STUDY OF MOISTURE VARIABILITY IN SAVITRI BASIN USING RS AND GIS DATA BASED

A Thesis submitted to

DR. BALASAHEB SAWANT KONKAN KRISHI VIDYAPEETH
DAPOLI - 415 712
Maharashtra State (India)

In the partial fulfillment of the requirements for the degree

of
MASTER OF TECHNOLOGY
(AGRICULTURAL ENGINEERING)

in
SOIL AND WATER CONSERVATION ENGINEERING

by
MISS BHAMBURE TEJASHRI VIJAY
(ENDPM 2015/090)

DEPARTMENT OF SOIL AND WATER CONSERVATION ENGINEERING
COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
DR. BALASAHEB SAWANT KONKAN KRISHI VIDYAPEETH
DAPOLI- 415 712, DIST. RATNAGIRI, M. S. (INDIA)
2017

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Approved by the advisory committee

Dr. Kishor Gharde
Chairman and Research Guide,
Assistant Professor
Department of Soil and Water Conservation Engineering,
College of Agricultural Engineering and Technology, Dapoli.

Members

Prof. dilip MAHALE
Professor and Head,
Department of Soil and Water
Conservation Engineering,
College of Agricultural Engineering
and Technology, Dapoli.

Dr. S. B. Nandgude
Professor, (CAS)
Department of Soil and Water
Conservation Engineering,
College of Agricultural Engineering
and Technology, Dapoli.

Dr. M. S. Mane
Professor, (CAS)
Department of Irrigation and
Drainage Engineering,
College of Agricultural Engineering
and Technology, Dapoli.

CANDIDATE'S DECLARATION

I hereby declare that this thesis or part of there has not been submitted

by me or any other person to any other

University or Institute

For a Degree or

Diploma

Place: Dapoli **(Tejashri V. Bhambure)**

Dated: **/** /2017 **(ENDPM 2015/090)**

Dr. Kishor Gharde
B. Tech. (Agril. Engg.), M. Tech. (SWCE), PhD (SWCE)
Assistant Professor,
Department of Soil and Water Conservation Engineering,
College of Agricultural Engineering and Technology,
Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth,
Dapoli- 415 712, Dist. Ratnagiri,
Maharashtra, India.

CERTIFICATE

This is to certify that the thesis entitled **"STUDY OF MOISTURE VARIABILITY IN SAVITRI BASIN USING RS AND GIS DATA BASED."** submitted to Faculty of Agricultural Engineering, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist.-Ratnagiri, (Maharashtra State) in the partial fulfilment of the requirements for the award of the degree of **Master of Technology (Agricultural Engineering)** in **Soil and Water Conservation Engineering,** embodies the results of bonafied research work carried out by **Miss. Tejashri Vijay Bhambure (ENDPM 2015/090)** under my guidance and supervision. No part of the thesis has been submitted for any other degree, diploma or publication in any other form.

The assistance and help received during the course of this investigation and source of the literature have been duly acknowledged.

Place: Dapoli
Dated: **/** **/**2017 **(K. D. Gharde)**

Prof. dilip MAHALE.
B. Tech. (Agril. Engg.), M. Tech. (SWCE)
Professor and Head,
Department of Soil and Water Conservation Engineering,
College of Agricultural Engineering and Technology,
Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth,
Dapoli- 415 712, Dist. Ratnagiri,
Maharashtra, India.

CERTIFICATE

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The assistance and help received during the course of this investigation and source of the literature have been duly acknowledged.

Place: Dapoli
Dated: **/** /2017 **(dilip MAHALE)**

Dr. Y. P. Khandetod
B.Tech. (Agril Engg.), M. Tech. (PHE), Ph.D. (AgFE)
Associate Dean,
College of Agricultural Engineering and Technology,
Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth,
Dapoli- 415 712, Dist. Ratnagiri,
Maharashtra, India.

CERTIFICATE

This is to certify that the thesis entitled **"STUDY OF MOISTURE VARIABILITY IN SAVITRI BASIN USING RS AND GIS DATA BASED."** submitted to Faculty of Agricultural Engineering, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist.-Ratnagiri, (Maharashtra State) in the partial fulfilment of the requirements for the award of the degree of Master of Technology (Agricultural Engineering) in Soil and Water Conservation Engineering is a record of bonafied research work carried out by **Miss. Tejashri Vijay Bhambure (ENDPM 2015/090)** under the guidance and supervision of **Dr. Kishor Gharde** Assistant Professor, Department of Soil and Water Conservation Engineering, College of Agricultural Engineering and Technology, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist. Ratnagiri. No part of the thesis has been submitted for any other degree, diploma or publication in any other form.

The assistance and help received during the course of this investigation and source of the literature have been duly acknowledged.

Place: Dapoli **(Y. P. Khandetod)**

Dated: **/** /2017

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'Definitely success can be achieved by hard work and sincere efforts. But behind this success there is knowing and unknowing involvement of many innovative minds and creative hands to beautify it. Emotions cannot be adequately expressed in words because then emotions are transferred into mere formalities. Nevertheless, formalities have to be completed. My acknowledgement are many more than what I am expressing here.

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Place: Dapoli

Dated: / /2017 **(Tejashri Vijay Bhambure)**

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LIST OF ABBREVATIONS AND SYMBOLS

Abbreviations	Description
CAET	College of Agricultural Engineering and Technology
E	East
N	North
et al.	And others
etc.	Etcetera
Fig	Figure
GIS	Geographic Information System
RS	Remote sensing
Vis	Vegetation Indices
Km	Kilometer
ETM	Enhanced Thematic Mapper
NDVI	Normalized Difference Vegetation Index
SAVI	Soil Adjusted Vegetation Index
MSAVI	Modified Soil Adjusted Vegetation Index
NDWI	Normalized Difference Water Index
TB	Brightness Temperature
LST	Land Surface Temperature
UTM	Universal Transverse Mercator
DOY	Day of Year
NIR	Near Infra-Red
SWIR	Short Wave Infra-Red
WRS	World-wide Reference System
%	Per cent
λ	Lambda
θ	Theta
π	Pie
σ	Sigma
ρ	Rho
ε	Epsilon
μ	Mu

ABSTRACT

"STUDY OF MOISTURE VARIABILITY IN SAVITRI BASIN USING RS AND GIS DATA BASED."

By

Tejashri Vijay Bhambure

College of Agricultural Engineering and Technology,
Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli.
Dist. - Ratnagiri, Maharashtra, India.
2017

Research Guide : Dr. Kishor Gharde

Department : Soil and Water Conservation Engineering

Geographic information systems (GIS) provide appropriate tools for the storage, retrieval, analysis, management and display of spatial and temporal data. Remote sensing (RS) is an important source of data for input into GIS. The soil moisture variability calculated by remote sensing data based is accurate, fast and realistic method compared to manual method.

Soil moisture is spatially and temporally highly variable, and it influences a range of environmental processes in a nonlinear manner. This leads to scale effects that need to be understood for improved prediction of moisture dependent processes. The characterization of temporal and spatial variability of soil moisture is highly relevant for understanding the many hydrological processes, to model the processes better and to apply them to conservation planning. In the field of remote sensing applications, scientists have developed vegetation indices (VI) for qualitatively and quantitatively evaluating vegetative covers using spectral measurements. The spectral response of vegetated areas presents a complex mixture of vegetation, soil brightness, environmental effects, shadow, soil colour and moisture. Moreover, the VI is affected by spatial-temporal variations. We found that the triangle method can be a fast and simple method to estimate regional soil moisture conditions.

The present study was undertaken for Savitri basin which is gauged at near Mahad city covering total geographical area of 994 sq. km. The Savitri basin lies between $18^0$20’N to $17^0$51’N and $73^0$22’ E to $73^0$41’E received average annual rainfall 3560 mm Daily mean

temperature ranges from a maximum of 35^{0}C (May) to minimum of 21^{0}C (January). The daily mean relative humidity varies from a minimum of 55.15 per cent (April) to a maximum of 99 per cent (July). Topography of the watershed is undulating with the land slope varying from more than 50 per cent.

This study investigates vegetation indices and soil moisture for Savitri basin for the period 1999-2003. Cloud Free Landsat satellite data of 1999, 2000, 2002 and 2003 for the study area has been downloaded from Landsat data and official website of USGS (www.earthexplorer.gov.in). All the data are pre-processed and projected to the Universal Transverse Mercator (UTM) projection system. The collected data was converted into radiance, reflectance and finally correcting reflectance using raster calculator in ArcGIS. The different vegetation indices such as Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI), Modified Soil Adjusted Vegetation Index (MSAVI) of study area was calculated with the help of RED, NIR and SWIR bands of RS imagery in ArcGIS 10.2.

A result of the study reveals that, the NDVI value varied from -0.71 to 0.83, -0.35 to 0.63, -0.50 to 0.74 and -0.16 to 0.76 for the year 1999, 2000, 2002 and 2003, respectively. The SAVI value varied from -0.10 to 0.60, -0.12 to 0.36, -0.15 to 0.50 and -0.34 to 0.40 for the year 1999, 2000, 2002 and 2003, respectively. The MSAVI value varied from -0.49 to 0.034, 0.54 to 0.95, -0.48 to 0.027 and 0.53 to 0.74 for the year 1999, 2000, 2002 and 2003, respectively. The highest value of NDVI and SAVI was obtained in year of 1999 while the highest value of MSAVI was obtained in year of 2000.

The two different vegetation moisture estimation methods namely MSAVI – LST (land surface temperature) feature space identified, Normalized Difference Water Index (NDWI) is applied to determine the vegetation moisture level. The results of two methods were classified and final moisture content map was produced with the help of ArcGIS. The NDWI was calculated with the help of NIR and SWIR bands in raster calculator. The NDWI image was normalized into 8-bit and classified to three moisture classes. The moisture variation level was high in Savitri basin in the year of 1999 with threshold of 137-255. The Land Surface Temperature was calculated with the help of thermal band. Finally MSAVI and LST image were stacked together to create feature space image. This image was classified using unsupervised classification method and then converted into three moisture classes. The moisture variation occurred between 16.15 to 28.54 percent. The highest moisture level was obtained in the year of 2002.

The moisture variation in the watershed estimated by NDWI and VI-LST method using Landsat data sets is very useful for proper crop planning management, estimate moisture stress period, decide cropping system and density, and estimate crop productivity. It will also help in deciding drought status in the basin in different seasons in the academic year. This study derived for estimation of moisture in vegetation.

I. INTRODUCTION

Soil moisture is an essential variable in climate and hydrological science through its impact on the energy and water balance. Knowledge about soil moisture and its spatio-temporal variability is helpful to identify the heterogeneity of different characteristics, such as soil texture, vegetation, topography and meteorological conditions etc. (Mittelbach and Seneviratne, 2012). The soil moisture variability calculated by remote sensing data based is accurate method. Also it is very fast and realistic to manual method. The manual method is tedious, time consuming and not spatial.

Soil moisture in the surface layers of the soil profile plays a critical role in the hydrologic cycle. Microwave remote sensing holds a great potential for providing areal estimates of soil moisture because of its capability to penetrate clouds, and to some extent, the vegetation canopy (Engman and Gurney, 1991). Passive microwave remote sensing employs measurements of thermal emission from the soil at longer microwave wavelengths (X > 10 cm) to determine moisture content in the surface layer of the soil.

Geographic information systems (GIS) provide appropriate tools for the storage, retrieval, analysis, management and display of spatial and temporal data. Remote sensing (RS) is an important source of data for input into GIS. Remote sensing platforms, either airborne or space borne, have capabilities of acquiring data concerning various hydrologic parameters on a repetitive basis, and hence, generate large volumes of spatial data.

There is currently an increasing interest in vegetation characterization with remote sensing techniques. Since, information contained in a single spectral band is usually insufficient to characterize vegetation status, vegetation indices are usually developed by combining two or more spectral bands. Vegetation Indices (VIs) are combinations of surface reflectance at two or more wavelengths designed to highlight a particular property of vegetation. They are derived using the reflectance properties of vegetation. Each of the VIs is designed to accentuate a particular vegetation property (Singh *et. al*., 2010). The vegetation indices are useful for assessing vegetation condition, foliage, cover, phenology, and processes such as evapotranspiration (ET) and primary productivity, related to the fraction of photo synthetically active radiation absorbed by a canopy (Glene and Huete, 2008). Spectral vegetation indices (VIs) have been used for monitoring of Earth's vegetative cover as a precise radiometric measure of green vegetation. The analysis of vegetation and the detection of change in vegetative patterns are keys to natural resource assessment and monitoring. One of the major applications for remote sensing data is the detection and quantification of green vegetation (Ahmad, 2012).

Land Surface Temperature (LST) means the temperature of the surface which we observe if directly contact or touches it with. It is also refer as skin temperature of the surface. When it rise it causes environmental unbalance situation like melts in glacier, vegetation, climatic condition of monsoon countries leading to unpredictable rainfall (Latif, 2014). Urban heat island effect, global warming, enhanced green-house effects and other environmental problems have become very important subjects to overcome in the last decades. Land surface temperature is an important parameter for many environmental models. LST retrieval using remotely sensed data is the most popular subjects in environmental studies during the last couple of decades (Hakan, 2015).

Soil moisture near the land surface affects a wide variety of earth system interactions over a changing spatial and temporal scale. Surface soil moisture plays a critical role in the interaction between land surface and the atmosphere, as well as in hydrological and ecological processes. It exerts a major control on the partitioning of net radiation into latent and sensible heat and on the conversion of rainfall into runoff and infiltration (Lekshmi *et al*., 2013). Given the importance of surface soil moisture to land surface system, quantification of its variability and patterns received increasing attention in recent years (Zhang *et. al*, 2011).

The use of Remote Sensing for computation of soil moisture can be started from 1970s. Recently, many new methods have emerged and one of them is the triangle method which uses a land surface temperature/vegetation index space to estimate regional soil moisture status. The space is a scatter plot of remotely sensed surface temperature and vegetation index which often results in a triangular shape. The basic idea of the triangle method is that, land surface temperature is sensitively associated with the soil moisture content and the vegetation cover. Vegetation index is not so sensitive to the soil moisture change because when the water stress begins, the leaves are still green. Land surface temperature is quite sensitive to the soil moisture conditions (Yang *et. al*, 2008).

The soil properties on which their classification and identification are based are known as index properties. Konkan division is one of the six administrative divisions of Maharashtraa state in India. Konkan is a coastal strip of land bounded by the Sahyadri hills on the east and the Arabian sea on the west. Maharashtra's Konkan area consists of Raigad, Ratnagiri, Sindhudurg, Thane and Palghar districts. Konkan region is located between $15^0$44' and 20°20' N latitude and $70^0$10' and $73^0$50' E longitude. In districts of Konkan region the flood problem is common. The estimation of soil moisture is best tool for the management of flood and its control measures.

The Savitri river basin is comes under the Western part of Sahyadri Ghat part of Konkan region. Study area belongs to Mahad and Poladpur Tahshils of Raigarh district in Konkan region of Maharashtra state. The latitude and longitude of the study area is $18^0$20'N to $17^0$51'N and $73^0$22' E to $73^0$41'E respectively and elevation ranges from 6.50 m to 1366.23 m above mean sea level**.** The main stream of the study is Savitri river basin has average length of 57.57 Km. Average annual rainfall in the area is 3560 mm in the form of intense storms and its distribution is highly erratic as more than 90 per cent is occurred during the monsoon months (June to October). Topography of the watershed is undulating with the land slope varying from more than per cent.

The usefulness of vegetation indices lies as an aid to remote sensing image interpretation, the detection of land use changes, and the evaluation of vegetative cover density, forestry, crop discrimination and crop prediction. Land surface temperature (LST) is a key parameter for many environmental studies such as global environmental change, climate models, and human-environment interactions. Land surface temperature (LST) is an important factor in vegetation growth, and glacier. Knowledge of surface soil moisture at the watershed scale would be useful for such critical applications as regional resource management during times of drought or flooding. Knowledge of soil moisture is useful for proper crop planning management, estimate moisture stress period, decide cropping system, density and estimate crop productivity. It will also help in deciding drought status in the basin in different seasons in the academic year. Also the estimation of soil moisture is adopted for crop planning and their management. Keeping this in mind the study is undertaken with following specific objectives:

1) To determine the Normalized Difference Vegetative Index (NDVI)

2) To determine Soil Adjusted Vegetative Index (SAVI) and Modified Soil Adjusted Vegetative Index (MSAVI)

3) To study the soil moisture variability.

II. REVIEW OF LITERATURE

This chapter deals with the review of research work done by various researchers on estimation and usefulness of Normalized Difference Vegetation Index, Soil Adjusted Vegetation Index, Modified Soil Adjusted Vegetation Index and Moisture content and its variation.

2.1 Determination of Normalized Difference Vegetation Index (NDVI):

Jackson and Huete (1991) studied to interpreting vegetation index. They reported that, NDVI are useful for assessing the amount and condition of vegetation using data from ground, aircraft and satellite based sensors. However, atmospheric constraints, sensor view and solar zenith angle as well as soil back ground and canopy architect must be accounted for if quantitative comparison of biomass and plant health is to be expected. The VI is able to respond to suitable changes in plant health status admit variable view, illumination and atmospheric conditions.

Bannari *et al*., (1995) studied a Review of Vegetation Indices. They showed that, the vegetation indices are quantitative measurements indicating the vigor of vegetation. They also showed better sensitivity than individual spectral bands for green vegetation detection. Their usefulness lies as an aid to remote sensing image interpretation, the detection of land use changes, the evaluation of vegetative cover density, forestry, crop discrimination and crop prediction.

Fuller (1998) studied trends in NDVI time series and their relation to rangeland and crop production in Senegal. He showed that, output of NDVI is a new image file/layer. Values of NDVI can range from -1.0 to +1.0, but values less than zero typically do not have any ecological meaning, so the range of the index is truncated to 0.0 to +1.0. Higher values signify the larger difference between the red and near infrared radiation recorded by the sensor and condition associated with highly photo synthetically active vegetation. Low NDVI values mean there is little difference between the red and near infrared signals. This happen when there is little photosynthetic activity, or when there is just very little NIR light reflectance (i.e., water reflects very little NIR lights).

Osaki (2000) studied seasonal change of NDVI calculated by JERS data with higher spatial resolution. He concluded that, abrupt change of NDVI might be useful to detect the abnormality in weather. Abrupt change of NDVI in vegetation area seems to reflect an abnormal meteorological phenomenon. Also he showed that, values of NDVI in OPS/JERS are larger by about 10% than in TM/LANDSAT. Future problem is the pursuit of good atmospheric correction for JERS imagery in summer season and dependency of ground resolution of satellite on NDVI.

Petrorelli *et al.,* (2005) studied the satellite derived NDVI to access ecological responses to environmental change. They reported that Normalized Difference Vegetation Index (NDVI) will become an extremely useful tool for terrestrial ecologist aiming to gain a better understanding of how vegetation dynamics and distribution affect diversity, life history traits, and movement pattern and population dynamics of animal populations. The global coverage of the NDVI suggest that, it could be used to predict the ecological effects of environmental change on ecosystem functioning and animal population dynamics and distributions, enabling researchers to better understand the impact of humans on the environment.

Maskova *et al*., (2008) studied a Normalized Difference Vegetation Index (NDVI) in the management of mountain meadows. They observed that, the relationship between green biomass and NDVI were statistically significant for all treatments during the period between the start and peak of the growing season, when the respective plots were mown or mulched. A statistically significant linear relationship between NDVI and GR was not detected in the mown and mulched plots even during that period. The NDVI can therefore, serve for detecting difference in the management of comparable grassland stands only with limitations.

Ghorbani *et al.*, (2012) studied utility of the NDVI for land/canopy cover mapping in Khalkhal County, (Iran). They observed that, for image of 1987 (TM), the NDVI value fluctuated from – 0.67 to +0.69 and for image of 2002 (ETM+) the derived values varies from -0.44 to +0.74 and for image of 2008 (IRS) values varies from -0.75 to +0.27. By considering the theory of NDVI at varies from -1 to +1, although the lowest values in three produced maps by existing cloud are acceptable, by interpretation of these produced maps using the NDVI, there are no 100% canopy cover at the study area. For bare soil as mentioned the amount of NDVI varies from -0.25 to 0.18 in three selected images.

Latif (2014) studied Normalized Difference Vegetation Index retrieval of Landsat-8 data. He found that, the range of NDVI is varies from 0 to 0.57 (zero for negative NDVI values using condition). Increase in NDVI range from 0 to 1 indicates for healthy and green vegetation cover area. From NDVI image he performs reclassification of NDVI layer for soil and vegetation separately and calculates NDVI for soil and vegetation.

Gandhi *et al.,* (2015) studied NDVI: vegetation change detection using remote sensing and GIS- A case study in Vellore district. They reported that, the multispectral images are giving best results for all the features at Normalized Difference Vegetation Index (NDVI) value of 0.3. The lowest values are found on the less vegetated soils and presumably because reflection from the soil is high, and produce low values in NIR band and high values in the RED band; hence, the NDVI values are low. The NDVI have been used widely to examine the relation between spectral variability and the changes in vegetation growth rate. It is also useful to determine the production of green vegetation as well as detect vegetation changes.

2.2 Determination of Soil Adjusted Vegetation Index (SAVI) and Modified Soil Adjusted Vegetation Index MSAVI:

Huete (1988) studied a soil-adjusted vegetation index (SAVI) and found the induced range in spectral index values for evaluating L-values. L was varied from 0 to 1 and from 1 to 100 in order to analyse the effect and sensitivity of NIR-red data space translation on vegetation index improvement. At L = 0, the behaviour of the NDVI is normal.

Chehbouni *et al*., (1994) studied a modified soil adjusted vegetation index and reported that, in relation to the SAVI (L=0.5), the dynamic range of the MSAVI, was increased for the ground based cotton data. Soil noise influences were also reduced and the VI response to percentage green cover becomes more linear. The vegetation estimate uncertainty reduced from 2.5% (SAVI) to 1.6% (MSAVI). The variable L function improves vegetation sensitivity, particularly in high vegetation densities.

Gilabert *et al*., (2002) studied a generalized soil-adjusted vegetation index and reported that, in all the cases, the new index (GESAVI) presents one of the highest signal-to-noise ratios. Some other indices such as SAVI and OSAVI also present high values and, thus, can be considered as belonging to the most efficient VI group. Traditional indices (RVI and NDVI) present low values for the signal-to-noise ratio, indicating their worse performance to retrieve biophysical characteristics from the vegetation canopies independently of the soil background.

Peters *et al.,* (2002) studied drought monitoring with NDVI-Based Standardized Vegetation Index. They showed that, the SAVI is a good indicator of vegetation response to short-term weather conditions. Also the SAVI is a useful tool and is capable of providing a near-real-time indicator of the onset, extent, intensity, and duration of vegetation stress.

Basso *et al*., (2004) studied remotely sensed vegetation indices: for Crop Management. They reported that, the measurements of vegetation indices are useful for yield estimation, plant population, pest management, nutrient management, estimation of crop growth, measurement of soil salinity.

Glenn and Huete, (2008) studied relationship between remotely-sensed vegetation indices, canopy attributes and plant physiological processes. They showed that, the VIs and their transformations and derivatives are extremely useful tools in monitoring processes related to PAR absorbed by vegetation. These include processes related to photosynthesis at the canopy or ecosystem scale (phenology, primary productivity, net carbon fixation, gross primary productivity), and processes related to plant transpiration (ET, rainfall use efficiency, groundwater withdrawal). VIs is measures of green foliage density, and they must be combined with ground data or appropriately calibrated models to produce accurate information about these processes.

Hadjimitsis *et al*., (2010) studied atmospheric correction for satellite remotely sensed data intended for agricultural applications: impact on vegetation indices. They reported that, for the calculation of DVI, NDVI, SAVI and MSAVI indices the effects of the atmosphere should be considered. Large variations in at-satellite reflectance values, in Landsat TM/ETM bands 1 and 3 suggest that, atmospheric effects were variable and significant for crop targets. It has been shown that by not taking into account the effects of the atmosphere leads to an overestimation of the evapotranspiration from 0.25 to 0.73 mmd^{-1} using Landsat TM bands 1, 2, 3 and 4.

Panda *et al*., (2010) studied application of vegetation indices for agricultural crop yield prediction using neural network techniques. They showed that, the corn yield was best predicted using BPNN models that used the means and standard deviations of PVI grid images. In all three years, it provided higher prediction accuracies, coefficient of determination (r^2), and lower standard error of prediction than the models involving GVI, NDVI, and SAVI image information. The GVI, NDVI, and SAVI models for all three years provided average testing prediction accuracies of 24.26% to 94.85%, 19.36% to 95.04%, and 19.24% to 95.04%, respectively while the PVI models for all three years provided average testing prediction accuracies of 83.50% to 96.04%.

Ahmad (2012) studied spectral vegetation indices performance evaluated for Cholistan Desert. He showed significant correlations between ETM+ bands and vegetation groups such as grasses, forbs, shrubs, and bushy trees. The vegetation indices, such as the soil-adjusted vegetation indices, considerably reduce these soils effects, estimation of the vegetation characteristics from the indices still suffers from some imprecision. The results of this research are encouraging and the techniques described provide an improved method for estimating the quantity of vegetative cover across large and complex desert environment with satellite imagery.

Ren and Feng (2014) studied are soil-adjusted vegetation indices for above-ground green biomass estimation in arid and semi-arid grasslands. They reported that, the performance of the soil-adjusted vegetation indices should be better than that of the soil-unadjusted vegetation indices for estimating above-ground green biomass Nevertheless, the soil-adjusted SAVI, MSAVI, OSAVI, TSAVI, ATSAVI and PVI accounted for only 61, 56, 67, 58, 56 and 47% of the variability in measured above-ground green biomass, which were lower values than that of the soil-unadjusted SR (72%) and NDVI (71%).

Linlin *et al*., (2015) studied evaluation of three MODIS-derived vegetation index time series for dryland vegetation dynamics monitoring. They showed the annual mean VI images with similar spatial patterns of vegetation conditions with varying magnitudes. NDVI, SAVI and EVI were all related to each other with varying correlation strengths among different vegetation types. The relationship between NDVI, SAVI and EVI were weakest with Pearson's correlation coefficients ranging from 0.29 to 0.66. In general, EVI exhibited high uncertainties in sparsely vegetated land and forest areas due to the disturbance of blue band reflectance. The largest deviations of phenological metrics (37.6 days in SOS and 47.0 days in EOS) were derived from NDVI time series, suggesting the index's sensitivity to soil background and atmospheric effects. Discrepancies of the histogram distributions of phenology metrics from different VIs further revealed their different sensitivities to variation of soil background and physiological development of vegetation.

2.3 Determination of Variability in Moisture:

Famiglietti *et al.,* (1997) studied Ground-based investigation of soil moisture variability within remote sensing footprints during the Southern Great Plains 1997 (SGP97) Hydrology Experiment. They showed that, the mean moisture content responds predictably to rainfall, increasing after storm events and decreasing thereafter. The observed standard deviations of moisture content within each field varied between upper and lower limits of 0.09 cm^3/cm^3 and 0.01 cm^3/cm^3 respectively. These data further suggested potential relationship between the standard deviation of soil moisture.

Jenifer *et al.*, (2002) studied biological indices of soil quality: an ecosystem case study of their use. They reported that, the soil chemical, physical and biological indicators to rank soil quality which is difficult, even over a small spatial scale. Ranking the soil quality indicators to conduct an unbiased comparison of a given number of sites allows the synthesis of many diverse soil and vegetation variables. However, the resultant ranking of soil or site quality is dependent on the objective or goal for that specific site. Attempting to determine the quality of a soil or a site, removed from the larger ecosystem in which it exists was inappropriate. Determining overall site quality is complex and must consider soil, vegetation and the surrounding ecosystem as well as potential changes in land use and social needs.

Zhang and Chen (2011) studied spatial variability and patterns of surface soil moisture in a field plot of Karst area in Southwest China. They reported that, in the dry season, the mean soil moisture was 15.05 per cent and 22.96 per cent with covariance values of 14.39 per cent and 9.28 per cent correspondingly. During the rainy season, the mean soil moisture reached 27.53 per cent and 20.71 per cent on June 14 and July 19 with covariance values of 8.25 per cent and 12.07 per cent, respectively. This meant that the mean soil moisture was higher, but with lower covariance values controlled by the antecedent rainfall (the total rainfall during 10 days before the sampling) either in dry or rainy season.

Hossain *et al*., (2006) studied mapping spatial variation in surface moisture using reflective and thermal aster imagery for Southern Africa. They showed that, surface moisture variation by different methods gives idea about drought monitoring in Southern Africa. Triangular space method was more accurate method for estimation of moisture variation.

