use that includes kharif crop (mostly winter rice called Sali rice), double crop (kharif and rabi) and tea gardens. Area under tea gardens was the highest

(1173.34 ha) which was 50% of the total area and 62% of agriculture land.

Nasre *et al.* (2013) characterized and assessed the land resources of Karanji watershed, Yavatmal district, Maharashtra using remote sensing data for their sustainable use. They delineated and mapped land used land cover classes as cultivated crop (single and double crop), degraded and moderately dense forest and wasteland with scrub.

Bhandari *et al.* (2014) studied the watershed of Tons river in Dehradun using LISS-III remote sensing data. They reported maximum area (60%)under forest followed by agriculture (28.9%), waterbed (4.74%), flood plains (4.38%) and scrub (1.04%) using a combination of two approaches i.e. visual image interpretation and digital image classification of FCC (1:50000 Scale).

Raju *et al.* (2013) characterized the land resources of Vizianagaram district of Andhra Pradesh using remote sensing and GIS data. they delineated the land used land cover classes as agriculture land (68%), built-up land (1%), forest (15%), wasteland (10%) and waterbodies (6%) of total geographical area.

Rane and Bhushan (2014) prepared the land used land cover map of Jalgaon district in Maharashtra using IRS-P6 LISS-III data. They identified and reported that agriculture remains the major land use class comprising about 65.81% followed by barren land (21.05%), forest cover (8.44%), water body (2.75%), built-up area (1.5%) and agriculture within the forest (0.55%)of the total geographical area.

Nagaraju *et al.* (2014) prepared the land used and cover classes of Savli village of Wardha district using Cartosat-1 merged IRS-P6 LISS-IV data. They identified the land use land cover classes as single crop, double crop, wasteland with and without scrub and degraded forest.

Nagaraju and Gajbhiye (2014) prepared land use/ land cover map of Kukadi Command of Ahmednagar district of Maharashtra and classified land use/ land cover classes in to cultivated land (single and double crop), degraded and moderately dense forest and wasteland with scrub.

Das *et al.* (2014) visually interpreted IRS-P6 LISS-III and LISS-IV data to derived information on land used land cover of Mawryngkneng district, Meghalaya and they have reported as the 32.2 per cent of the total geographical area (TGA) is under dense forest followed by wastelands (28.8 %), open forest (16.1 %), cultivated area (13.6 %), built up area (8.2 %) and water body (0.9 %).

Nagaraju *et al.* (2015) delineated five land use/land cover classes namely single crop, double crop, wasteland, water body and habitation usingIRS-P6 LISS-III data in Saraswati watershed, Buldhana district, Maharashtra.

Sahu *et al.* (2016) characterized the land resources of Miniwada Panchayat, comprising of three villages in a basaltic terrain of Central India, using high resolution IRS-P6 LISS-IV data and Cartosat-1 DEM. They delineated six land use/land cover classes namely single crop, double crop, orchard, land with and without scrub and degraded forest.

Sadanshiv (2016) studied the Nagalwadi micro-watershed, Karanja tehsil, Wardha district, Maharashtra on scale 1:10000 scale based on Cartosat-1 merged IRS-P6 LISS-IV data. They delineated land use/land cover classes as forest, agriculture land, (single and double crop) fallows, wastelands and barren/rocky.

Cheruto *et al.* (2016) studied land use and land cover change of Makueni County, Kenya using multispectral satellite data obtained from Landsat-7 and GIS. They identified and classified the country into seven major LU/LC classes *viz.*, Built up areas, croplands, water bodies, evergreen forests, bush-lands, grassland and barren land.

Veeraswamy *et al.* (2017) studied land use land cover of Gudur area in Nellore district, Andhra Pradesh using Survey of India toposheet and IRSP6-LISS-III (FCC) image. They delineated six land use/land cover classes as built-up, cultivated, water bodies, forest, barren and uncultivated land and observed that agriculture lands cover 159.83 km^2 (65%), forest occupies 15.22 km^2 (6.0%), built up urban and rural area covers 5.31 km^2 and 6.56 km^2, respectively. Quarry and industrial area covers 1.78 km^{2}and 0.43 km^2, water bodies and uncultivated lands occupy 24.62 km^2.

Surya *et al.* (2018) prepared land use and land cover map of Richhoha micro-watershed (1763.76 ha), Kheragarh tehsil, Agra district, Uttar Pradesh using IRS-P6-LISS-IV and Cartosat-1 merged data. Out of the total area of the watershed, 949.61 ha (53.84 %) was under cultivation and mostly under single crop (29.67%) followed by stony waste/ pasture (37.33%) and pasture/grazing/ thin shrubby forest (7.51%).

Savita *et al.* (2018) worked in Kanakanala reservoir sub-watershed and identified agriculture with an extent of 139.28 km^2 (71.43%). Similarly, scrubland, barren land, rock outcrop, water body and settlements covered 32.12 km^2(16.47%), 11.66 km^2 (5.98%), 7.19 km^2(3.68%), 2.77 km^2 (1.41%) and 1.97 km^2 (1.01%), respectively.

Bora *et al.* (2018) characterized the land resources of Tarai region of Udham Singh Nagar district of Uttarakhand using IRS R-2 LISS-Iv data and identified major area under agriculture followed by forest plantation which is about 36 and 34 percent, respectively.

Kumar *et al.* (2018) studied the Object Based Image Analysis (OBIA) to create broad level urban Land Use / Land Cover (LU/LC) map using high resolution ResourceSat-2 LISS-4 and Cartosat-1 pan-sharpened image and mapped the 4 major land used land cover classes *viz.,* vegetation, water, built up and barren land.

Borse *et al.* (2018) prepared land use land cover map of Barela village in Seoni district, Madhya Pradesh using IRS LISS-IV and GIS. They mapped land use land cover as single crop, double crop, degraded forest, wasteland, river, waterbody and habitation.

Krishnaiah*et al.* (2019) studied the land use/land cover and change detection in Chikodi Taluk, Belagavi district, Karnataka using Object Based Image Analysis (OBIA) method and multi-resolution segmentation They identified four land use/ land cover classes such as agriculture, built-up, wasteland and water-body.

2.1.2 Physiography-soil mapping

Kashiwar *et al.* (2009) used IRS-1D LISS-III and PAN sharpened LISS-III data for characterization of Salai watershed of Nagpur district, Maharashtra. Three physiographic unit *viz.*, subdued table land, upper valley and isolated mound with pediments were identified and mapped.

Ardak *et al.* (2010) studied the physiography of Khapri village of Nagpur district of Maharashtra on 1:12500 scale using IRS-P6 LISS-IV and IRS-1D PAN sharpened LISS-III. They classified the watershed into six major physiographic units*viz.,* isolated hillocks, plateau top, escarpment, pediment, upland and valley plain.

Patil *et al.* (2010) prepared the physiography map of Lendi watershed of Chandrapur district of Maharashtra using IRS-1D LISS-Ill data. They delineated the watershed into five major physiographic units *viz.,* isolated mounds, subdued plateau, uplands (upper reaches), midlands (interfluves) and lowland (stream channel) and prepared soil map. Eleven soil series viz., Salori-1, Salori-2, Salori-3, Kutbala-1, Kutbala-2, Mowada, Shegaon-1, Shegaon-2 and Bandra were identified and mapped.

Wadodkar and Ravisankar (2011) prepared physiography map of Mohammadabad village in Nalgonda district, Andhra Pradesh using

Resourcesat-1 LISS-IV + Cartosat-1 merged data. They identified four major physiographic units *viz.,* hills, undulating plain, gently sloping plain and valley.

Nasre *et al.* (2013) studied the physiography of Karanji watershed of Yavatmal district, Maharashtra using remote sensing data and digital elevation model (DEM). They delineated seven physiographic units comprising plateau top, escarpment, isolated hillock, foot slopes, undulating land, alluvial plain and valley.

Bhandari *et al.* (2014) characterized the physiography of Tons watershed, Dehradun. They divided study area into three major landforms (hilly, piedmont plains and flood plains) and further divided into 10 physiographic units. Most part of the area was covered by Himalayan mountains and piedmont plains.

Singh (2014) interpreted IRS -1C LISS–III data of Mohanrao watershed which exists between two states Haridwar district of Uttarakhand and Saharanpur district of Uttar Pradesh on 1:50000 scale. They delineated different physiographic units *viz.,* Shiwalik hills, piedmont plain, alluvial plain, residual hills.

Nagaraju *et al.* (2014) used a high-resolution DEM with a posting of 10 m generated from a cartosat-1 stereo pair to derive terrain attributes. Based on erosional and depositional processes, five major land forms, namely plateau top, escarpment, pediment (erosional), alluvial plain and narrow valley (depositional), have been delineated using 3D perspective viewing of the landscape. Nine soil series were identified and a detailed soil map has been developed through the PLU-soil relationship.

Singh *et al.* (2015) characterized the physiography of Subarnarekha catchment, Chhotanagpur plateau using ASTER (30 m) DEM and geocoded IRS-ID LISS-III data with adequate field surveys. They delineated five physiographic units comprising moderately steeply sloping upland, moderately sloping undulating upland, moderately sloping terraced land, gently sloping low land and narrow valley bottom.

Nagaraju *et al.* (2015) prepared the physiographic map of Saraswati watershed in Buldhana district of Maharashtra and identified four physiographic units *viz.,* plateau, pediments, board and narrow valley. They revealed that soils of plateau are shallow to slightly deep shallow (Lithic Ustorthents/ Typic Haplustepts/ Vertic Haplustepts); soils of pediments are very shallow to shallow (Lithic Ustorthents/ Vertic Haplustepts) and soils of broad and narrow valley are deep (Vertic Haplustepts/ Typic Haplustepts).

Sahu *et al.* (2016) prepared the physiography map of Miniwada Panchayat comprising three villages in a basaltic terrain of Central India using high-resolution IRS-P6 LISS-IV data and Cartosat-1 DEM. They revealed that physiographically, the area is delineated in to six classes as plateau top, scarp slopes, plateau spurs, pediment, undulating plain, broad valley, narrow valleys and floodplain.

Sadanshiv et al. (2016) studied and prepared the physiography-soil map of Nagalwadi micro-watershed, Karanja tehsil, Wardha district, Maharashtra using geocoded false colour composite (FCC) Cartosat-1 merged IRS-P6 LISS-IV data. They identified the area into plateau, pediment and valley. These physiographic units were further sub-divided based on slope, land use/land cover and image characteristics. Five soil series were tentatively identified in the area on different physiographic units.

Borse *et al.* (2018) prepared physiography map of Barela village in Seoni district, Madhya Pradesh using geocoded false colour composite (FCC) Cartosat-1 (30 m) resolution topography information and identifiedplateau, escarpment, mounds, pediments and alluvial plain. Five soil series *viz.*, Barela-1, Barela-2, Barela-3, Barela-4 and Barela-5 have been tentatively identified and mapped in to 16 mapping units.

2.2 Length of growing period using meteorological data

Robeson (2002) used the daily minimum air-temperature ($T_{\min}$) data from the state of Illinois, the dates of spring and fall freezes and examined the resulting growing season length for the period 1906–1997. They found that the length of the growing season in Illinois (as defined by daily minimum air temperatures of 0°C) has increased by nearly one week over the last 100 years as this change was the result of earlier spring freezes, which also are occurring nearly one week earlier (when spatially averaged over Illinois).

Liu *et al.* (2006) studied the temporal trends and variability of daily maximum and minimum, extreme temperature events and growing season length over the eastern and central Tibetan Plateau during 1961–2003. They found that the warming trends in winter night time temperatures were among the highest when compared with other regions as the warming in regional climate caused the number of frost days to decrease significantly and the number of warm days to increase resulting into the length of the growing season increased by approximately 17 days during the 43-year study period.

Vaidya *et al.* (2008) studied the moisture availability index based crop planning in assured rainfall region of South Gujarat. They revealed that with the variation of rainfall, length of growing period (LGP) varied between 12 to 24 weeks in different districts of South Gujarat in which crops like paddy, sorghum, pearl millet and other millets, pigeonpea, gram, maize and other pulses are found suitable in Bharuch, Surat and Navsari districts whereas, the long duration crops like sugarcane, cotton and paddy can be taken in areas having higher LGP and they found that the area was also suitable for crops like mango, sapota and banana *etc*.

Mugalavai *et al.* (2008) analysed the rainfall onset, cessation and length of growing season for western Kenya by using the historical daily climatic data of a 15–34 year period and soil data from 26 stations, distributed in the study area and revealed that there exists organized progression of rainfall onset within the western Kenya region with the long rains showing a southerly progression, while, the short rains showed a south-westerly progression cessation of rainfall for both seasons and showed strong localized influences, mainly surrounding Lake Victoria and forested areas, including orographic features and for stations with long length of growing season, the length varies more than the onset date.

Kesavarao *et al.* (2008) studied the agroclimatic assessment of watersheds for crop planning and water harvesting in Malleboinpally (Alfisols) in Jadcherla Mandal of Mahabubnagar district and Nandavaram (Vertisols) in Banaganapalle Mandal of Kurnool district, Andhra Pradesh using agrometeorological data for the period 1971-2006. They revealed that Nandavaram has LGP ranging from 120 to 195 days and Malleboinpally has LGP ranging from 100 to 160 days and this resulted into the early and mid-season droughts at Nandavaram in which the watershed would require crop/varieties tolerant to early or mid-season droughts depending upon the location, while, Malleboinpally has greater potential for water harvesting and offers opportunity for supplemental irrigation.

Joshi *et al.* (2009) classified the agro climatic zones of the Maharashtra state using weekly rainfall and estimated potential evapotranspiration of 47 stations and the length of growing season, wet spells and dry spell and identified six zones as arid, semi-arid, dry sub humid, sub-humid, humid and per humid.

Bal *et al.* (2012) studied the agro-climatic resource inventory characterization of Punjab State in spatial domain by using climatic data from meteorological department of State Agricultural Universities, India for generating the thermal maps and LGP maps using GIS, they divided the Punjab into five zones for temperature and seven zones for Length of Growing Period. They found that area under annual average temperature of 23-24°C was highest (58% of total geographical area) followed by annual average temperature 24-25 °C and the least area was under annual average temperature of 21-22°C. They observed that the state has highest area (29.5%), where, LGP varies from 120-140 days (L3 zone) followed by L4 and L5 and the less than 1 per cent of the total area of the state has LGP of >160 days. They also revealed that the temperature and LGP variation in the entire state depicted a reverse trend, being maximum temperature in south-western part with lowest LGP, while, lowest temperature being recorded in the northern most parts with highest LGP.

Mugandani *et al.* (2012) studied the agro-ecological regions of Zimbabwe and reclassified this natural regions (NRs) using soil data, mean-annual rainfall and length of growing season because of the climate variability and change, in which rainfall data selected from meteorological stations covered the period of 1972- 2006 and soil data were obtained from the soil map of Zimbabwe, while length of growing seasons data were obtained from the FAO New Local Climate database. They found that the number of NRs in Zimbabwe has not changed based on average climatic conditions of 1972–2006 and the mean annual rainfall for the new zones were also not significantly different ($p<0.05$) from the current zones, but resulting in changes in the sizes of the NRs with NRs I, IV and V increasing by 106, 5.6 and 22.5 %, respectively, while, NRs II and III decreased by 49 and 13.9 %, respectively.

Manish Kumar *et al.* (2013) assessed the length of growing season and drought incidence in different districts of Bihar under the 3 agro climatic zones viz., Zone I, Zone II and Zone III (Zone IIIA and Zone IIIB) by using the mean weekly rainfall and mean weekly PET and found that the highest LGP at Madhepura (239 days) followed by Motihari (224 days) and the lowest in the Nalanda region (144 days). The LGP calculated for Patna and Bikaramganj regions (Zone IIIB) of the state were 199 and 194 days, respectively. LGP calculated for Sabour (Bhagalpur) region in Zone IIIA was 216 days and revealed that

Intercropping, mixed and multiple cropping based on extended length of growing period could be worked out in this region and LGP value of 144 days in the Nalanda region of Zone IIIB is suitable for growing mono and inter-cropping system with irrigation provision.

Rajkumar *et al.* (2013) studied on the inter-seasonal and intra-seasonal relationship of metrological and agricultural drought indices in the Rajasthan state of India for 24 years between the rainfall and NDVI and between the SPI (standardize precipitation Index) and Trend Adjusted VCI (vegetation condition Index) to understand the crop response to water availability. They found significant linear relationship between NDVI and rainfall but phase of the crop season affected the strength of this relationship and observed that SPI and VCI_{Tadj} were linearly related in all four seasons.

Hadgu *et al.* (2013) studied and compared the trend and variability of rainfall with farmers' perception in Tigray, Northern Ethiopia by using daily rainfall data obtained from five meteorological stations located in different agro-ecological zones. They found that trends of rainfall events such as onset date, cessation date, LGP and dry spell length were changed with rainfall variability in most of the stations, which agreed with the farmers' perception in which most of the stations experienced drought conditions in the last decade and concluded that there is need for designing appropriate agronomic and water management strategies to offset the negative impacts of rainfall variability in the study area.

