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It is certified that the work contained in the thesis titled ***"Mining land use/land cover information and changing landscape pattern analysis using remote sensing aided machine learning techniques"*** by ***Varun Narayan Mishra*** has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

It is further certified that the student has fulfilled all the requirements of comprehensive examination, candidacy and SOTA for the award of Ph.D. Degree.

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DECLARATION BY THE CANDIDATE

I, "***Varun Narayan Mishra***", certify that the work embodied in this thesis is my own bona fide work and carried out by me under the supervision of "***Prof. Rajendra Prasad***" from "***July 2013***" to "***December 2017***", at the "***Department of Physics***", Indian Institute of Technology (BHU), Varanasi. The matter embodied in this thesis has not been submitted for the award of any other degree/diploma. I declare that I have faithfully acknowledged and given credits to the research workers wherever their works have been cited in my work in this thesis. I further declare that I have not willfully copied any other's work, paragraphs, text, data, results, *etc.*, reported in journals, books, magazines, reports dissertations, theses, *etc.*, or available at websites and have not included them in this thesis and have not cited as my own work.

Varun

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(*Varun Narayan Mishra*)

Date: 26.04.18
Place: IIT (BHU), Varanasi

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It is certified that the above statement made by the student is correct to the best of my/our knowledge.

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LIST OF ABBREVIATIONS

Syntax	Description
AIC	Akaike Information Criterion
ANN	Artificial Neural Network
AWiFS	Advanced Wide Field Sensor
CA-MC	Cellular Automata-Markov chain
CSI	Classification Success Index
DT	Decision Tree
EMR	Electromagnetic Radiation
ETM+	Enhanced Thematic Mapper plus
EVI	Enhanced Vegetation Index
FCC	False Colour Composite
GIS	Geographic Information System
GLCM	Gray Level Co-occurrence Matrix
GPS	Global Positioning System
GWLR	Geographically Weighted Logistic Regression
GWR	Geographically Weighted Regression
ICSI	Individual Classification Success Index
IQR	Inter-Quartile Range
IR	Infrared
LISS	Linear Imaging Self-Scanner
LSWI	Land Surface Water Index
LULC	Land use and land cover
LULCC	Land use and land cover changes
MAH	Hellden's Mean Accuracy
MAS	Short's Mapping Accuracy

MC	Markov Chain
MLC	Maximum Likelihood Classifier
MLP-MC	Multi-Layer Perceptron-Markov chain
NDVI	Normalized Difference Vegetation Index
OA	Overall Accuracy
OLI	Operational Land Imager
OLSR	Ordinary Least Square Regression
PA	Producer's Accuracy
QUAC	Quick Atmospheric Correction
QUEST	Quick, Unbiased, Efficient, Statistical Tree
RADAR	Range Detection and Ranging
RF	Random Forest
RISAT-1	Radar Imaging Satellite-1
ROC	Receiver Operating Characteristic
ROI	Region of Interest
RS	Remote Sensing
RSS	Residual Sum of Squares
SAR	Synthetic Aperture Radar
SSI	Speckle Suppression Index
ST-MC	Stochastic-Markov chain
SVM	Support Vector Machine
TD	Transformed Divergence
TIR	Thermal Infrared
TM	Thematic Mapper
UA	User's Accuracy
UTM	Universal Transverse Mercator
WGS-84	World Geodetic System-1984

PREFACE

Land use and land cover (LULC) are assumed to be a fundamental constituent of the terrestrial ecosystem. It is an outcome of various natural processes and anthropogenic activities. Accurate and up-to-date LULC information is vital to scientists, planners, and decision-makers in forming strategies regarding economic, demographic and environmental issues from regional to global level. This information also assists to understand the impacts of natural phenomena better and convene the increasing demands for necessary human requirements and welfare. The changes in LULC termed as the alteration of Earth's terrestrial ecosystem by various human or natural activities. These changes are the comparatively new addition to the core concerns of global environmental changes research including climate change, biodiversity loss, global warming and the pollution of water, soils, and air. Remote sensing technologies, especially space-borne sensors offer a tremendous wellspring of information for concentrate understanding of earth's surface and its dynamics. It has been emerged as a powerful tool in deriving LULC information and its spatio-temporal distribution. However, LULC classification and information extraction from remote sensing images still remains a challenging task because of frequent cloud cover, heterogeneity of landscapes and varied climatic zone in countries like India. In the last few decades, the remote sensing technologies have evolved dramatically to include a series of sensors operating at a wide range of imaging scales with potential attention and significance to researchers. The aim of thesis presented here are: (1) to establish a robust classification process in improving LULC mapping accuracy by using multi-source remote sensing data (i.e. optical data, SAR backscatter) combined with textural information, (2) to investigate the feasibility of dual-polarimetric SAR data at C-band for rice crop mapping, (3) to estimate the spatial variation in accuracy measures of remote sensing image classification, (4) to assess the changes in LULC using multi-temporal remote sensing images, and (5) to model, simulate and predict the changes in LULC over a period by applying an integrated approach of remote sensing, geographic information system and land change modeling tools.