Yingxin *et al*., (2008) evaluated of MODIS, NDVI and NDWI for vegetation drought monitoring using Oklahoma Mesonet soil moisture data. They found that, relation between vegetation indices and soil moisture is highly dependent on the land cover heterogeneity and soil type. Homogeneous vegetation cover had the highest correlation between FWI and both vegetation- related indices (r = 0.73), while heterogeneous vegetation cover had the lowest correlation (r = 0.22).

Yang *et al*., (2008) studied modified triangle method to estimate soil moisture status with moderate resolution imaging spectro-radiometer (MODIS) products. They showed the temporal trend of TVDI in conjunction with rainfall data. The modified triangle method can clearly define the shape of Ts/VI space in most of the cases. NDVI-calculated TVDI is much sensitive to the soil moisture in 20cm, while EVI-calculated TVDI is much sensitive to the soil moisture in 10cm. Comparing with NDVI-calculated TVDI, EVI-calculated TVDI is much better in estimating soil moisture condition in most cases.

Jameli *et al*., (2009) investigated temporal relationships between rainfall, soil moisture and modis-derived NDVI and EVI for six sites in Africa. They found that, vegetation growth indicators (NDVI and EVI) are highly correlated with soil moisture at upper 1 m depth (0.40-0.89) at all sites during growing season for the same period. Also EVI shows slightly higher correlations with soil moisture than NDVI at all sites during the growing season. In addition, EVI responds to soil moisture changes earlier than NDVI by about 0-4 days at the sub-Saharan sites where rainfall is a controlling factor. These slightly stronger relationships with EVI might occur because of improved corrections for variations in atmosphere, soil, and canopy background which make it sufficient for monitoring open canopy areas such as grasslands and savannas.

Mhasake and Chaudhary (2009) studied application of GIS-GPS for mapping soil index properties. They reported that, there were the fluctuations in ground water table from 0.5 m to 3.5 m below ground level, due to the tidal effect of sea. The brownish medium stiff clay, bluish grey silty clay are available at a depth ranging from 2 m to 3 m and upto 20 m at some places like Chembur, Kurla and Wadala respectively. The places such as Bandra, Tilaknagar and Dharavi, black clay is available at a depth of 1.8 m to 6.3

Pandey and Pandey (2010) studied spatial and temporal variability of soil moisture and reported that, the krigged values are more consistent and true representative of soil moisture values. Hence, on the basis of past soil moisture values the krigged values of soil moisture at particular time ans space may be estimated. Statistical parameters reflect that the variability of soil moisture reduces significantly after kriging. These estimated values help in proper irrigation scheduling along with necessary information on the crops to be grown and expected yield of the same.

Singh *et al*., (2010) studied spatial variation of vegetation moisture mapping using advanced spaceborne thermal emission & reflection radiometer (ASTER) Data and reported that, out of three methods the NDWI and MSAVI-LST Triangular method has potential to estimate vegetation moisture variation more accurately than VDI method.

Mittelbach and Seneviratne (2012) studied a new perspective on the spatio-temporal variability of soil moisture: temporal dynamics versus time-invariant contributions. They reported that, frequently used frameworks assessing spatio-temporal characteristics of soil moisture networks need not generally apply to temporal soil moisture anomalies. Indeed, for the investigated data set, the analysis of the decomposed soil moisture reveals a small contribution of the dynamics to the overall variability of soil moisture. Reversely, this indicates a smaller spatial variability of the temporal dynamics than possibly inferred from the spatial variability of the mean soil moisture content and its mean value. Relative variability clearly decreases with increasing moisture content.

McNally *et al*., (2013) estimated the soil moisture using the Normalized Difference Vegetation Index for Sahelian and East Africa. They provide a novel way to estimate soil moisture from NDVI, using the NSM 25 multiple regression model that predicts the previous dekad's soil moisture using current and negative lag one NDVI. Finally, by developing a way to reasonably estimate soil moisture with NDVI we increase the potential utility of NDVI data by transforming it into a variable commonly used in land surface and water balance models.

III. MATERIAL AND METHODS

This chapter deals with the description of study area, data collected, procedure adopted to determine Normalized Difference Vegetation Index, Soil Adjusted Vegetation Index, Modified Soil Adjusted Vegetation Index and procedure for estimation of variation of moisture in study area is discussed in this material and method chapter, as per prescribed objectives.

3.1 Study Area

The Savitri river basin is comes under the Western part of Sahyadri Ghat of Konkan region. Study area belongs to Mahad and Poladpur Tahshils of Raigarh district in Konkan region of Maharashtra state. It started from Mahabaleswar in Sahyadri ranges and fed to Arabian Sea. Total area of Savitri river catchment under study is considered as 994 sq. km at the outlet point which gauged at near Mahad city.

3.2 Features of Study Area

The location of study area and location of sub catchment is given in Fig. 3.1. The latitude and longitude of the study area is 18^{0}20'N to 17^{0}51'N and 73^{0}22' E to 73^{0}41'E respectively and elevation ranges from 6.50 m to 1366.23 m above mean sea level**.** The main stream of the study is Savitri river basin has average length of 57.57 Km. The Savitri river basin comprises of four rivers namely Gandhari, Kal, Savitri and Bhaovira having catchment area of 137, 332, 354 and 47 Sq. Km respectively. Each has hydrological and meteorological gauging stations located at Koturde, Birwadi, Kangule and Bhave at their outlets point (Gharde and Kothari, 2015).

3.2.1 Climate

The region falls within sub-tropical climate with alternate dry and wet periods with three well defined seasons i.e. summer, monsoon and winter. Average annual rainfall in the area is 3560 mm in the form of intense storms and its distribution is highly erratic as more than 90% is occurred during the monsoon months (June to October). Daily mean temperature ranges from a maximum of 35^{0}C (May) to minimum of 21^{0}C (January). The daily mean relative humidity varies from a minimum of 55.15 per cent (April) to a maximum of 99 per cent (July). The mean daily evaporation, wind speed and sunshine hours were 4.66 mm, 2.48 m/s and sunshine duration was 11.12 hours, respectively.

3.2.2 Physiography

Topography of the watershed is undulating with the land slope varying from more than per cent. The general aspect of the area is from west and southwest to north and northeast. The drainage pattern is up to fifth to seventh order as per Strainers method of drainage network classification.

3.2.3 Soils

Predominant soil textures of the catchment are sandy loam (73.6 per cent) and sandy clay loam (26.4 per cent). The soils of the watershed were classified into Mahad, Sakhar and Mangaon series, which belong to clay-skeletal to fine, mixed Isohyperthermic, Typic Halusstepts soil series. These soils are coarse, mixed calcareous, non-saline, dark brown to very dark brown in colour and have moderate permeability and well drainage. Most of the watershed area comes under degraded land with less soils depth (25-50 cm).

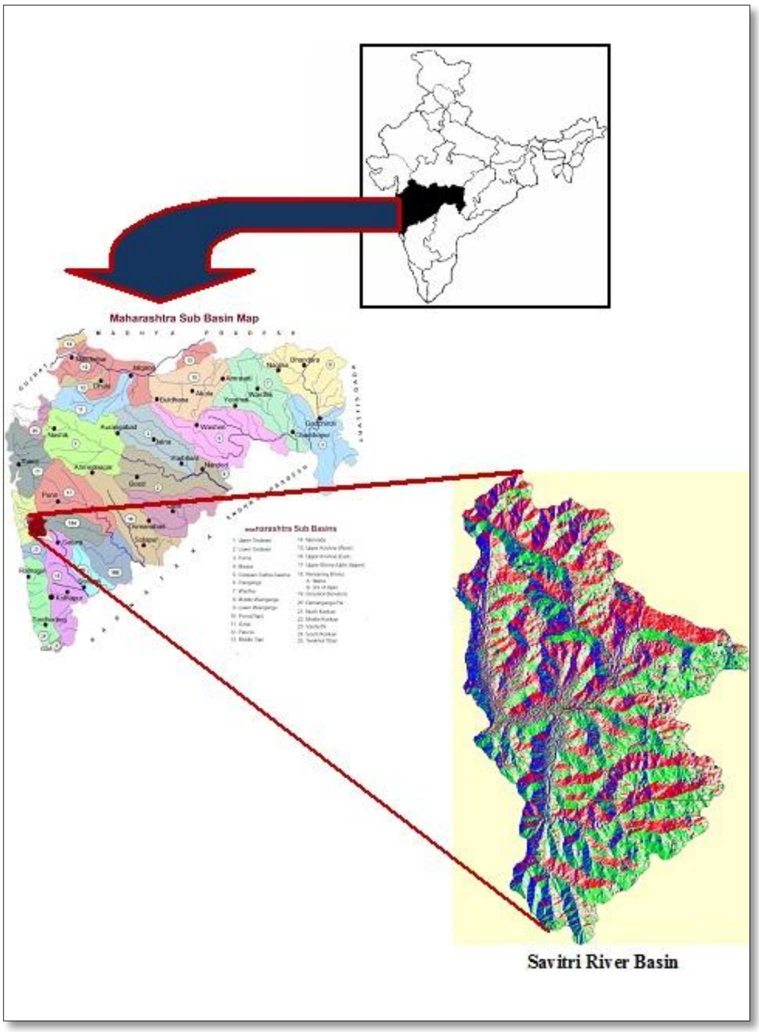


Fig. 3.1 Location Map of Savitri Basin

3.3 Data Collection

1. Cloud Free Landsat satellite data of 1999, 2000, 2002 and 2003 for the study area has been downloaded from Landsat data and official website of USGS (www.earthexplorer.gov.in).
2. All the data were pre-processed and projected to the Universal Transverse Mercator (UTM) projection system.
3. The details of the satellite data collected and Band designation are given in the Table 3.1 and Table 3.2.

Table 3.1 Details of satellite data collected

Sr. No.	Image Details	Satellite/Sensor	Reference System	Path/Row
1.	November 1999	Landsat 7/ ETM+	World Wild Reference System –II (WRS-II)	147/47 and 147/48
2.	October 2000	USGS Earth Explorer	WRS-II	147/47 and 147/48
3.	September 2002	USGS Earth Explorer	WRS-II	147/47 and 147/48
4.	March 2003	USGS Earth Explorer	WRS-II	147/47 and 147/48

(www.earthexplorer.gov.in)

Table 3.2 Band Designation in Landsat 7

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

(*ETM+ band 6 is acquired at 60 m resolution, but products are resampled to 30-m pixels)

3.4 Software/Programme

1. Arc GIS 10.2
2. MS-office

3.5 Methodology

Spatial analysis will be performed to determine moisture variation in study area or basin using vegetative and soil indices. A very large percentage of imagery is severely contaminated by aerosols, clouds, and cloud shadows. Thematic Mapper images can be potentially more useful if we can remove the effects of aerosols, thin clouds and cloud shadows. The steps to be followed for computing soil moisture variation in study area are given in Fig. 3.2.

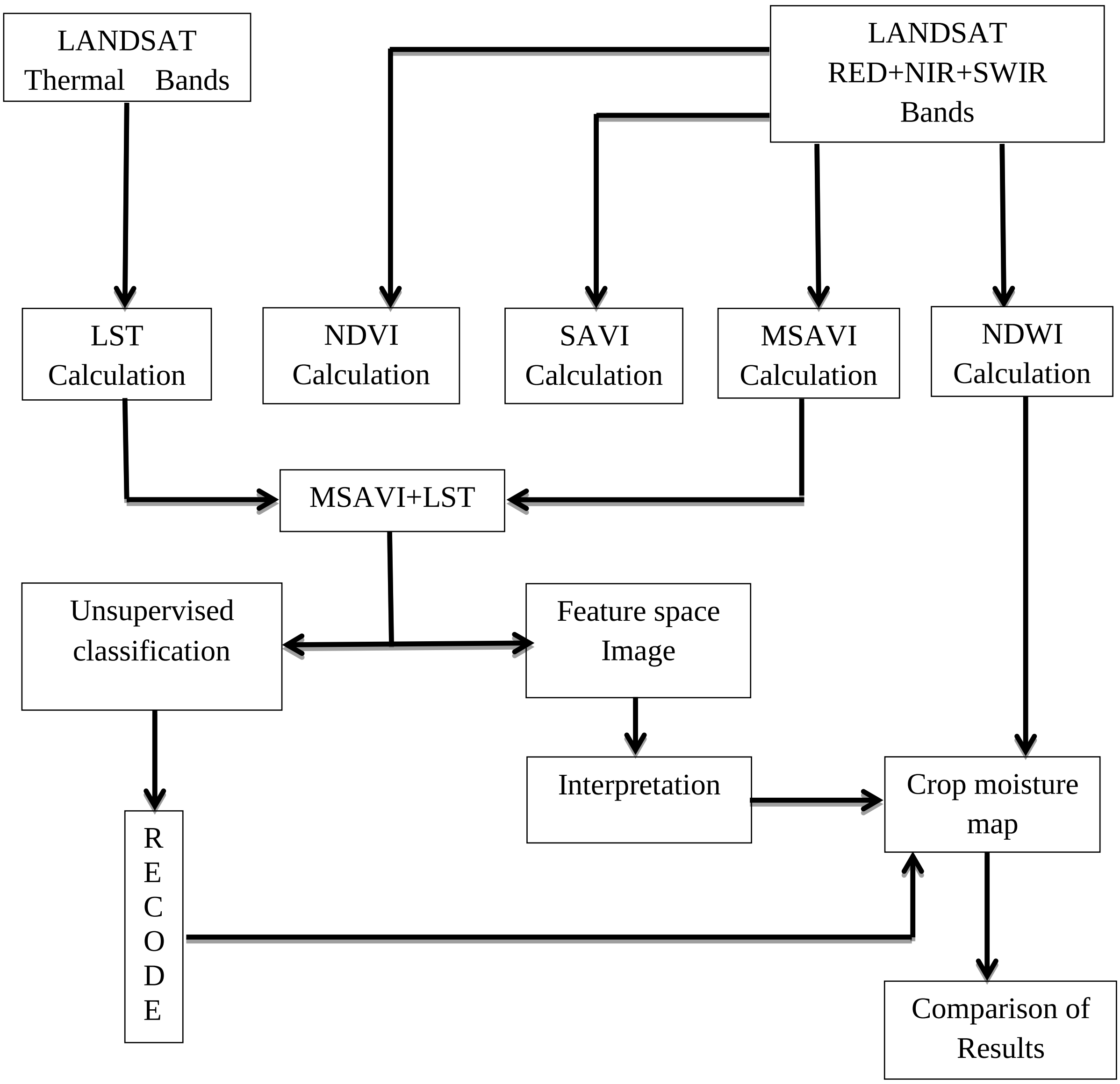


Fig. 3.2 Flow Chart for computing moisture variation

3.5.1 Calculating radiance value from satellite data

Before converting to reflectance data, one must convert the Digital Number (DN) data to radiance. This is done using the Eq. 3.1.

$$L_\lambda = (gain_\lambda * DN_7) + bias_\lambda \quad ...(3.1)$$

Where,

L_λ = Radiance, Watts / (sq. meter * µm * ster),

DN = Landsat 7 ETM+ DN data,

gain and bias = band-specific numbers.

The latest gain and bias numbers for the Landsat 7 ETM+ sensor are given in the Table 3.3. Radiance values were calculated from image by using Raster Calculator tool in ArcGIS map. The steps for calculating radiance values are given in Fig. 3.3.

Table 3.3 gain and bias number for landsat-7 image

Band Number	Gain	Bias
1	0.778740	-6.98
2	0.798819	-7.20
3	0.621654	-5.62
4	0.639764	-5.74
5	0.126220	-1.13
7	0.043898	-0.39

(Grant, 2011)

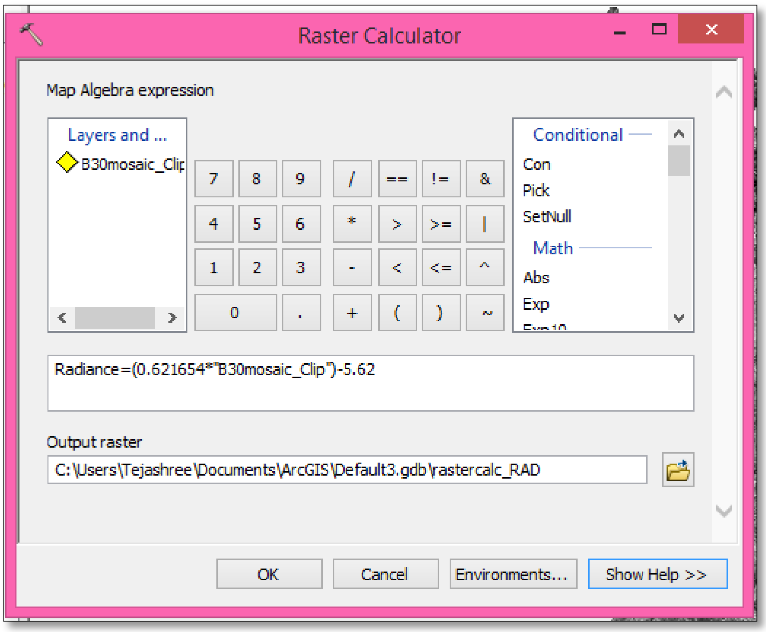


Fig. 3.3 Calculation of radiance value in ArcGIS

3.5.2 Calculating reflectance value from satellite data:

While radiance is measured by the Landsat sensors, a conversion to reflectance facilitates better comparison among different scenes. It does this by removing differences caused by the position of the sun and the differing amounts of energy output by the sun in each band. It can be calculated using the Eq. 3.2.

$$R_\lambda = \frac{\pi * L_\lambda * d_2}{E_{sun,\lambda} * \sin(\theta_{SE})} \qquad \ldots(3.2)$$

Where,

R_λ = Reflectance, unitless ratio

L_λ = Radiance, Watts / (sq. meter *µm * ster)

d_2 = earth sun distance, astronomical units

$E_{sun,\lambda}$ = band specific radiance

θ_{SE} = solar elevation angle

The Earth-Sun distance as a function of day of the year is given in Appendix. Reflectance values were calculated from image by using raster calculator tool in ArcGIS map. The steps for calculating reflectance values are given in Fig. 3.4. The band specific radiance is given in Table 3.4.

Table 3.4 Band specific radiance

Band Number	**$E_{sun,\lambda}$[Watts/(sq.meter*µm)]**
1	1997
2	1812
3	1533
4	1039
5	230.8
7	84.9

(Grant, 2011)

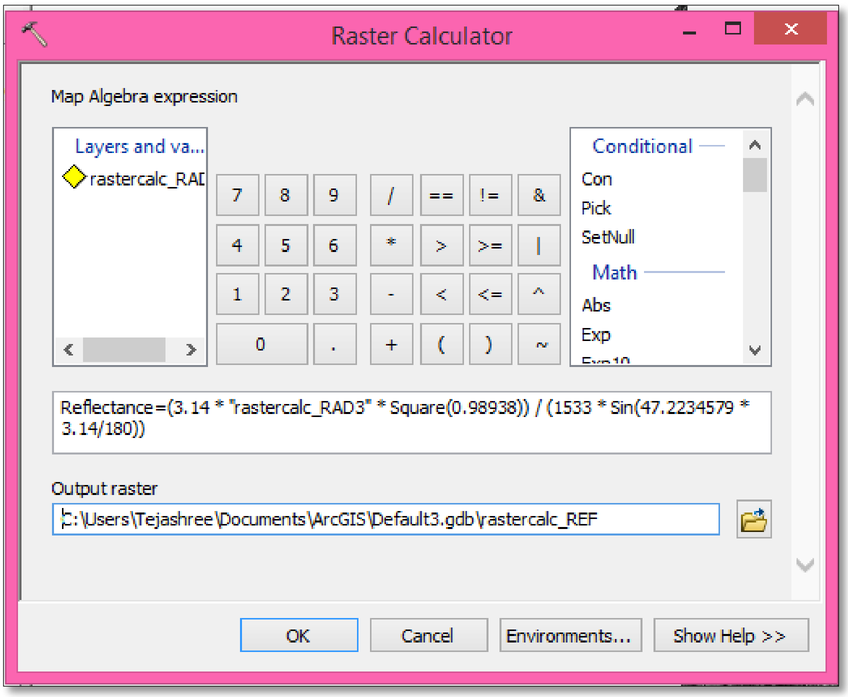


Fig. 3.4 Calculation of reflectance value in ArcGIS

3.5.3 Correcting the reflectance value

During the conversion from DN data to reflectance, it is possible to create small negative reflectance's. These values are not physical and should be set to zero. It should be noted that only very small negative numbers should be produced with this procedure. If large negative numbers are calculated, this may signify a problem with the implementation of this procedure. By using raster calculator to check for negative values and replace them with zero. It can be calculated using the Eq. 3.3.

Corrected reflectance = Con ([reflectance] < 0.0, 0.0, [reflectance]) …(3.3)

The correcting reflectance values were calculated from image by using raster calculator tool in ArcGIS map. The steps for calculating correcting reflectance values are given in Fig. 3.5.

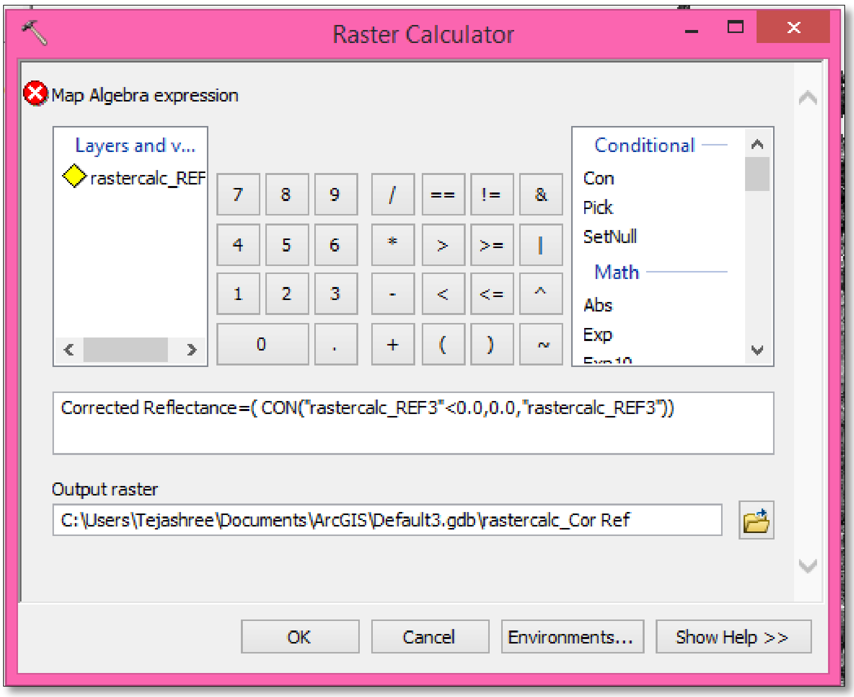


Fig. 3.5 Calculation of correcting reflectance value in ArcGIS

3.5.4 Calculating NDVI from RED and NIR bands

The Normalized Difference Vegetation Index (NDVI) is a simple graphical indicator that can be used to analyse remote sensing measurements, typically but not necessarily from a space platform, and assess whether the target being observed contains live green vegetation or not (Ferl and Carter, 2011). The Normalized Differential Vegetation Index (NDVI) is a standardized vegetation index which allows user to generate an image showing the relative biomass. The chlorophyll absorption in Red band and have relatively high reflectance of vegetation in Near Infrared band (NIR) were used for calculating NDVI. Monitoring the intensity and the density of the green vegetation growth can be done using the reflection from the red band and the infrared band. Green vegetation reflects more energy in the near-infrared band than in the visible range. It observe red band more for the photosynthesis process. Leaves reflect less in the near-infrared region when they are stressed, diseased or dead. Features like Clouds, water and snow show better reflection in the visible range than the near-infrared range, while the difference is almost zero for rock and bare soil.

Output of the NDVI method creates a single-band dataset that only shows greenery. Values close to zero represent rock and bare soil where negative values represent water, snow and clouds. Taking ratio or difference of two bands makes the vegetation growth signal differentiated from the background signal. NDVI method was developed by the NASA scientist popularly known as Normalized Difference Vegetation Index (NDVI). By taking a ratio of two bands drop the values between -1 to +1. Water has an NDVI value less than 0, bare soils between 0 and 0.1, and vegetation over 0.1. Increase in the positive NDVI value means greener the vegetation.

The NDVI is calculated from reflectance measurements in the red and near infrared (NIR) portion of the spectrum with the help of Eq. 3.4.

$$NDVI = \frac{\mathrm{NIR-RED}}{\mathrm{NIR+RED}} \qquad \ldots(3.4)$$

Where,

NDVI = Normalized Difference Vegetation Index,

NIR = Near Infrared band value for a cell,

RED = Red band value for the cell.

NDVI can be calculated for any image that has a red and a near infrared band. The biophysical interpretation of NDVI is the fraction of absorbed photo synthetically active radiation. These index vary between -1 and 1. This is estimated using following flow chart given in Fig. 3.6.

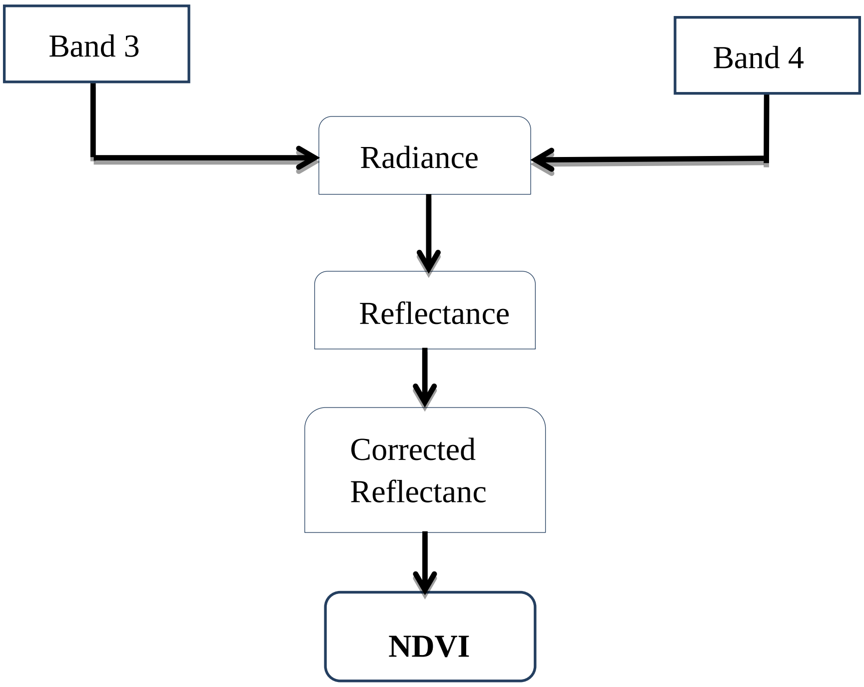


Fig. 3.6 Flow chart for calculating NDVI

The NDVI values were calculated from image by using raster calculator tool in ArcGIS map. The screen shot is given in Fig. 3.7.

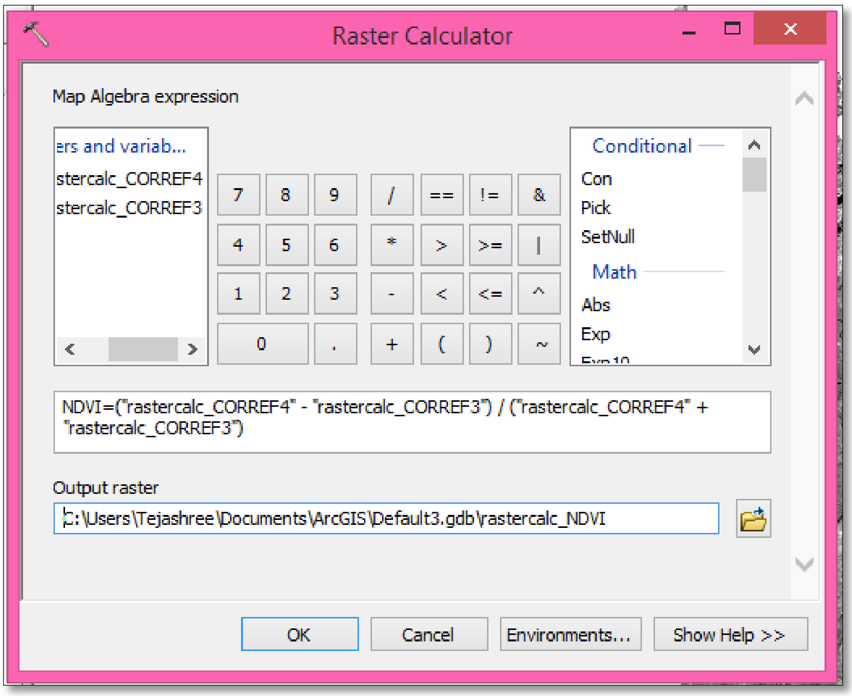


Fig. 3.7 Calculation of NDVI value in ArcGIS

3.5.5 Calculating SAVI from reflectance

Soil Adjusted Vegetation Index shows background soil conditions. SAVI is a hybrid between NDVI and PVI (Perpendicular Vegetation Index). The SAVI is calculated using Eq. 3.5.

$$SAVI = \frac{\text{NIR}-\text{RED}}{\text{NIR}+\text{RED}+\text{L}} * (1 + L) \qquad \ldots(3.5)$$

Where,

SAVI = Soil Adjusted Vegetation Index,

NIR = Near Infrared band value for a cell,

RED = Red band value for the cell,

L = constant to minimize soil brightness influences and to produce vegetation iso-lines independent of the soil background equal to 0.5.