Hema Malini and Endris (2013) computed the ideal length of growing period (LGP) for the rainfed crops of Amhara state of Ethiopia by using Thornthwaite's 1955 water balance method using monthly rainfall and temperature data for the station collected from the records of National Meteorological Agency (NMSA) of Ethiopia for a period of 1968–2010. The LGP for study area is 150 days from July to November and revealed that the December month are not suitable for crop production due to insufficient moisture.

Fiwa *et al.* (2014) studied the effect of rainfall variability on the length of crop growing period over the past three decades in Central Malawi. They obtained the length of growing period for a particular season from the difference between the onset and cessation of that particular season using 30 years historical daily climatic data (1980-2009) from five metrological stations within central region of Malawi and observed that the delay onset and early cessation of the growing period resulted in a shorter length of growing period and seasonal rainfall amounts did not change much but the number of rainfall events has become wetter recently than before, Including higher rainfall intensity.

Ramesh *et al.* (2016) used the weekly rainfall or precipitation (RF) and Potential Evapotranspiration (PET) data of 52 standard weeks for 20 years’ period (1996-2015) of Southern Transitional Zone (STZ) of Karnataka and determined the length of growing period for efficient crop planning and sustaining farm productivity in the rainfed area. They found that successful crop production activities were possible for a period of 210 days starting from April second fortnight to November 1st week in this zone during which the RF is sufficient enough to satisfy the minimum PET demand (RF/PET ratio of >0.50). However, the 26th standard week (RF/PET ratio of <0.50) in the growing season (May 4th week and partly July 1st week) found critical for moisture for the kharif sown crops during which, RF is not sufficient enough to meet the minimum PET demand of the crops/vegetation in the region, On the other hand, 41st- 42nd standard weeks (RF/PET ratio of >1.50) from middle September to first week of October could create water logged /saturated conditions in the field for the rabi crop.

Raman *et al.* (2017) studied the Impact of climate change on Length of Growing Period in 16 districts falling in the Western Zone of Tamil Nadu using data for four years viz., 2000, 2005, 2010 and 2013 in which precipitation product downloaded from NASA website using the Warehouse Inventory Search Tool and PET is estimated from a set of meteorological products estimated through remote sensing. They revealed that the shift and change in the LGP as ascertained from this project for the western districts of Tamil Nadu resulted that there is certain shift in both positive and negative direction and the blocks with positive shift like increase in LGP with not much change in the start of season are potential areas for diversifying crops and possibilities of crop intensification, whereas, the blocks that show negative trend with major shift in the start of season and reduction in the LGP are areas of major concern and they suggested that alternate crop planning is important.

Sathymoorthy *et al.* (2017) studied the rainfall pattern and length of growing period over North Western Zone (NWZ) of Tamil Nadu and explored the rainfall and its variability over space along with its length of growing period to make the crop based decisions. They found that the annual normal rainfall of NWZ is 811 mm. Denkanikottai (998mm) had highest rainfall among all the locations, while, Paramathi (518mm) had the lowest and reported that southwest monsoon contributes 47% of rainfall followed by Northwest monsoon contributing 34% from July to November and good amount of rainfall was witnessed with peak during September over NWZ. They also reported that the location Salem had the highest LGP, while, Paramathi had the lowest.

Lotfie *et al.* (2018) studied the length of growing season for dry rainfed farming under monsoon climate in Gedarif, Sudan and determined the start, end and length of growing season based on dependable rainfall during wet (20%), normal (50%) and dry (80%) years which were retrieved from historical rainfall records. They analysed seven stations in Gedarif state for the period 1985 to 2014 and categorized into two groups according to total seasonal rainfall. They observed that during wet years, group first had about 900 mm/year and group second had about 700-790 mm/year. In normal years, group first had about 660-700 mm/year and group second had 515-570 mm/year and during dry years, group first had 490-550 mm/year and group second had 350-425 mm/year. The result showed consistent trend of starting dates of the growing season regardless of high seasonal variability and variation in amount and distribution of rainfall among the stations and seasons. They used the MODIS Enhanced Vegetation Index and obtained similar results for three different year representing different probability levels (2013, dry;2000, normal;2007, wet) and observed that group first and group second in normal and wet years had 70 to 90 % of the total annual rainfall growing season, whereas, in dry year, group first had 70 to 80% of the total rainfall during growing season, while, group second had only 50 to 65%. They concluded that length of growing season increases with early start of season and wetter years.

Bhuarya *et al.* (2018) characterized the agro-climatic zone of Chhattisgarh and found that the annual rainfall during post-global warming period decreased by about 30-40% in Mahasamund area, 20-30% in central part of Chhattisgrah and 10-20% in southern (Bastar) and northern parts of Chhattisgrah as compared to pre-global warming period and observed that the highest LGP of >120 days was recorded in Bastar, Bijapur and Dantewada district and the lowest of <110 days was recorded in Bilaspur, Dhamtari, Durg, Janjgir, Mahasamund, Raigarh, Raipur, Kawardha and Rajnandgaon.

Lupi and Mamo (2018) studied the start, end and Length of the Growing Season and the number of rainy days in semi-arid Central Rift Valley of Ethiopia by using the daily weather data. They found that mean start, end and length of growing season are May 26, September 14, and 99 days in Mieso site; May 27, October1st and 97 days in Melkassa site, whereas, May 26, September 11 and 109 days in Adami Tulu site and the rainy days ranged from 92-165, 92-147, and 92-110 days in Mieso, Melkassa and Adami Tulu, respectively.

Sattar *et al.* (2019) studied the climatic water balance for assessment of growing season in Bihar by using the historical weekly rainfall data of 110 rain-gauge stations for a period ranging from 30 to

55 years, normal weekly potential evapotranspiration (PET) and available water holding capacity. They found that there is a wide variation in LGP, which ranged from 121 to 272 days over different districts in the state and the potential of rainfed crop and cropping plan in different districts of Bihar have been worked out for sustainable crop production under rainfed condition on the basis of LGP.

Bisht *et al.* (2019) delineated agro-ecological zones of Uttarakhand based on land use/land cover (agriculture, forest, barren land, built up land, waterbody and snow bound region), slope (0-5°, 5-15°, 15-30°, 30-50° and >50°), soil texture (frigid soils, loamy soils and sandy soils), temperature (<0°C, 0-15°C, and >15°C) and length of growing period (<120 days and >120 days) using remote sensing and GIS and categorized the entire Uttarakhand state into 38 agro-ecological zones (AEZs).

2.3 Length of growing period using remote sensing data

Chopra (2006) studied the drought risk assessment using remote sensing and GIS for Gujarat state from NOAA-AVHRR on the basis of NDVI and meteorological based standard precipitation index (SPI) and found that NDVI and rainfall was highly correlated in water limiting areas with highest correlation of NDVI-rainfall obtained for rainfed crop followed by irrigated crop and minimum for forest. It was also observed that NDVI, SPI and food grain yield had positive linear correlation with each other and concluded that the central and north eastern part of Gujarat are more prone to either agricultural or meteorological drought.

Sarma and Kumar (2006) studied the crop growing period and NDVI in relation to water balance components and revealed that the relation of the rainfall with NDVI is weak compared to soil moisture adequacy, whereas, in the case of cumulative rainfall, the results revealed better positive correlation with NDVI.

Duo *et al.* (2007) studied the sensitivity of Normalized Difference Vegetation Index (NDVI) to seasonal and Inter-annual climate conditions in the Lhasa Area, Tibetan Plateau and found the correlation between NDVI and precipitation in Lhasa area is higher than the correlation between NDVI and temperature. They also found that NDVI is sensitive to precipitation than temperature in this semi-arid climate zone. They also observed that the time series of NDVI demonstrated a positive trend from 1985 to 1999, which means that the vegetation biomass present on land surface is increasing and also this trend is strongly correlated to increased rainfall and temperature from mid-1980 to 1990 in the area.

Karlsen *et al.* (2008) studied the MODIS-NDVI-based mapping of the length of the growing season in northern Fennoscandia and used the phenology data on birch from 13 stations and 16-day MODIS NDVI composite data with 250 m resolution for the period 2000 to 2006 and found that moderately high correlation between NDVI and birch phenology with the earliest onset of growing season.

Brown and Beurs (2008) evaluated multi-sensor and semi-arid crop season parameter based on NDVI and rainfall and presented a new phenological model in the semi-arid monsoonal ecosystem of the West African Sahel and used humidity instead of calendar dates to identify the beginning of the season. They implemented this model on vegetation index from AVHRR, SPOT-Vegetation and MODIS and evaluated the existing methods using ground observations of sowing date, and compared the same metrics across multiple sensors and to rainfall based start of season (SOS).

Benhadj *et al.* (2012) studied the land use, vegetation dynamics and crop evapotranspiration in Tensift /Marrakesh Plain and inter annual analysis based on MODIS satellite Data of 16-days composite NDVI images from 2000-2001 to 2005-2006. They mapped the land use comprising three classes (orchard, bare soil and annual crop) for agricultural water management and estimated evapotranspiration from the FAO-56 algorithm, which computed crop water needs from a reference evapotranspiration and cultural crop coefficients. The spatial and temporal variations of MODIS estimates were found coherent with the main characteristics available to describe the Tensift /Marrakesh plain (land use, climate and water availability).

Willem *et al.* (2013) studied NDVI derived productivity and phenology alongside the Andes Mountains using thirty years of the new generation biweekly NDVI time series data and observed significant land cover specific trends and variability in annual productivity and land surface phenological response. The arid and semi-arid and sub-humid vegetation types across Argentina, northern Chile, northwest Uruguay and southeast Bolivia showed negative trends in productivity, while, some temperate forest and agricultural areas in Chile and sub-humid and humid areas in Brazil, Bolivia and Peru showed positive trends in productivity. Some of the areas have significant shifts in start of season and length of season of one to several months. The SOS and LOS of the growing season results showed large variability and regional hot spots, where later SOS often coincides with reduced productivity. A longer LOS is found for some locations in the south of Chile and Argentina, while, central Argentina has a shorter LOS. Some of the areas have significant shifts in SOS and LOS of one to several months impacting on vegetation productivity and phenology in south-eastern and north-eastern Argentina, central and southern Chile, and Paraguay.

Meng *et al.* (2013) studied remote sensing-based detection of crop phenology for agricultural zones in China using a new Threshold Method for each of 43 agricultural zones with different crop proportions which can achieve the highest percentage of Accepted Pixels (AP) for start of season (SOS) and end of season (EOS0 of each zone. They observed relatively good agreement between in situ SOS dates and the SOS dates based on remote sensing data using the proposed method with an average root mean square error (2000–2002) for SOS and EOS of17.14 days and 17.44 days, respectively.

Araya *et al*, (2013) studied the crop phenology based on MODIS satellite imagery as an indicator of plant available water content (PAWC) and revealed that the green up rate of the curve (GU-rate) showed the most consistent difference between soils of different PAWC as the rate of green up is higher for the soil points with relatively low PAWC and this variability between the sites with low and high PAWC could be explained with rainfall amount and seasonality.

Narumalani *et al.* (2013) assessed vegetation response to drought in Nebraska using Terra-MODIS Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI) and reported that the majority of the land cover pixels experienced significantly higher daytime and night-time LSTs and lower NDVI during the drought-year growing season ($p < 0.01$). They also observed that among the land cover types, grassland experienced the highest increase in daytime LST and decrease in NDVI.

Vrieling *et al.* (2013) studied the variability of Length of Growing Period and trend from 30 years of NDVI time series data over Africa and observed high LGP variability in arid and semi-arid areas and significant negative trends in LGP in northern parts of the Sahel, parts of Tanzania and northern Mozambique. They also observed positive trends across western and southern Africa.

Kouadio *et al.* (2014) assessed the performance of MODIS NDVI and EVI for seasonal wheat crop yield forecasting across western Canada with the Integrated Canadian Crop Yield Forecaster (ICCYF) across two spatial scales: the eco-district and Census Agricultural Region (CAR). They observed a significant improvement in forecasting skill obtained at the finer in eco district scale compared to the coarser CAR scale and opined that statistical-based forecasting error could be significantly reduced by making use of MODIS-EVI and

NDVI indices at different times in the crop growing season and within different sub-regions.

Kaushalya *et al.* (2014) studied NDVI variations to analyse the length of growing period in various agro-ecological sub-regions (AESR) in Andhra Pradesh and found that agriculture was vulnerable in AESR 3.0, 8.3 and 6.2 covering Anantapur, Chittoor and large parts of northern Telangana and relatively safe in AESR 7.2 covering southern Telangana and 6.3 including parts of Adilabad, marginally vulnerable in AESR 7.1 covering Kurnool and Kadapa and in 7.3 and 18.3 covering coastal districts of Nellore, Prakasam, Guntur and Krishna.

Thirupati *et al.* (2015) studied the variability on the length of growing period (LGP) using ground and space based (MODIS) data for the selected mandals of Warangal district of Andhra Pradesh and found that LGP assessed from weather station data (1996-2010) were found to be 128 to 182 days for different mandals. However, MODIS–based NDVI data revealed that the LGP ranged from 141 to 181 days for the selected mandals. Both the LGP data were compared and it was found that the two datasets were not significantly different.

Khan *et al.* (2016) studied the short-term drought assessment in Pakistan and adjoining south Asian areas by remote sensing MODIS-NDVI data and analysed the time series of the NDVI maps and time series of different variable i.e. rainfall, soil moisture, evapotranspiration and soil temperature model data and found a strong positive relationship among NDVI, rainfall and soil moisture that showed seasonal variations of rainfall are also having effects on evapotranspiration, soil temperature and soil moisture conditions.

Park *et al.* (2016) studied the changes in growing season duration and productivity of North America and Eurasia region using 33 year (1982–2014) long record of satellite observations in metrics of growing season (onset: SOS, end: EOS and length: LOS) and seasonal total gross primary productivity In earlier part of the data record (1982–1999), they found that LOS has lengthened by 2.60 d dec^{-1} ($p<0.05$) due to earlier onset of SOS (-1.61 d dec^{-1}, $p<0.05$) and delay EOS (0.67 d dec^{-1},$p<0.1$) at the circumpolar scale over the past three decades. In later part (2000–2014), they observed that delayed SOS and earlier EOS as for seasonal productivity and found that 42.0%of northern vegetation shows a statistically significant greening trend over a last three decades and this greening translates total20.9% gaining productivity since1982.

Bhavani *et al.* (2017) used AVHRR GIMMS NDVI (1982–2015) and socio-economic data sets for Andhra Pradesh and Telangana for monitoring the agricultural growth and agricultural drought vulnerability. They carried out the trend analysis of climate and soil moisture to understand their impact on the agriculture growth/stress, length of the growing period (LGP) and NDVI for IPCC climate AR5 2050 RCP 2.6 scenario and revealed that climate and soil moisture have a significant impact on LGP and agriculture condition and predicted agricultural NDVI are near like normal years (2007 and 2013) indicating climate change signatures are not expected in near future. They concluded that there is a need to improve the understanding using higher resolution soil moisture data to plan appropriate adaptive and mitigation strategies for the agricultural drought conditions in changing climate scenario.

Patel *et al.* (2018) studied the long-term trend of vegetation in Bundelkhand region of India using SPOT-VGT NDVI datasets and linear regression model and revealed that varying spatial pattern of vegetation trend in the area: the northern and north western parts are characterized by positive NDVI trend, whereas, the southern and south-eastern parts indicate negative or decreasing trend. They concluded that rainfall plays a major role in such pattern of NDVI trend at regional level.

Chapter - III

MATERIAL AND METHODS

The materials used and methods followed during the course of the investigation are described in this chapter under the following heads and sub-heads:

3.1 General description of the study area

- 3.1.1 Location
- 3.1.2 Climate
- 3.1.3 Natural vegetation and agricultural land use
- 3.1.4 Physiography

3.2 Datasets used

- 3.2.1 Meteorological data
- 3.2.2 Satellite data
- 3.2.3 MODIS data processing

3.3 Characterization and mapping of land resources

- 3.3.1 Land use/Land cover mapping
- 3.3.2 Physiography mapping

3.4 Assessment of length of growing period (LGP)

- 3.4.1 LGP using meteorological data
- 3.4.2 LGP using MODIS satellite data

3.5 Comparison of estimated LGP based on meteorological and MODIS data

3.1 General description of the study area

3.1.1 Location

The study area is Nagpur district of Vidarbha region of Maharashtra lies between 20°30′ to 21°45′N latitudes and 78°15′ to

79°40′E longitudes with a total geographical area (TGA) of 9892.30 km^2 (Fig.3.1).

3.1.2 Climate

The climate of Nagpur district is sub-tropical dry sub-humid with a mean annual temperature of 26.8°C and mean total rainfall of about 1127 mm. The soil temperature and moisture regimes are *Hyperthermic* and *Ustic*, respectively. The climatic data of the study area is presented in table 3.1.

