

EVALUATING THE TOPOGRAPHY AND CLIMATIC VARIABILITY ON AGRICULTURAL LAND USE CHANGES IN SEMI-ARID TERRAIN. USING EO-1 ALI AND ETM+ DATA

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ABSTRACT:

The growth of human population, increasing demand for agricultural production and concerns about food security in the world are among the reasons for growing interest in land monitoring based on satellite remote sensing. The semi-arid regions are also very sensitive to global climate change and all vegetation there depends strongly on weather conditions and water availability. The objective of this study is to evaluate the topographical changes and climatic variability on agricultural land use changes in semi-arid terrain using hyperspectral and multi spectral remote sensing data. Multi temporal Landsat TM & ETM+ and EO-1 ALI data were used for extracting agricultural land use changes. Through these analyses describe the changing character of agriculture in this region, and by integrating this hyperspectral data with biophysical information on climate and hydrology it is possible to evaluate the hydrologic impact of various water extraction and diversion schemes. The information provided in this study has many areas of application, including in environmental management and planning, hydrological watershed analysis and modeling, landform and natural resource evaluations, and hydropower infrastructure planning and construction.

1. INTRODUCTION

The growing need for quantitative studies on biogeophysical and – chemical processes in vegetation analysis for agricultural purposes on the one hand, and ecosystem functioning on the other hand, implies both higher spectral and spatial resolution of spaceborne remote sensing devices, together with improved radiometric performance and accurate reallocation. Environmental variability is the key issue when addressing agricultural production in arid and semi-arid regions. Alternating periods of variable length of relatively dry and wet years are common in these regions.

Climate variability, which mainly affects rainfall, is inherently part of the system. Considerable effort has been expended in studies on large-scale and general circulation modeling to assess climatic risk. However, downscaling to the local level to assess climate risk for agricultural areas and crops has proven difficult. In addition, there have been attempts to account for inter-annual climate variability. The interactions between climate and water availability have been fundamental to many human activities, in particular agricultural production, in the past and will continue in the future as well. An increase in temperatures could also lead to a net deficit in atmospheric water content, thus excessive evaporation from soil, water and plant surfaces would occur.

Multitemporal satellite data provide the capability for mapping and monitoring land cover and land use changes, but require the development of accurate and repeatable techniques that can be extended to a broad range of environments and conditions. In this study, the suitability of Landsat ETM+ and EO-1 ALI data for Agricultural land use classification and changes in a typical arid agricultural environment with its small-spaced fields is evaluated. Land use determination from Multispectral data is performed using both a well established image processing approach (PCA and Band

Ratios) and a multiscale object-oriented method which allows to derive meaningful image segments on the one hand and to describe the segment's physical and contextual characteristics on the other hand.

2. OBJECTIVES

The objective of this study was to explore the use of multi-temporal Landsat TM & ETM+ and EO-1 ALI data from the same growing season for the classification of agricultural land cover changes in the semiarid environment.

3. STUDY AREA

The study area is located in Vellore district, Northern Tamilnadu, between latitudes, 13°12'32" N and longitudes, 78°24'16" E in the west of Vellore city figure 1. Study area covers an area of 825 sq km with a variety of geological formations, climatic conditions and vegetation types (i.e., forests, scrublands, grasslands and agricultural lands).

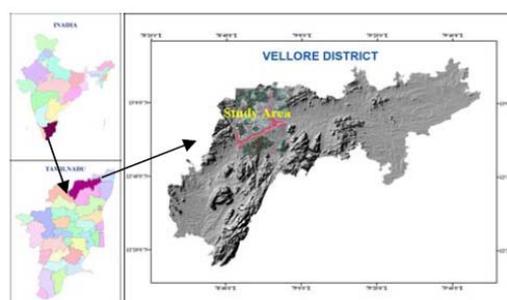


Figure 1. Location of the Study Area

3.1 Physiography and Climate

Physiographically the study area is undulated terrain with local elevation and low-lying areas figure 2 (A). The study area is of an elevation varying from 250 to 830m above MSL in the mountain areas. Diversity in land forms of study area has resulted in a variety of forest and agricultural systems in the region. Vellor river is the main lifeline of the district with most of the settlements located alongside the river. Generally subtropical climate prevails over the district. The temperature rises slowly to maximum in summer months up to May after which it drops slowly. The mean maximum temperature ranges from 28.2oC to 36.5o C and the mean minimum temperature from 17.3oC to 27.4oC. The normal mean maximum and minimum temperature for Vellore and Tiruppathur stations are recorded Table 1. The normal average rainfall of this district is 953.4 mm Table 2.