The Soil Adjusted Vegetation Index is estimated using following flow chart given in Fig. 3.8. The SAVI values were calculated from image by using raster calculator tool in ArcGIS map. The screen shot is given in Fig. 3.9

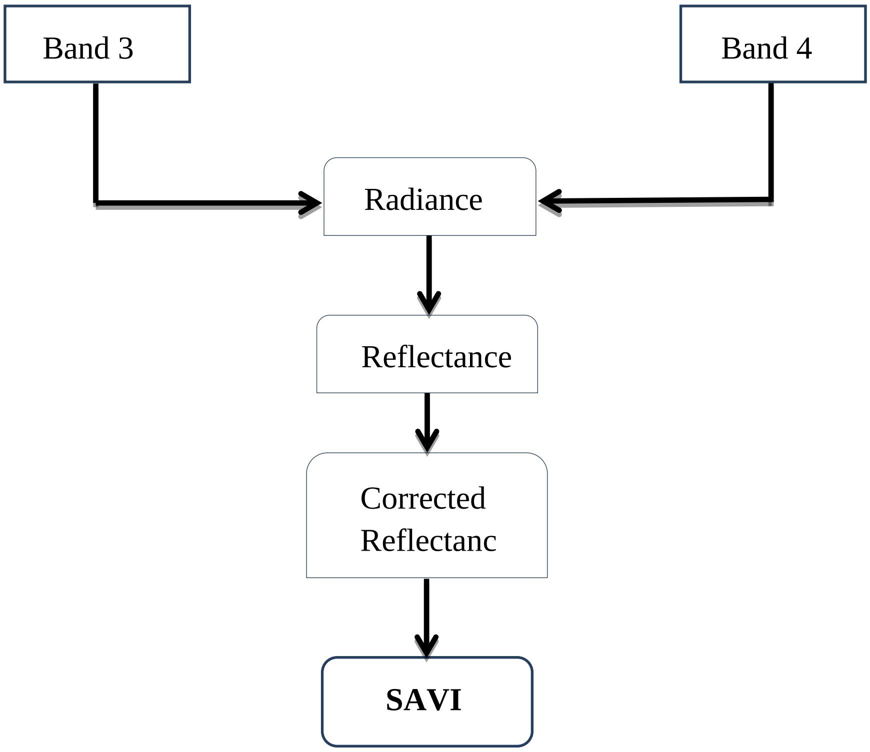


Fig. 3.8 Flow chart for calculating SAVI

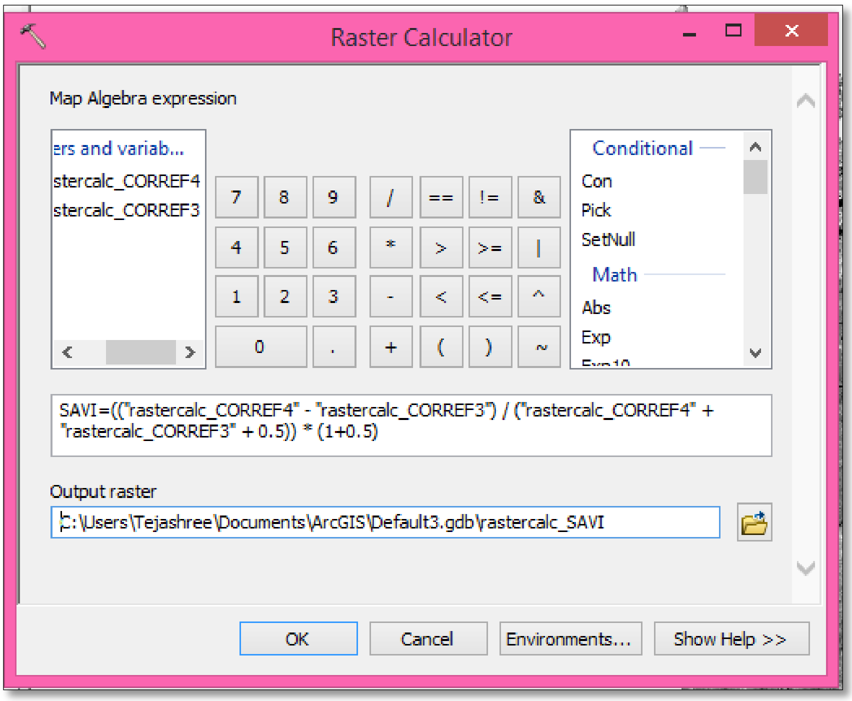


Fig. 3.9 Calculation of SAVI value in ArcGIS

3.5.6 Calculating MSAVI from reflectance

A Modified Soil Adjusted Vegetation Index (MSAVI), proposed by Qi and others (1994) was created using VNIR and RED band. The MSAVI is calculated using Eq. 3.6.

$$\mathrm{MSAVI} = \rho_n + 0.5 - \sqrt{(\rho_n + 0.5)^2 - 2(\rho_n - \rho_r)} \qquad \ldots(3.6)$$

Where,

MSAVI = Modified Soil Adjusted Vegetation Index,

ρn = Reflectance at Near Infra-Red (NIR) band,

ρr = Reflectance at Red (R) band.

The Modified Soil Adjusted Vegetation Index is estimated using following flow chart given in Fig. 3.10. The MSAVI values were calculated from image by using raster calculator tool in ArcGIS map. The screen shot is given in Fig. 3.11.

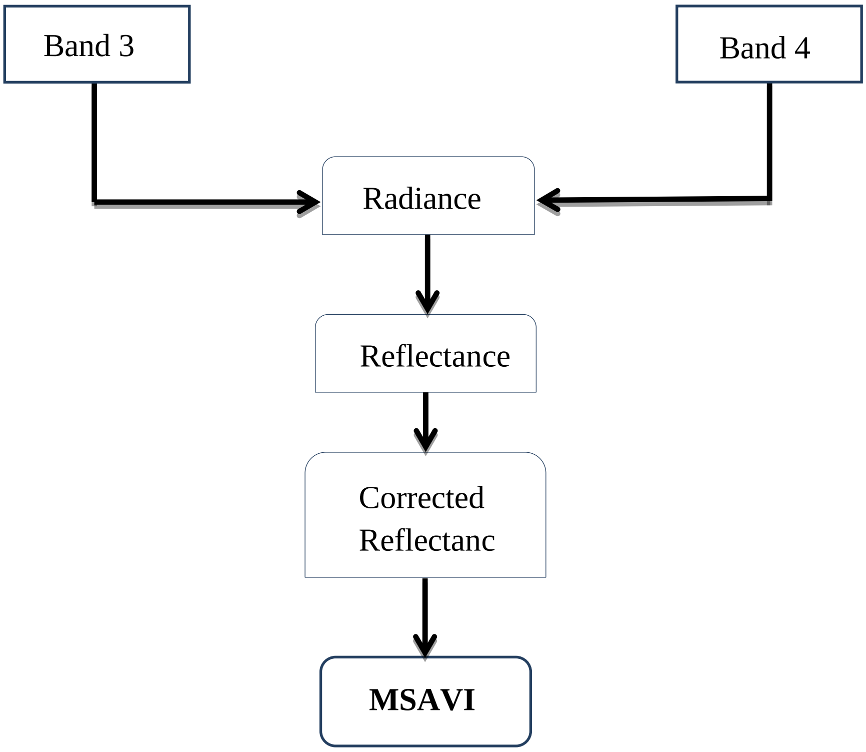


Fig. 3.10 Flow chart for calculating MSAVI

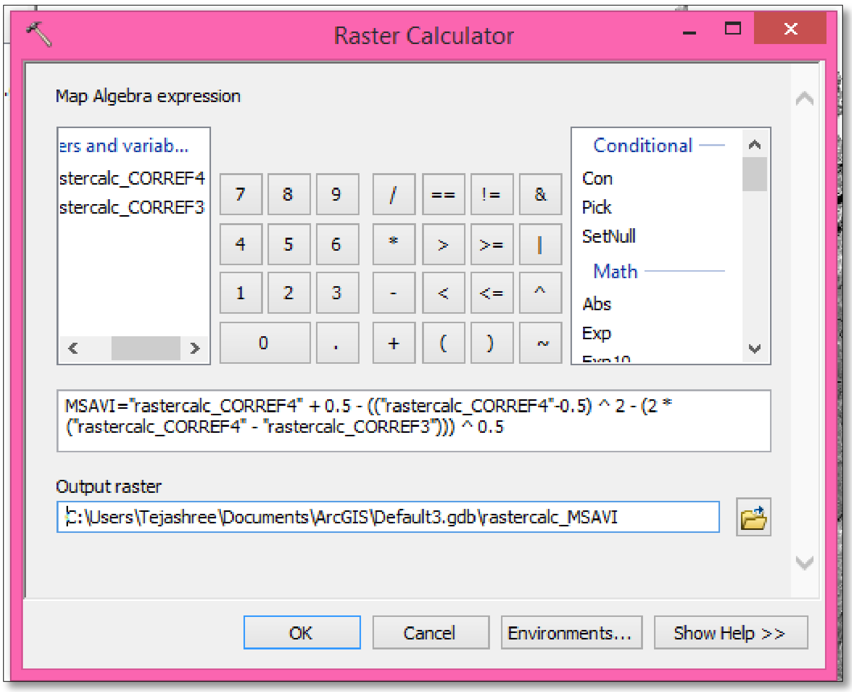


Fig. 3.11 Calculation of MSAVI value in ArcGIS

3.5.7 Calculating Moisture Variation

Soil moisture is an essential variable in climate and hydrological science through its impact on the energy and water balance. Knowledge about soil moisture and its spatio-temporal variability is helpful to identify the heterogeneity of different characteristics, such as soil texture, vegetation, topography and meteorological conditions etc. There are two approaches to calculate the moisture variation:

1) Normalized Difference Water Index (NDWI) Method
2) VI-LST Triangular Space Method

3.5.7.1 Normalized Difference Water Index

The Normalized Difference Water Index was calculated using the NIR and SWIR Landsat imagery. The NDWI is calculated using Eq. 3.7.

$$NDWI = \frac{\text{NIR}-\text{SWIR}}{\text{NIR}+\text{SWIR}} \qquad \ldots(3.7)$$

Where,

NDWI = Normalized Difference Water Index,

NIR = Near Infrared band value for a cell,

SWIR = Short Wave Infra-Red value for a cell

The Normalized Difference Water Index is estimated using following flow chart given in Fig. 3.12.

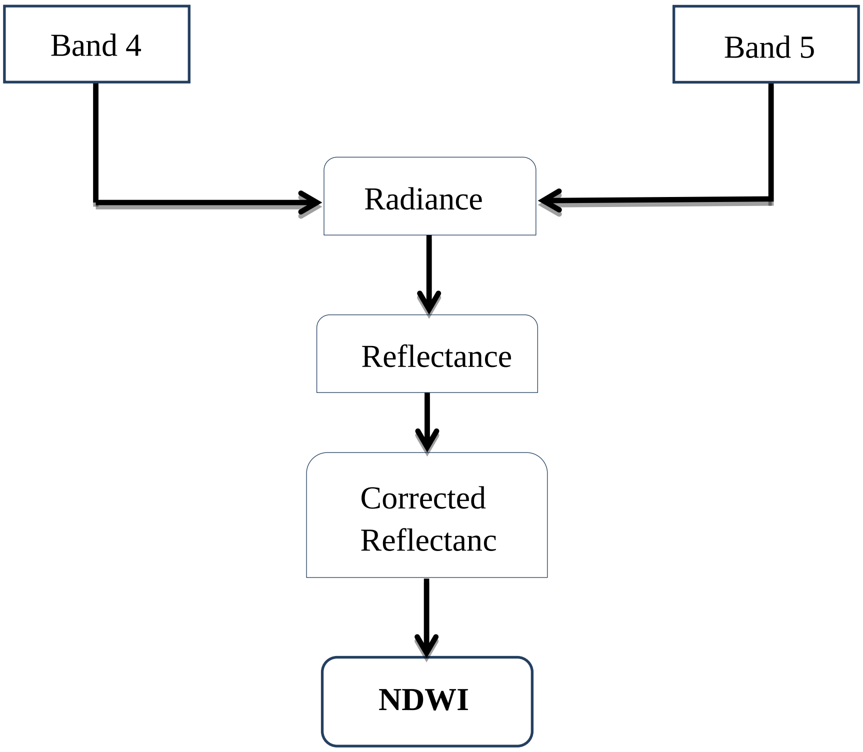


Fig. 3.12 Flow chart for calculating NDWI

The NDWI values were calculated from image by using Raster Calculator tool in ArcGIS map. The screen shot is given in Fig. 3.13.

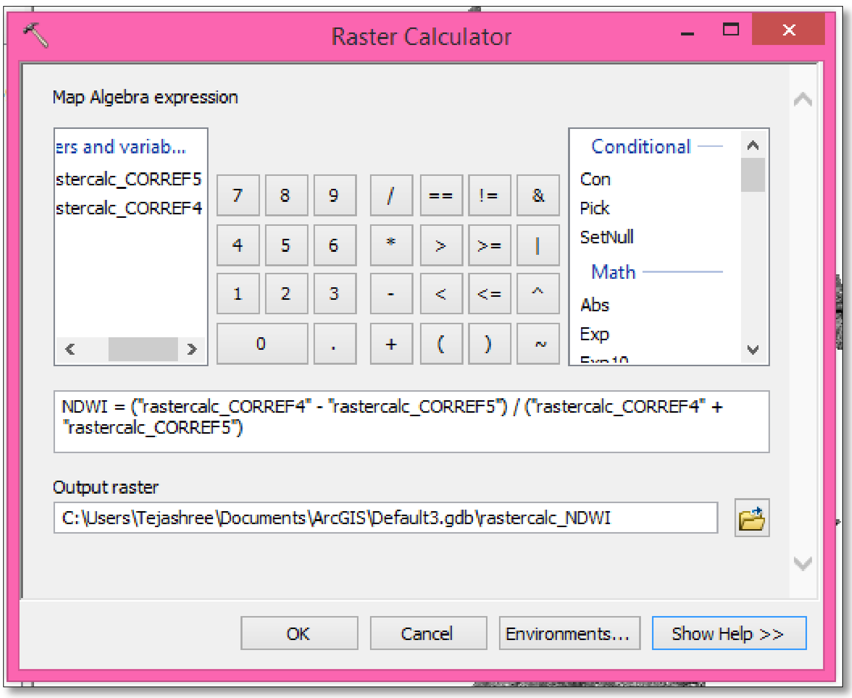


Fig. 3.13 Calculation of NDWI value in ArcGIS

3.5.7.2 VI-LST Triangular Space Method

The Vegetation Index (VI) – Land Surface Temperature (LST) Triangular Space Method was used to map the relative variation of crop moisture within a field. The MSAVI created from NIR image was used as VI and land surface temperature from TIR image was used as LST.

a) Calculating Radiance

Landsat TM and ETM+ have a single thermal band (band 6) which is the thermal infrared (TIR) channel that records radiation within a 10.4 to 12.5µm spectral range of the electromagnetic spectrum (Sundarakumar *et al.*, 2012). Different LST retrieval methods have been developed according to different data sources (thermal bands on a sensor), such as the split-window, temperature/emissivity separation, mono-window, and the single-channel methods. The radiance of thermal band of Landsat 7 image is calculated using Eq. 3.8.

$$L_\lambda = \frac{\mathrm{LMAX-LMIN}}{\mathrm{QCALMAX+QCALMIN}} * DN - 1 + L_{MIN} \qquad \ldots(3.8)$$

Where,

L_λ = Radiance of thermal band,

LMAX = the spectral radiance that is scaled to QCALMAX in W/(m^2 * sr * µm)

LMIN = the spectral radiance that is scaled to QCALMIN in W/(m^2 * sr * µm)

QCALMAX = the maximum quantized calibrated pixel value (corresponding to LMAX) in DN = 255

QCALMIN = the minimum quantized calibrated pixel value (corresponding to LMIN) in DN = 1

LMAX and LMIN are obtained from the Meta data file available with the image.

b) Calculating Brightness Temperature

The effective at-sensor brightness temperature (TB) also known as black body temperature is obtained from the spectral radiance using Plank's inverse function. The Brightness Temperature is calculated using Eq. 3.9.

$$T_B = \frac{K_2}{In\ (1+\frac{K_1}{L_\lambda})} \qquad \ldots(3.9)$$

Where,

T_B = Brightness Temperature,

L_λ = Radiance of thermal band,

K_1 and K_2 = calibration constants.

The calibration constants K_1 and K_2 obtained from Landsat data user's manual are given in the Table 3.5.

Table 3.5 Calibration constants for thermal band

Sensor	K_1	K_2
Landsat 7 / ETM+	666.09	1282.71

(Sundarakumar *et al*., 2012)

The Brightness temperature values were calculated from image by using raster calculator tool in ArcGIS map. The screen shot is given in Fig. 3.14.

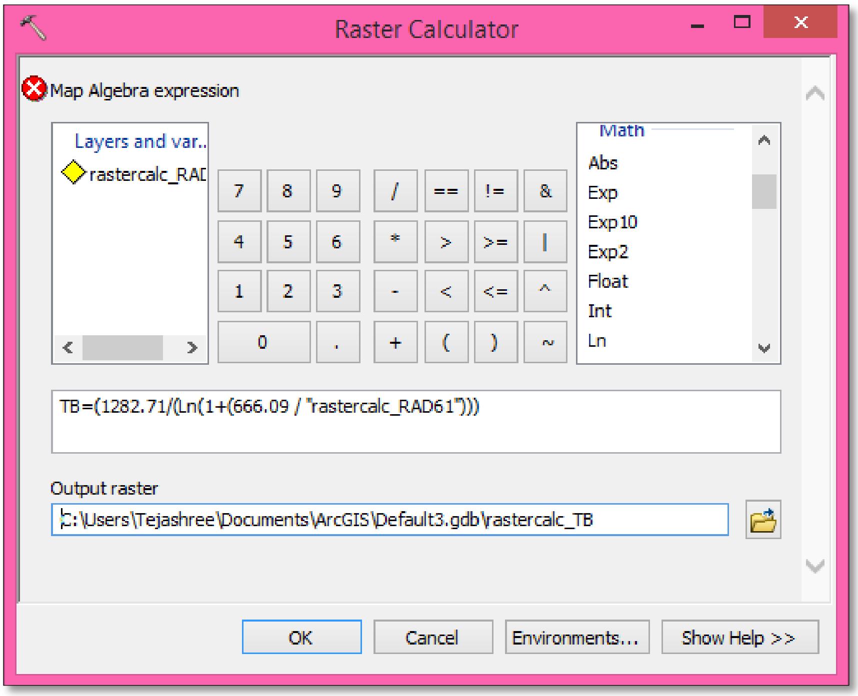


Fig. 3.14 Calculation of TB value in ArcGIS

c) Calculating Land Surface Temperature

The land surface temperature is calculated with the help of brightness temperature. The final Land Surface Temperature (LST) is estimated using Eq. 3.10.

$$LST = \frac{TB}{1+\left(\lambda+\frac{TB}{\rho}\right)*\ln\varepsilon} \qquad \ldots(3.10)$$

Where,

LST = Land Surface Temperature,

T_B = Brightness Temperature,

λ = Wavelength of the emitted radiance which is equal to 11.5μm,

ρ = h.c/σ,

σ = Stefan Boltzmann's constant which is equal to 5.67×10^{-8} Wm^{-2} K^{-4},

h = Plank's constant (6.626×10^{-34} J Sec),

c = velocity of light (2.998×10^{8} m/sec),

ε = spectral emissivity which is equal to unity.

The Land Surface Temperature values were calculated from image by using raster calculator tool in ArcGIS map. The screen shot is given in Fig. 3.15.

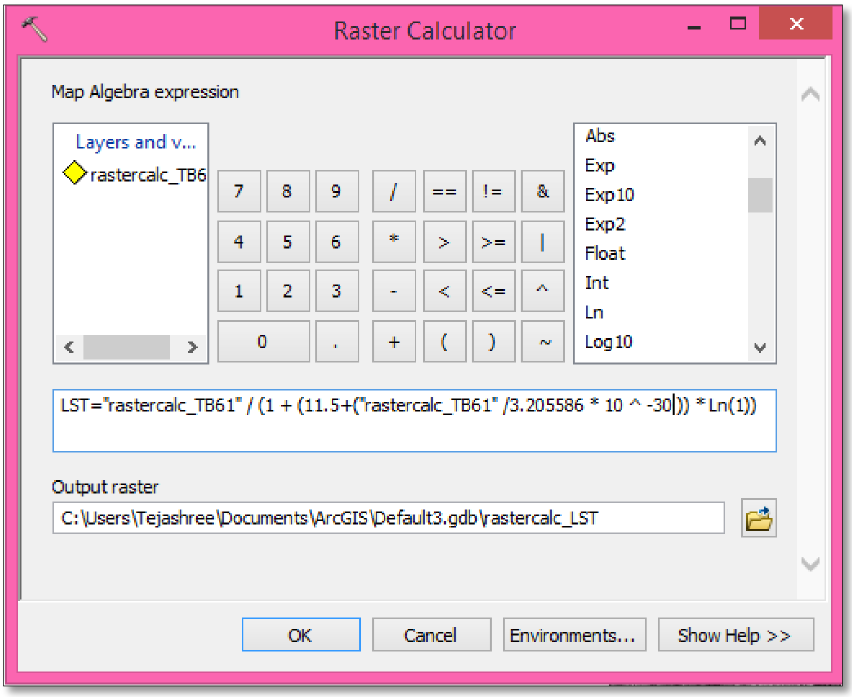


Fig. 3.15 Calculation of LST value in ArcGIS

d) Calculating Crop Moisture of Study Area

The MSAVI (RED and NIR bands) image and LST (Thermal band) image were stacked to create a two layer image that was then classified using unsupervised classification method. A feature space image was created using the two layer image. The MSAVI image layer was used along X axis and the LST image layer was used along Y axis. The feature space image was used to identify the signatures of the classified image. The initial classified images were recoded into three classes: normal moisture, low to moderate moisture, low moisture. The steps were adopted to compute soil moisture in study area is given in Fig. 3.16.

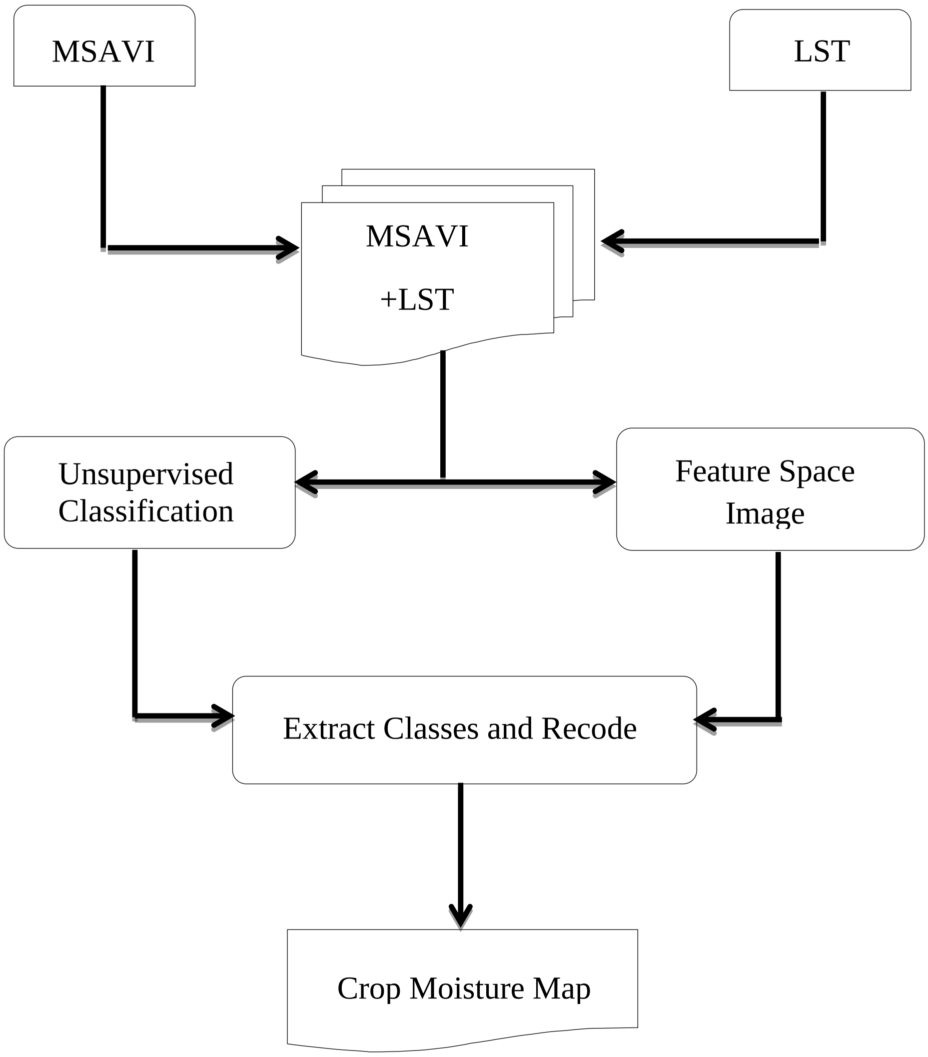


Fig. 3.16 Flow chart for calculating Crop Moisture

IV. RESULTS AND DISCUSSION

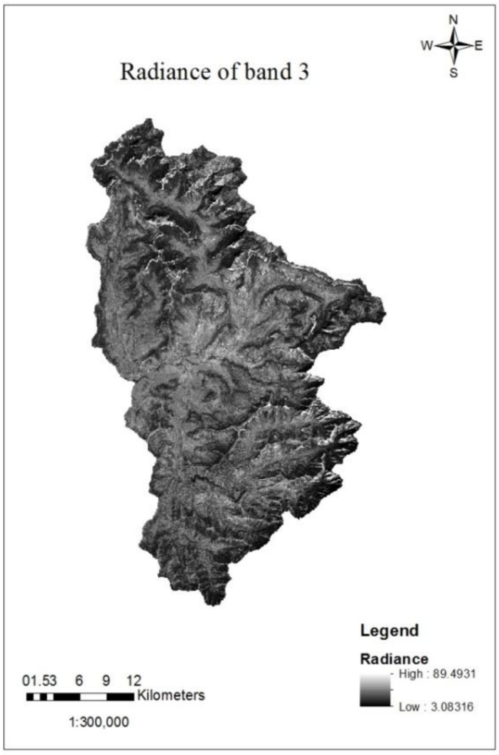
The data analysis, results and interpretation of different outcomes are discussed in this chapter. Using the Geographic Information System (GIS) all outcomes was determined. In the present study, efforts were made to determine the Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI), Modified Soil Adjusted Vegetation Index (MSAVI) and variation of moisture in basin. The data set was downloaded from Landsat data from official website of USGS (www.earthexplorer.gov.in) for Landasat7 images of year 1999, 2000, 2002 and 2003. It was desired to collect the data set of recent year i.e. 2014 onwards, but this data was not available. Due to this, 1999, 2000, 2002 and 2003 year data set was analysed for computation of moisture variation in study area.