Table No.3.1. Climatic data of Nagpur district (1969-2010)

Month	Rainfall (mm)	PET (mm)	Temperature (°C)			Relative Humidity (%)		
			Max.	Min.	Mean	Morning	Evening	Mean
January	15.3	196	28.9	6.4	13.1	60.2	48.6	54.4
February	20.8	227	31.8	7.4	15.6	49.8	37.5	43.6
March	18.1	260	36.5	10.1	19.7	30.6	28.7	29.7
April	8.6	289	40.7	16.2	24.2	27.8	23.2	25.5
May	18.2	299	42.7	20.4	27.8	29.7	26.2	27.9
June	163.4	254	37.8	21.0	26.4	61.2	49.3	55.3
July	304.0	195	31.7	19.5	24.2	83.8	70.9	77.4
August	275.0	173	30.6	19.8	23.7	85.6	73.9	79.7
September	170.1	192	32.2	16.6	23.1	79.5	69.9	74.7
October	61.2	219	33.0	12.6	20.0	66.8	53.6	60.2
November	16.8	210	30.9	7.0	15.8	59.7	49.3	54.5
December	11.7	193	28.8	5.7	12.6	63.4	52.3	57.8

3.1.3 Natural vegetation and agricultural land use

The natural vegetation consists of trees, shrubs and grasses. The dominant tree species of the area of babul (*Acacia arabica*), jujube (*Zizyphus jujuba*), palas (*Butea frondosa*), neem (*Azadirachta indica*), teak (*Tectona grandis*) *etc*.

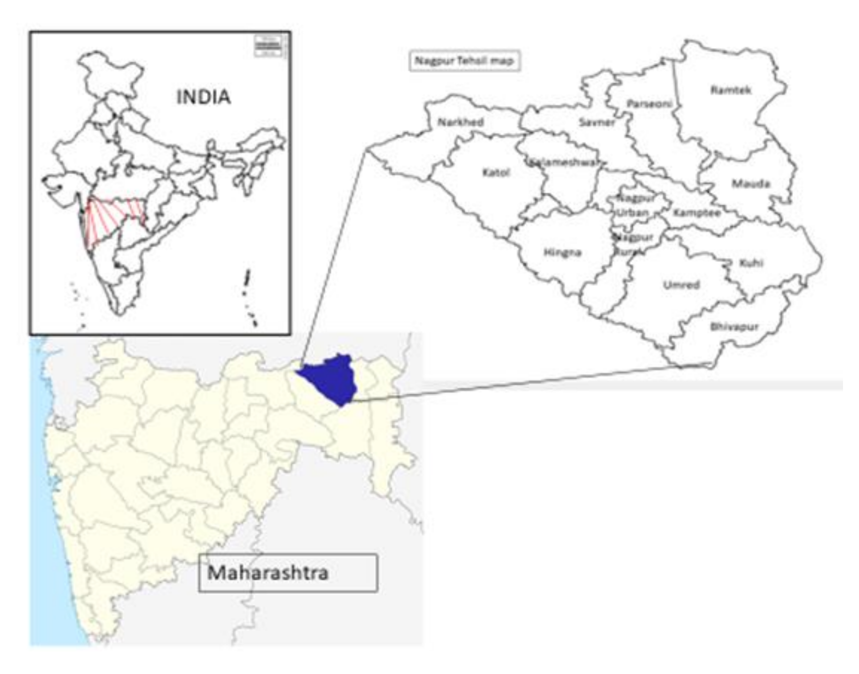


Fig. 3.1 Location map of the study area

The dominant *kharif* crops are cotton (*Gossypium spp.)*, soybean (*Glycine max*), paddy (*Oryza sativa*), pigeonpea (*Cajanus cajan*), sorghum (*Sorghum bicolor*), cowpea (*Vigna sinensis*), while, wheat (*Triticum spp*.) and gram (*Cicer arietinum*) are *rabi* crops. Mandarin *(Citrus reticulate* Blanco*)* is an important horticultural crop of the district.

3.1.4 Physiography

The major geological formations are Deccan Traps in west and south and granite-gneisses in the eastern part of the district. The general elevation of the district ranges between 150 and 600 m above mean sea level (MSL). Much of the topography of the area is typically that of Deccan Trap having flat topped hills and isolated knolls. The eastern and south-eastern part exhibit a comparatively plain terrain with some isolated hillocks. The elevation of the terrain progressively declines from north to south.

Wainganga and its tributaries *viz*., Kanhan, Kolar, Pench, Sur and Nag drain about 2/3rd of the north-eastern and east-central parts. The tributaries while flowing from hill to plain, have carved rocky valleys in the northern part but give an appearance of severe bank-cutting when they reach the plain in the east-central part. The western and south-western parts are drained by Wardha river and its tributaries like Jam, Nandkar and Wunna rivers. Physiographically, Nagpur district covers very gently to gently sloping plateau, hills and ridges, escarpments with steep slopes, subdued plateau, nearly level to very gently sloping alluvial plain and valley.

3.2 Datasets used

3.2.1 Meteorological data

Rainfall data: Long term daily rainfall data for the past 30 years were collected from the www.worldclimate.com for the 14 blocks of Nagpur district of Maharashtra state. The mean monthly rainfall for different Blocks of the Nagpur district are in presented in table 3.2

Table No. 3.2. Rainfall data of Nagpur district

Sr. No.	Stations	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
1	Ramtek	15	4	19	13	8	143	355	284	221	50	6	6
2	Savner	11	5	19	12	13	144	297	240	193	41	6	10
3	Narkhed	13	5	13	11	14	150	287	244	183	42	9	11
4	Katol	12	5	13	13	18	156	278	249	181	44	9	11
5	Kalameshwar	11	7	18	13	16	155	296	254	189	45	7	14
6	Mauda	17	8	24	18	13	142	367	311	229	48	8	9
7	Kamptee	13	7	21	16	13	148	334	268	209	48	6	11
8	Umred	12	9	19	15	13	154	380	337	237	46	6	9
9	Hingana	12	11	17	13	17	164	298	276	189	48	8	17
10	Nagpur-Urban	12	10	19	15	16	163	317	271	195	50	7	17
11	Bhivapur	11	8	21	15	12	151	430	377	264	51	8	9
12	Nagpur-Rural	11	13	19	12	8	177	516	474	274	54	3	8
13	Kuhi	9	7	14	11	12	166	286	259	182	49	7	8
14	Parseoni	12	5	13	13	18	158	285	254	180	45	10	12

Temperature data: Long term daily temperature data for the past 30 years were collected from the www.worldclimate.com for the 14 blocks of Nagpur district of Maharashtra state. The monthly minimum and maximum temperatures for different blocks of the Nagpur district are presented in table 3.3

Table No. 3.3 Temperature data of Nagpur district

Tehsils	Temperature	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec
Ramtek	Min	13	15.3	19.4	24.1	27.8	26.2	23.9	23.9	23.3	20.1	15.1	12.2
	Max	27.9	31.3	36	39.9	42.3	37.1	30.8	30.3	31.4	31.8	29.5	27.6
Savner	Min	13.1	15.2	19.4	24.1	27.7	26.2	24	23.7	23.1	19.9	15.2	12.4
	Max	28.2	31.4	36.1	40	42.3	37.2	30.9	30.2	31.5	32	29.8	27.8
Narkhed	Min	13	14.9	19.1	23.7	27.2	25.8	23.6	23.1	22.5	19.3	14.6	12.4
	Max	27.8	31	35.4	39.2	41.6	36.7	30.2	29.3	30.6	31.4	29.3	27.8
Katol	Min	13.3	15.3	19.3	23.9	27.4	25.8	23.5	23.1	22.5	19.5	15.1	12.6
	Max	28	31.2	35.6	39.5	41.8	36.7	30.3	29.5	30.8	31.5	29.4	27.8
Kalameshwar	Min	13.1	15.4	19.5	24.2	27.7	26.1	24	23.5	23	19.9	15.3	12.5
	Max	28.3	31.4	36.1	40.2	42.3	37	31	30.2	31.5	32.1	29.7	27.8
Mauda	Min	13.3	15.6	19.8	24.6	28.2	26.7	24.3	24.1	23.6	20.5	15.5	12.5
	Max	28.4	31.7	36.4	40.4	42.7	37.5	31.2	30.6	31.8	32.1	29.8	27.8
Kamptee	Min	13.2	15.5	19.8	24.4	28	26.3	24.1	24.1	23.5	20.2	15.5	12.4
	Max	28.3	31.6	36.6	40.5	42.7	37.2	31.3	30.7	31.9	32.3	29.8	27.7
Umred	Min	13.3	15.6	19.8	24.6	28.1	26.5	24.1	23.8	23.4	20.4	15.5	12.5
	Max	28.6	31.6	36.3	40.2	42.5	37.3	31.1	30.4	31.6	31.9	29.7	27.9
Hingana	Min	13.3	15.6	19.8	24.5	27.9	26.4	24.2	23.8	23.2	20.1	15.6	12.7
	Max	28.7	31.6	36.4	40.6	42.6	37.4	31.4	30.6	31.9	32.4	30.1	28
Nagpur Urban	Min	13.1	15.4	19.7	24.4	27.9	26.1	24	23.8	23.3	20.1	15.6	12.5
	Max	28.4	31.5	36.5	40.6	42.7	37	31.3	30.5	31.9	32.3	29.8	27.7
Bhivapur	Min	13.5	15.7	19.9	24.8	28.4	26.8	24.2	24.1	23.6	20.7	15.5	12.7
	Max	28.7	31.8	36.4	40.2	42.7	37.6	31	30.5	31.5	31.9	29.7	28.1
Nagpur Rural	Min	13.1	15.3	19.4	24.4	28.7	27.3	24.2	24.1	23.9	21	15.1	12.6
	Max	27.6	31	35.1	39	42.1	38	30.4	29.9	30.8	30.9	29.2	27.7
Kuhi	Min	15.6	17.8	21.7	25.7	29	26.6	24.1	23.6	23.2	21	16.9	15
	Max	29.6	32.9	37.3	40.6	43	38.1	31.5	30.5	31.5	32.3	30.3	29.1
Parseoni	Min	13.2	15.2	19.2	23.7	27.1	25.4	23.2	22.8	22.3	19.4	14.9	12.6
	Max	27.8	30.9	35.3	39.1	41.4	36.4	29.9	29.2	30.5	31.2	29.1	27.6

3.2.2 Satellite data

The satellite images used in the present study aresentinel-2 d (10m), ALOS Digital Elevation Model (DEM) (12.5m), MODIS (250m) along with soil and rainfall data.

Sentinel 2A: Sentinel-2A is an optical mission with a multi-spectral instrument mainly for agricultural application such as crop monitoring and management, climate change etc. The satellite carries a single Multispectral Instrument (MSI) which provides 13 bands in the visible, near-infrared, and shortwave infra-red at different ground resolution.

The data has been downloaded from USGS site which is freely available.

ALOS-2 DEM: Advanced Land Observing Satellite 2, also called Daichi 2, is a 2-ton Japanese satellite launched in 2014.The ALOS has three remote-sensing instruments: the Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) for digital elevation mapping, the Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2) for precise land coverage observation, and the Phased Array type L-band Synthetic Aperture Radar (PALSAR) for day-and-night and all-weather land observation. High resolution ALOS digital elevation model (DEM) with a resolution of 12.5 m datasets of Nagpur district have been downloaded from ALOS PALASAR which is freely available and used in landforms delineation in the study area.

MODIS: The MODIS instrument is operating on both the Terra and Aqua spacecraft. It has 36 spectral bands between 0.405 and 14.385 µm and acquires data at three spatial resolutions *i.e*. 250m, 500m, and 1,000m MODIS-based NDVI data was obtained from 2000 to 2018 from the United States Geological Survey (USGS) archives and used in computation of length of growing period in the study area.

Legacy data: The information available on soil and other attributes both in the maps and reports of Nagpur district and other legacy data have been utilized for computation of length of growing period using meteorological data.

3.3 Characterization and mapping of land resources

3.3.1 Land use/land cover (LULC) mapping

The methodology followed for the interpretation of the satellite data sentinel-2 (10 m resolution) is visual interpretation of object-based classification technique using image interpretation elements *viz.*, tone, texture, pattern size, shape, shadow, site and association. Object-based approaches operate on sets of pixels (objects/regions) that have been grouped together by an image segmentation technique. The land used land cover of Nagpur district has been classified by following three main steps.

3.3.1.1 FCC generation

Satellite data used for land use land cover classification is sentinel-2 10m resolution of September, 2018 which carries an innovative wide swath high resolution multispectral image with 13 spectral bands. Out of the 13 bands, we selected three bands *viz.*, B08 (NIR band of 840 nm wavelength), B04 (Red band of 664.5nm wavelength), and B03 (Green band of560nm wavelength) having 10m resolution. For generating the FCC, we assigned red colour to NIR band, green colour to red band and blue colour to green band for the visual interpretation of land use/ land cover classes.

In this type of false colour composite, vegetation appears in different shades of red depending on the type and conditions of vegetation, as it has high reflectance in the NIR band. Clear water appears dark bluish (higher green band reflectance), while turbid water appears cyan (higher red reflectance due to sediments) compared to clear water. Bare soils, roads and buildings appeared in various shades of blue, yellow or grey.

3.3.1.2 Segmentation

eCognition software has been used for segmentation and object-based classification. Shape characteristics and neighbourhood relationships can also be added to spectral/textural information to aid in the classification process. Satellite data is segmented into three different shapes of objectas the Object based segmentation was applied to the FCC and NDVI images with three different scales *i.e.* 10000, at 2000, and at 500.

3.3.1.3 Visual interpretation

Large scale object based satellite image is first visually interpreted and classified into different major classes as agricultural land, fallow land, built up, water, river, mining and forest land. Each LULC class in the larger segments (10000) was corrected with segments generated with scale parameter of 2000 which was further corrected with segments generated with scale parameter of 500. The figure 13 shows the LULC maps generated with the three levels of segmentations. The flow chart of the methodology is given in figure 3.2.

3.3.2 Landform mapping

Physiographic mapping was done using ALOS DEM (12.5m resolution). The flow chart of methodology for landform delineation is given in the figure 3.3 and the details are discussed in the following sections.

3.3.2.1 Digital Terrain Analysis

The terrain analysis was done in ArcGIS desktop. The DEM data were first projected to Universal Transverse Mercator (UTM) projection and then a model was prepared in the Model Builder of ArcGIS to generate all the surfaces in one go. The *fill* operation was run on the DEM for getting a smoothed elevation raster with minimized voids. The slope raster was derived through the *slope tool* in spatial analyst module of the ArcGIS. The slope percentage were generated and classified into different slope categories for further analysis. The drainage channels were generated from the DEM using the flow direction and flow accumulation raster.

A flow direction raster contains the direction of flow from every cell in the elevation raster. It was generated using the *flow direction* tool in the spatial analyst module. A flow accumulation raster was generated using the *flowaccumulation* tool. It shows the number of upslope cells that flow into each cell of the elevation raster. Cells with a

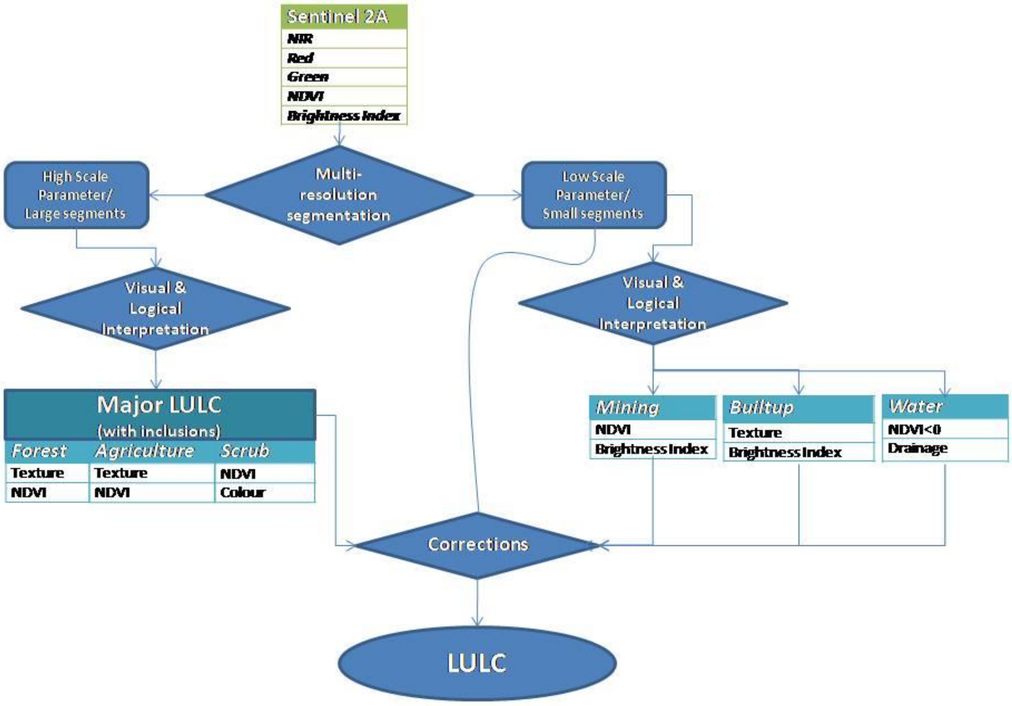


Fig. 3.2 Flow chart of land use/land cover analysis

flow accumulation of 0 are local topographic highs and may be used to identify ridges. Cells with a high flow accumulation are areas of concentrated flow and were used to identify stream channels (Jenson and Domingue, 1988).