The LULC classification using remote sensing data has drawn a lot of attention with the launch of Landsat series satellites in the 1970s. Several classification algorithms have been developed and utilized for LULC classification using multi-source remote sensing data. The selection of a classification algorithm is always vital for successful and accurate mapping of land surface features. In spite of many studies in the field of remote sensing image classification, another current research interest is the reasonable selection of suitable input variables, which may have the same importance as the selection of classifier. Textural features as supplementary information can be incorporated into image bands in improving LULC classification accuracy. The quality of thematic maps derived from remotely sensed data also needs to be studied and requires enhanced methods or tools for estimating and describing the spatial distribution of errors in complex landscape mapping. The timely, accurate, and reliable LULC information provided by remote sensing technologies can be applied efficiently to monitor and analyze the past and current trends as well as to predict future LULC scenario. The multi-source remote sensing images namely the Linear Imaging Self-Scanner-IV (LISS-IV), Linear Imaging Self-Scanner-III (LISS-III), Landsat 8-OLI (Operational Land Imager), Advanced Wide Field Sensor (AWiFS), Radar Imaging Satellite (RISAT-1) and Sentinel-1A SAR data were acquired covering Varanasi district of Uttar Pradesh, India. Also, multi-temporal remote sensing images of Landsat 5-Thematic Mapper

(TM), Landsat 7-Enhanced Thematic Mapper Plus, and Landsat 8-OLI (Operational Land Imager) were acquired over a period of 1988-2015 to study LULC changes. The thesis begins with a brief introduction and state of the art explaining current trends on classification and mapping of LULC using multi-source remote sensing images and approach.

In the first phase, the research work focusing on the incorporation of textural features into spectral/radiometric images for LULC classification is presented subsequently, followed by the comparison of different classification algorithms. The research work provides explicitly a comprehensive evaluation of textural features extracted from the multi-source remote sensing data to examine how the varying spatial resolutions of different sensor image affect the selection of the textural component. The results show the efficacy of incorporating textural features into spectral or radiometric images in improving the LULC classification accuracy than individual datasets. The ability of textural features in reducing speckles and inherent heterogeneity within the same LULC type makes it significant for improved LULC information extraction, especially in case of the SAR and high spatial resolution multispectral LISS IV data. The Support Vector Machine (SVM) was found to provide more reliable and realistic results in comparison to the Artificial Neural Network (ANN), Random Forest (RF), and Maximum Likelihood Classifier (MLC) algorithms for LULC classification of remote sensing images. However, the performances of ANN, RF, and MLC were also found useful. A study was also conducted to explore the feasibility of RISAT-1 SAR data at C-band in delineating rice crop fields from other land cover features using Decision Tree (DT) classifier. The performance of DT classifier was found reasonably good for mapping spatial distribution of rice crop area accurately. The results were further compared with

Landsat 8-OLI optical sensor-derived rice crop map and found very good spatial agreement between both the outputs.

In the second phase, a geographically weighted method was used in combination with logistic regression for producing and visualizing the spatial variation of remote sensing image classification accuracy. This work showed how the logistic regression can be applied to create the probabilities of User's Accuracy (UA), Producer's Accuracy (PA), and Overall Accuracy (OA). The geographically weighted extension to logistic regression generates spatial distributions describing the variation of these probabilities. The results demonstrated that the geographically weighted method could offer additional and valuable insights for examining the spatial variation in the measures of classification accuracies varied across geographical space.