4.1 Radiance

Radiance of remote sensing imagery for year 1999, 2000, 2002 and 2003 of Landsat7 was calculated using Eq. 3.1 in ArcGIS environment. The radiance value is measured in sq. meter * μm * ster. These values of radiance are needed to compute the reflectance from the object at various bands and resolution. The radiance is computed for study area is given in Fig. 4.1(a-c), Fig. 4.2 (a-c), Fig. 4.3 (a-c) and Fig. 4.4 (a-c) for the year 1999, 2000, 2002 and 2003 respectively. It is observed that, the radiance values varied from 1.00 to 121.57, 0.88 to 152.90, 0.38 to 121.27 and 0.51 to 72.31 for the year 1999, 2000, 2002 and 2003, respectively for study area.

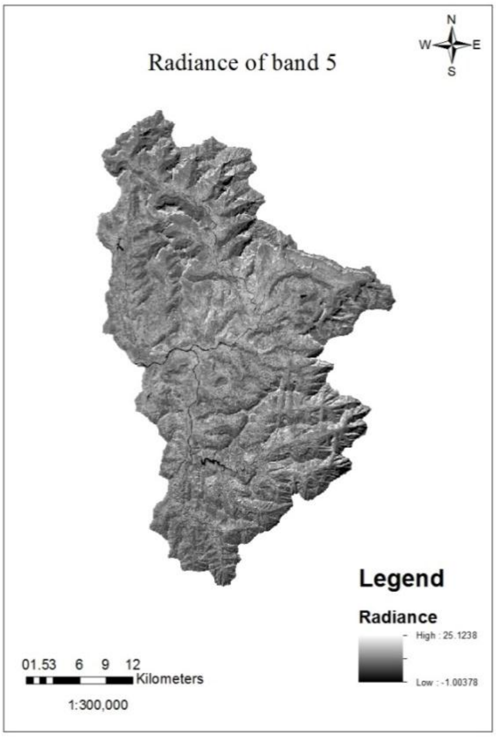
4.2 Reflectance

Reflectance of remote sensing imagery for year 1999, 2000, 2002 and 2003 of Landsat7 was calculated using Eq. 3.2 in Arc GIS environment. The reflectance was dimensionless quantity. These values of reflectance are used to compute the different vegetation indices i.e. Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI) and Modified Soil Adjusted Vegetation Index (MSAVI). The reflectance is computed for study area is given in Fig. 4.4 (a-c), Fig. 4.6 (a-c), Fig. 4.7 (a-c) and Fig. 4.8 (a-c) for the year 1999, 2000, 2002 and 2003 respectively. It is observed that, the reflectance values varied from -0.018 to 0.46, 0.014 to 0.51, 0.006 to 0.52 and 0.020 to 1.15 for the year 1999, 2000, 2002 and 2003, respectively.



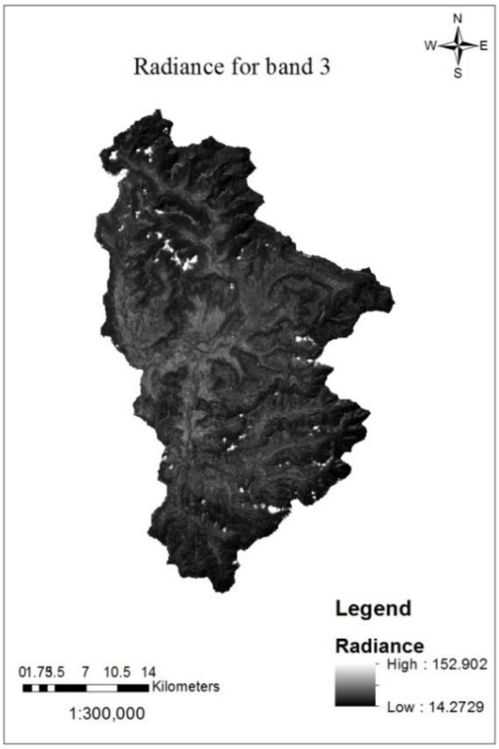
4.1 (a) Radiance of band 3 (RED)

4.1 (b) Radiance of band 4 (NIR)



4.1 (c) Radiance of band 5 (SWIR)

Fig. 4.1 (a-c) Radiance of year 1999 for different bands



4.2 (a) Radiance of band 3 (RED)

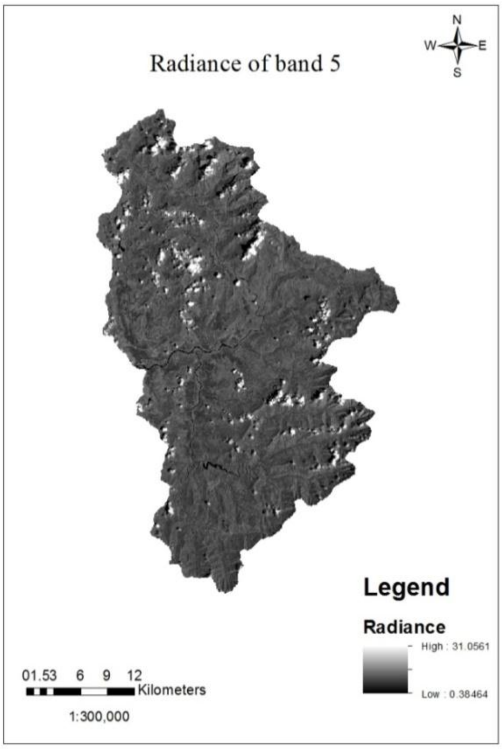
4.2 (b) Radiance of band 4 (NIR)

4.2 (c) Radiance of band 5 (SWIR)

Fig. 4.2 (a-c) Radiance of year 2000 for different bands

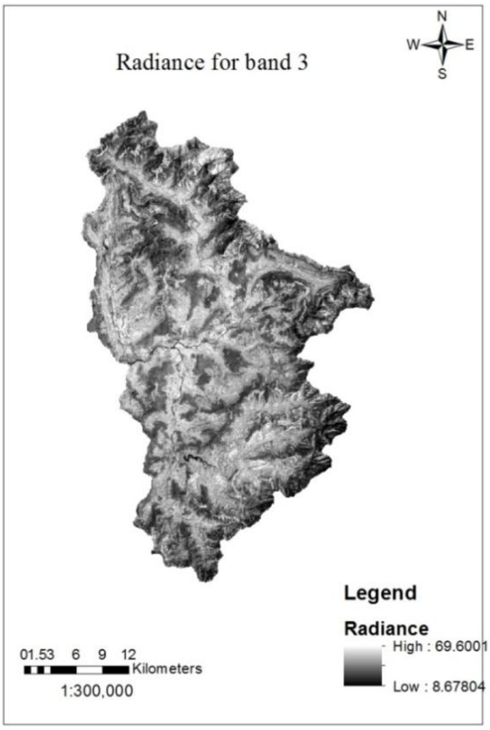
4.3 (a) Radiance of band 3 (RED)

4.3 (b) Radiance of band 4 (NIR)

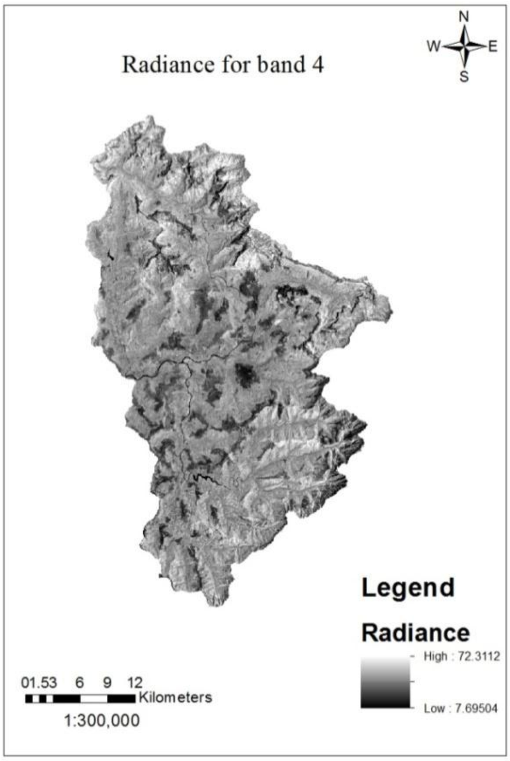


4.3 (c) Radiance of band 5 (SWIR)

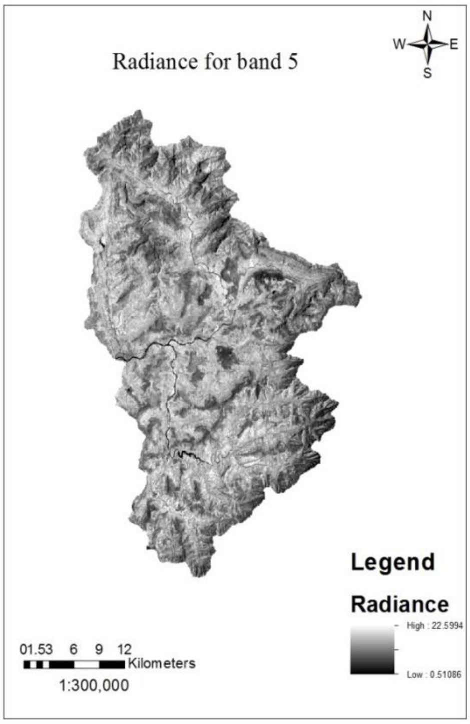
Fig. 4.3 (a-c) Radiance of year 2002 for different bands



4.4 (a) Radiance of band 3 (RED)



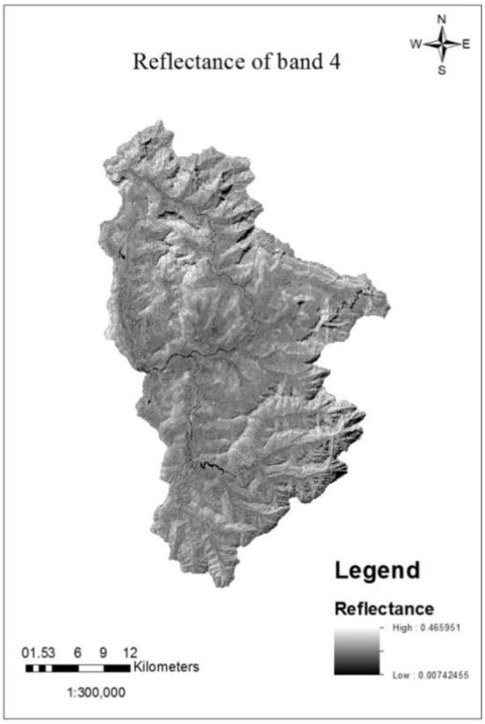
4.4 (b) Radiance of band 4 (NIR)



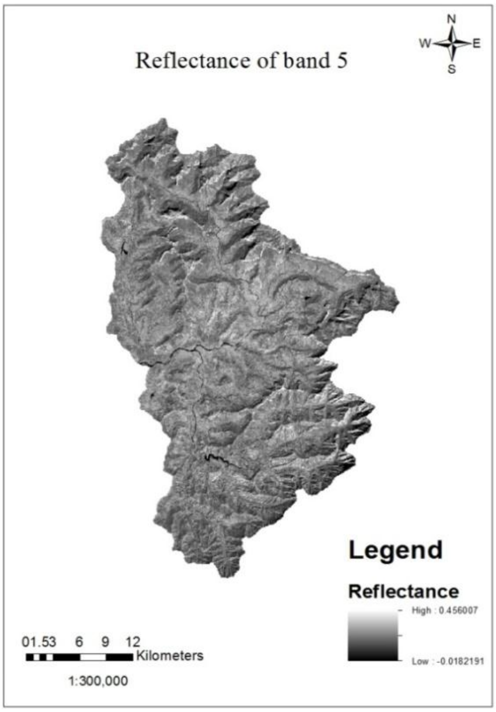
4.4 (c) Radiance of band 5 (SWIR)

Fig. 4.4 (a-c) Radiance of year 2003 for different bands

4.5 (a) Reflectance of band 3 (RED)

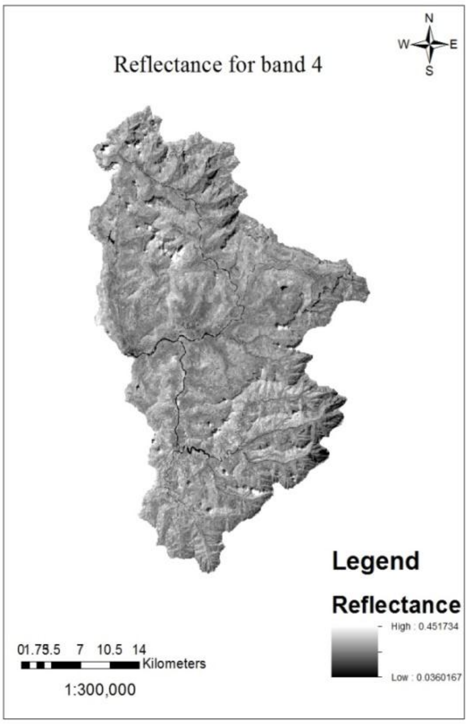


4.5 (b) Reflectance of band 4 (NIR)



4.5 (c) Reflectance of band 5 (SWIR)

Fig. 4.5 (a-c) Reflectance of year 1999 for different bands

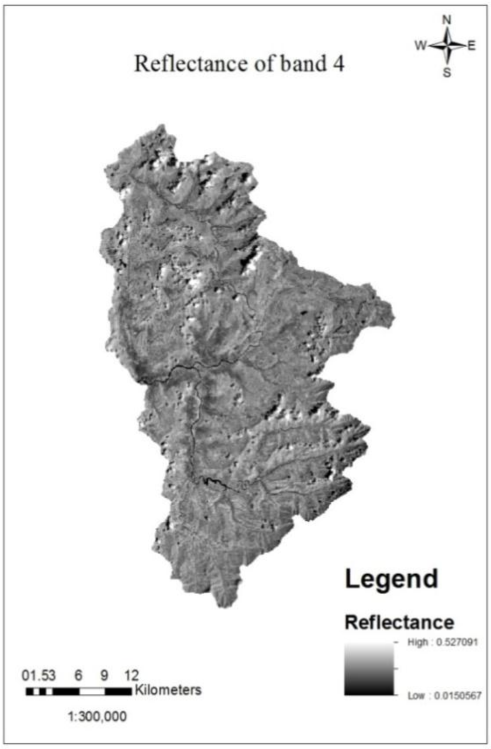


4.6 (a) Reflectance of band 3 (RED)

4.6 (b) Reflectance of band 4 (NIR)

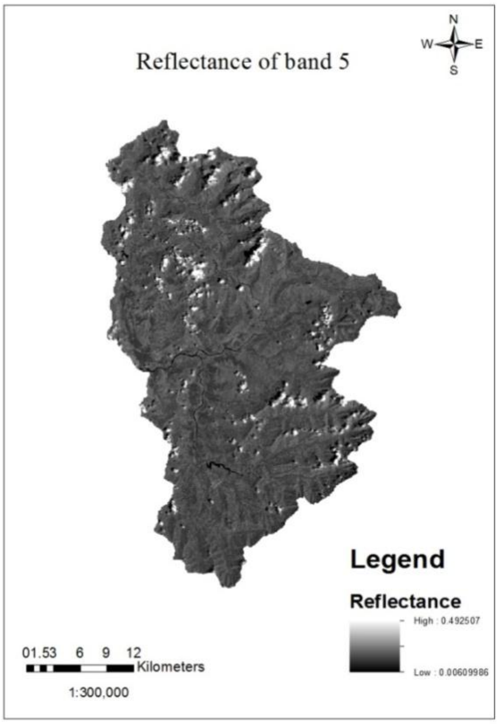
4.6 (c) Reflectance of band 5 (SWIR)

Fig. 4.6 (a-c) Reflectance of year 2000 for different bands



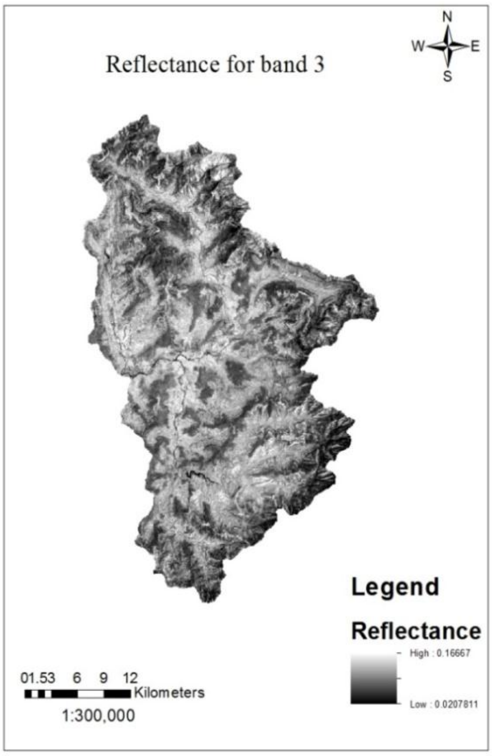
4.7 (a) Reflectance of band 3 (RED)

4.7 (b) Reflectance of band 4 (NIR)

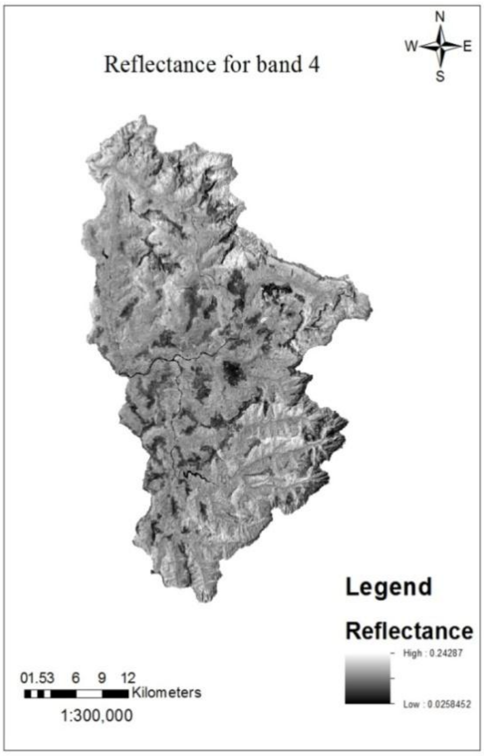


4.7 (c) Reflectance of band 5 (SWIR)

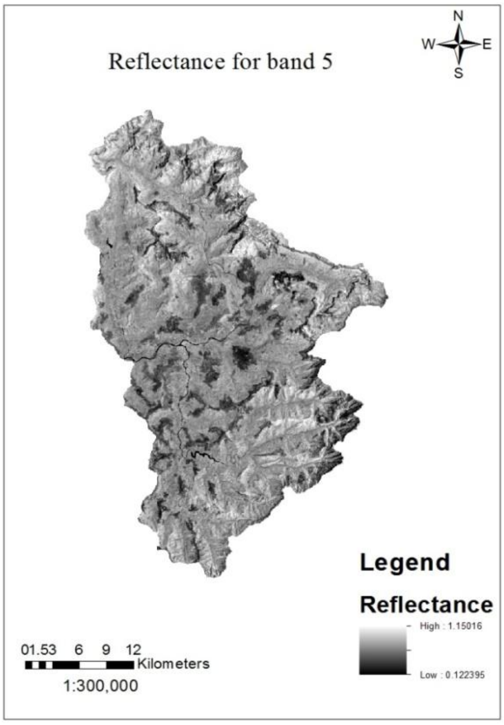
Fig. 4.7 (a-c) Reflectance of year 2002 for different bands



4.8 (a) Reflectance of band 3 (RED)



4.8 (b) Reflectance of band 4 (NIR)



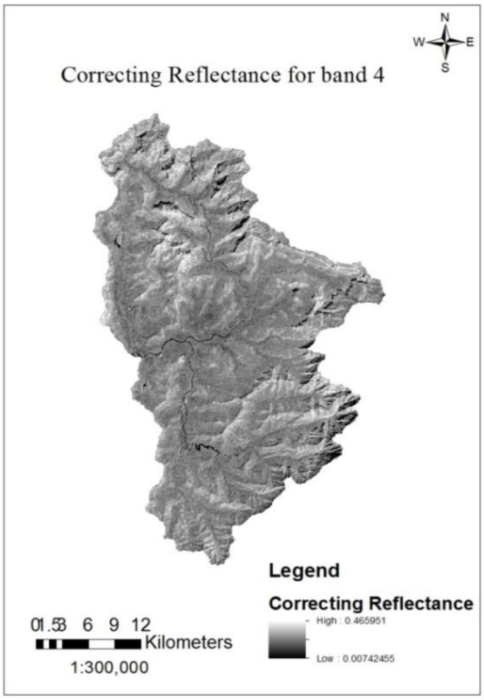
4.8 (c) Reflectance of band 5 (SWIR)

Fig. 4.8 (a-c) Reflectance of year 2003 for different bands

4.3 Correcting Reflectance

To compute the NDVI, SAVI and MSAVI, it is necessary to have the reflectance value should more than zero for accurate estimation. Therefore, it is necessary to correct the image reflectance by replacing zero value to correcting reflectance. The correcting reflectance of remote sensing imagery of Landsat7 was calculated using Eq. 3.3 in ArcGIS environment. The Eq. 3.3 is conditional probability calculated in ArcGIS software and placed zero value to correcting reflectance. The correcting reflectance is computed for study area is given in Fig. 4.9 (a-c), Fig. 4.10 (a-c), Fig. 4.11 (a-c) and Fig. 4.12 (a-c) for the year 1999, 2000, 2002 and 2003 respectively. It is observed that, the correcting reflectance values varied from 0 to 0.46, 0.014 to 0.51, 0.015 to 0.52 and 0.020 to 1.15 for the year 1999, 2000, 2002 and 2003, respectively.

4.9 (a) Correcting reflectance of band 3 (RED)

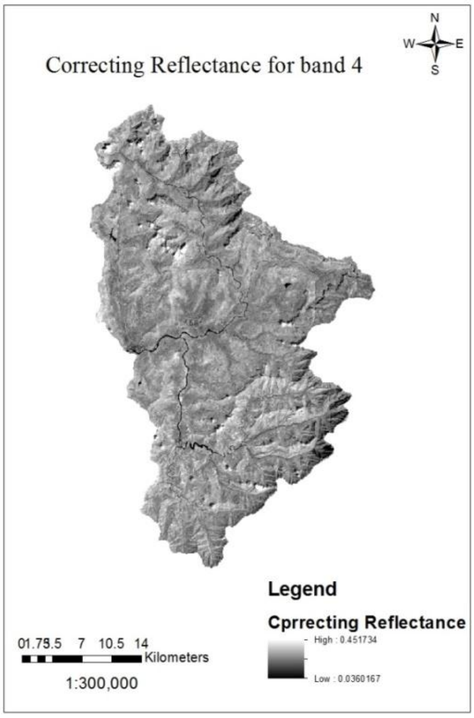


4.9 (b) Correcting reflectance of band 4 (NIR)

4.9 (c) Correcting reflectance of band 5 (SWIR)

Fig. 4.9 (a-c) Correcting reflectance of year 1999 for different bands

4.10 (a) Correcting reflectance of band 3 (RED)

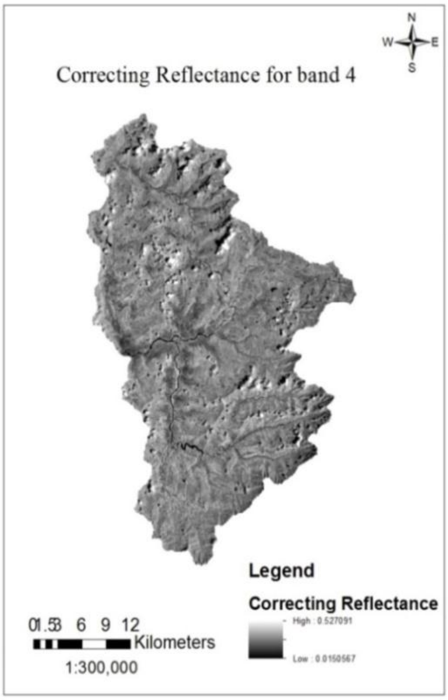


4.10 (b) Correcting reflectance of band 4 (NIR)

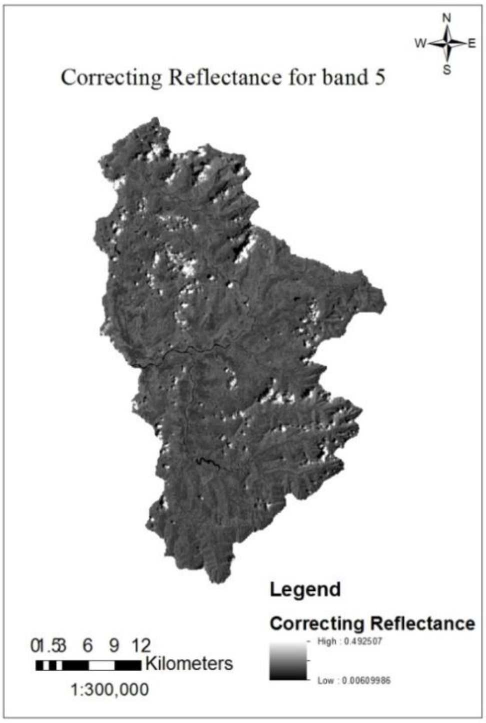
4.10 (c) Correcting reflectance of band 5 (SWIR)

Fig. 4.9 (a-c) Correcting reflectance of year 2000 for different bands

4.11 (a) Correcting reflectance of band 3 (RED)

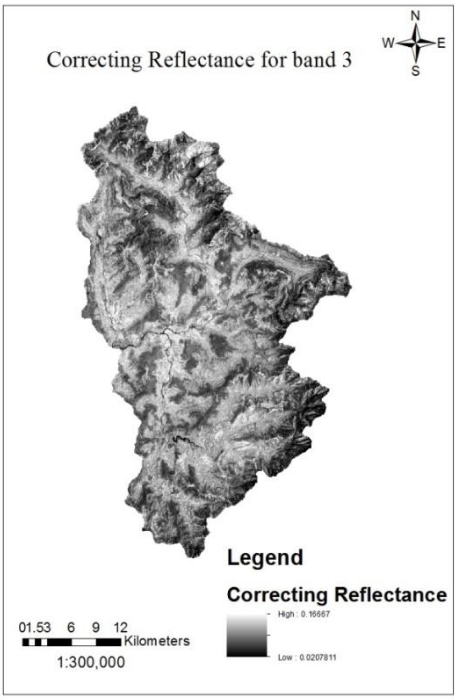


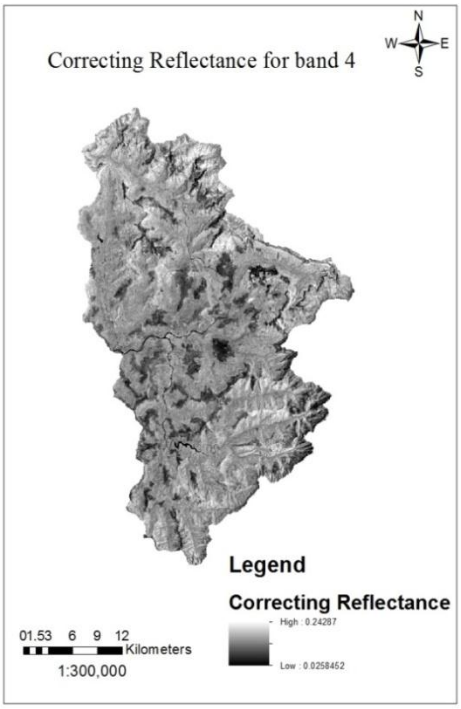
4.11 (b) Correcting reflectance of band 4 (NIR)



4.11 (c) Correcting reflectance of band 5 (SWIR)

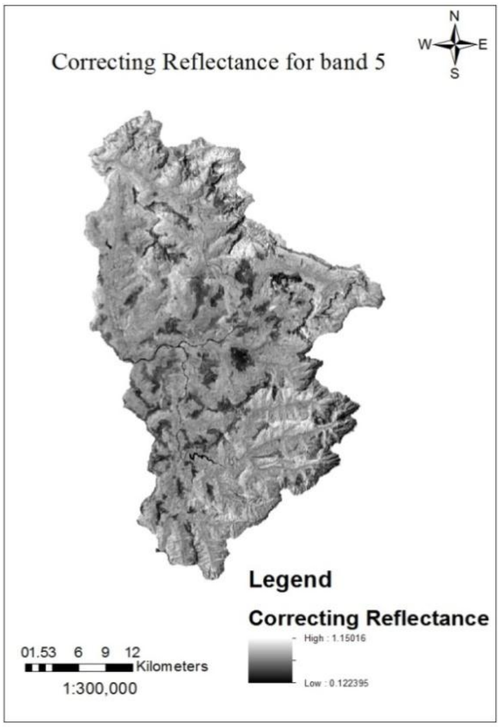
Fig 4.11 (a-c) Correcting reflectance of year 2002 for different bands





4.12 (a) Correcting reflectance of band 3 (RED)

4.12 (b) Correcting reflectance of band 4 (NIR)



4.12 (c) Correcting reflectance of band 5 (SWIR)

Fig. 4.12 (a-c) Correcting reflectance of year 2003 for different bands

4.4 Normalized Difference Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI) has been used widely to examine the relation between spectral vegetation variability and the changes in vegetation growth rate. It is also useful to determine the production of green vegetation as well as to detect vegetation changes. These indices values are vary between -1 and 1. Higher values of NDVI indicate the good and healthier vegetation. The lower values are found on the less vegetated soils and presumably because reflection from the soil is high, and produce low values in near infra-red band and high values in red band; hence the NDVI values are low. In the present study, NDVI's were determined as per discussed in section 3.5.4 in ArcGIS environment. The NDVI computed for study area is given in Fig. 4.13, Fig. 4.14, Fig. 4.15 and Fig. 4.16 for the year 1999, 2000, 2002 and 2003, respectively. It is observed that, the NDVI value of study area varied from -0.71 to 0.83, -0.35 to 0.63, -0.50 to 0.74 and -0.16 to 0.76 for the year 1999, 2000, 2002 and 2003 respectively. The highest value of NDVI i.e. 0.83 was obtained in year 1999. For year 2002 and 2003 the values of NDVI was almost same. The lowest value (-0.16) of NDVI was obtained in year 2003.