By applying a threshold value using the *Con tool* to the results of the *Flow Accumulation* tool, a stream network was delineated. Threshold flow accumulation values were identified for each district empirically to delineate desired stream networks. A low threshold value identifies a dense network of streams with finer and lower order streams and vice-versa (Tarboton *et al.* 1991). The identified stream networks were linked using the *stream link* tool. Links are the sections of a stream channel connecting two successive junctions, a junction and the outlet, or a junction and the drainage divide (Tarboton *et al.* 1991). These raster linear networks were accurately converted to feature data with the *Stream to Feature tool*.

3.3.2.2 Sentinel Data Processing

Sentinel bands 8 (NIR), 4 (Red), and 3 (Green) were layer stacked in ArcGIS Desktop® ver 10.4.1 for both scenes and were latter stitched together to get a mosaic image. The prepared FCC was then clipped with the help of district boundary. NDVI was calculated using the raster calculator tool of ArcGIS. Normalized Difference Vegetation Index (NDVI) is a useful indicator of plant growth condition (Tucker, 1979), and is calculated as a normalized ratio between Red and Near-infrared (NIR) bands.

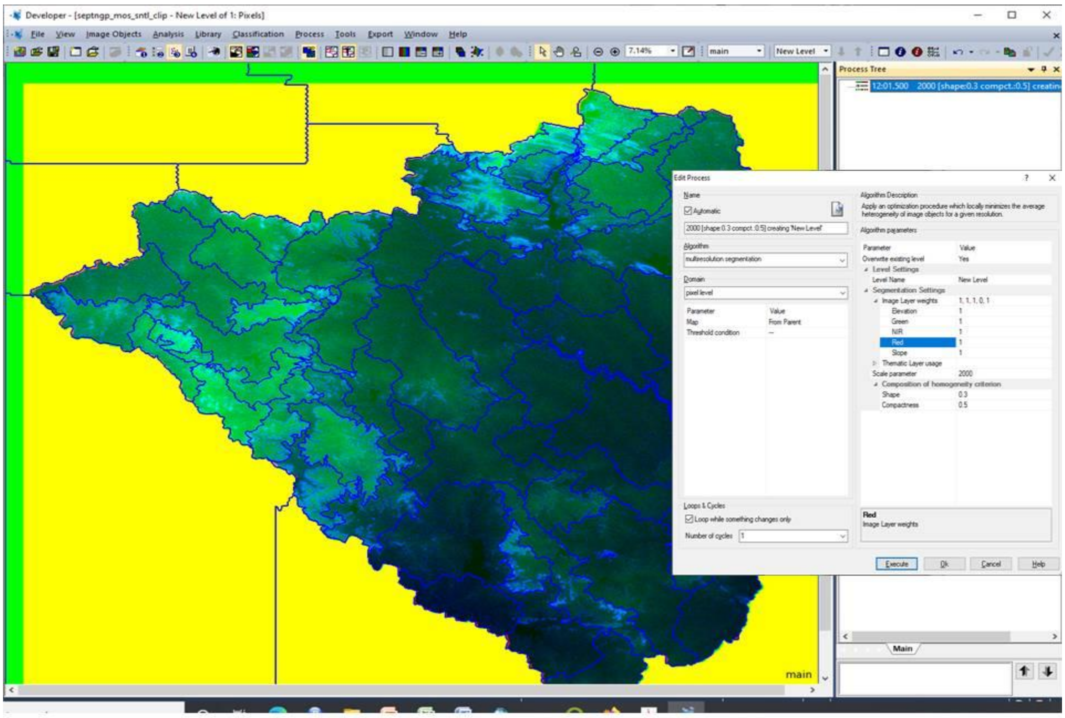
$$NDVI = {}^{(\rho_{NIR} - \rho_R)}\!\big/_{(\rho_{NIR} + \rho_R)} \qquad [1]$$

Where, ρ_{NIR} and ρ_R stands for the surface reflectance measurements of NIR and Red bands, respectively, which in turn correspond to the eighth and forth bands of Sentinel-2A images. The values of NDVI range from minus one (–1.0) to plus one (+1.0), and negative values typically correspond to open water and positive values (over 0.05) represent the amount of green vegetation present (Myneni et al. 1997).

3.3.2.3 Object Based Segmentation

The derived layers from digital terrain analysis, the FCC, and the NDVI were stacked in a single file for object based segmentation. Multi-resolutionsegmentationtool of eCognition® was used for the purpose. Multi-resolutionsegmentationidentifies single image objects of one pixel and merges them with their neighbours, based on relative homogeneity criteria, with the intent of minimizing the heterogeneity of the resulting objects. The homogeneity among the pixels is identified based on spectral and the shape criteria **(**Benz *et al.* 2004**).** The spectral homogeneity is based on the standard deviation of the spectral colours, whereas, the shape homogeneity is based on the deviation of a compact (or smooth) shape. The size of the segments is decided by the scale parameter. The values of the shape and spectral criteria and the scale parameters were defined empirically based on several trials to get optimum results. An example of segments generated from these layer stacked data with the scale parameter of 2000, a shape weighing of 0.3 (spectral weighing 0.7), and compactness weighing of 0.5 (smoothness 0.5) is shown in figure 3.3.

Two set of segments were generated with scale parameter of 2000 and 100 for delineation of landforms. The segments were exported to shape file format containing the mean values of the pixels occurring under each polygon of a particular layer. Thus the segments were having values for each layer including elevation, slope, NDVI and reflectance values of different bands. These databases were used for identification of landforms. A semi-automated approach was adopted for delineation of broad landforms. The flow chart of the methodology for delineation of landforms is presented in figure 3.4.



Edit Process

Name

☑ Automatic

2000 [shape:0.3 compct.:0.5] creating 'New Level'

Algorithm: multiresolution segmentation

Domain: pixel level

Parameter	Value
Map	From Parent
Threshold condition	—

Loops & Cycles

☑ Loop while something changes only

Number of cycles: 1

Algorithm Description

Apply an optimization procedure which locally minimizes the average heterogeneity of image objects for a given resolution.

Algorithm parameters

Parameter	Value
Overwrite existing level	Yes
Level Settings	
Level Name	New Level
Segmentation Settings	
Image Layer weights	1, 1, 1, 0, 1
Elevation	1
Green	1
NIR	1
Red	1
Slope	1
Thematic Layer usage	
Scale parameter	2000
Composition of homogeneity criterion	
Shape	0.3
Compactness	0.5

Red
Image Layer weights

Fig. 3.3 Generation of segments from layer stacked data

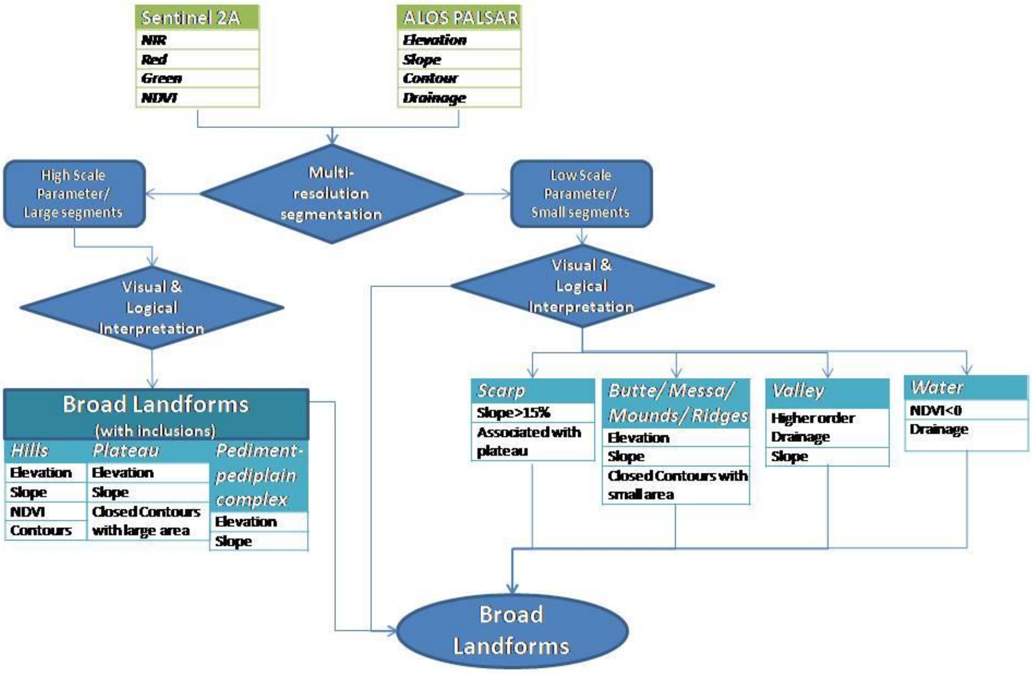


Fig. 3.4 Flow chart of landform analysis

3.3.3 Soil Database

The soil map of Nagpur district (ICAR-NBSS&LUP, 1990) on 1:50000 (soil series association) scale was digitized. The existing soil map was superimposed on landform map and correlated with new landform units and their boundaries. During this process, the soil database has been upgraded and used in length of growing period (LGP) computations.

3.4 Assessment of length of growing period (LGP)

3.4.1 LGP computation using meteorological data

3.4.1.1 Computation of Potential Evapotranspiration (PET)

For the assessment of LGP, climate data (1988-2018) were downloaded for each block (14blocks) of Nagpur district from www.worldclimate. The evapotranspiration rate from a reference surface, not short of water, is called the reference crop evapotranspiration or reference evapotranspiration and is denoted as ET_o. The reference surface is a hypothetical grass reference crop with specific characteristics. The concept of the reference evapotranspiration was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development and management practices. As water is abundantly available at the reference evapotranspiring surface, soil factors do not affect ET. Relating ET to a specific surface provides a reference to which ET from other surfaces can be related (fao.org).

The ET_o is a climatic parameter and can be computed from weather data. ET_o expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider the crop characteristics and soil factors. The FAO Penman-Monteith method is recommended as the sole method for determining ET_o. The FAOPenman-Monteith equation requires data on air temperature, humidity, radiation and wind speed for PET calculations. In the present study, PET of Nagpur district was assessed in the ETo calculator software using the FAO Penman-Monteith equation.

$$\mathrm{ET_o} = \frac{0.408\Delta(\mathrm{R}_n - \mathrm{G}) + \gamma \frac{900}{\mathrm{T}+273} \mathrm{u}_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34\mathrm{u}_2)}$$

where

$\mathrm{ET_o}$ = reference evapotranspiration [mm day-1]G

Rn = net radiation at the crop surface [MJ m-2 day-1]

G = soil heat flux density [MJ m-2 day-1]

T = mean daily air temperature at 2 m height [°C]

u2 = wind speed at 2 m height [m s-1]

es = saturation vapour pressure [kPa]

ea = actual vapour pressure [kPa]

es - ea = saturation vapour pressure deficit [kPa]

Δ = slope of vapour pressure curve [kPa °C-1]

γ = psychrometric constant [kPa °C-1]

3.4.1.2 Computation of available water capacity

The available water capacity of soils is the difference between moisture held between -33 kPa (field capacity) and -1500 kPa (wilting point). The control section of the soil is considered for available water content. In the present study, the available water holding capacity of different soils for each tehsil has been collected from legacy data (Mandal *et al.* 1999).

3.4.1.3 Computation of Length of Growing Period (LGP)

The available water holding capacity of soils of each block has been collected from legacy data. Using the meteorological data and legacy data, the length of growing period has been calculated following the FAO model (Higgins and Kassam, 1981) (Fig.3.5). According to this model, the growing period starts when precipitation (P) exceeds 0.5 of potential evapotranspiration and ends with the utilization of assumed

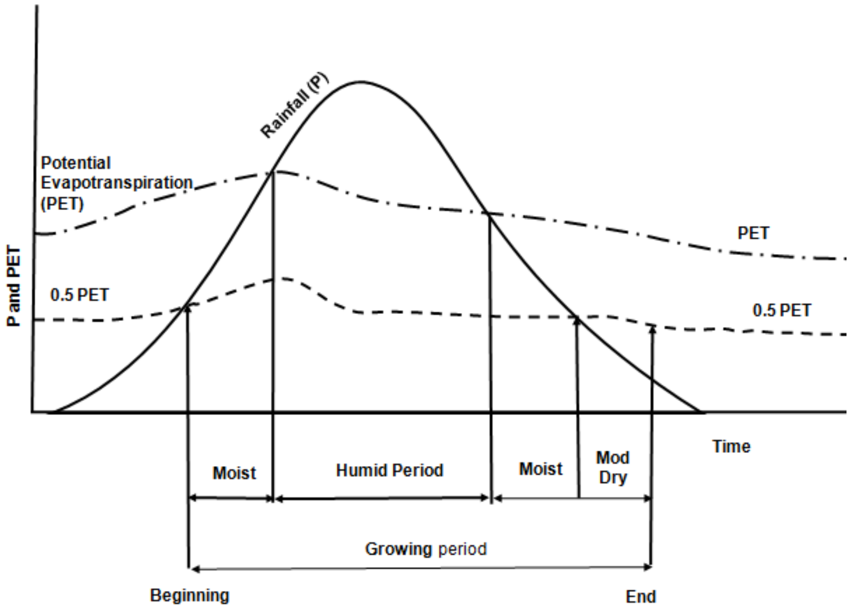


Fig. 3.5 Length of growing period (LGP) model

quantum of stored soil moisture (100 mm) after P falls below PET and this is conditioned by threshold temperature value of 5^{o}C. The period for LGP is noted when the soil moisture tensions vary from -33 to -1500 kPa and temperature ranges from 5 to 45 ^{o}C, ideally suited for growing C3 and C4 plants (Mandal *et al.* 2016). The flow chart of the methodology is presented in figure 3.6.

3.4.1.4 Normalization of datasets

The interpolation methods that are used to prepare surface map of LGP gives the best result, if the data is normally distributed (a bell-shaped curve). If the data is skewed, it needs to be transformed to make it normal. Thus, it is important to understand the distribution of the datasets of LGP. Several transformation functions are available, but, in general, logarithmic transformation function is commonly applied. In the present study, logarithmic transformation functions available in geostatistical analyst of ArcGIS software were applied for normalization of LGP datasets.

3.4.1.5 Surface map of LGP

To prepare the surface of LGP from point data, various interpolation techniques available in ArcGIS: 1. Kriging (Geostatistical interpolation technique) utilizes the statistical properties of the measured points and quantify the spatial autocorrelation among measured points and account for the spatial configuration of the sample points around the prediction location (Isaacs and Srivastava, 1989). 2. The IDW (Deterministic interpolation technique) uses the method of interpolation that estimates cell values by averaging the values of sample data points in the neighbourhood of each processing cell. The closer a point is to the centre of the cell being estimated, the more influence, or weight, it has in the averaging process. This method assumes that the variable being mapped decreases in influence with distance from its sampled location (Watson and Philip, 1985). 3. Radial basis functions (RBF) interpolation (Deterministic interpolation

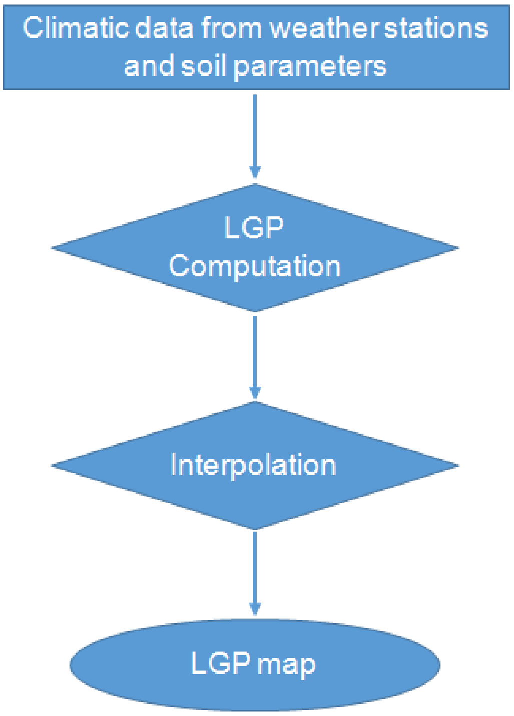


Fig.3.6 Flow chart of the methodology

technique) is an advanced method in approximation theory for constructing high-order accurate interpolants of unstructured data, possibly in high-dimensional spaces. The interpolant takes the form of a weighted sum of radial basis functions.RBF are conceptually similar to fitting a rubber membrane through the measured sample values while minimizing the total curvature of the surface. It’s an exact interpolator means the surface passes through the data points. This makes it different from other global and local polynomial interpolators. When compared to IDW (which is also an exact interpolator), RBF can predict values above the maximum and below the minimum measured values. However, IDW will never predict values above the maximum measured value or below the minimum measured value. These methods have been tested to prepare the surface map of LGP point data and the best interpolation method has been adopted based on lowest root-mean-square error.