In the third phase, an integrated approach of remote sensing images, geospatial analysis, and modeling, along with the assortment of socio-economic factors and environmental variables was employed to study the changes in LULC and predict the future scenario in Varanasi district of Uttar Pradesh, India. In the first part of this research work, the post-classification method was employed to assess the changes in LULC occurred between 2000 and 2014. A paired samples t-test was also performed to test whether the changes are statistically significant or not between study periods. In the second part, three Markov chain-based hybrid models namely Stochastic-Markov chain (ST-MC), Cellular automata-Markov chain (CA-MC) and Multi-layer perceptron-Markov chain (MLP-MC) were evaluated and compared to model the spatio-temporal changes in LULC between 1988 and 2015 and predict the future scenarios for 2030 and 2050. The t-test only states that the changes do not correspond to a significant quantity statistically, even though LULC changes occurred in study periods. The outcomes of this research exhibited the overall constant increase of built up area and a considerable reduction in agricultural land. The results also show the potentiality of an integrated MLP-MC model for better understanding of spatio-temporal dynamics and predicting future scenario in Varanasi district of Uttar Pradesh, India. Therefore, the findings of this study might support the planners and decision-makers for sustainable management and development of this area.

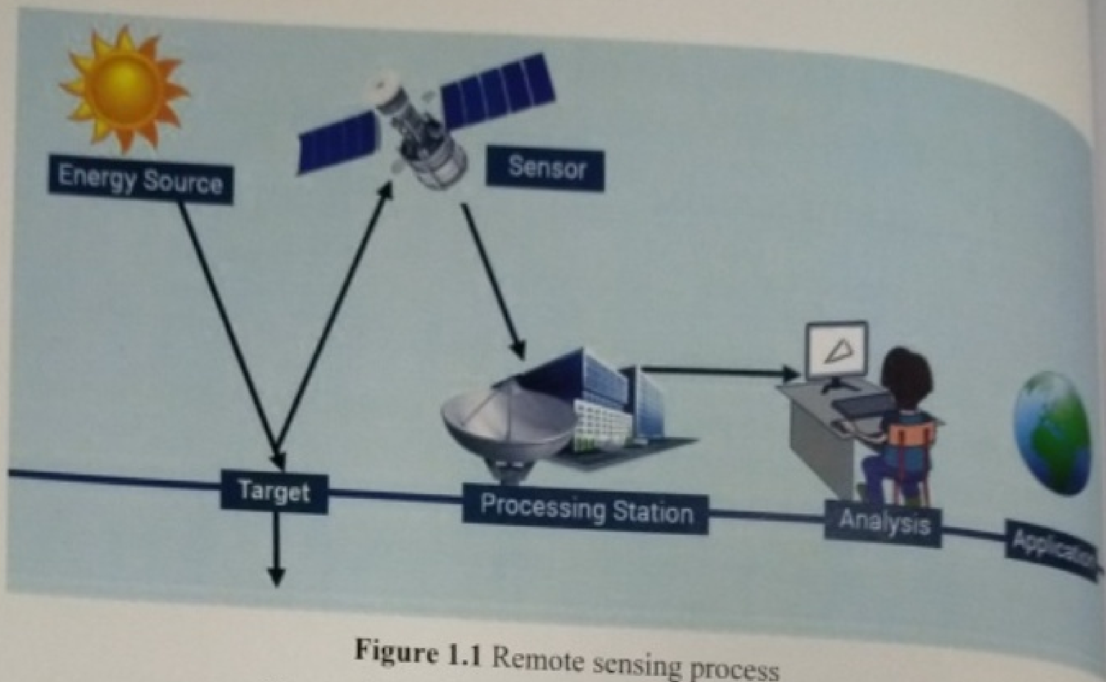

Figure 1.1 Remote sensing process
(**Source:** http://byjus.com/physics/remote-sensing)

1.2 BRIEF HISTORY OF REMOTE SENSING

Remote sensing has been with us for the longer time. In the 1600s, Galileo used optical enhancements to survey celestial bodies. In 1858, Parisian photographer Gaspard Felix Tournachon used his balloon to made photographs over Bievre, France. In later years, kites, messenger pigeons, rockets and unmanned balloons were also used for the acquisition of images. The modern regime of remote sensing arose with the development of aircraft and satellites. The field of remote sensing has experienced some major changes during the period from 1960-2010.

The word remote sensing was first introduced in 1960s and before that, it was generally termed as aerial photography. During 1960s to 1970s, the airborne platforms carrying remote sensing devices were moved to the spaceborne platforms or satellites. It facilitates observations across larger extents of Earth's surface than is possible by traditional ground-based observations at regular interval. During the 1960s, National Aeronautics and Space