The 50 per cent area comes under the NDVI value 0.59 to 0.83 and 10 per cent area comes under NDVI value -0.71 to 0.32 for year 1999. The 35 per cent area comes under NDVI 0.42 to 0.63 and 15 per cent area comes under NDVI value -0.35 to 0.17 for year 2000. The 31 per cent area comes under NDVI value 0.54 to 0.74 and 12 per cent area comes under NDVI value -0.50 to 0.17 for year 2002. The 10 per cent area comes under NDVI value 0.41 to 0.78 and 60 per cent area comes under NDVI value -0.16 to 0.17 for year 2003.

The average NDVI for study period is ranges between -0.43 to 0.74 for the study period 1999-2003. Hence, for study period i.e. 1999 to 2003 (four years period) lowest NDVI is -0.43 and highest NDVI is 0.74. It indicates that, Savitri river basin has good vegetation cover throughout the year's period. There may more moisture stress found even in the month of March.

During the year 1999-2003, there is variations occurred in NDVI values. From year 1999 to 2003, the NDVI values were not reaches to 1. Therefore, it is concluded that, the vegetation is not increased during the year 1999 to 2003. The data of 1999, 2000 and 2002 was in month of September, October and November i. e. just after the monsoon. So the climatic conditions were approximately similar. Data of year 2003 was in month of March i.e. there is moisture stress in this month. Therefore, there is no correlation between data of year 2003 and others.

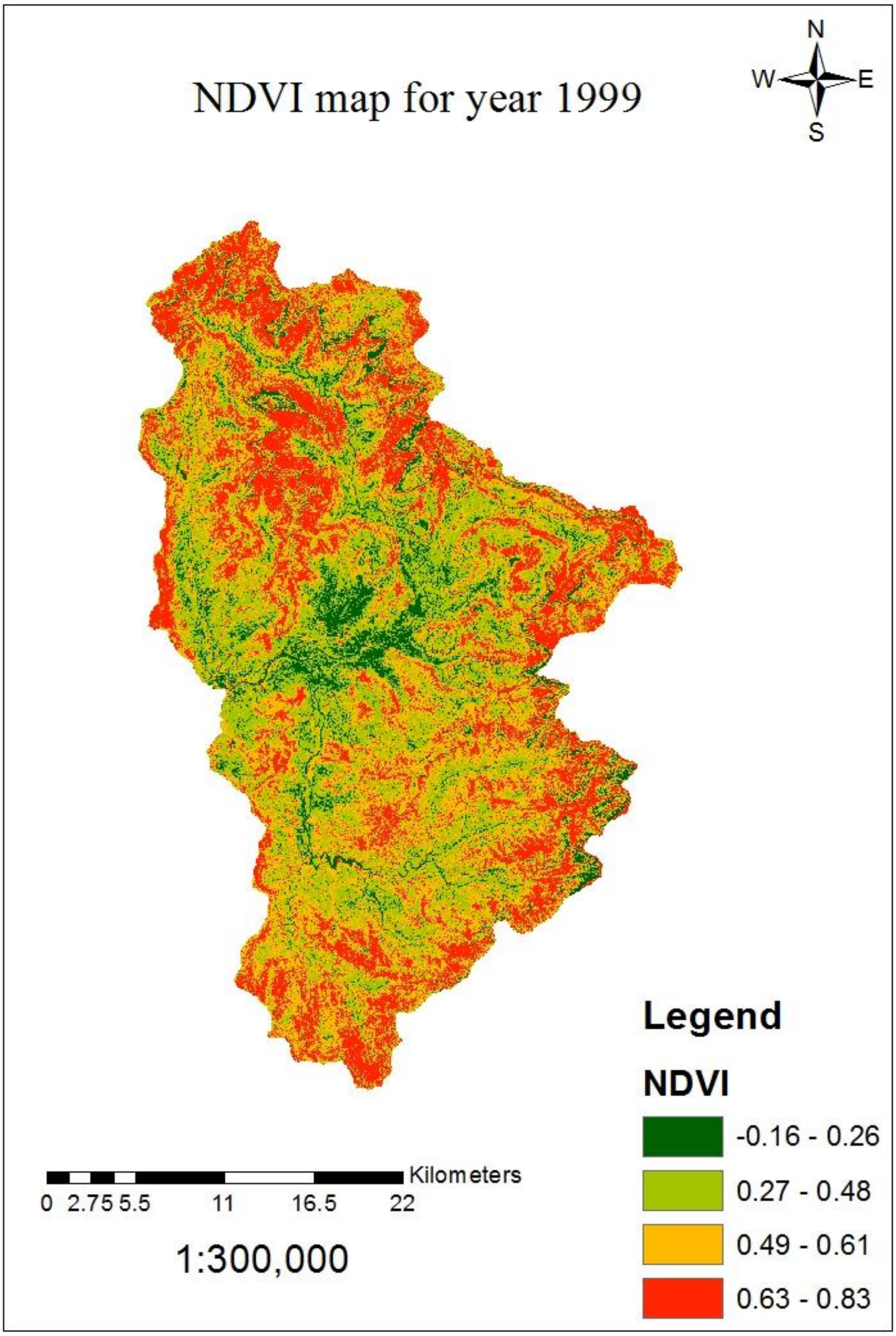


Fig. 4.13 Computed NDVI for year 1999

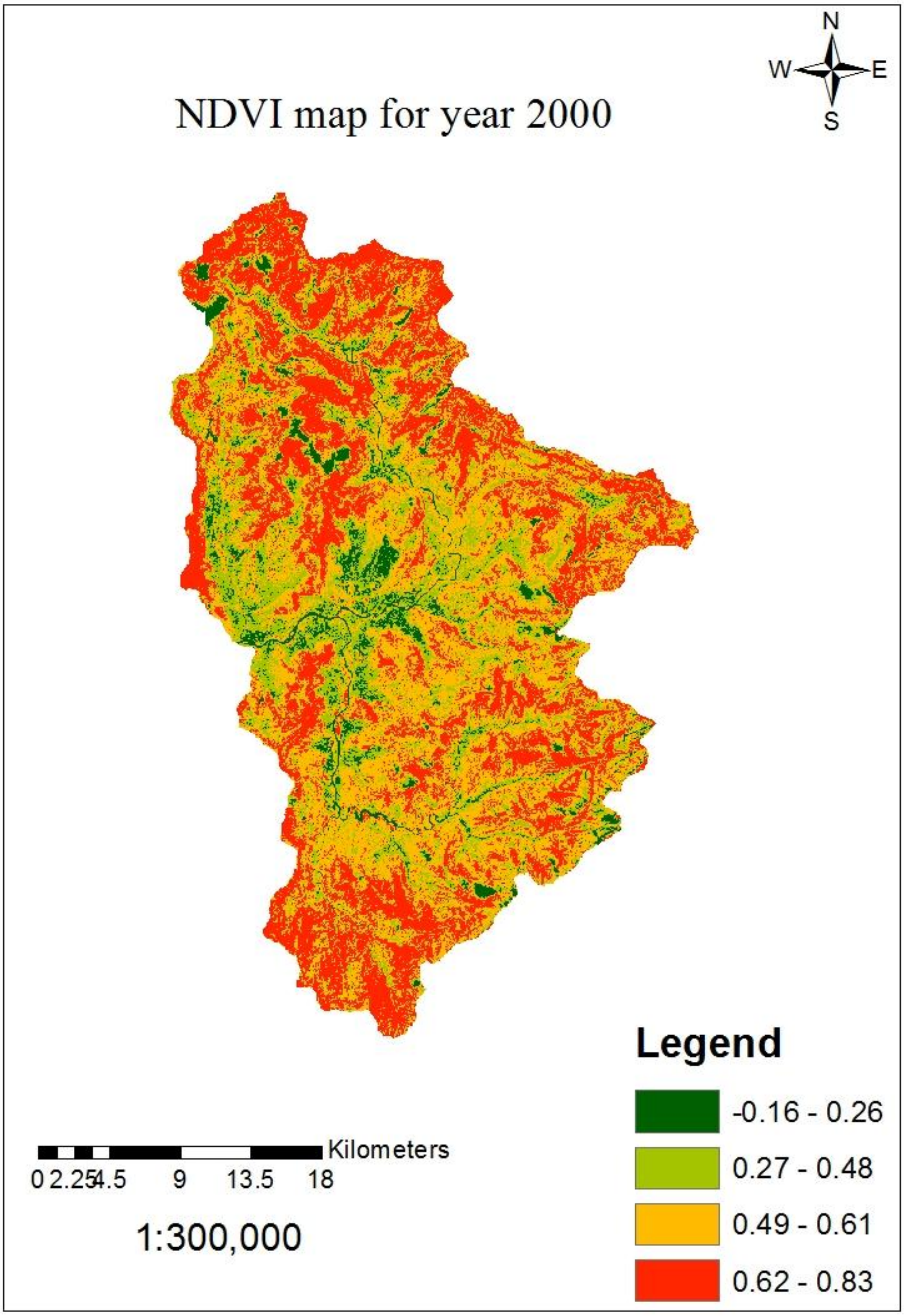


Fig. 4.14 Computed NDVI for year 2000

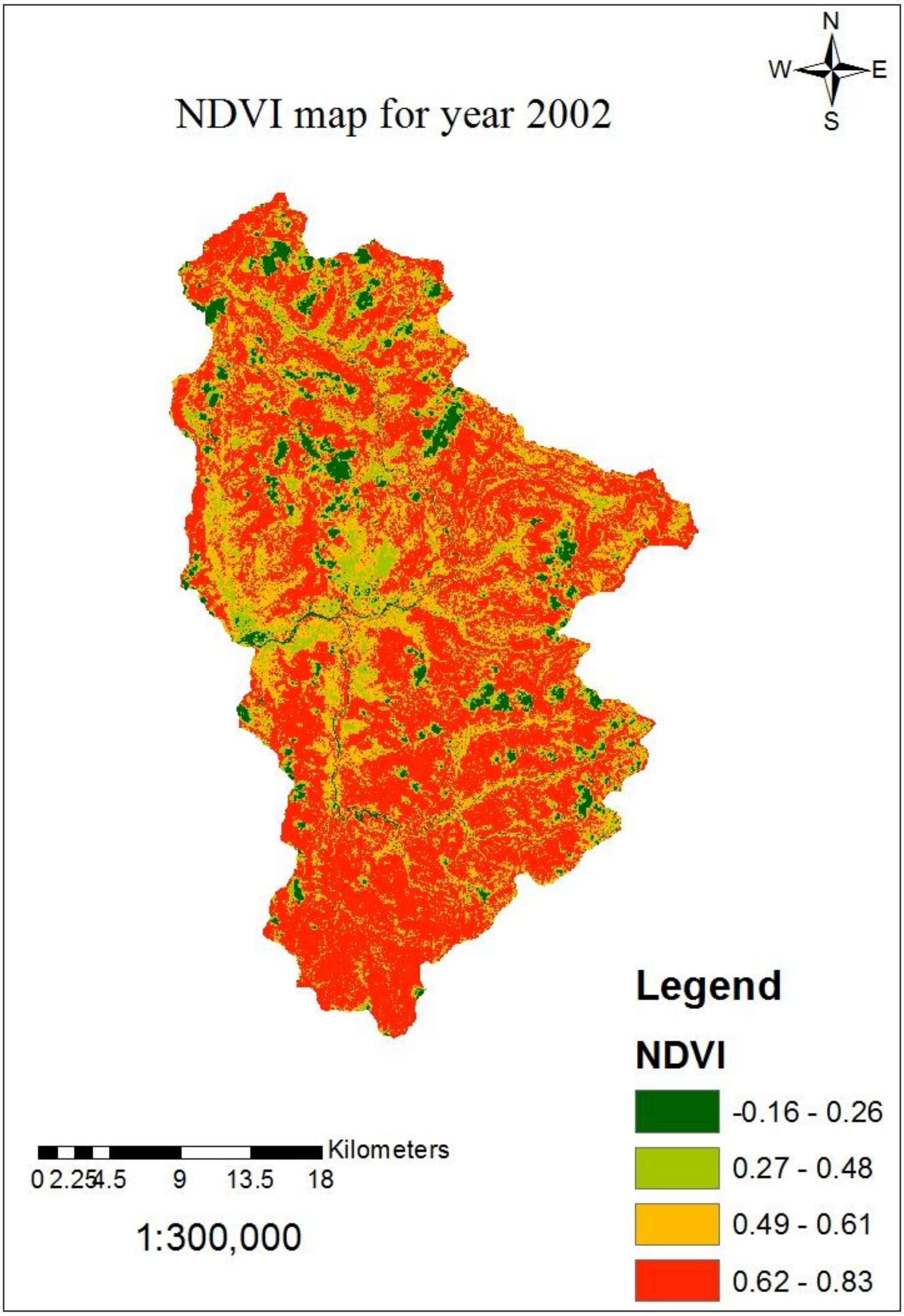


Fig. 4.15 Computed NDVI for year 2002

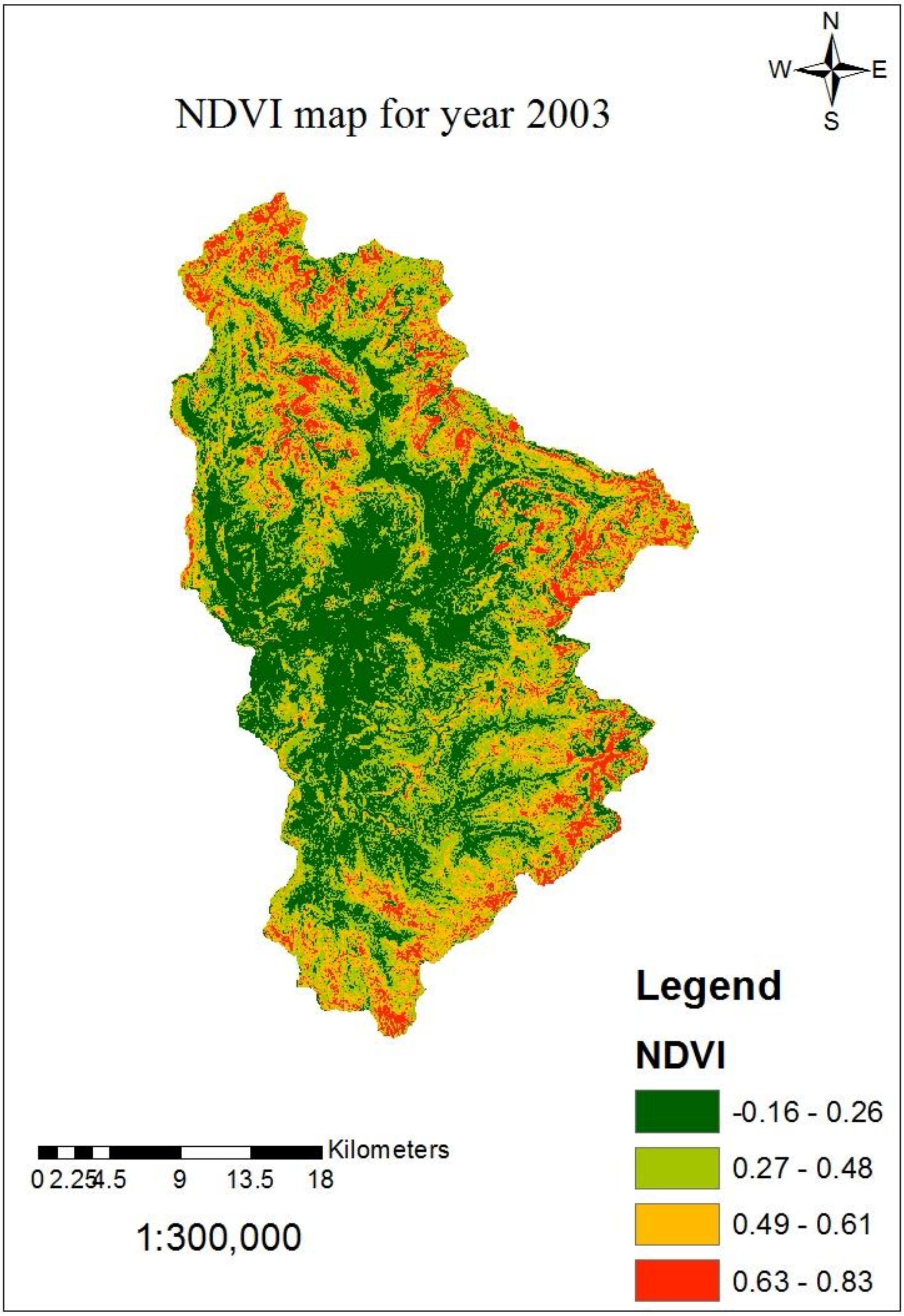


Fig. 4.16 Computed NDVI for year 2003

4.5 Soil Adjusted Vegetation Index (SAVI)

The Soil Adjusted Vegetation Index (SAVI) calculated using correcting reflectance values of band 3 (RED) and 4 (NIR) and soil brightness constant which is equal to 0.5 which shows background soil conditions. SAVI is a hybrid index between NDVI and PVI (Perpendicular Vegetation Index). The variable soil brightness constant (L) function improves vegetation sensitivity, particularly in high vegetation densities. These indices are varied between -1 and 1. The SAVI is a good indicator of vegetation response to short-term weather conditions. In the present study, SAVI's were determined as per discussed in section 3.5.5 in ArcGIS environment. The SAVI computed for study area is given in Fig. 4.17, Fig. 4.18, Fig. 4.19 and Fig. 4.20 for the year 1999, 2000, 2002 and 2003 respectively. It is observed that, the SAVI value of study area varied from -0.10 to 0.60, -0.12 to 0.36, -0.15 to 0.50 and -0.34 to 0.40 for the year 1999, 2000, 2002 and 2003, respectively. The highest value of SAVI i.e. 0.60 was obtained in year 1999. The high value of SAVI indicates good and healthier vegetation and low value indicates vegetation is scare. The results of the years 2002 and 2003 were almost same. The value near or equal to 1 is good vegetation and SAVI value near or equal to -1 is vegetation is not there i.e. it is barren land.

The 50 per cent area comes under SAVI value 0.37 to 0.60 and 12 per cent area comes under SAVI value -0.10 to 0.18 for year 1999. The 60 per cent area comes under SAVI value 00.22 to 0.36 and 15 per cent area comes under SAVI value -0.12 to 0.08 for year 2000. The 65 per cent area comes under SAVI value 0.30 to 0.50 and 10 per cent area comes under SAVI value -0.15 to 0.09 for year 2002. The 7 per cent area comes under SAVI value 0.19 to 0.40 and 60 per cent area comes under SAVI value -0.03 to 0.07 for year 2003. For year 1999, 2000 and 2002 the area more than 75 per cent of Savitri basin is having high SAVI value whereas for year 2003, most i.e 80 per cent area shows low SAVI values. It is due to years 2003 image is of March month have seviour moisture stress comparatively to years 1999, 2000, and 2002 are the images of September, October and November months, respectively. The variation of SAVI is also have direct and indirect correlation with season and time of acquisition of data.

The average SAVI for study period is ranges between -0.17 to 0.46 for the study period 1999-2003. Hence, for study period i.e 1999 to 2003 (four years period) lowest SAVI is -0.17 and highest SAVI is 0.46. It indicates that, Savitri river basin has good vegetation cover throughout the year's period. There may more moisture stress found even in the month of March.