3.4.2 LGP using MODIS Satellite data

3.4.2.1 MODIS data pre-processing

The MODIS data downloaded are in.hdf format with 12 bands. Further, they are in sinusoidal format and are scaled by a multiplying factor of 10000. Pre-processing of MODIS data includes: extraction of the NDVI layer from the 12 layered data, calculation of original NDVI values, conversion of projection system and data format from.hdf to .tif using R software. The workable format is shown in figure 3.7. Thus all the 437 images were converted into workable format.

3.4.2.2 LGP computation from MODIS NDVI time series data

Timesat ver. 3.3 (Eklundh et al. 2017) was used for smoothing the time series data and to get the seasonal parameters (Fig. 3.8). Savitzky-Golay filter (Savitzky and Golay 1964) was then applied to the images to get a smoothen data (Fig. 3.9).

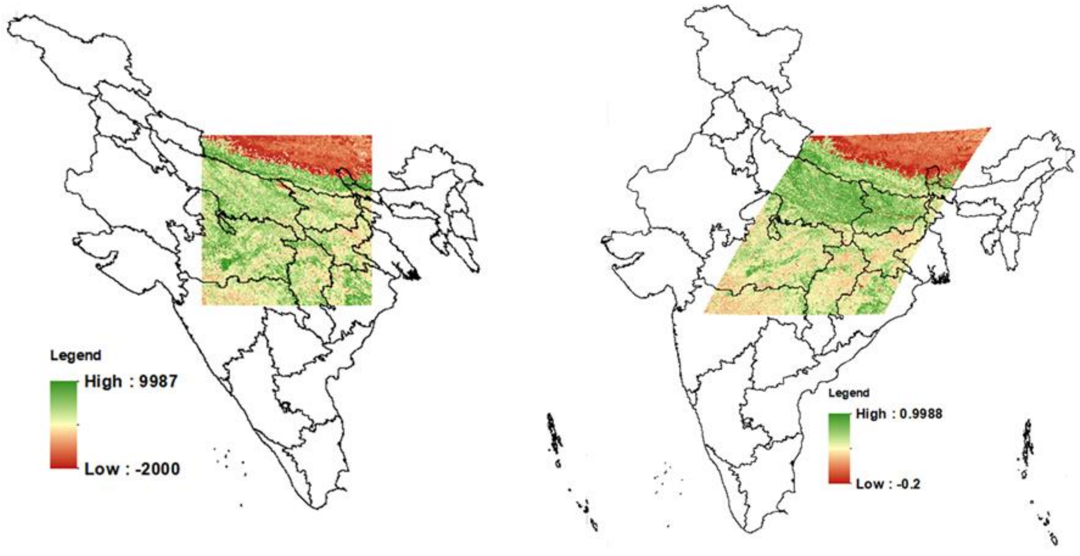
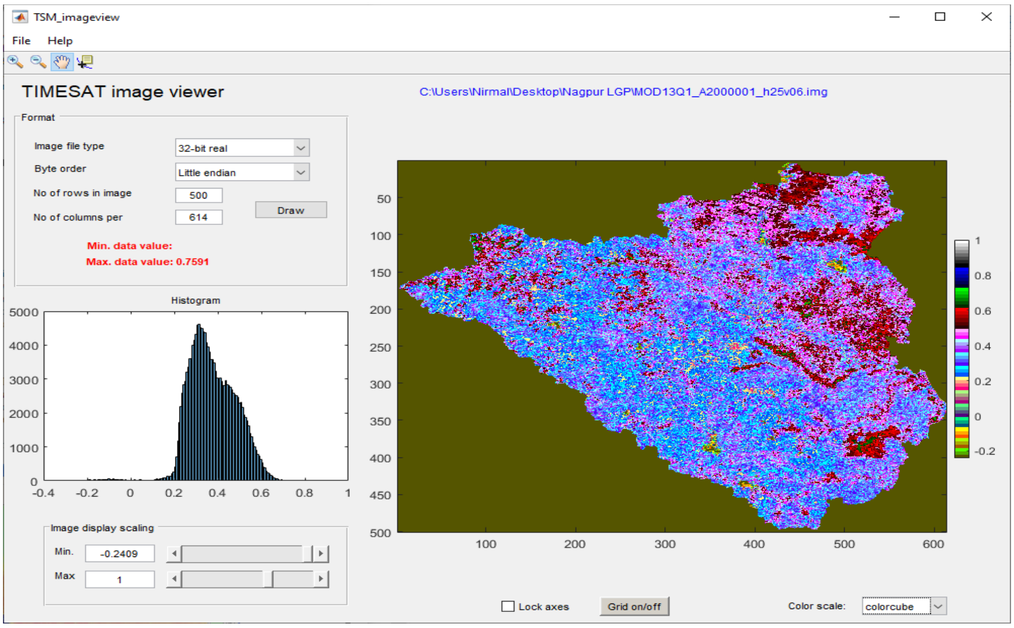


Fig. 3.7 A comparison of raw MODIS data and the processed MODIS NDVI data



TIMESAT image viewer

C:\Users\Nirmal\Desktop\Nagpur LGP\MOD13Q1_A2000001_h25v06.img

Format

Image file type: 32-bit real

Byte order: Little endian

No of rows in image: 500

No of columns per: 614

Min. data value:

Max. data value: 0.7591

Image display scaling

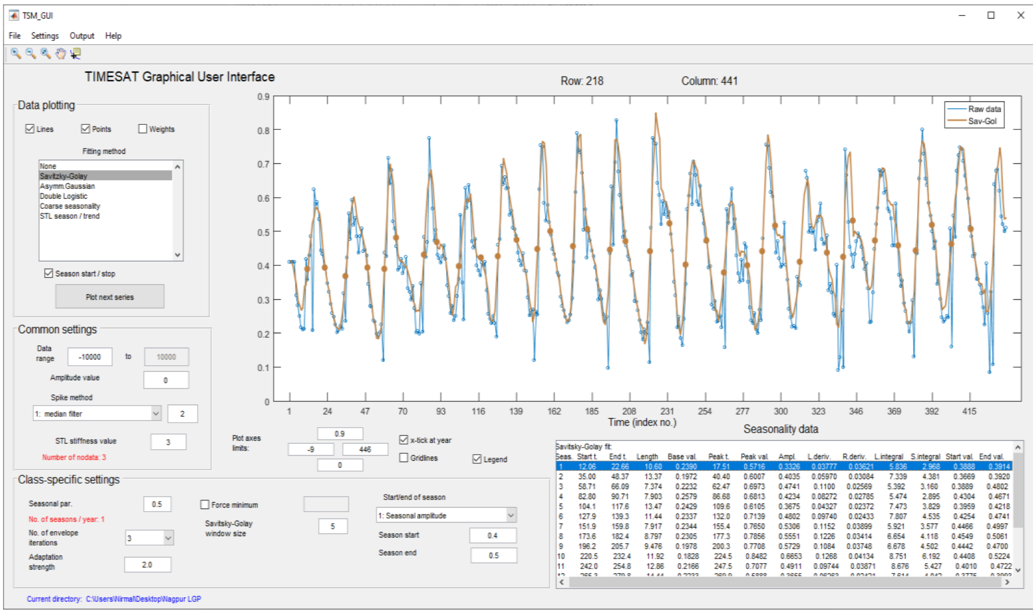
Min.: -0.2409

Max: 1

☐ Lock axes

Color scale: colorcube

Fig. 3.8 Use of Timesat for filtering time series data



TIMESAT Graphical User Interface

Row: 218 Column: 441

Data plotting

☑ Lines ☑ Points ☐ Weights

Fitting method: Savitzky-Golay

☑ Season start / stop

Common settings

Data range: -10000 to 10000

Amplitude value: 0

Spike method: 1: median filter 2

STL stiffness value: 3

Number of nodata: 3

Plot axes limits: 0.9 -9 446 0

☑ x-tick at year

☐ Gridlines

☑ Legend

Class-specific settings

Seasonal par.: 0.5

No. of seasons / year: 1

No. of envelope iterations: 3

Adaptation strength: 2.0

☐ Force minimum

Savitsky-Golay window size: 5

Start/end of season: 1: Seasonal amplitude

Season start: 0.4

Season end: 0.5

Current directory: C:\Users\Nirmal\Desktop\Nagpur LGP

Seasonality data

Savitsky-Golay fit:

Seas.	Start t.	End t.	Length	Base val.	Peak t.	Peak val.	Ampl.	L.deriv.	R.deriv.	L.integral	S.integral	Start val.	End val.
1	12.06	22.66	10.60	0.2390	17.51	0.5716	0.3326	0.03777	0.03621	5.836	2.968	0.3888	0.3914
2	35.00	48.37	13.37	0.1972	40.40	0.6007	0.4035	0.05970	0.03084	7.339	4.381	0.3669	0.3920
3	58.71	66.09	7.374	0.2232	62.47	0.6973	0.4741	0.1100	0.02569	5.392	3.160	0.3889	0.4802
4	82.80	90.71	7.903	0.2579	86.68	0.6813	0.4234	0.08272	0.02785	5.474	2.895	0.4304	0.4671
5	104.1	117.6	13.47	0.2429	109.6	0.6105	0.3675	0.04327	0.02372	7.473	3.829	0.3959	0.4218
6	127.9	139.3	11.44	0.2337	132.0	0.7139	0.4802	0.09740	0.02433	7.807	4.535	0.4254	0.4741
7	151.9	159.8	7.917	0.2344	155.4	0.7650	0.5306	0.1152	0.03899	5.921	3.577	0.4466	0.4997
8	173.6	182.4	8.797	0.2305	177.3	0.7856	0.5551	0.1226	0.03414	6.654	4.118	0.4549	0.5061
9	196.2	205.7	9.476	0.1978	200.3	0.7708	0.5729	0.1084	0.03748	6.678	4.502	0.4442	0.4700
10	220.5	232.4	11.92	0.1828	224.5	0.8482	0.6653	0.1268	0.04134	8.751	6.192	0.4408	0.5224
11	242.0	254.8	12.86	0.2166	247.5	0.7077	0.4911	0.09744	0.03871	8.676	5.427	0.4010	0.4722

Fig. 3.9 Use of Timesat for filtering time series data

3.4.2.3 Savitzky-Golay filter (SGF)

Savitzky-Golay filter (SGF) is a polynomial function fitting method based on a weighted least squares regression approach. It tends to preserve features of the data set such as relative maxima, minima, and widths in the time series. The filter could be viewed as a weighted moving average filter with weighting given as a polynomial of a certain degree. This filter can be applied to any consecutive data when the data points are located at fixed and uniform intervals along the chosen abscissa. The curve formed by graphing the points must be continuous and more or less smooth. In this study, the consecutive points were VI values at regular intervals (every 16 days). NDVI values (MOD13Ql data) are distributed in 16-day composites, which do not mean that the data for any given pixel occurred on a regular frequency of 16 days. A comparison of the data before and after the filtering is shown in figure 3.10.

3.4.2.4 Start and end of season

Once the images were smoothened, the season end and start time in each year was determined using the fraction of the amplitude of the NDVI, defined between the base level and the maximum value for each individual season. The start occurs when the left part of the fitted curve has reached a specified fraction of the amplitude counted from the base level. The end of season is defined similarly but for the right side of the curve. The flow chart of the methodology is presented in figure 3.11.

3.5 Comparison of estimated LGP based on meteorological and MODIS data

The length of growing period (LGP) estimated based on meteorological observations and from MODIS satellite data will be compared in terms of their variability using simple statistical procedures and their advantages and limitations.

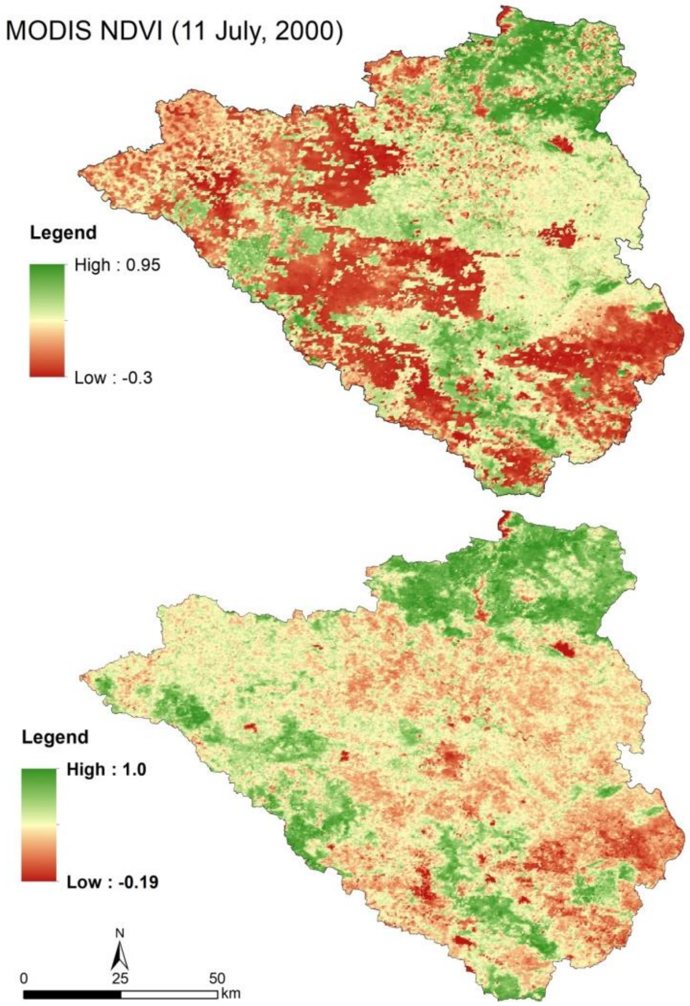


FIG. 3.10 A COMPARISON OF A) RAW AND B) FILTERED DATA

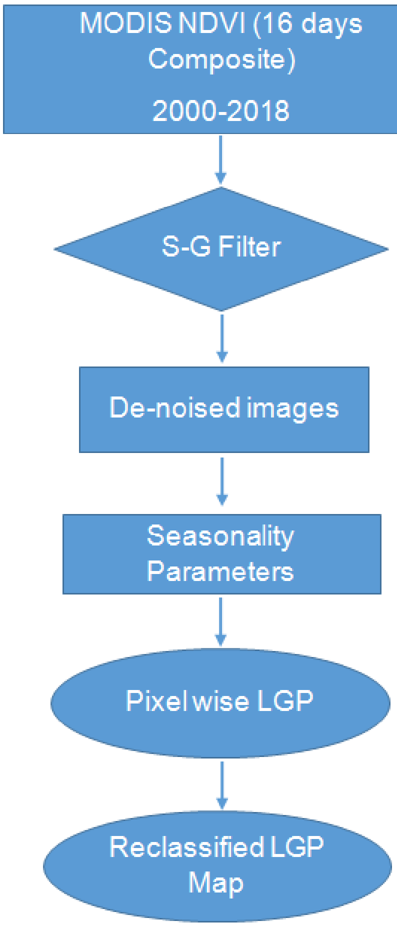


Fig. 3.11 Flow chart of the methodology

Chapter - IV

RESULTS AND DISCUSSION

The results of present investigation have been presented and discussed below under the following heads.

4.1 Database development

4.1.1 Landforms

4.1.2 Land use/Land cover

4.1.3 Soils

4.2 Length of growing period (LGP)

4.2.1 LGP using meteorological data

4.2.1.1 LGP in different tehsils of Nagpur district

4.2.1.2 Surface map of LGP

4.2.2 LGP using MODIS satellite data

4.2.2.1 LGP in different tehsils of Nagpur district

4.2.2.2 LGP in different landforms

4.2.2.3 LGP in different land use/land cover

4.3Comparison of LGP computed by meteorological and remote sensing data

4.4 Suggested land use

4.1 Database development

4.1.1 Landforms

Ten major landforms *i.e*. hills, plateau, scarp slope, pediments, pediplain, valley, gullied land, butte/mesa/ridge, mining area and waterbodies have been identified. The pediplains were further divided in to pediplains (hillside), upper pediplains and lower pediplains. The landform map is presented in figure 4.1. The extent of area under different landforms is presented in table 4.1. The data indicate that major area is under lower pediplains (44.4% of TGA) followed by pediments (20.9% of TGA) and plateau (10.5% of TGA).