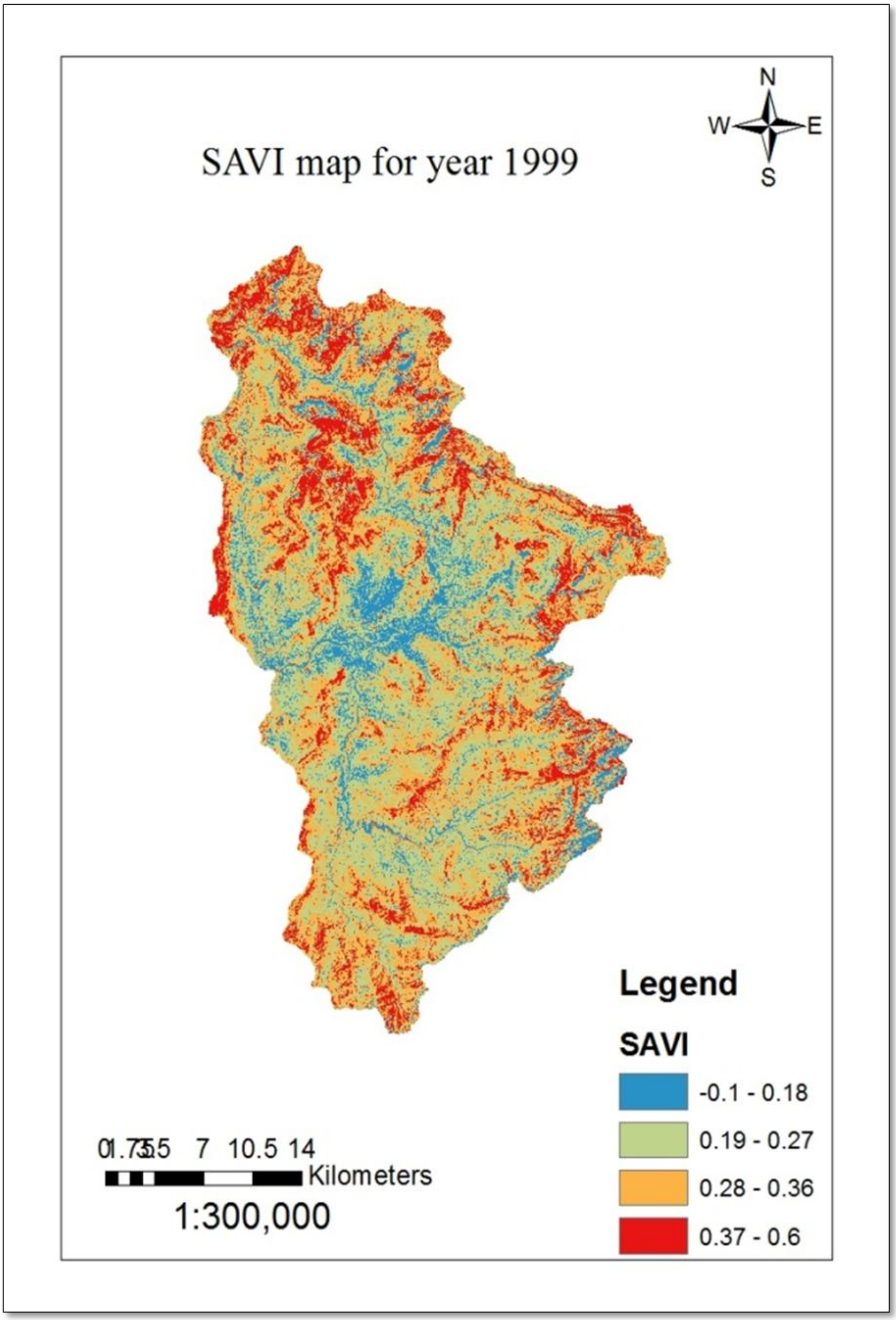


Fig. 4.17 Computed SAVI for year 1999

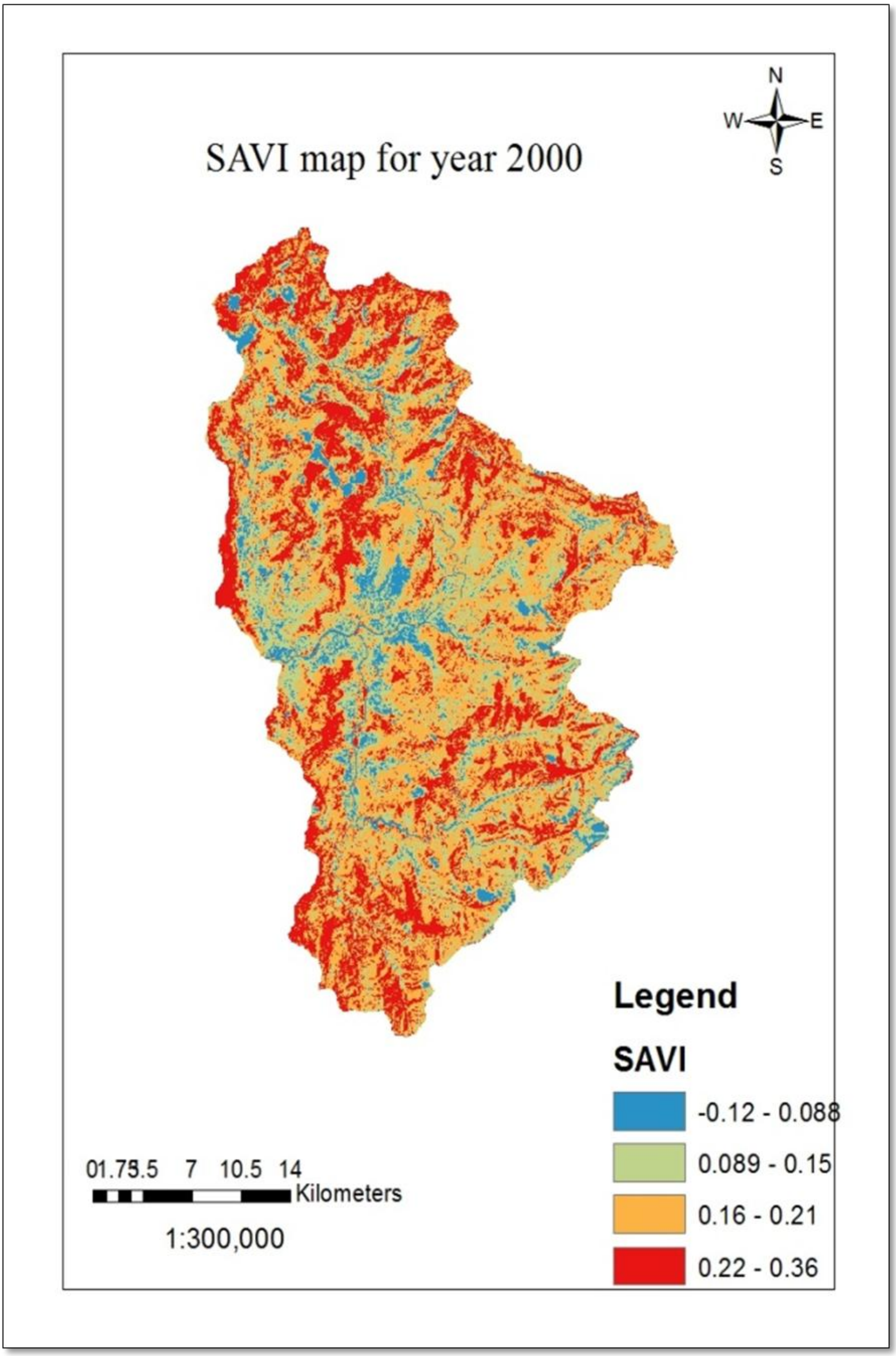


Fig. 4.18 Computed SAVI for year 2000

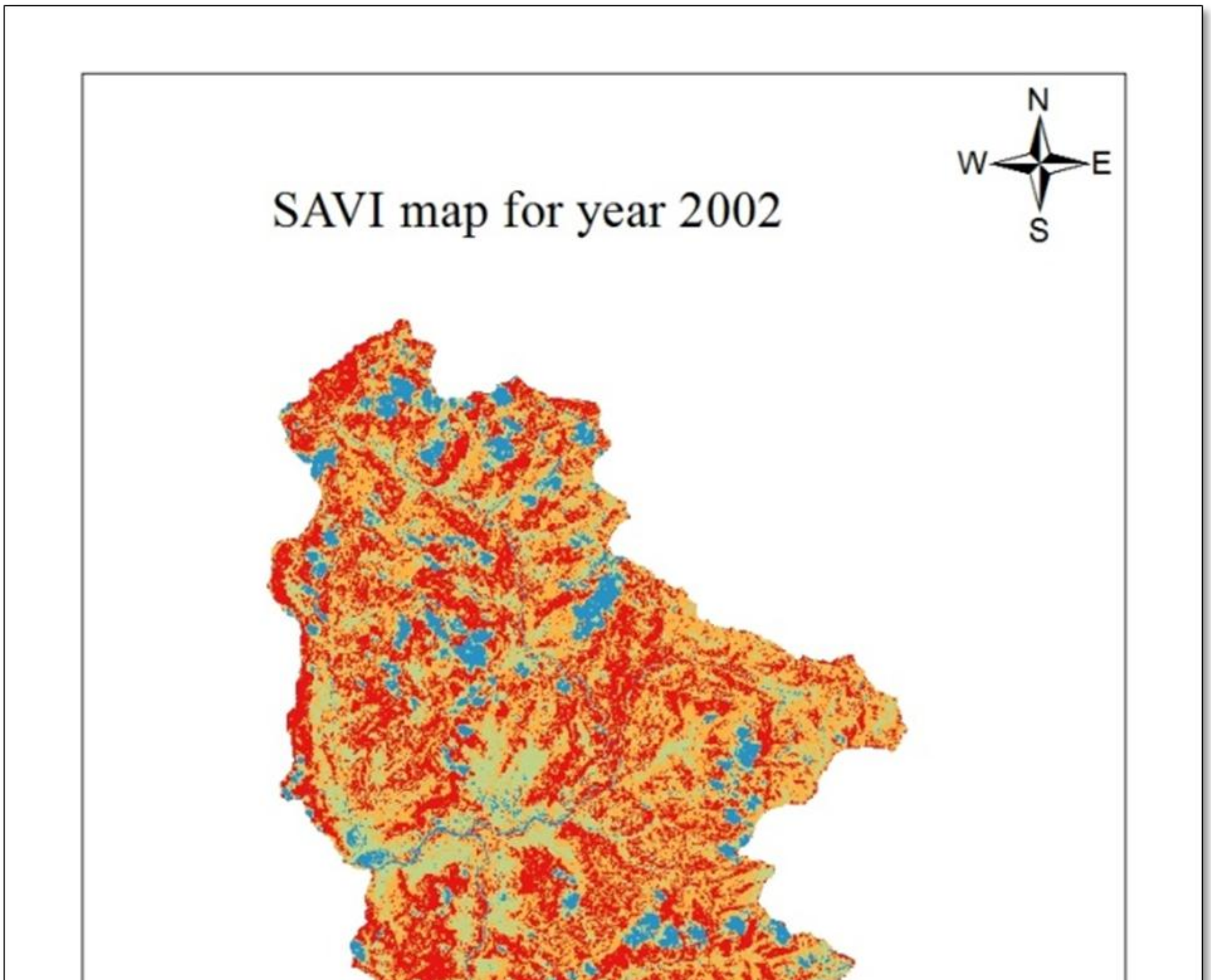


Fig. 4.19 Computed SAVI for year 2002

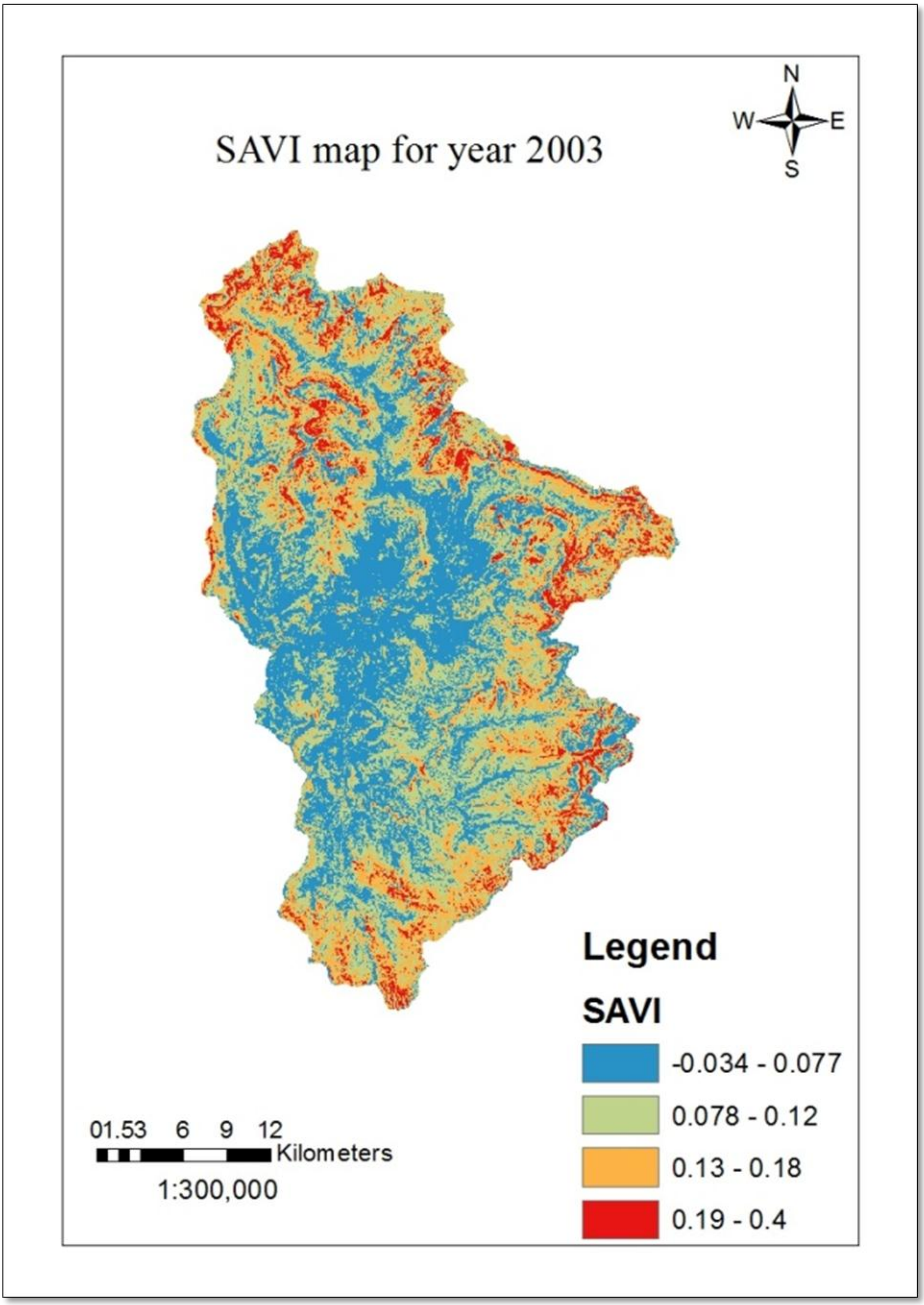


Fig. 4.20 Computed SAVI for year 2003

4.6 Modified Soil Adjusted Vegetation Index (MSAVI)

The Modified Soil Adjusted Vegetation Index (MSAVI) calculated using reflectance values of band 3 (RED) and 4 (NIR). These indices are varied between -1 and 1. The MSAVI and their transformations and derivatives are extremely useful tools in monitoring processes related to PAR absorbed by vegetation. PAR include processes related to photosynthesis at the canopy or ecosystem scale (phenology, primary productivity, net carbon fixation, gross primary productivity) and processes related to plant transpiration (ET, rainfall use efficiency, groundwater withdrawal). In the present study, MSAVI's were determined as per discussed in 3.5.6 in ArcGIS environment. The MSAVI computed for study area is given in Fig. 4.21, Fig. 4.22, Fig. 4.23 and Fig. 4.24 for the year 1999, 2000, 2002 and 2003, respectively. It is observed that, the MSAVI value of study area varied from 0.36 to 0.64, 0.47 to 0.76, 0.54 to 0.95 and 0.14 to 0.49 for the year 1999, 2000, 2002 and 2003 respectively. The highest value of MSAVI i.e. 0.95 was obtained in year 2000. The high value of MSAVI indicates good and healthier vegetation. The value near or equal to -1 indicates there is no vegetation i.e. it is barren land. The lowest value of MSAVI (0.14) was obtained in year 2003.

The 40 per cent area comes under MSAVI value 0.58 to 0.64 and 10 per cent area comes under MSAVI value 0.36 to 0.41 for year 1999. The 52 per cent area comes under MSAVI value 0.69 to 0.76 and 15 per cent area comes under MSAVI value 0.47 to 0.51 for year 2000. The 60 per cent area comes under MSAVI value 0.69 to 0.95 and 17 per cent area comes under MSAVI value 0.54 to 0.62 for year 2002. The 30 per cent area comes under MSAVI value 0.32 to 0.49 and 25 per cent area comes under MSAVI value 0.14 to 0.19 for year 2003. All the values of MSAVI for study period i.e 1999 to 2003 are positive and highest values near to (0.95) and lowest value is 0.14. It indicates that, MSAVI is showing good vegetation even during month of March also.

The average MSAVI for study period is ranges between 0.63 to 0.71 for the study period 1999-2003. Hence, for study period i.e 1999 to 2003 (four years period) lowest MSAI is 0.63 and highest MSAVI is 0.71. It indicates that, Savitri river basin has good vegetation cover throughout the year's period. There may more moisture stress found even in the month of March.

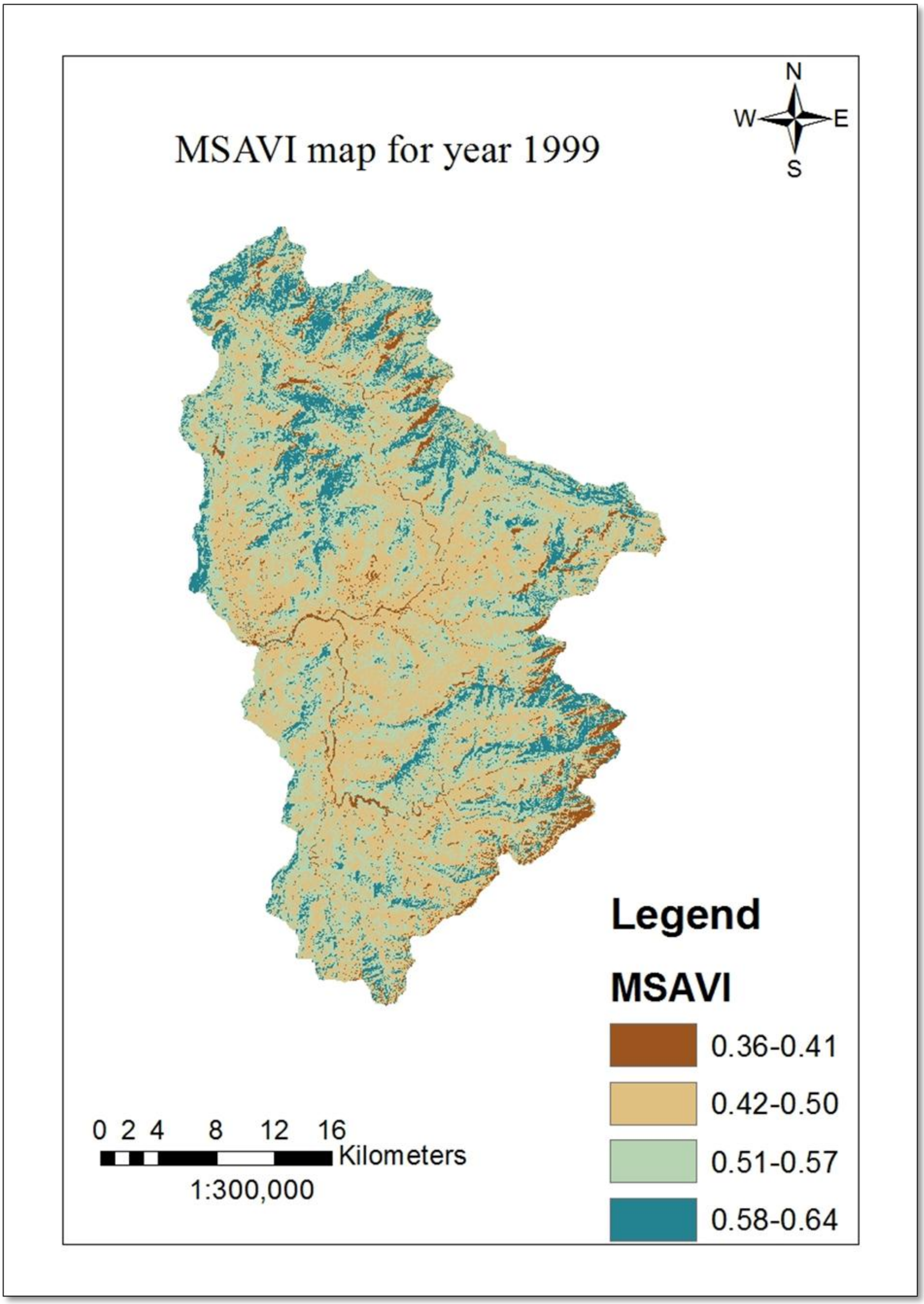


Fig. 4.21 Computed MSAVI for year 1999

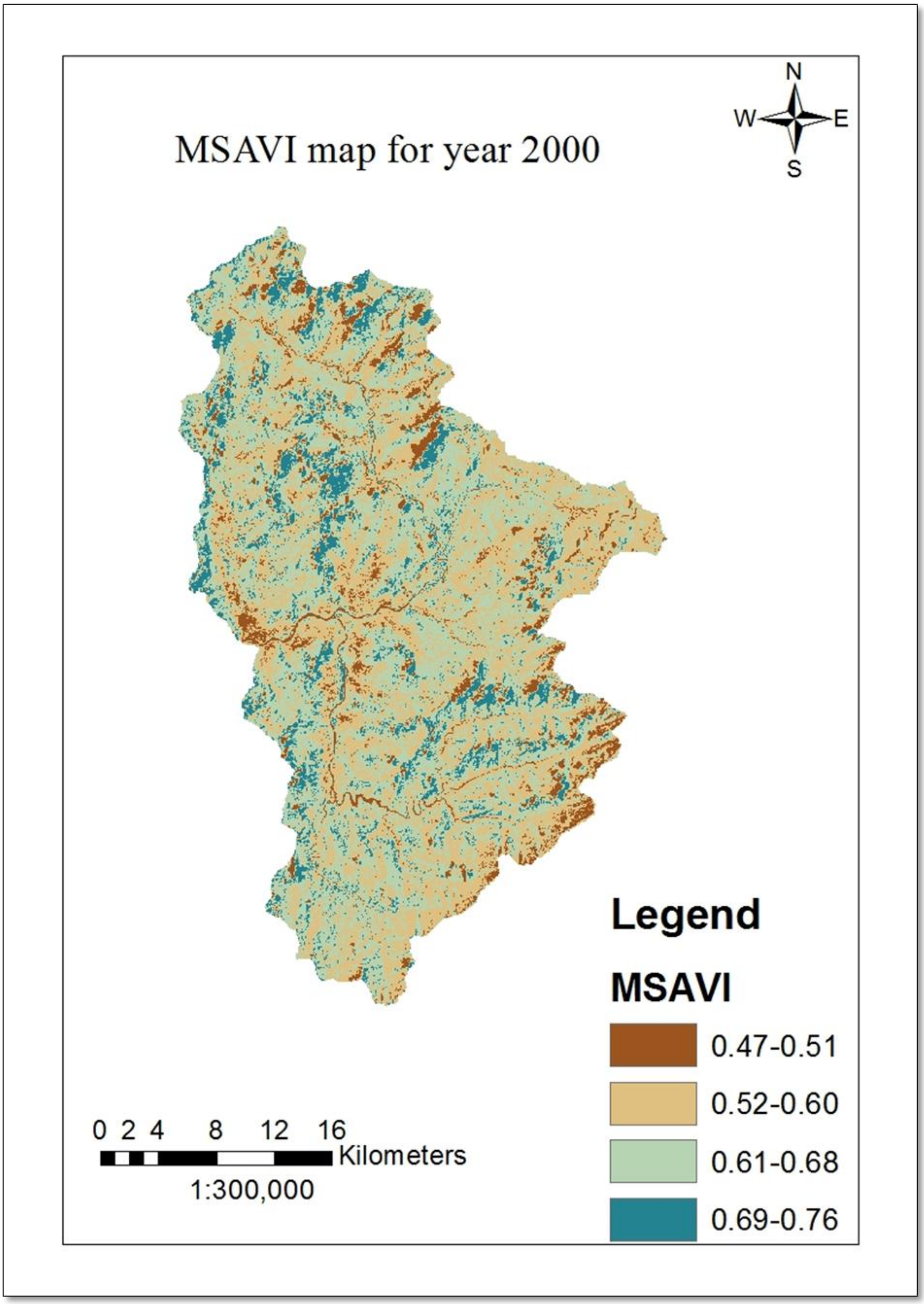


Fig. 4.22 Computed MSAVI for year 2000

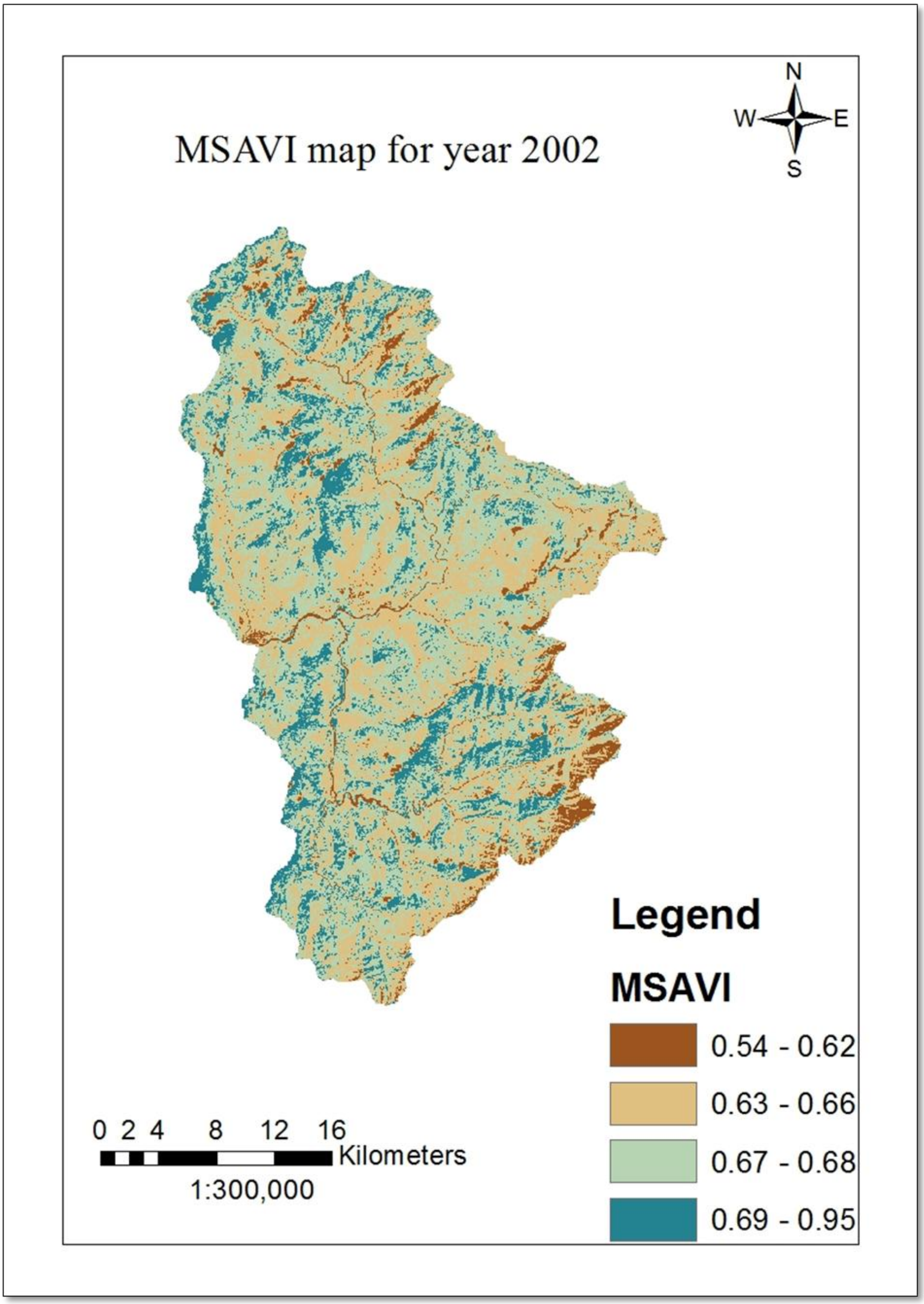


Fig. 4.23 Computed MSAVI for year 2002

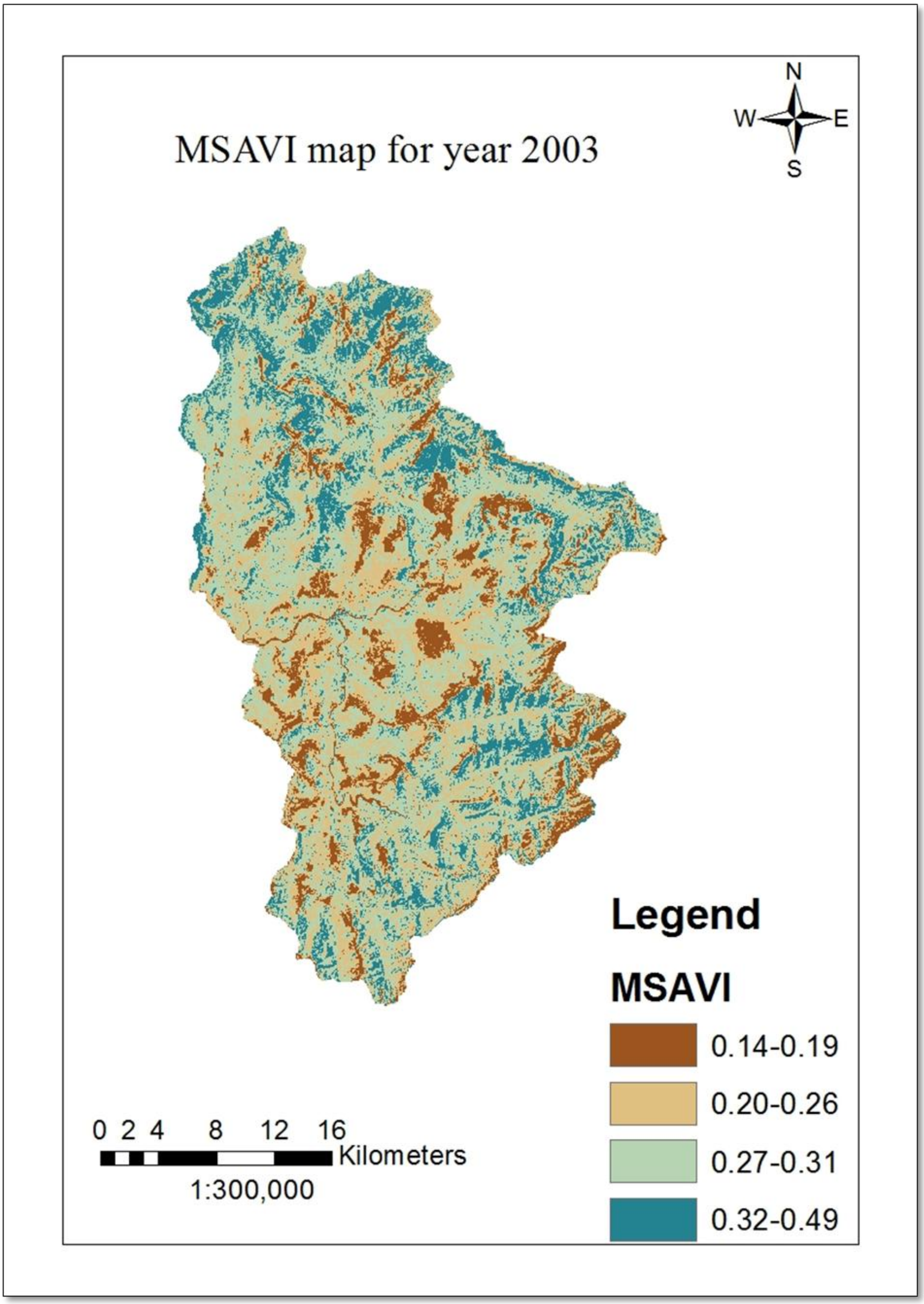


Fig. 4.24 Computed MSAVI for year 2003

The different vegetation indices such as NDVI, SAVI and MSAVI were calculated from reflectance values of Landsat7 imagery in ArcGIS environment. The comparative performance of all vegetation indices was given in Table 4.1.

Table 4.1 Comparative study of vegetation indices

Sr. No.	Year	NDVI		SAVI		MSAVI	
		low	high	low	high	low	high
1	November, 1999	-0.71	0.83	-0.10	0.60	0.36	0.64
2	October, 2000	-0.35	0.63	-0.12	0.60	0.47	0.76
3	September, 2002	-0.50	0.74	-0.15	0.50	0.54	0.95
4	March, 2003	-0.16	0.76	-0.34	0.40	0.14	0.49
	Average	**-0.43**	**0.74**	**-0.17**	**0.52**	**0.37**	**0.71**

From Table 4.1, it is observed that, the average value of NDVI was varied from -0.43 to 0.74, the average SAVI was value varied from -0.17 to 0.52 and the average value of MSAVI was varied from 0.37 to 0.71 for study period 1999 to 2003. It implies that, all the values of MSAVI for study period i.e 1999 to 2003 are positive and highest values near to (0.71) and lowest value is 0.37. MSAVI is over predicting vegetation cover and status in the study area i.e. Savitri basin compared to NDVI and SAVI. Comparatively, the NDVI and SAVI have lowest value to MSAVI during the study period 1999-2003. But MSAVI is calculating the moisture reflectance from both soil and vegetation whenever the NDVI and SAVI is not. Therefore, MSAVI values are higher in study period as compared to NDVI and SAVI. So, MSAVI values were used to compute soil moisture by VI-LST method (Hossain *et al*., 2006 and Singh *et al*., 2010).

4.7 Moisture Variation

4.7.1 Normalized Difference Water Index (NDWI) Method

The Normalized Difference Water Index (NDWI) has been widely used to flood and drought monitoring. The NDWI method was best approach for determining moisture content in the top layer of the soil. In the present study, NDWI's were determined as per discussed in section 3.5.7.1 in ArcGIS environment. The computed NDWI for study area is given in Fig. 4.25, Fig. 4.26, Fig. 4.27 and Fig. 4.28 for the year 1999, 2000, 2002 and 2003, respectively. The index image was normalized to 8-bit and classified into the three classes of crop moisture variation as very low moisture, low moisture and moderate moisture. Thresholds DN values were determined by feature physical inspection of the VNIR image. The thresholds DN values for the respective classes are given in Table 4.2.

Table 4.2 Thresholds DN values for NDWI image classification

Class	Threshold DN value
Moderate Moisture	137-255 (60 to 70 per cent)
Low Moisture	123-136 (35 to 59 per cent)
Very Low Moisture	0-122 (16 to 34 per cent)

For threshold DN value 0-122, the moisture variation is 16 to 34 per cent. For threshold DN value 123-136, the moisture variation is 35 to 59 per cent. For threshold DN value 137-255, the moisture variation is 60 to 72 per cent. It is inferred that, the high moisture percentage was obtained in the year 1999, the threshold DN value for this year was 137-255.