Table No. 4.1. Area under different landforms of Nagpur district

Landforms	Area	
	Hectare	**% of TGA**
Hill	56884	5.8
Plateau	103218	10.5
Scarp slope	13987	1.4
Pediment	205230	20.9
Hills pediplain	18581	1.9
Upper pediplain	63985	6.5
Lower pediplain	436161	44.4
Valley	8730	0.9
Gullied land	3616	0.4
Butte/Mesa/ridge	7291	0.7
Reservoir/river	55671	5.7
Quarry	9921	1.0
Total	983275	100

4.1.2 Land use /Land cover

Six major land use/land cover classes *viz.* agriculture, forest, scrubland, builtup area, mining and waterbodies have been identified based on satellite image analysis (Fig.4.2). The extent of area under each land use/land cover is presented in table 4.2. The results indicate that major area is under agriculture (65.9% of TGA) followed by forest (19.6% of TGA). Scrubland, waterbodies and builtup area occupied 4.4, 5.7 and 3.4 per cent of TGA, respectively.

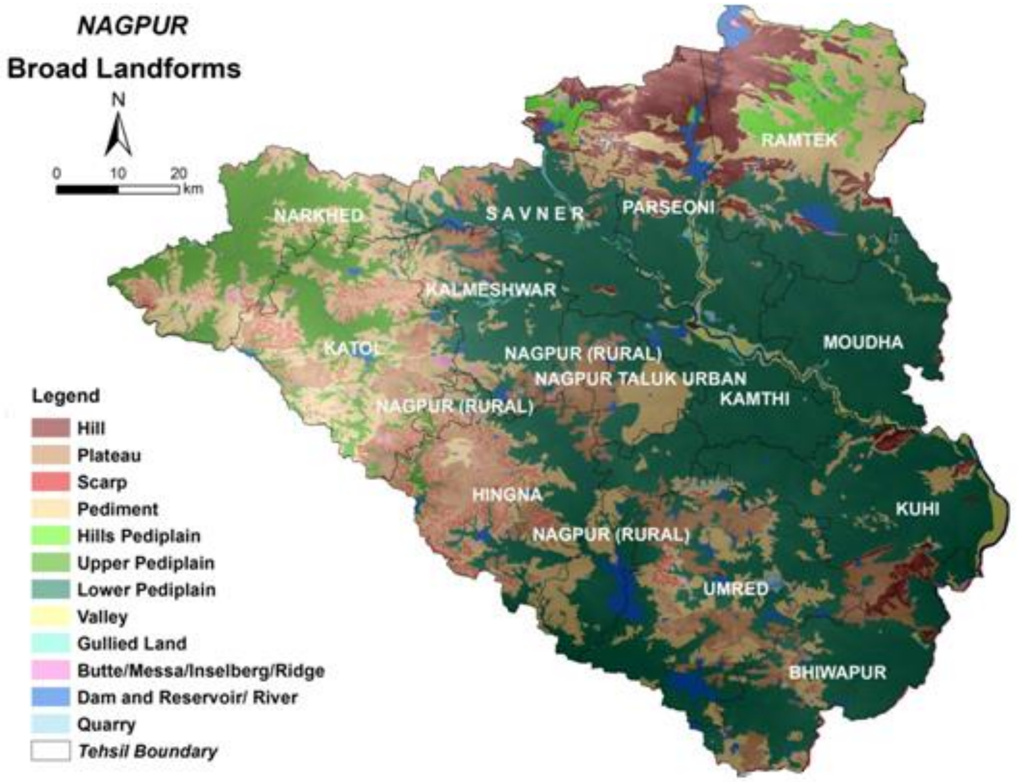


Fig. 4.1 Landforms map of Nagpur district

Table No. 4.2. Land use/land cover classes of Nagpur district

Land use/land cover	**Area**	
	Hectares (ha)	**% of TGA**
Agriculture	647502	65.9
Forest	192763	19.6
Scrubland	43809	4.4
Builtup	33609	3.4
Mining	9921	1.0
Waterbody	55671	5.7
Total	**983275**	100

4.1.3 Soils

Soil mapping comprises the identification, description and delineation of different kinds of soils based on morphological observations in the field and laboratory investigations (Challa *et. al.* 1995). Soil map (Thelkar, 2019) provides a means of communicating our knowledge about the distribution of soil attributes and occurrence of different soil classes in nature which vary in terms of morphological, physical and chemical characteristics. The salient characteristics of the 23 soil series are identified and presented in table 4.3. The Information on soil properties becomes essential to compute potential evapotranspiration (PET) which was used in the computation of length of growing period (LGP).

Table No. 4.3. Soil series of Nagpur district and their characteristics

Soil series	**Characteristics**
Malegaon (Meg) series	Soils of Malegaon are deep, moderately well drained, very dark gray, clayey soils occur on very gently to gently sloping plateau, developed on weathered basalt
Muserkhapa (Msk) series	Soils of Muserkhapa are moderately deep, well drained, dark yellowish brown to dark brown, clayey soils occur on very gently to gently sloping plateau and developed on weathered basalt
Chankapur (Ckp) series	Soils of Chankapur are shallow to moderately deep, well drained, very dark grayish brown to very dark brown, clayey soils, developed on weathered basalt and occur on moderately to steeply sloping escarpments
Pardi (Prd) series	Soils of Pardi are shallow well drained, dark yellowish brown, sandy loam to loam soils occur on very gently to gently sloping subdued plateau and developed over weathered basalt

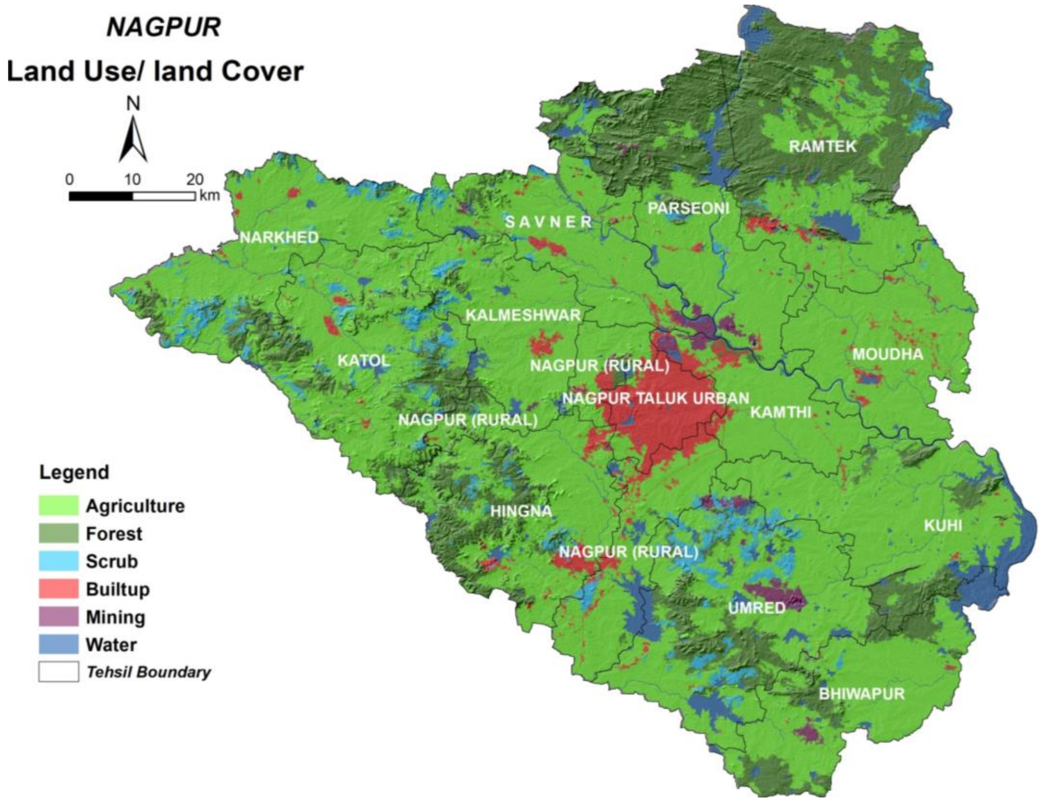


Fig. 4.2 Land use/land cover map of Nagpur district

Yenwa (Ynw) series	Soils of Yenwa are shallow, well to excessively drained, dark red to dark reddish brown, clay loam soils. They are neutral in reaction, highly base saturated and non-calcareous. They occur on moderately sloping escarpments and developed over weathered basalt
Karla (Krl) series	Soils of Karla are moderately deep, moderately well drained, dark brown to dark grayish brown, clayey soils occur on nearly level to gently sloping pediments and developed over weathered basalt
Linga (Lng) series	Soils of Linga are very deep, poorly drained, dark to very dark grayish brown, clayey soils developed over basaltic alluvium and occur on level to gently sloping alluvial plain
Panjra (Pjr) series	Soils of Panjra are very deep, moderately well drained, dark brown to very dark grayish brown, clayey soils, developed over basaltic alluvium and occur on very gently sloping alluvial plain
Wadhona (Wdn) series	Soils of Wadhona are deep, moderately well drained, dark brown, medium textured soils which occur on nearly level to gently sloping alluvial plain, developed over alluvium
Aroli (Arl) series	Soils of Aroli are very deep, moderately well drained, dark reddish brown, clayey soils developed over alluvium and occur on nearly level to very gently sloping alluvial plain
Kirnapur (Krn) series	Soils of Kirnapur are very deep, well drained, brown to very dark grayish brown, clayey soils, developed over basaltic alluvium and occur on nearly level to very gently sloping alluvial plain
Bagbori (Bgb) series	Soils of Bagbori are moderately deep, moderately well drained, dark to very dark grayish brown, clayey soils developed over basaltic alluvium and occur on nearly level to gently sloping valley
Khapri (Kpr) series	Soils of Khapri are deep, moderately well drained, very dark grayish brown in colour, clayey soils developed over sandstone and occur on nearly level to very gently sloping pediments
Sur (Sur) series	Soils of Sur are very deep, well drained, dark brown to dark yellowish brown, medium textured soils occur on nearly level to gently sloping valley and developed over alluvium
Semda (Smd) series	Soils of Semda are moderately deep, well drained, reddish brown with sandy loam to sandy clay loam texture developed over sandstone and occur on very gently to gently sloping subdued plateau
Jam (Jam) series	Soils of Jam are very deep, well drained brown to dark brown, sandy clay loam soils, developed on basaltic out wash and occur on nearly level to very gently sloping pediments
Gaimukh (Gmk) series	Soils of Gaimukh are deep, well drained, sandy clay loam, dark yellowish brown to dark brown developed over out wash material laid over quartzite mica schist on very gently sloping pediments
Gunjapur (Gjp) series	Soils of Gunjapar are moderately deep, moderately well drained, brown to dark brown in colour, sandy clay loam to clay soils, developed over concretionary materials and occur on very gently sloping pediments
Rongha (Rng) series	Soils of Rongha are moderately deep, well drained, reddish brown, sandy loam to sandy clay loam textured soils, developed on mica schists and occur on nearly level to moderately sloping plateau
Magarli (Mgr) series	Soils of Magarli are well drained, moderately deep, dark brown in colour, loamy soils, developed on colluvium and occur on very gently to gently sloping pediment
Sewadoli (Sdl) series	Soils of Sewadoli are moderately deep, well drained reddish brown with sandy clay loam texture, developed over quartzitic mica schists on hills and ridges
Ramtek (Rtk) series	Soils of Ramtek are shallow, well to excessively drained, reddish brown, sandy loam to sandy clay loam texture, developed over micaeous schists and occur on moderately to strongly slopping hills and ridges
Devdipar (Dvp) series	Soils of Devdipar are moderately deep, well drained, dark brown clay loam to sandy clay loam developed over ferruginous concretions and occur on nearly level to very gently sloping pediments

The tehsil-wise distribution of soil series association in Nagpur district is given in table 4.4.

Table No. 4.4 Tehsil-wise distribution of soil series of Nagpur district

Name of the Tehsil	Soil series association
Bhiwapur	Arl-Lng, Lng-Pjr, Lng-Wdn, Pjr-Krl, Wdn-Sur
Hingna	Arl-Krn, Arl-Wdn, Lng-Arl-Pjr, Lng-Pgrl, Pjr-Krl, Wdn-Sur
Kalmeshwar	Lng-Krl, Pjr-Krl, Lng-Pjr, Wdn-Sur, Lng-Arl-Pjr
Kamptee	Arl-Krn, Krn-Arl, Wdn-Sur
Katol	Lng-Krl, Lng-Pjr, Lng-Wdn, Wdn-Sur
Kuhi	Arl-Krn, Krn-Arl, Jam-Gmk, Lng-Pjr, Wdn-Sur
Mauda	Arl-Krn, Krn-Arl, Wdn-Sur, Wdn-Lng
Nagpur-Rural	Arl-Krn, Krn-Arl, Arl-Wdn, Lng-Arl-Pjr, Lng-Pjr, Lng-Wdn, Wdn-Sur
Narkhed	Lng-Krl, Lng-Pjr, Lng-Wdn
Parseoni	Arl-Krn, Bgb-Sur, Lng-Krl, Lng-Wdn, Krn-Arl, Bgb-Msk, Wdn-Lng, Wdn-Sur
Ramtek	Arl-Krn, Krn-Arl, Bgb-Msk, Wdn-Sur
Umrer	Arl-Krn, Krn-Arl, Arl-Lng, Jam-Gmk, Lng-Wdn, Wdn-Sur, Pjr-Krl
Saoner	Bgb-Sur, Lng-Krl, Lng-Pjr, Lng-Wdn, Pjr-Krl, Wdn-Lng, Wdn-Sur

4.2 Length of growing period (LGP)

4.2.1 LGP using meteorological data

The data on rainfall, potential evapotranspiration (PET), available water content(AWC) and length of growing period (LGP) computed using the meteorological data is presented in table 4.5. The results indicate that the highest rainfall was observed in Nagpur-Rural tehsil (1569 mm) and the lowest rainfall was observed in Narkhed tehsil (982 mm). Highest PET was observed in Hingna tehsil (1758 mm) and the lowest PET was observed in Nagpur-Rural tehsil (1656 mm). LGP varied from 139 to 155 days. Maximum LGP was observed in Nagpur Rural (155 days) followed by Bhivapur (151 days), Umred (150 days) and the lowest LGP was observed in kalmeshwar and Katol (139 days). The variability in the rainfall in Nagpur district has reflected in LGP. In general, higher LGP was observed in areas with higher rainfall. Significant and positive correlation has been observed between rainfall and LGP (r = 0.60*). A positive correlation between AWC and LGP (r =

0.17) and a negative correlation between PET and LGP (r = -0.41) was found non-significant.