The area under very low moisture, low moisture and moderate moisture were 99.4 sq. km, 298.2 sq. km and 596.4 sq. km, respectively for year 1999. The area under very low moisture, low moisture and moderate moisture were 198.8 sq. km, 298.2 sq. km and 497 sq. km, respectively for year 2000. The area under very low moisture, low moisture and moderate moisture were 248.5 sq. km, 298.2 sq. km and 447.3 sq. km, respectively for year 2002. The area under very low moisture, low moisture and moderate moisture were 397.6 sq. km, 248.5 sq. km and 347.9 sq. km, respectively for year 2003. The average area (472.16 sq, km) under moderate moisture availability in the basin is moderate, which is 47.5 per cent of total area of basin, area under low moisture availability was 285.77 sq. km (28.75 per cent) and 236.07 sq. km (23.75 per cent) found in very low moisture availability of the basis during

1999 to 2003. Hence, Moisture variation found in the basin but availability is good with different season for supporting vegetation.

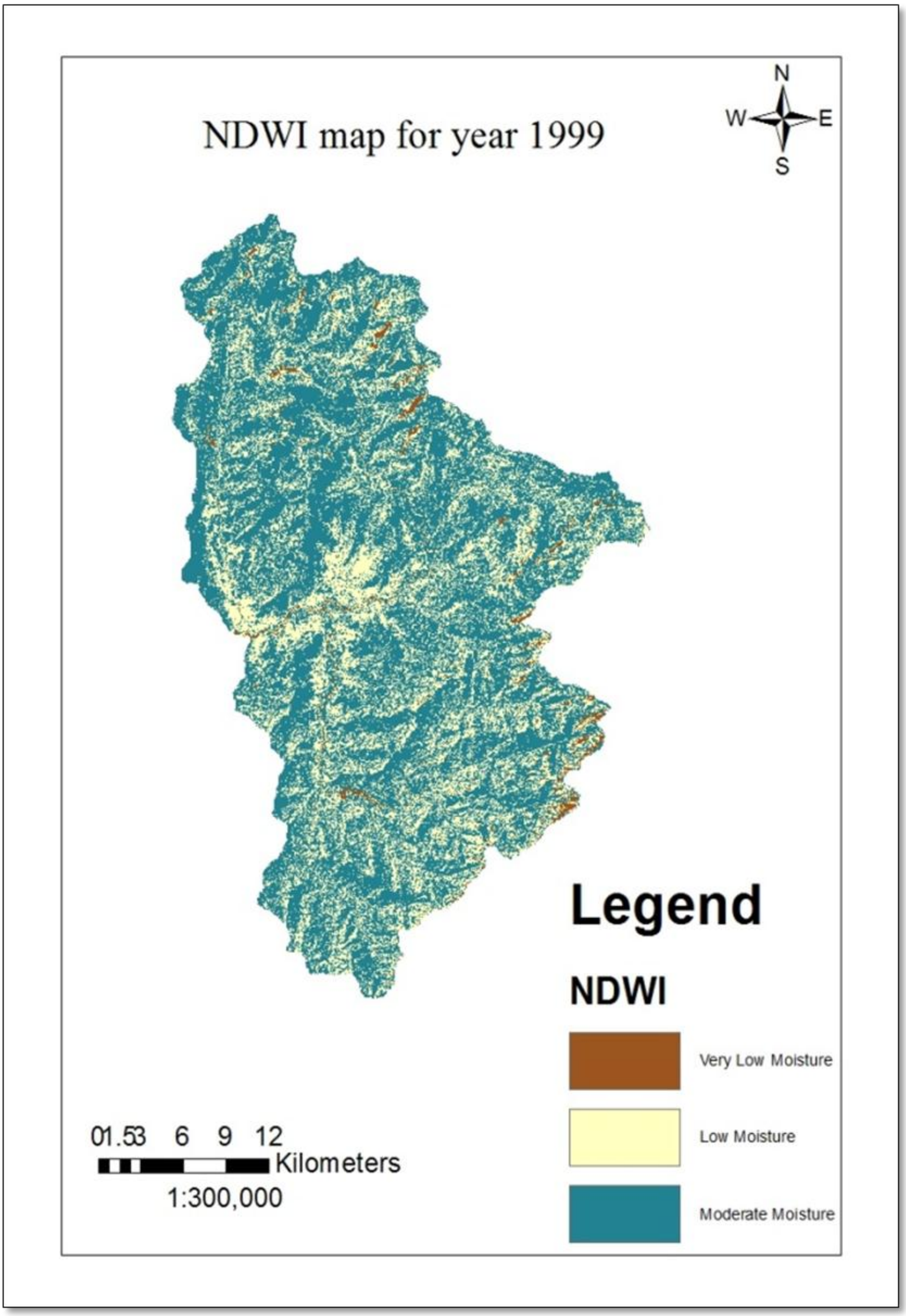


Fig. 4.25 Computed NDWI for year 1999

Fig. 4.26 Computed NDWI for year 2000

Fig. 4.27 Computed NDWI for year 2002

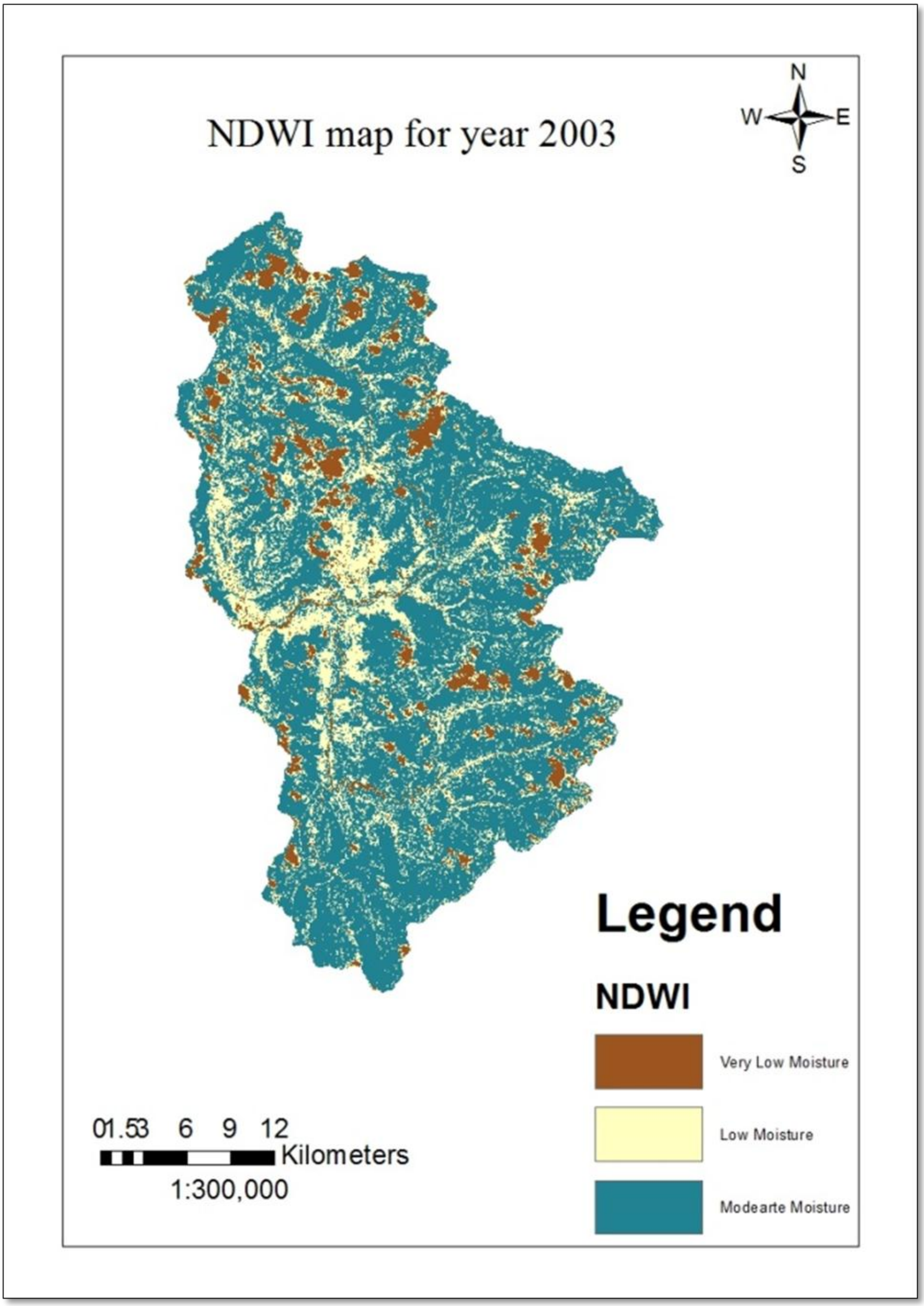


Fig. 4.28 Computed NDWI for year 2003

4.7.2 Land Surface Temperature (LST):

Land Surface Temperature (LST) means the temperature of the surface which we observe if directly contact or touches it with. It is also refer as skin temperature of the surface. Land surface temperature is an important parameter for many environmental models. The Land Surface Temperature (LST) of remote sensing imagery for 1999, 2000, 2002 and 2003 of Landsat7 was calculated using Eq.3.10 in ArcGIS environment. The land surface temperature was calculated from thermal band (band 6) of Landsat 7 which is the Thermal Infrared (TIR) channel that records radiation within a 10.4 to 12.5μm spectral range of the electromagnetic spectrum. These LST value is used in VI-LST method to determine the moisture variation in the study area.

The LST is computed for study area is given in Fig. 4.29, Fig. 4.30, Fig. 4.31 and Fig. 4.32 for the year 1999, 2000, 2002 and 2003, respectively. It is observed that, the LST value of study area varied from 23.13 to 24.8^{0}C, 22.13 to 23.96^{0}C, 21.13 to 22.96^{0}C and 24.12 to 31.83^{0}C for the year 1999, 2000, 2002 and 2003, respectively. The highest value of LST was obtained in the year 2003 in month of March i.e. in summer season.

The area under 23.13 to 23.76 ^{0}C, 23.77 to 23.96 ^{0}C, 23.97 to 24.12 ^{0}C and 24.13 to 24.80 ^{0}C were 196.12 sq. km, 294.918 sq. km, 351.729 sq. km and 151.011 sq. km, respectively for the year 1999. The area under 22.13 to 22.83 ^{0}C, 22.84 to 23.05 ^{0}C, 23.06 to 23.18 ^{0}C and 23.19 to 23.96 ^{0}C were 124.337 sq. km, 311.592 sq. km, 434.67 sq. km and 123.848 sq. km, respectively for year 2000. The area under 21.13 to 21.83 ^{0}C, 21.84 to 22.05 ^{0}C, 22.06 to 22.18 ^{0}C and 22.19 to 22.96 ^{0}C were 55.732 sq. km, 84.258 sq. km, 597.807 sq. km and 265.203 sq. km, respectively for year 2002. The area under 24.12 to 26.42 ^{0}C, 26.43 to 27.45 ^{0}C, 27.46 to 28.63 ^{0}C and 28.64 to 31.83 ^{0}C were 465.55 sq. km, 246.39 sq. km, 159.10 sq. km and 122.96 sq. km, respectively for year 2003.

Finally the MSAVI image and LST image were stacked to create feature space image. Then feature space image was classified using unsupervised classification method into the three classes of crop moisture variation as very low moisture, low moisture and moderate moisture.

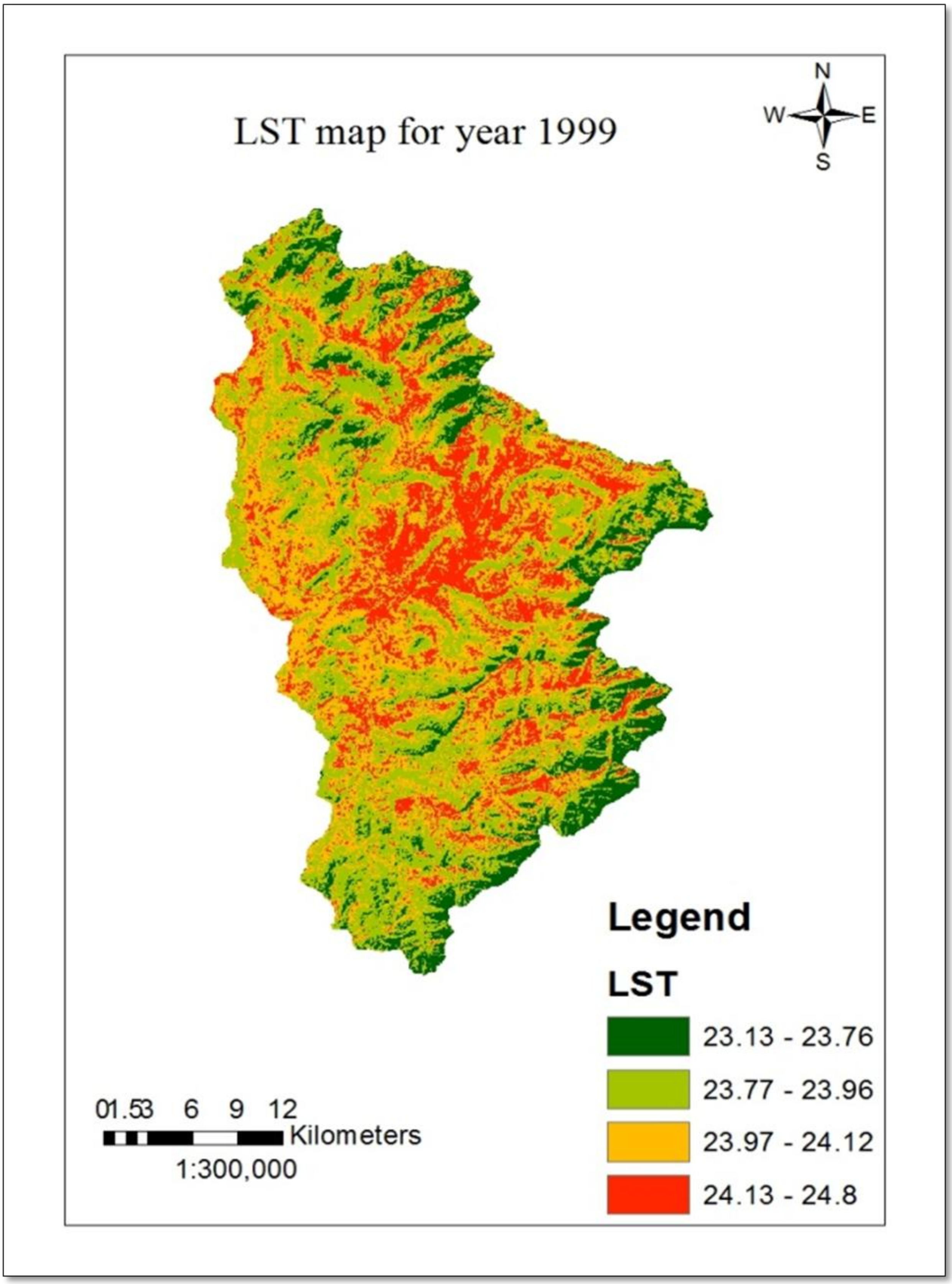


Fig. 4.29 Computed LST for year 1999

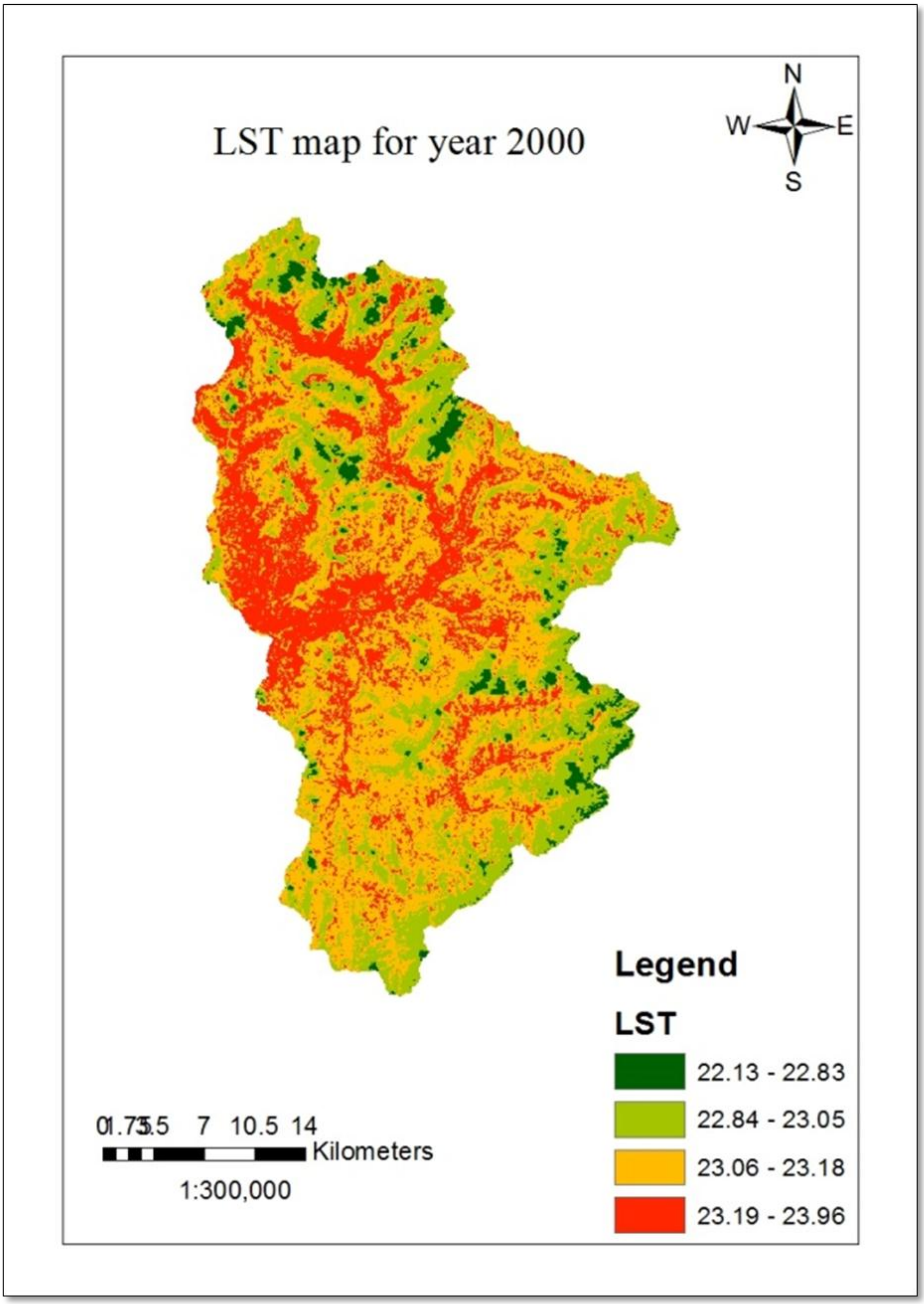


Fig. 4.30 Computed LST for year 2000

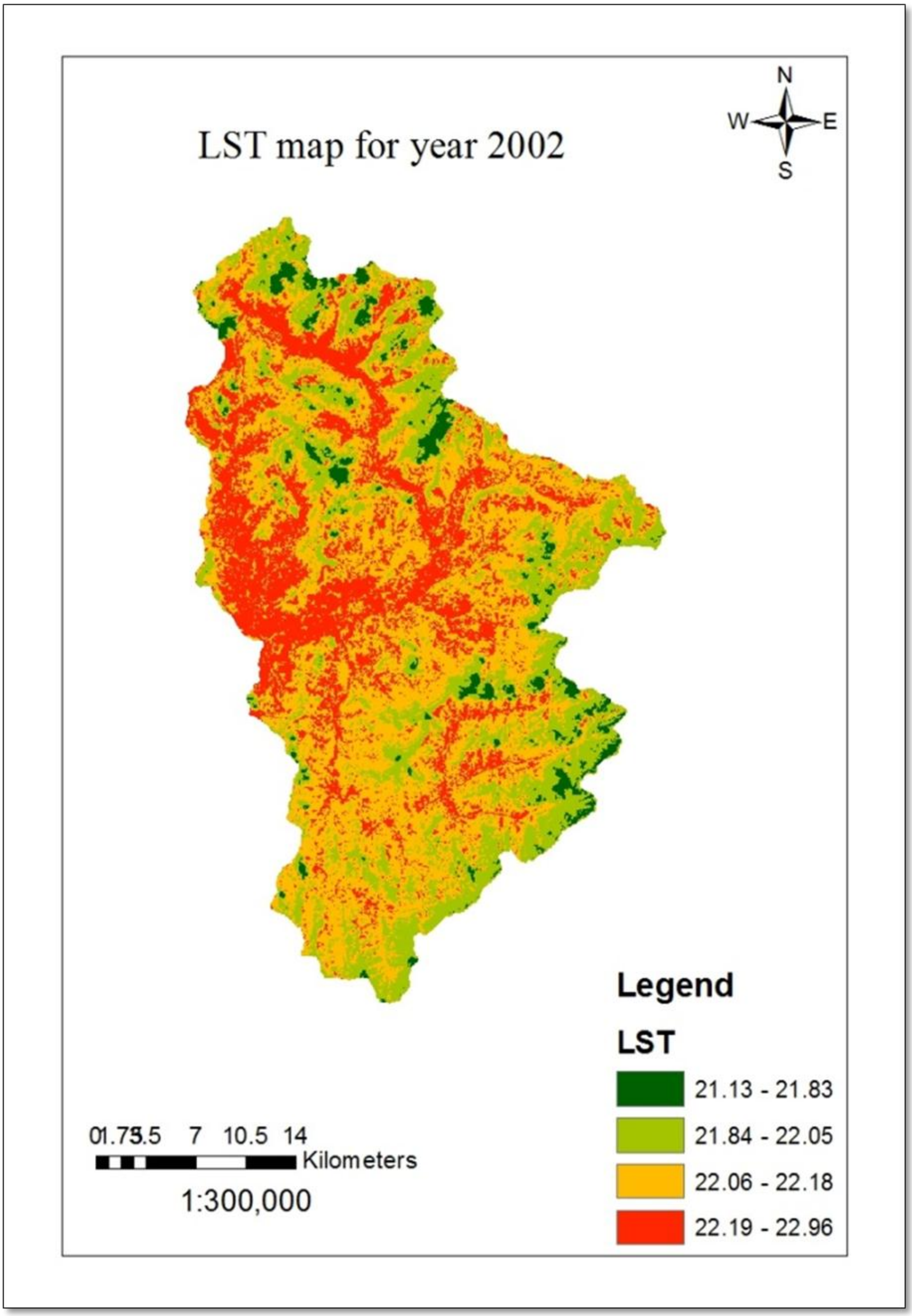


Fig. 4.31 Computed LST for year 2002

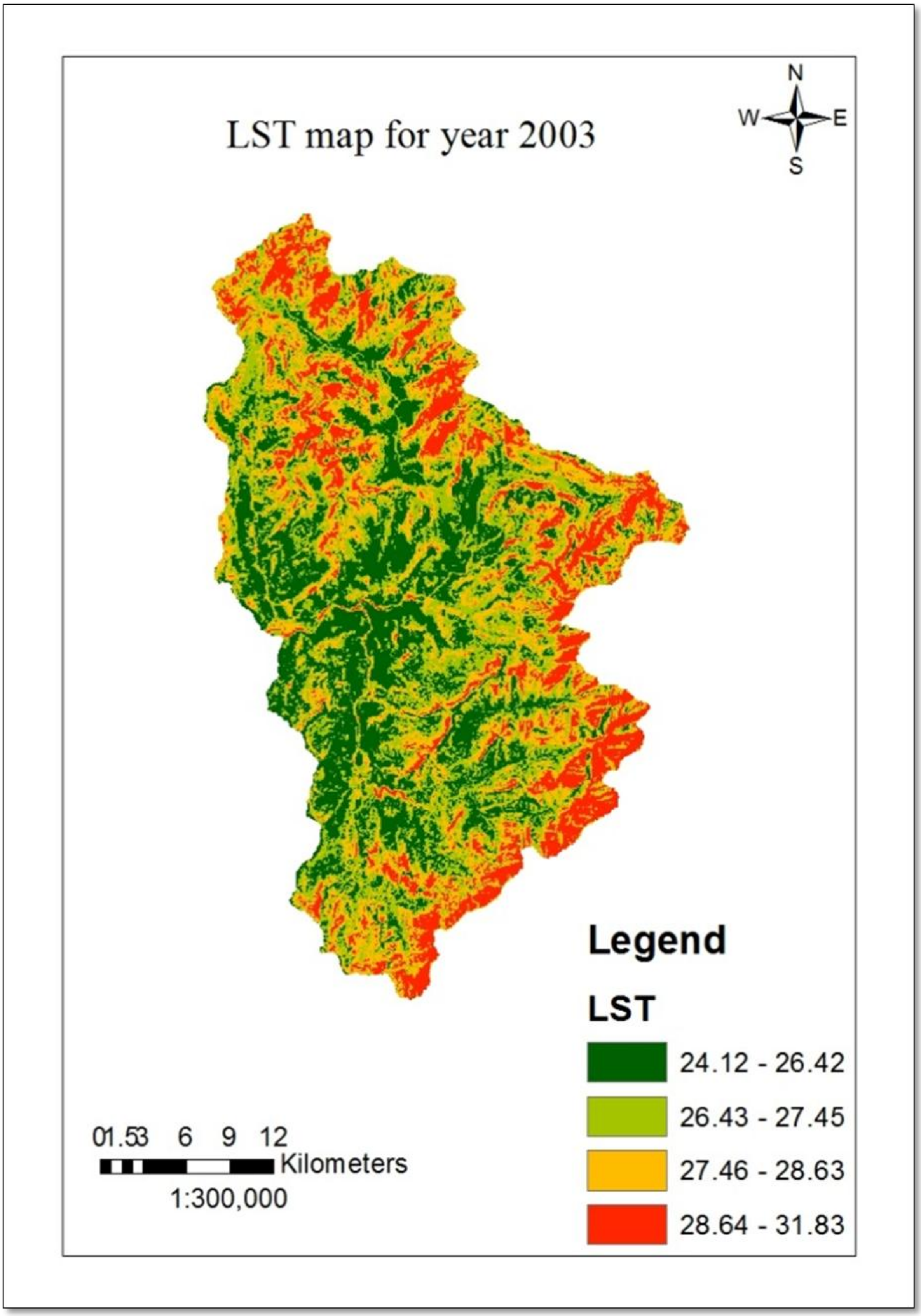


Fig. 4.32 Computed LST for year 2003

4.7.3 VI-LST Triangular Method

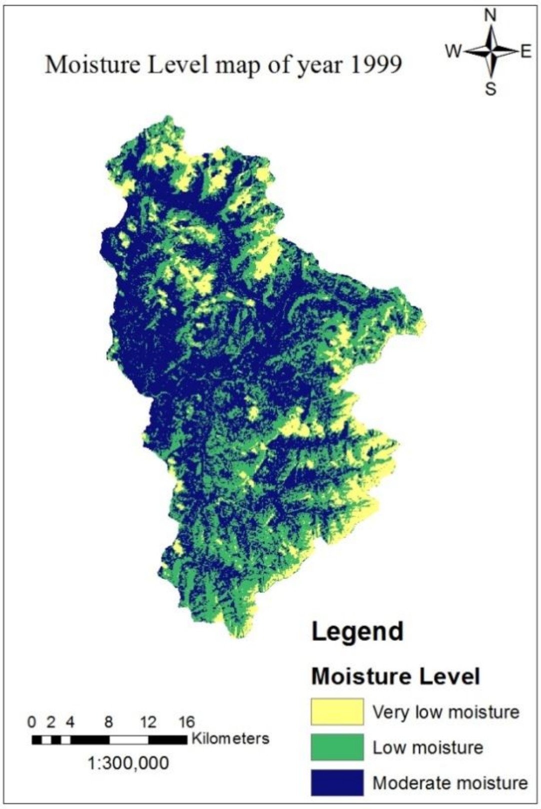
a) Moisture Variation for year 1999

The moisture variation in the top layer of soil was determined by NDWI and VI-LST method. The VI-LST gives the moisture variation comparatively. The surface moisture of study area i.e. Savitri basin was estimated as per discussed in 3.5.7.2 in ArcGIS environment.