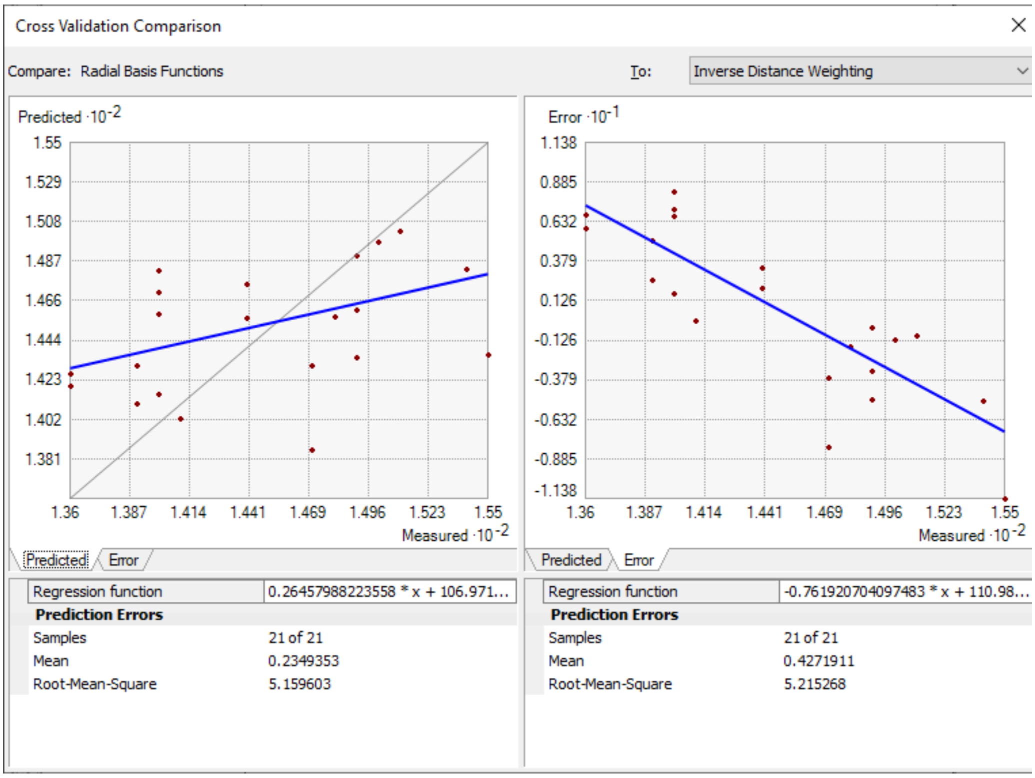
Table No. 4.5 Rainfall, PET, AWC LGP in different tehsils of Nagpur district

S.No.	Tehsil Name	Rainfall (mm)	PET (mm)	AWC (mmm^{-1})	LGP (days)
1	Bhivapur	1357	1730	165	151
2	Hingna	1070	1758	165	140
3	Kalmeshwar	1025	1735	163	139
4	Kamtee	1094	1747	161	149
5	Katol	989	1704	162	139
6	Kuhi	1010	1743	159	149
7	Moudha	1194	1734	156	148
8	Nagpur Rural	1569	1656	168	155
9	Narkhed	982	1694	157	147
10	Parseoni	1005	1682	158	149
11	Ramtek	1124	1716	155	140
12	Umred	1237	1733	170	150
13	Savner	991	1731	158	147
14	Nagpur Urban	1092	1751	165	140

4.2.1.2 Surface map of LGP

The point data of LGP computed from meteorological observations has been interpolated using interpolation techniques *viz*. kriging, IDW (Inverse Distance Weighing) and Radial Basis Functions (RBF). The interpolation using kriging has not given good results due to limited point data. When compared between IDW and RBF (Fig.4.3), RBF was found best fit for interpolation with lowest Root-Mean-Square error and used to generate LGP map(figure 4.4)

The surface map of LGP (Fig. 4.4) indicate that LGP ranged from 138 to 155. The higher LGP has been observed in south and south-east parts of the district covering Biwapur, Kuhi, Umred, Nagpur-Rural, Kamtee and Moudha tehsils, medium LGP was observed in central and northern parts of the district covering Parseoni and Saoner tehsils and the lower LGP has been observed in western part and northern part of the district covering Nagpur-Urban, Hingna, Katol,



Compare: Radial Basis Functions

To: Inverse Distance Weighting

Regression function	0.26457988223558 * x + 106.971…
Prediction Errors	
Samples	21 of 21
Mean	0.2349353
Root-Mean-Square	5.159603

Regression function	-0.761920704097483 * x + 110.98…
Prediction Errors	
Samples	21 of 21
Mean	0.4271911
Root-Mean-Square	5.215268

Fig. 4.3 Comparison of Interpolation between RBF and IDW

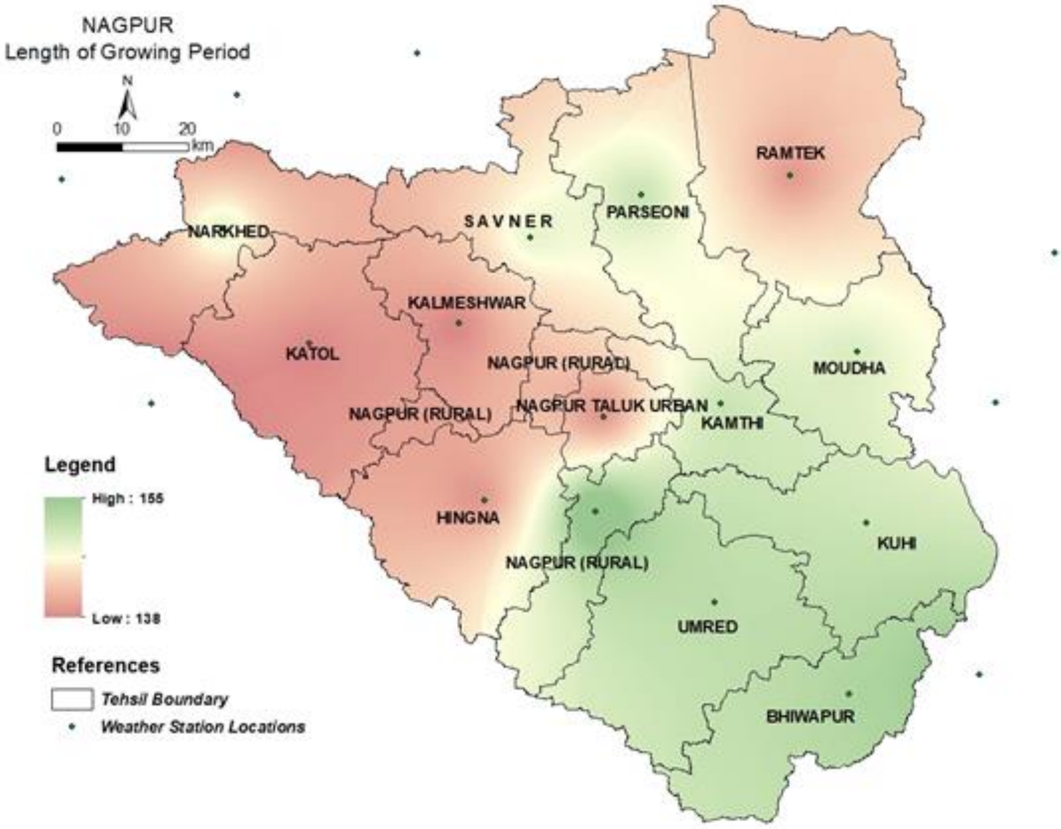


Fig. 4.4 Length of growing period (days) using metrological data

Kalmeshwar, Narkhed and part of Savner tehsils. Vaidya et al. (2008) reported variability in LGP of 12 to 24 weeks with variation in rainfall in South Gujarat. Based on 30-year climatic data, Kadu et al. (2003) reported a length of growing period of 183 days in Nagpur using water-balance approach. Wide variability in LGP with variation in rainfall has been reported by many workers (Hadgu *et al.* 2013; Sathymoorthy *et al.* (2017) Bhuarya *et al.* 2018; Lotlfie *et al.* (2018) Sattar et al. (2019).

4.2.2 LGP using MODIS satellite data

4.2.2.1 LGP in different tehsils of Nagpur district

The pixel-wise LGP data computed using MODIS NDVI time series data has been reclassified in to 5 classes *viz.*, 90-120, 120-150, 150-180, 180-210 and 210-240 days (Table 4.6). The reclassified map generated is presented in figure 4.5. The data indicate that LGP class 150-180 occupied maximum area (40.7%) followed by LGP class 210-240 days (17.7%), LGP class 180-210 days (15.4%), LGP class 120-150 days (14.8%), whereas, LGP class 90-120 days has least area (11.8%).

Data on LGP (Table 4.6) indicate that Bhiwapur tehsil had maximum area under LGP class 150-180 days (26.7%) followed by LGP class 90-120 days (26.2%) and LGP class 120-150 days (22.7%), whereas, least area was observed under LGP class 180-210 days (10.7%). Hingna tehsil has maximum area under LGP class 150-180 days (52.1%) followed by LGP class 180-210 days (15.5%), LGP class 120-150 days (11.6%), whereas, least area was observed under LGP class 90-120 days (9.2%). Kalmeshwar tehsil had maximum area under LGP class 150-180 days (48.3%) followed by LGP class 210-240 days (14.7%), LGP class 120-150 days (14.2%), whereas, least area was observed under LGP class 90-120 days (9.5%). Kamthi tehsil had maximum area under LGP class 210-240 days (32.6%) followed by LGP class 150-180 days (24.7%), LGP class 180-210 days (19.6%), whereas, least area was observed under LGP class 120-150 days

(11.4%). In Katol tehsil, maximum area is under LGP class 150-180 days (47.3%) followed by LGP class 210-240 days (18.3%), LGP class 120-150 days (14.3%), whereas, least area was observed under LGP class 90-120 days (9.1%). Kuhi tehsil had maximum area under LGP class 150-180 days (31.5%) followed by LGP class 210-240 days (23%), LGP class 180-210 days (20.3%), whereas, least area was observed under LGP class 90-120 days (11.3%). In Moudha tehsil, maximum area is under LGP class 150-180 days (39.3%) followed by LGP class 120-150 days (20%), LGP class 180-210 days (16.3%), whereas, least area was observed under LGP class 90-120 days (10.2%). Nagpur (Rural) tehsil had maximum area under LGP class 150-180 days (49.3%) followed by LGP class 180-210 days (14.7%), LGP class 120-150 days (12.7%), whereas, least area was observed under LGP class 90-120 days (10.4%). In Narkhed tehsil, maximum area is under LGP class 150-180 days (33.6%) followed by LGP class 210-240 days (26.8%), LGP class 180-210 days (16.3%), whereas, least area was observed under LGP class 90-120 days (9.6%). Parseoni tehsil had maximum area under LGP class 150-180 days (47.9%) followed by LGP class 180-210 days (18.7%), LGP class 120-150 days (12.2%), whereas, least area was observed under LGP class 90-120 days (10%). In Ramtek tehsil, maximum area is under LGP class 150-180 days (53.6%) followed by LGP class 180-210 days (15.3%), LGP class 120-150 (13.3%), whereas, least area was observed under LGP class 210-240 days (7.5%). Savner tehsil had maximum area under LGP class 150-180 days (45.3%) followed by LGP class 210-240 days (20.1%), LGP class 180-210 days (14.4%), whereas, least area was observed under LGP class 90-120 days (8.4%). In Umred tehsil, maximum area is under LGP class 150-180 days (36%) followed by LGP class 120-150 days (18%), LGP class 210-240 days (16.5%), whereas, least area was observed under LGP class 180-210 days (14.6%), In Nagpur (Urban) tehsil, maximum area is under LGP class 150-180 days (25.2%) followed by LGP class 90-120 days (21%), LGP class 180-210 days (18.7%), whereas, least area was observed under LGP class 220-240 days (16.3%). The data also indicate that 56.1 per cent of total geographical area (TGA) is occupied by LGP from 150-210 days and gives an idea that these areas have sufficient storage of moisture for the second crop after the kharif harvest. The variability in LGP in the study area is attributed to the variability in NDVI. Thirupati *et al.* (2015) studied the variability on the length of growing period (LGP) using space based (MODIS) data for the selected Mandals of Warangal district of Andhra Pradesh reported LGP ranging from 141 to 181 days for the selected Mandals. Estimating LGP through the direct use of multi-temporal remote sensing data is gaining importance with the availability of continuous time series data from many satellites. The Normalized Difference Vegetation Index (NDVI) reflects growing status of green vegetation, hence, crop monitoring could be realized by using remote sensing technique on the basis of time series NDVI data together with agriculture calendars. Time series of vegetation indices derived from optical sensors onboard satellites, provide information about the green-up and senescence of vegetation during the year. A good number of studies indicated that NDVI and rainfall was highly correlated in water limiting areas with highest correlation of NDVI-rainfall obtained for rainfed crop followed by irrigated crop (Chopra, 2006; Duochu *et al.* 2007; Benhadj *et al.* 2012; Rajkumar *etal.* 2013; Patel *et al.* 2018).

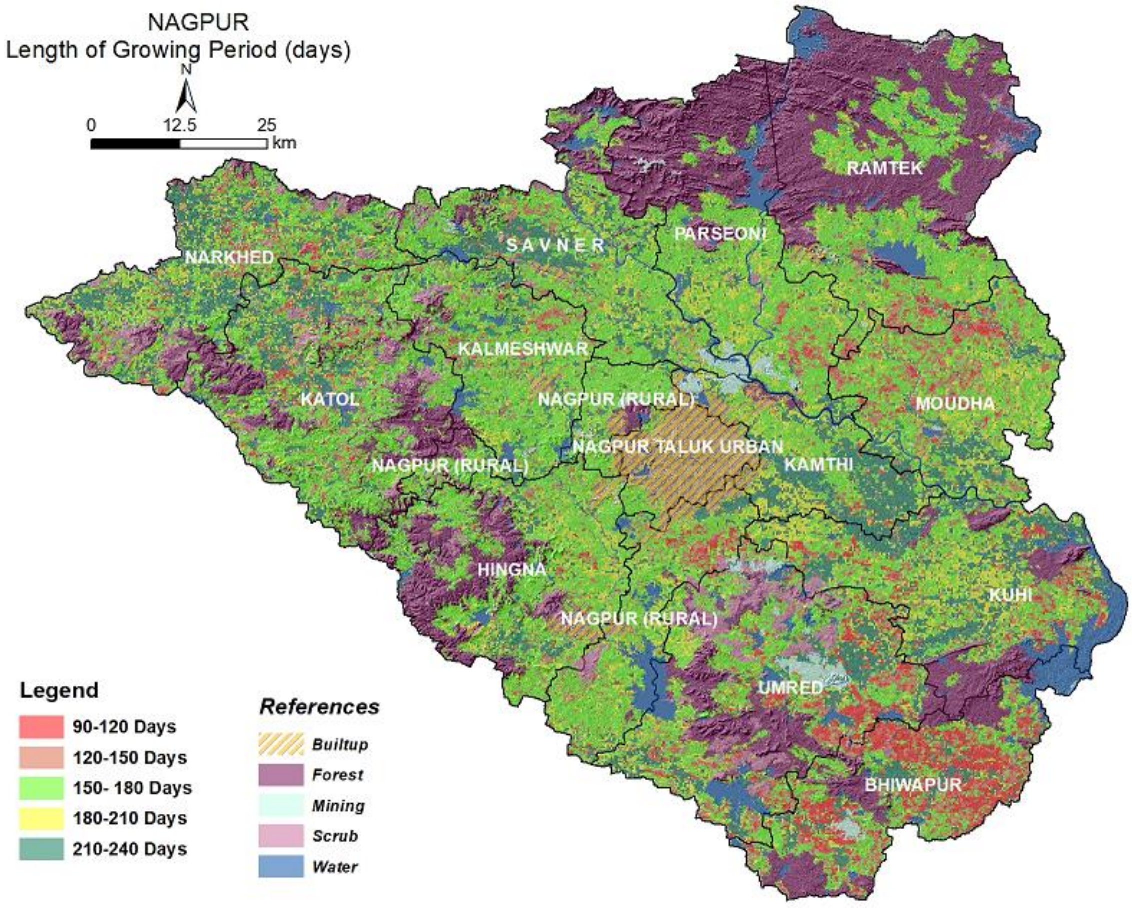


Fig. 4.5 Length of growing period (days) using MODIS data

Table N0. 4.6 Tehsil-wise area (ha) under each LGP class of Nagpur district generated with NDVI time series data

Blocks	90 - 120 Days	120 - 150 Days	150 - 180 Days	180 - 210 Days	210 - 240 Days	Total
Bhiwapur	18788.35 (26.2)	16314 (22.7)	19133.21 (26.7)	7670.71 (10.7)	9699 (13.5)	71605.3
Hingna	6525.85 (9.2)	8239.46 (11.6)	36895.71 (52.1)	11020.71 (15.5)	8105.25 (11.4)	70787.0
Kalmeshwar	6507.1 (9.5)	9758.21 (14.2)	33070.71 (48.3)	8989.46 (13.1)	10049.64 (14.7)	68375.1
Kamthi	6388.14 (11.6)	6283.21 (11.4)	13595.71 (24.7)	10776.96 (19.6)	17949.64 (32.6)	54993.7
Katol	7725.84 (9.1)	12170.71 (14.3)	40233.21 (47.3)	9189.46 (10.8)	15568.39 (18.3)	84887.6
Kuhi	9494.6 (11.3)	11639.46 (13.8)	26520.71 (31.5)	17089.46 (20.3)	19398.93 23	84143.2
Moudha	8257.1 (10.2)	16120.71 (20)	31864.46 (39.3)	13201.96 (16.3)	11574.64 (14.2)	81018.9
Nagpur (rural)	7307.1 (10.4)	8939.46 (12.7)	34595.71 (49.3)	10351.96 (14.7)	8912.14 (12.7)	70106.4
Narkhed	7525 (9.6)	10589.46 (13.5)	26376.96 (33.6)	12801.96 (16.3)	21049.64 (26.8)	78343.0
Parseoni	6600.84 (10)	8020.71 (12.2)	31495.71 (47.9)	12289.46 (18.7)	7224.64 (11)	65631.4
Ramtek	6875.85 (10)	9064.46 (13.3)	36589.46 (53.6)	10458.21 (15.3)	5168.39 (7.5)	68156.4
Savner	6250.85 (8.4)	8758.21 (11.7)	33689.46 (45.3)	10708.21 (14.4)	14955.89 (20.1)	74362.6
Umred	12163.35 (14.7)	14926.96 (18)	29826.96 (36)	12083.21 (14.6)	13655.89 (16.5)	82656.4
Nagpur taluk urban	5932 (21)	5258.21 (18.6)	7120.71 (25.2)	5289.46 (18.7)	4607.89 (16.3)	28208.3
Total	116342 (11.8)	146083.2 (14.8)	401008.7 (40.7)	151921.2 (15.4)	167920 (17.7)	

4.2.2.2 LGP in different landforms

The length of growing period (LGP) under different landforms was obtained by superimposing the LGP map on landform map in ArcGIS. The length of growing period in different landforms of the district is presented in table 4.7. The data indicate that maximum LGP was observed in lower pediplains (46.4%) followed by pediments (21.7%) and plateau (11.1%). Lower LGP was observed in upper pediplains (7.1%), hills (5.4%), pediplain (hillside) (2.5%), scarp slope (1.9%), valley (1.6%) and gully land (0.9%). The lower pediplains are associated with depositional surfaces. The soils are fine textured with shrink–swell potential, more than 150 cm thick, and calcareous in nature with progressive development of pedogenic calcium carbonate (Pal *et al.* 2009). Higher finer fractions of soil separate with concomitant higher cation exchange capacity, moisture retention, and available water capacity may be the reason for higher LGP in these landforms (Obi-Reddy *et al.* 2013), whereas, landforms associated with hills, pediplain (hillside), scarpslope and gullied land are erosional surfaces with severe erosion and manifested through sheet wash, rill, and gullies with dissected landscape.