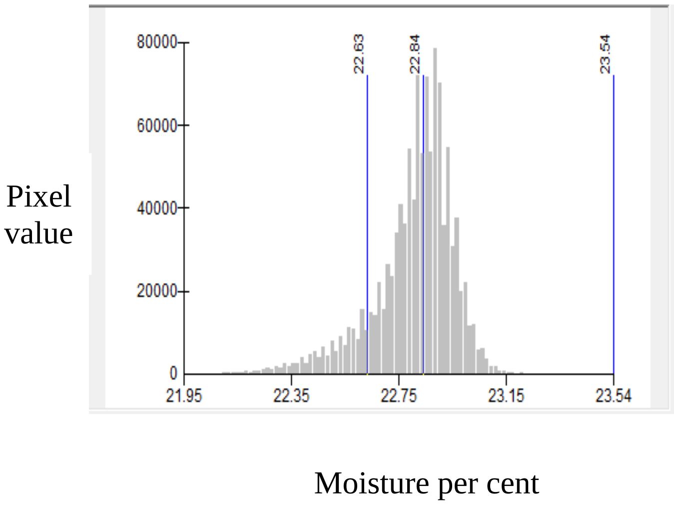
The status of moisture in the study area is varied with the season, depth of soil and climatic conditions. The data of different season was downloaded and present moisture in the top layer of soil was determined in ArcGIS environment. The moisture variation for year 1999 is given in Fig. 4.33 (a). The histogram shows the variation of moisture with DN values is presented in Fig. 4.33 (b). Also the statistics of moisture variation from histogram is given in Table 4.3. It is observed from Fig. 4.33 (a) and histogram that, the moisture variation occurred between 21.95 to 23.54 per cent at DN value of 80000. The average moisture variation in study area was 22.8 per cent at DN value 10000. The area under very low moisture, low moisture and moderate moisture were 251.66 sq. km, 334.73 sq. km and 407.61 sq. km, respectively. This indicates that, most of area (74.68 per cent) comes under low to moderate moisture availability for basin in November 1999. It is also observed from Fig. 4.33 that, Moderate to low moisture found in valley portion of the basin and very low moisture in hilly section of the basin. This implies that, the moisture variation computed by the VI-LST is best suited for the basis in tropical humid climate of Konkan region.

b) Moisture Variation for year 2000

The surface moisture of study area i.e. Savitri basin was estimated as per discussed in 3.5.7.2 in ArcGIS environment. The status of moisture in the study area is varied with the season, depth of soil and climatic conditions. The moisture variation for year 2000 is given in Fig. 4.34 (a). The histogram shows the variation of moisture with DN values is presented in Fig. 4.34 (b). Also the statistics of moisture variation from histogram is given in Table 4.4. It is observed from Fig. 4.34 (a) and histogram that, the moisture variation occurred between 21.75 to 23.49 per cent at DN value of 80000. The average moisture variation in study area was 22.62 per cent at DN value 15000. The area under very low moisture, low moisture and moderate moisture were 246.33 sq. km, 315.06 sq. km and 432.61 sq. km, respectively. This indicates that, most of area (75.21 per cent) comes under low to moderate moisture availability for basin in November 2000.



4.33 (a) Moisture level map

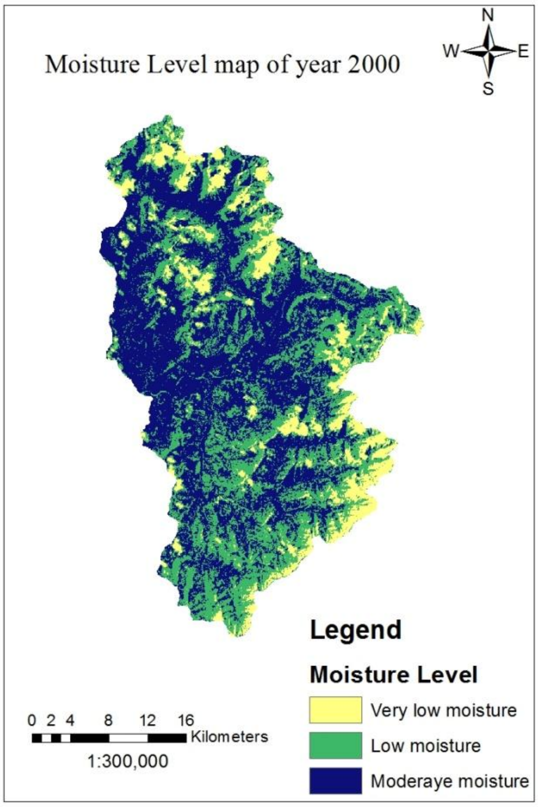


4.33 (b) Histogram

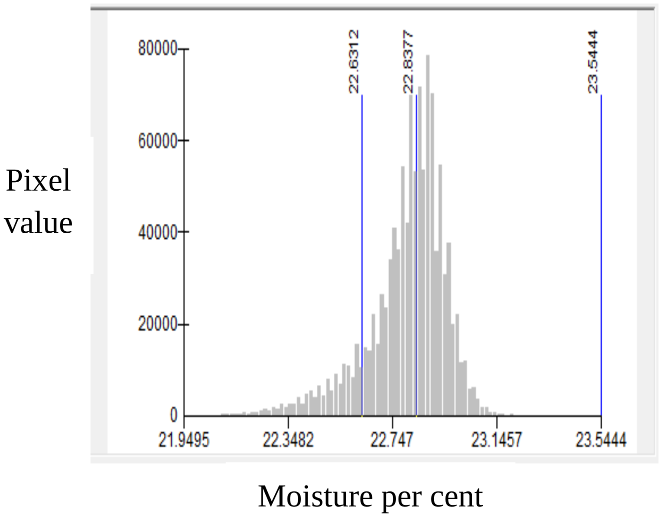
Table 4.3 statistics for the year 1999

Count	1107560
Minimum	21.95
Maximum	23.54
Sum	25260000
Mean	22.8
Standard Deviation	0.15

Fig. 4.33 Computed moisture variation in Savitri basin for year 1999



4.34 (a) Moisture level map



4.34 (b) Histogram

Table 4.4 statistics for the year 2000

Count	1107560
Minimum	21.94
Maximum	23.54
Sum	25257300
Mean	22.80
Standard Deviation	0.15

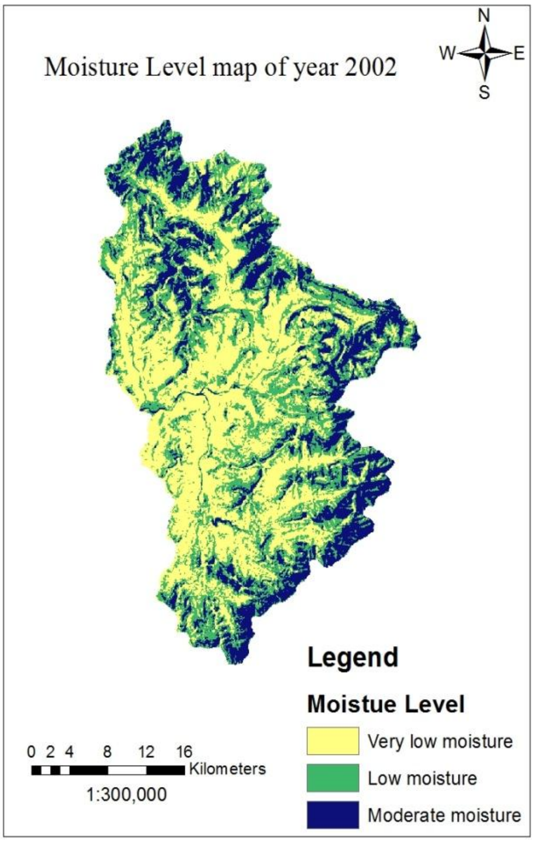
Fig. 4.34 Computed moisture variation in Savitri basin for year 2000

c) Moisture Variation for year 2002

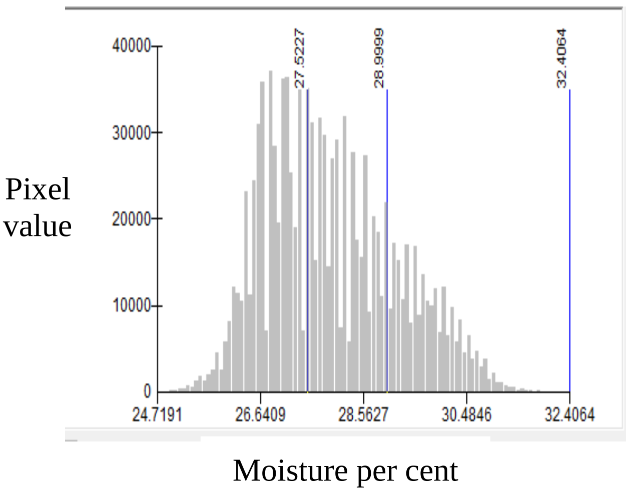
The surface moisture of study area i.e. Savitri basin was estimated as per discussed in 3.5.7.2 in ArcGIS environment. The status of moisture in the study area is varied with the season, depth of soil and climatic conditions. The moisture variation for year 2002 is given in Fig. 4.35 (a). The histogram shows the variation of moisture with DN values is presented in Fig. 4.35 (b). Also the statistics of moisture variation from histogram is given in Table 4.5. It is observed from Fig. 4.35 (a) and histogram that, the moisture variation occurred between 24.71 to 32.40 per cent at DN value of 40000. The average moisture variation in study area was 27.95 per cent at DN value 32000. The area under very low moisture, low moisture and moderate moisture were 231.33 sq. km, 305.06 sq. km and 457.61 sq. km, respectively. This indicates that, most of area (76.72 per cent) comes under low to moderate moisture availability for basin in November 2002. This implies that, the moisture variation computed by the VI-LST is best suited for the basis in tropical humid climate of Konkan region.

d) Moisture Variation for year 2003

The surface moisture of study area i.e. Savitri basin was estimated as per discussed in 3.5.7.2 in ArcGIS environment. The status of moisture in the study area is varied with the season, depth of soil and climatic conditions. The moisture variation for year 2003 is given in Fig. 4.36 (a). The histogram shows the variation of moisture with DN values is presented in Fig. 4.36 (b). Also the statistics of moisture variation from histogram is given in Table 4.6. It is observed from Fig. 4.36 (a) and histogram that, the moisture variation occurred between 7.92 to 24.07 per cent at DN value of 30000. The average moisture variation in study area was 16.60 per cent at DN value 25000. The area under very low moisture, low moisture and moderate moisture were 248.21 sq. km, 533.61 sq. km and 212.20 sq. km, respectively. This indicates that, most of area (75.03 per cent) comes under low to moderate moisture availability for basin in November 2003. This implies that, the moisture variation computed by the VI-LST is best suited for the basis in tropical humid climate of Konkan region.



4.35 (a) Moisture level map

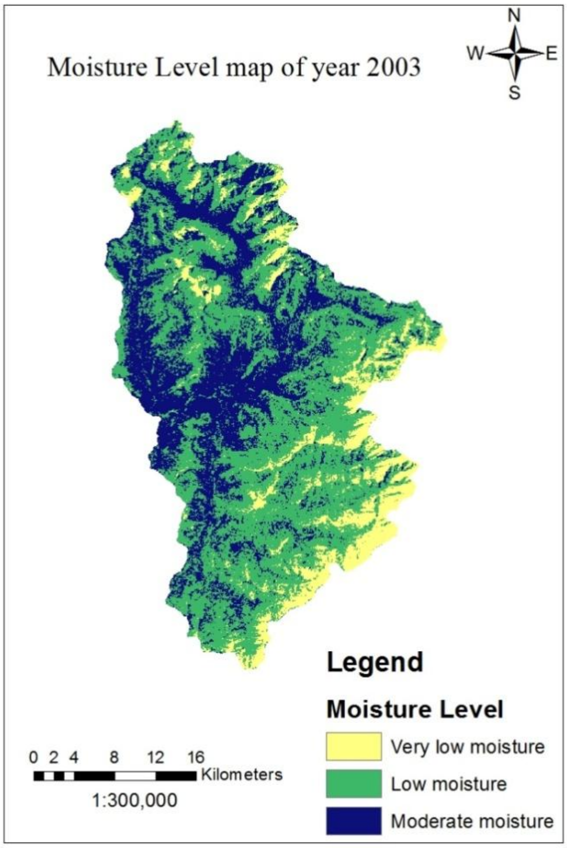


4.35 (b) Histogram

Table 4.5 statistics for the year 2002

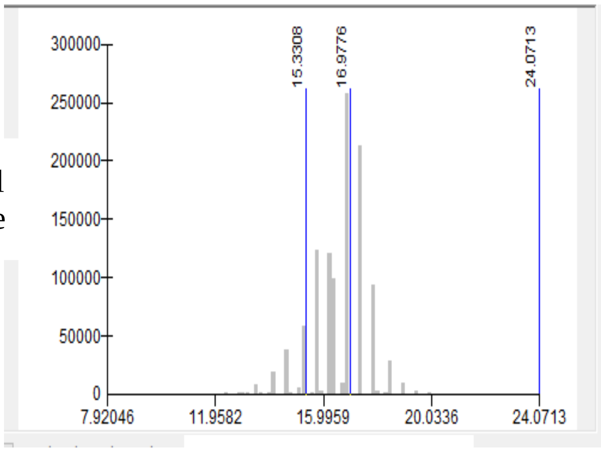
Count	1107560
Minimum	21.94
Maximum	23.54
Sum	25257300
Mean	22.80
Standard Deviation	0.15

Fig. 4.35 Computed moisture variation in Savitri basin for year 2002



4.36 (a) Moisture level map

Pixel value



Moisture per cent

4.36 (b) Histogram

Table 4.6 statistics for the year 2003

Count	1107560
Minimum	21.94
Maximum	23.54
Sum	25257300
Mean	22.80
Standard Deviation	0.15

Fig. 4.36 Computed moisture variation in Savitri basin for year 2003

The moisture variation was calculated by NDWI and VI-LST method of Landsat7 imagery in ArcGIS environment. The comparative performance of all vegetation indices was given in Table 4.7.

Table 4.7 Comparative study of moisture variation method

Sr. No.	Year	Area (sq. km) NDWI method			Area (sq. km) VI-LST method		
		Very low moisture	**Low moisture**	**Moderate moisture**	**Very low moisture**	**Low moisture**	**Moderate moisture**
1	November, 1999	99.4	298.2	596.4	251.66	334.73	407.61
2	October, 2000	198.8	298.2	497.00	246.33	315.06	432.61
3	September, 2002	248.5	298.2	447.3	231.33	305.06	457.61
4	March, 2003	397.6	248.5	347.9	248.21	533.61	212.20
	Average	**236.07**	**285.78**	**472.15**	**244.39**	**372.11**	**377.50**

From Table 4.7, it is observed that, the average area comes under very low moisture; low moisture and moderate moisture were 236.07 sq. km, 258.78 sq. km and 472.15 sq. km from NDWI method for study period 1999 to 2003. The average area comes under very low moisture; low moisture and moderate moisture were 244.39 sq. km, 372.11sq.km and 377.50 sq. km from VI-LST method for study period 1999 to 2003. The MSAVI-LST Triangular method (using RED, NIR and thermal bands) has more potential to estimate crop moisture variation more accurately than NDWI method (using NIR and SWIR bands) (Hossain *et al.*, 2006). Hence, it can be concluded that, the VI-LST method is most suitable to compute moisture variation than NDWI method.

V. SUMMARY AND CONCLUSION

5.1 Summary

Vegetation indices are quantitative measurements indicating the vigor of vegetation. They show better sensitivity than individual spectral bands for green vegetation detection. Their usefulness lies as an aid to remote sensing image interpretation, the detection of land use changes, and the evaluation of vegetative cover density, forestry, crop discrimination and crop prediction. Land surface temperature (LST) is a key parameter for many environmental studies such as global environmental change, climate models and human-environment interactions. Land surface temperature (LST) is an important factor in vegetation growth and glacier. Its impact will be more in monsoon area because of failure of monsoon and uncertainty and unpredictable in rainfall.

Soil moisture near the land surface affects a wide variety of earth system interactions over a changing spatial and temporal scale. Surface soil moisture plays a critical role in the interaction between land surface and the atmosphere, as well as in hydrological and ecological processes. It exerts a major control on the partitioning of net radiation into latent and sensible heat and on the conversion of rainfall into runoff and infiltration. Given the importance of surface soil moisture to land surface system, quantification of its variability and patterns received increasing attention in recent years. The vegetation indices, brightness temperature and land surface temperature were required for estimation of moisture variation in Savitri basin.

The Savitri river basin is comes under the Western part of Sahyadri Ghat part of Konkan region. Study area belongs to Mahad and Poladpur tahashil of Raigarh district in Konkan region of Maharashtra state. The latitude and longitude of the study area is 18^{0}20’N to 17^{0}51’N and 73^{0}22’ E to 73^{0}41’E respectively and elevation ranges from 6.50 m to 1366.23 m above mean sea level**.** The main stream of the study is Savitri river basin has average length of 57.57 Km. Average annual rainfall in the area is 3560 mm. Topography of the watershed is undulating with the land slope varying from more than 50 %. Predominant soil textures of the catchment are sandy loam (73.6%) and sandy clay loam (26.4%). Most of the watershed area comes under degraded land with less soils depth (25-50 cm).

The Cloud Free Landsat satellite data of 1999, 2000, 2002 and 2003 for the study area has been downloaded from Landsat data and official website of USGS (www.earthexplorer.gov.in). All the data were pre-processed and projected to the Universal Transverse Mercator (UTM) projection system. The seven bands are available with the satellite imagery. The data downloaded for the year November 1999, October 2000, September 2002 and March 2003.

The radiance, reflectance and correcting reflectance were calculated as per discussed in material and method. These correcting reflectance values were used to estimate vegetation indices such as NDVI, SAVI and MSAVI. The NDVI was calculated using RED and NIR bands of Landsat imagery. The NDVI value of study area varied from -0.71 to 0.83, -0.35 to 0.63, -0.50 to 0.74 and -0.16 to 0.76 for the year 1999, 2000, 2002 and 2003 respectively. The highest value of NDVI i.e. 0.83 was obtained in year 1999. For year 2002 and 2003 the values of NDVI was almost same. The lowest value (-0.16) of NDVI was obtained in year 2003.

The SAVI was calculated using RED, NIR bands of Landsat imagery and soil brightness constant L. The SAVI value of study area varied from -0.10 to 0.60, -0.12 to 0.36, -0.15 to 0.50 and -0.34 to 0.40 for the year 1999, 2000, 2002 and 2003 respectively. The highest value of SAVI i.e. 0.60 was obtained in year 1999. The MSAVI was calculated using RED, NIR bands of Landsat imagery. MSAVI value of study area varied from 0.36 to 0.64, 0.47 to 0.76, 0.54 to 0.95 and 0.14 to 0.49 for the year 1999, 2000, 2002 and 2003 respectively. The highest value of MSAVI i.e. 0.95 was obtained in year 2000. The lowest value of MSAVI (0.14) was obtained in year 2003.

The two different methods i.e. NDWI and VI-LST method were used for estimation of moisture variation of study area. The NDWI was calculated using NIR and SWIR bands of Landsat imagery for year 1999, 2000, 2002 and 2003. The index image was normalized into 8-bit and classified to three moisture classes i.e. very low moisture, low moisture and moderate moisture. The moisture percentage was determined by threshold DN values. The LST was calculated using thermal band (band 6) of Landsat imagery. The LST value of study area varied from 23.13 to 24.8, 22.13 to 23.96, 21.13 to 22.96 and 24.12 to 31.83 for the year 1999, 2000, 2002 and 2003 respectively.

Finally the MSAVI image and LST image were stacked to create feature space image. Then feature space image was classified using unsupervised classification method into the three classes of crop moisture variation as very low moisture, low moisture and moderate moisture. The status of moisture in the study area is varied with the season, depth of soil and climatic conditions. For year 1999, the moisture variation occurred between 21.95 to 23.54 per cent at DN value of 80000. For year 2000, the moisture variation occurred between 21.75 to 23.49 per cent at DN value of 80000. For year 2002, the moisture variation occurred between 24.71 to 32.40 per cent at DN value of 40000. For year 2003, the moisture variation occurred between 7.92 to 24.07 per cent at DN value of 30000.

5.2 Conclusions

From present study the following conclusions were drawn:

- The NDVI is ranges between -0.43 to 0.74 for the study period 1999-2003. The SAVI is ranges between -0.17 to 0.46 for the study period 1999-2003. The MSAVI is ranges between 0.63 to 0.71 for the study period 1999-2003.
- MSAVI is over predicting vegetation cover and status in the study area i.e. Savitri basin compared to NDVI and SAVI. Hence, MSAVI values were more suitable to compute soil moisture by VI-LST method.
- By NDWI method, the high moisture percentage was obtained in the year 1999, the threshold DN value for this year was 137-255 (60 to 72 per cent).
- The highest value of LST (24.12 to 31.83^{0}C) was obtained in the year 2003 in month of March i.e. in summer season.
- By VI-LST method, the moisture variation was high in year 2002 (24.71 to 31.40 per cent) with mean value of 27.95 per cent.
- By VI-LST method, the area under very low moisture, low moisture and moderate moisture were 251.66 sq. km, 334.73 sq. km and 407.61 sq. km, respectively for year 1999. The area under very low moisture, low moisture and moderate moisture were 246.33 sq. km, 315.06 sq. km and 432.61 sq. km, respectively for year 2000. The area under very low moisture, low moisture and moderate moisture were 231.33 sq. km, 305.06 sq. km and 457.61 sq. km, respectively for year 2002. The area under very low moisture, low moisture and moderate moisture were 248.21 sq. km, 533.61 sq. km and 212.20 sq. km, respectively for year 2003.
- The moisture availability in valley of the Savitri basin is more comparative to hilly portion of Savitri basin in 1999 to 2003. The moisture available is moderate in low land portion and hilly section is very low.
- It is observed that, the average area comes under very low moisture; low moisture and moderate moisture were 236.07 sq. km, 258.78 sq. km and 472.15 sq. km from NDWI

method for study period 1999 to 2003 respectively. The average area comes under very low moisture; low moisture and moderate moisture were 244.39 sq. km, 372.11sq.km and 377.50 sq. km from VI-LST method for study period 1999 to 2003.

- The MSAVI-LST Triangular method (using RED, NIR and thermal bands) has more potential to estimate crop moisture variation more accurately than NDWI method (using NIR and SWIR bands). Hence, it can be concluded that, the VI-LST method is most suitable to compute moisture variation than NDWI method.
- Knowledge of soil moisture is useful for proper crop planning management, estimate moisture stress period, decide cropping system and density, estimate crop productivity. It will also help in deciding drought status in the basin in different seasons in the academic year.

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APPENDIX - I

Earth-Sun distance as a function of day of the year

DOY	d	DOY	d	DOY	d	DOY	d	DOY	d
1	0.98331	30	0.98509	59	0.9906	88	0.9984	117	1.00635
2	0.9833	31	0.98523	60	0.99084	89	0.99868	118	1.00679
3	0.9833	32	0.98536	61	0.99108	90	0.99897	119	1.00705
4	0.9833	33	0.98551	62	0.99133	91	0.99926	120	1.00731
5	0.9833	34	0.98565	63	0.99158	92	0.99954	121	1.00756
6	0.98332	35	0.9858	64	0.99183	93	0.99983	122	1.00781
7	0.98333	36	0.98596	65	0.99208	94	1.00012	123	1.00806
8	0.98335	37	0.98612	66	0.99234	95	1.00041	124	1.00831
9	0.98338	38	0.98628	67	0.9926	96	1.00069	125	1.00856
10	0.98341	39	0.98645	68	0.99286	97	1.00098	126	1.0088
11	0.98345	40	0.98662	69	0.99312	98	1.00127	127	1.00904
12	0.98349	41	0.9868	70	0.99339	99	1.00155	128	1.00928
13	0.98354	42	0.98698	71	0.99365	100	1.00184	129	1.00952
14	0.98359	43	0.98717	72	0.99392	101	1.00212	130	1.00975
15	0.98365	44	0.98735	73	0.99419	102	1.0024	131	1.00998
16	0.98371	45	0.98755	74	0.99446	103	1.00269	132	1.0102
17	0.98378	46	0.98774	75	0.99474	104	1.00297	133	1.01043
18	0.98385	47	0.98794	76	0.99501	105	1.00325	134	1.01065
19	0.9893	48	0.98814	77	0.99529	106	1.00353	135	1.01087
20	0.98401	49	0.98835	78	0.99556	107	1.00381	136	1.01108
21	0.9841	50	0.98856	79	0.99584	108	1.00409	137	1.01129
22	0.98419	51	0.98877	80	0.99612	109	1.00437	138	1.0115
23	0.98428	52	0.98899	81	0.9964	110	1.00464	139	1.0117
24	0.98439	53	0.98921	82	0.99669	111	1.00492	140	1.01191
25	0.98449	54	0.98944	83	0.99697	112	1.00519	141	1.0121
26	0.9846	55	0.98966	84	0.99725	113	1.00546	142	1.0123
27	0.98472	56	0.98989	85	0.99754	114	1.00573	143	1.01249
28	0.98484	57	0.99012	86	0.99782	115	1.006	144	1.01267
29	0.98496	58	0.99036	87	0.99811	116	1.00626	145	1.01286

DOY	d	DOY	d	DOY	d	DOY	d	DOY	d
146	1.01304	175	1.01642	204	1.01592	233	1.01165	262	1.00457
147	1.01321	176	1.01647	205	1.01584	234	1.01145	263	1.0043
148	1.01338	177	1.01652	206	1.01575	235	1.01124	264	1.00402
149	1.01355	178	1.01656	207	1.01565	236	1.01103	265	1.00374
150	1.01371	179	1.01659	208	1.01555	237	1.01081	266	1.00346
151	1.01387	180	1.01662	209	1.01544	238	1.0106	267	1.00318
152	1.01403	181	1.01665	210	1.01533	239	1.01037	268	1.0029
153	1.01418	182	1.01667	211	1.01522	240	1.01015	269	1.00262
154	1.01433	183	1.01668	212	1.0151	241	1.00992	270	1.00234
155	1.01447	184	1.0167	213	1.01497	242	1.00969	271	1.00205
156	1.01461	185	1.0167	214	1.01485	243	1.00946	272	1.00177
157	1.01475	186	1.0167	215	1.01471	244	1.00922	273	1.00148
158	10.1488	187	1.0167	216	1.01458	245	1.00898	274	1.00119
159	1.015	188	1.01669	217	1.01444	246	1.00874	275	1.00091
160	1.01513	189	1.01668	218	1.01429	247	1.0085	276	1.00062
161	1.01524	190	1.01666	219	1.01414	248	1.00825	277	1.00033
162	1.01536	191	1.01664	220	1.01399	249	1.008	278	1.00005
163	1.01547	192	1.01661	221	1.01383	250	1.00775	279	0.99976
164	1.01557	193	1.01658	222	1.01367	251	1.0075	280	0.99947
165	1.01567	194	1.01655	223	1.01351	252	1.00724	281	0.99918
166	1.01577	195	1.0165	224	1.01334	253	1.00698	282	0.9989
167	1.01586	196	1.01646	225	1.01317	254	1.00672	283	0.99861
168	1.01595	197	1.01641	226	1.01299	255	1.00646	284	0.99832
169	1.01603	198	1.01635	227	1.01281	256	1.0062	285	0.99804
170	1.0161	199	1.01629	228	1.01263	257	1.00593	286	0.99775
171	1.01618	200	1.01623	229	1.01244	258	1.00566	287	0.99747
172	1.01625	201	1.01616	230	1.01225	259	1.00539	288	0.99718
173	1.01631	202	1.01609	231	1.01205	260	1.00512	289	0.9969
174	1.01637	203	1.01601	232	1.01186	261	1.00485	290	0.99662

DOY	d	DOY	d	DOY	d	DOY	d	DOY	d
291	0.99634	306	0.99228	321	0.98872	336	0.98592	351	0.98407
292	0.99605	307	0.99202	322	0.98851	337	0.98577	352	0.98399
293	0.99577	308	0.99177	323	0.9883	338	0.98562	353	0.98391
294	0.9955	309	0.99152	324	0.98809	339	0.98547	354	0.98383
295	0.99522	310	0.99127	325	0.98789	340	0.98533	355	0.98376
296	0.99494	311	0.99102	326	0.98769	341	0.98519	356	0.9837
297	0.99467	312	0.99078	327	0.9875	342	0.98506	357	0.98363
298	0.9944	313	0.99054	328	0.98731	343	0.98493	358	0.98358
299	0.99412	314	0.9903	329	0.98712	344	0.98481	359	0.98353
300	0.99385	315	0.99007	330	0.98694	345	0.98469	360	0.98348
301	0.99359	316	0.98983	331	0.98676	346	0.98457	361	0.98332
302	0.99332	317	0.98961	332	0.98658	347	0.98446	362	0.98327
303	0.99306	318	0.98938	333	0.98641	348	0.98436	363	0.98321
304	0.99279	319	0.98916	334	0.98624	349	0.98426	364	0.98316
305	0.99253	320	0.98894	335	0.98608	350	0.98416	365	0.98309

(Grant, 2011)