Table No. 4.7 LGP in different landforms of Nagpur district

Landforms/LGP	**90-120**	**120-150**	**150-180**	**180-210**	**210-240**	**Total**
Hill	181.3 (0.33)	1412.6 (2.63)	21800.1 (40.67)	16579.5 (30.9)	13618.5 (25.41)	53592 (5.4)
Plateau	1668.8 (1.52)	37918.8 (34.68)	48287.6 (44.1)	9706.3 (8.87)	11743 (10.74)	109324.5 (11.1)
Scarp slope	25 (0.12)	3350 (17.08)	10287.5 (52.45)	981.3 (5)	4968.6 (25.33)	19612.4 (1.9)
Butte/ Messa/Ridge	12.5 (0.1)	1887.6 (15.44)	4387.5 (35.9)	993.8 (8.13)	4937.3 (40.4)	12218.7 (1.24)
Pediment	5000.1 (2.33)	70106.3 (32.77)	86543.8 (40.46)	37293.8 (17.43)	14949.8 (6.98)	213893.8 (21.7)
Pediplain (hillside)	68.8 (0.27)	4706.3 (19.09)	12225.1 (49.6)	2537.5 (10.29)	5106 (20.71)	24643.7 (2.5)
Upper Pediplain	1662.6 (2.3)	13943.8 (19.9)	13343.8 (19.07)	9956.3 (14.2)	31031 (44.3)	69937.5 (7.1)
Lower Pediplain	30025.1 (6.6)	144200 (31.6)	127781.3 (28)	66406.3 (14.5)	87412.3 (19.2)	455825 (46.4)
Valley	306.3 (1.9)	1925 (12.3)	4418.8 (28.3)	2431.3 (15.6)	6525.5 (41.8)	15606.9 (1.6)
Gullied land	81.3 (0.9)	856.3 (9.9)	1781.3 (20.6)	712.5 (8.2)	5187 (60.1)	8618.4 (0.9)

The soils are very shallow, underlaid by either hard basalt or regolith with paralithic contact.The water movement in these PLU units is mainly overland flow with a low weathering front (Nagaraju *et al.* 2014). Catenary soil development occurs in many landscapes in response to the way water moves through and over the landscape, and terrain attributes can characterize these flow paths and the interactions with the soil attributes (Dobos *et al.* 2000).

4.2.2.3 LGP in different land use/land cover

We obtained the length of growing period (LGP) under different land use/land cover after superimposing the LGP map on land use/land cover map in ArcGIS. The results of length of growing period in different land use/land cover are presented in table 4.8. The data indicated that maximum LGP is under agriculture (69.5%) followed by forest (23.3%) and scrubland (7.1%). Out of the 5 classes of LGP, 93.7 per cent of total agricultural area had LGP from 120-240 days. The crop phenological parameters like crop initiation and end of the crop season (senescence) have been derived from NDVI-based MODIS data. Willem *et al.* (2013) studied NDVI-derived productivity and phenology and observed significant land cover specific trends and variability in annual productivity and land surface phenological response. Significant correlation between NDVI and crop phenology has been reported by several researchers (Karlsen *et al.* 2008; Brown *et al.* 2010). The LGP <90 days indicated areas under waterbodies, barren land and habitation, whereas, LGP from 195 to 240 days indicate the areas under plantation crops, particularly, citrus orchards in the study area. Substantial area under scrubland (99%) has LGP from 90 to 240 days which indicate that these areas have sufficient soil moisture to grow vegetation and have great potential for agroforestry, agrihorticulture and silvipasture.

Table 4.8 Length of growing period in different land use/land cover

Land use/LGP	90-120	120-150	150-180	180-210	210-240	Total
Forest	7959.57 (3.4)	25753.27 (11.2)	97047.07 (42.3)	70547.07 (30.7)	28097.07 (12.2)	229404.1 (23.3)
Agriculture	42190.87 (6.1)	229672 (33.6)	206665.7 (30.2)	89847.07 (13.1)	115097 (16.8)	683472.6 (69.5)
Scrubland	8090.87 (11.5)	22728.37 (32.2)	21434.57 (30.4)	9878.37 (14)	8265.87 (11.7)	70398.05 (7.15)

4.3Comparison of LGP computed by meteorological and remote sensing data

Length of growing period (LGP) was computed using rainfall data, potential evapotranspiration and available water content of soils. The LGP computed from meteorological data ranged from 139 to 155 days, whereas, MODIS-based Normalized Difference Vegetation Index (NDVI) revealed LGP of five classes *viz.*, 90-120, 120-150, 150-180, 180-210 and 210-240 days. Thirupati *et al.* (2015) reported that LGP derived from meteorological data and NDVI-derived MODIS data were not significantly different.

4.4 Suggested land use

Soybean, cotton, rice, wheat, gram and pigeon pea occupy major area of the district. Several workers have used the weekly rainfall or precipitation (RF) and Potential Evapotranspiration (PET) data and determined the length of growing period for efficient crop planning and sustaining farm productivity in the rainfed area (Vaidya *et al.* 2008; Kesavarao *et al.*2008; Hema Malini and Endris 2013; Ramesh *et al.* 2016; Raman *et al.* 2017). Based on length of growing period and soil characteristics, a tehsil-wise land use plan has been prepared and presented in table 4.9. The suggested land use includes major crops of the area for intensive cultivation, agri-horticulture, agroforestry, silvipasture, vegetable cultivation and floriculture in agricultural and wastelands to improve the productivity of these lands. Afforestation programmes need to be undertaken on large scale in degraded forest areas during the monsoon season with suitable tree species.

Table No. 4.9 Suggested land use plan of Nagpur district

Tehsil	LGP (days)	Soil series	Agriculture	Wasteland
Bhiwapur	120-135, 135-150	Arl-Lng, Lng-Pjr, Lng-Wdn, Pjr-Krl, Wdn-Sur	Chilies, cotton, pigeon pea, black gram, green gram, papaya, groundnut, floriculture, millets, fodder crops	Energy plantation, custard apple, Aonla, multi-purpose tree, pastures, neem, Acacia spp., Pongamia spp.
Hingna	150-165, 135-150, 165-180	Arl-Krn, Arl-Wdn, Lng-Arl-Pjr, Lng-Pgrl, Pjr-Krl, Wdn-Sur	Groundnut, red gram, green gram, sunflower, chilies, oilseed crops, fodder crops, wheat	Custard apple, aromatic plant, multi-purpose tree species, agri-silvi-pasture system
Kalmeshwar	135-150, 150-165, 165-180	Lng-Krl, Pjr-Krl, Lng-Pjr, Wdn-Sur, Lng-Arl-Pjr	Maize, fodder crops, red gram, green gram, horticultural crops, wheat	Afforestation, agri-silvi-pasture system, energy plantation
Kamtee	210-240, 150-165, 165-180	Arl-Krn, Krn-Arl, Wdn-Sur	Cotton, soybean, pigeon pea, gram, green gram, black gram, vegetables, sorghum	Afforestation, silvi-pastoral system, tree species, fodder
Katol	150-165, 135-150, 165-180	Lng-Krl, Lng-Pjr, Lng-Wdn, Wdn-Sur	Soybean, gram, green gram, black gram, vegetables, red gram, sorghum, citrus spp., sapota, guava	Energy plantation, custard apple, multi-purpose tree species, agri-silvi-pasture System
Kuhi	210-240, 135-150, 195-210	Arl-Krn, Krn-Arl, Jam-Gmk, Lng-Pjr, Wdn-Sur	Cotton, soybean, pigeon pea, gram, green gram, black gram, vegetables, sorghum	Agroforestry, leafy vegetable, horse gram, custard apple, jujube, multi-purpose tree species, neem, Acacia spp., Pongamia spp.
Moudha	135-150, 120-135, 150-165	Arl-Krn, Krn-Arl, Wdn-Sur, Wdn-Lng	Paddy, soybean, chilies, gram, vegetables	Custard apple, aromatic plant, multi-purpose tree species, agri-silvi-pasture system

Nagpur	150-165, 135-150, 165-180	Arl-Krn, Krn-Arl, Arl-Wdn, Lng-Arl-Pjr, Lng-Pjr, Lng-Wdn, Wdn-Sur	Pearl millet, sorghum, groundnut, sesame, red gram, green gram	Custard apple, ber, subabul, multi-purpose tree species, agri-silvi-pasture system, horticulture, floriculture
Narkhed	135-150, 150-165, 210-240	Lng-Krl, Lng-Pjr, Lng-Wdn	Cotton, soybean, pigeon pea, gram, acid lime, red gram, green gram, sesame, vegetables	Multi-purpose tree species, energy plantation, afforestation
Parseoni	165-180, 150-165, 180-195	Arl-Krn, Bgb-Sur, Lng-Krl, Lng-Wdn, Krn-Arl, Bgb-Msk, Wdn-Lng, Wdn-Sur	Cotton, soybean, pigeon pea, gram, sorghum, millets, castor, cluster bean, cowpea, sapota, pomegranate, green gram	Aromatic tree species, multi-purpose tree species, neem, Acacia spp., Pongamia, spp., solar harvesting, water harvesting
Ramtek	180-195, 165-180, 150-165	Arl-Krn, Krn-Arl, Bgb-Msk, Wdn-Sur	Vegetable crops, green gram, sorghum, groundnut, fodder crops, sesame, red gram	Horse gram, custard apple, multi-purpose tree species, agri-silvi-pasture system, energy plantation, solar harvesting, water harvesting
Savner	135-150, 150-165, 165-180	Arl-Krn, Krn-Arl, Arl-Lng, Jam-Gmk, Lng-Wdn, Wdn-Sur, Pjr-Krl	Soybean, cotton, pigeon pea, gram, sorghum, millets, castor, coriander, pearl millet, cowpea, sapota, fodder crops, acid lime	Ber, subabul, multi-purpose tree species, neem, Acacia spp.
Umred	135-150, 150-165, 120-135	Bgb-Sur, Lng-Krl, Lng-Pjr, Lng-Wdn, Pjr-Krl, Wdn-Lng, Wdn-Sur	Sorghum, millets, castor, cluster bean, cowpea, sapota, pomegranate, red gram, green gram, vegetables	Horse gram, custard apple, multi-purpose tree species, neem, Acacia spp., Pongamia spp., afforestation, agroforestry

Chapter-V

SUMMARY AND CONCLUSIONS

The present investigation was carried out in Nagpur district, Maharashtra to assess the length of growing period using meteorological and remote sensing data. The meteorological data of different meteorological observatories located in Nagpur district was collected from the climatic database and potential evapotranspiration (PET) was computed using Penman-Monteith equation. Landforms and land use/land cover were characterized using ALOS-2 digital elevation model (DEM) and Sentinel-2 data. The existing soil database was upgraded using the landform and land use/land cover information. Length of growing period (LGP) was computed using PET and soil attributes and using time-series NDVI-based MODIS data. The results of the present investigation have been summarized below.

- Ten major landforms *i.e.*, hills, plateau, scarp slope, pediments, pediplain, valley, gullied land, butte/mesa/ridge, mining area and waterbodies have been identified. The pediplains were further divided in to pediplains (hillside), upper pediplains and lower pediplains.

- Six major land use/land cover classes *viz*., agriculture, forest, scrubland, built up area, mining and waterbodies have been identified based on satellite image analysis

- The existing soil database has been upgraded using the boundaries of landforms and land use/land cover information of Nagpur district (legacy data) has been used in present study

- Highest rainfall was observed in Nagpur-Rural tehsil (1569 mm) and the lowest rainfall was observed in Narkhed tehsil (982 mm).

- Highest PET was observed in Hingna tehsil (1758 mm) and the lowest PET was observed in Nagpur-Rural tehsil (1656 mm).

- The length of growing period (LGP) varied from 139 to 155 days. Maximum LGP was observed in Nagpur Rural (155 days) followed by Bhivapur (151 days), Umred (150 days) and the lowest LGP was observed in Kalmeshwar and Katol (139 days).

- Significant and positive correlation has been observed between rainfall and LGP (r = 0.60*). A positive correlation between AWC and LGP (r = 0.17) and a negative correlation between PET and LGP (r = -0.41) but non-significant.

- The surface map of LGP indicate that LGP ranged from 139 to 155. The higher LGP has been observed in south and south-east parts of the district covering Biwapur, Kuhi, Umred, Nagpur-Rural, Kamtee and Moudha tehsils, medium LGP was observed in central and northern parts of the district covering Parseoni and Saoner tehsils and the lower LGP has been observed in western part and northern part of the district covering Nagpur-Rural, Hingna, Katol, Kalmeshwar, Narkhed and part of Savner tehsils.

- The pixel-wise LGP data computed using MODIS-NDVI-time-series data has been reclassified in to 5 classes *viz.*, 90-120, 120-150, 150-180, 180-210, 210-240 days.

- LGP class 150-180 has occupied maximum area (40.7%) followed by LGP class 210-240 (17.7%), LGP class 180-210 (15.4%), LGP class 120-150 (14.8%), whereas, LGP class 90-120 has least area (11.8%).

- Bhiwarpur tehsil has maximum area under LGP class 150-180 (26.7%) and lowest area was observed under LGP class 180-210 (10.7%).

- Hingna tehsil has maximum area under LGP class 150-180 (52.1%) and lowest area was observed under LGP class 90-120 (9.2%).

- Kalmeshwar tehsil has maximum area under LGP class 150-180 (48.3%) and lowest area was observed under LGP class 90-120 (9.5%).

- Kamtee tehsil has maximum area under LGP class 210-240 (32.6%) and least area was observed under LGP class 120-150 (11.4%).

- Katol tehsil has maximum area under LGP class 150-180 (47.3%) and least area was observed under LGP class 90-120 (9.1%).

- Kuhi tehsil has maximum area under LGP class 150-180 (31.5%) and least area was observed under LGP class 90-120 (11.3%).

- Moudha tehsil has maximum area under LGP class 150-180 (39.3%) and least area was observed under LGP class 90-120 (10.2%).

- Nagpur (Rural) tehsil has maximum area under LGP class 150-180 (49.3%) and least area was observed under LGP class 90-120 (10.4%).

- Narkhed tehsil has maximum area under LGP class 150-180 (33.6%) and least area was observed under LGP class 90-120 (9.6%).

- Parseoni tehsil has maximum area under LGP class 150-180 (47.9%) and least area was observed under LGP class 90-120 (10%).

- Ramtek tehsil has maximum area is under LGP class 150-180 (53.6%) and least area was observed under LGP class 210-240 (7.5%).

- Savner tehsil has maximum area under LGP class 150-180 (45.3%) and least area was observed under LGP class 90-120 (8.4%).

- Umred tehsil has maximum area under LGP class 150-180 (36%) and least area was observed under LGP class 180-210 (14.6%).
- Nagpur (Urban) tehsil has maximum area under LGP class 150-180 (25.2%) and least area was observed under LGP class 210-240 (16.3%).
- LGP in different landforms indicated that maximum LGP was under lower pediplains (46.3%) followed by pediments (21.7%) and plateau (11.1%). Lower LGP was observed in upper pediplains (7.1%), hills (5.4%), pediplain (hillside) (2.5%), scarp slope (1.9%), valley (1.6%) and gully land (0.8%).
- LGP in different land use/land cover indicate thatmaximum LGP is under agriculture (69.5%) followed by forest (23.3%) and scrubland (7.1%). Out of the 5 classes of LGP, 65.7 per cent of total agricultural area has LGP from 120-240 days.
- Based on length of growing period and soil characteristics, a tehsil-wise land use plan has been prepared.
- The suggested land use includes major crops of the area for intensive cultivation, agri-horticulture, agroforestry, silvipasture, vegetable cultivation and floriculture in agricultural and wastelands to improve the productivity of these lands. Afforestation has been suggested in degraded forest areas.

Conclusions:

1. It is concluded that the length of growing period (LGP) computed using point meteorological observatories and soil database has been interpolated to prepare the surface map of LGP. The LGP ranged from 138 to 155.

2. The LGP map generated using MODIS NDVI time series data has 5 LGP classes with 90-120 days to 210-240 days.

3. The study is useful in understanding the utility of remote sensing data in determining the length of growing period over large areas having limitations of weather data collection in remote and inaccessible areas.

Chapter - VI

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