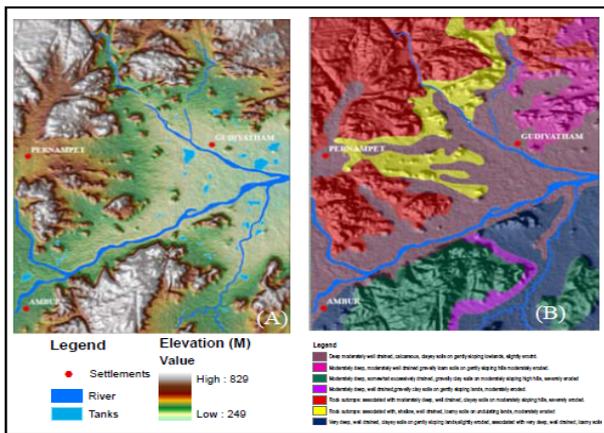


Figure 2. (A) Topography Map B). Soil Map of the Study Area

Station	J	F	M	A	M	J	J	A	S	O	N	D
VELLORE												
Max	28.3	29.7	31.7	33.3	35.6	36.5	34.4	33.9	33.5	31.2	29.2	28.2
Min	20.8	20.8	22.9	25.8	27.4	27.2	25.8	25.4	25.4	24.4	22.7	21.4
THIRUPPATHUR												
Max	29.5	32.5	35.4	36.5	36.5	34.9	32.9	33.4	32.9	30.6	28.9	28.4
Min	17.3	17.5	19.6	23.1	24.1	23.7	23.0	22.9	22.3	21.5	19.4	17.6

Table 1: Normal Mean Temperature (Celcius)

Sl. No	Season	Period	Rainfall in mm	Percentage
1.	Winter	January to February	23.2	2.4
2.	Hot Weather Period	March to May	102.1	10.7
3.	South West Monsoon	June to September	448.8	47.1
4.	North East Monsoon	October to December	379.3	39.8
Total			953.4	100.0

Table 2: Normal Average Annual Rainfall (Season wise)

3.2 Geology and Soil

Geologically the study area consists of mainly Charnockite, Fissile hornblende-biotite gneiss and sand and silt. Mountains with dense and scattered vegetations, weathered and solid rocks, complex slopes with exposures, south and north looking faces, and various soil types (alluvial, colluvial and/or residuals) with varying depth normally show a great variability figure 2 (B).

3.3 Agriculture

Two methods of water withdrawal currently dominate irrigated agriculture in the study area: (1) floodplain irrigation, (2) groundwater extraction. Combinations of the three are also observed. From the perspective of spatial distribution, floodplain irrigation represents the most “traditional” irrigation system. In the relatively flat floodplain crops can draw on the moisture of natural river floods, can be watered using small gravity-driven diversions and levee breaks, or can be irrigated to some distance (though little topographic rise) using low-power diesel and electric pumps. Under this irrigation regime agriculture is limited to the fertile valley that surrounds the river figure 3. In this system more powerful diesel pumps are used to draw irrigation water from tens to hundreds of meters below the surface, servicing one or two fields at a time. In marked contrast to the floodplain system, irrigation by groundwater withdrawal does not require that farms be clustered around a surface water body; a dispersed distribution of farms may, in fact, be favorable in order to avoid local drawdown of the water table or depletion of an isolated aquifer. For the well irrigator the distribution of water is defined by hydrogeology rather than surface drainages, and the distribution of agriculture reflects this change.

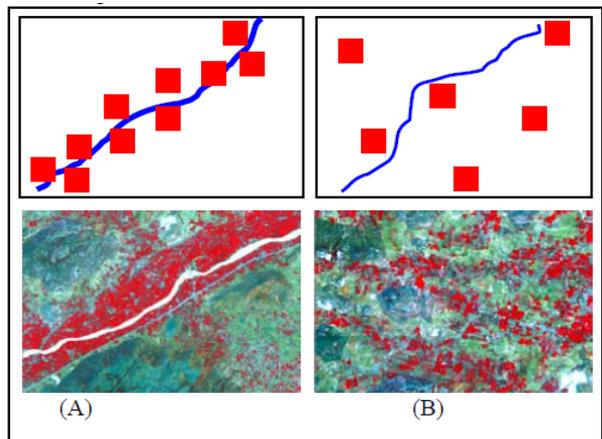


Figure 3. Schematic Diagrams of Identified Agricultural Field Distribution under (A) Floodplain and (B) Groundwater, with 5-4-3 False Color ALI Images of Example in the Study area

4. DATA USED

Landsat TM and ETM + were used in this study. The Landsat ETM+ image (Path143, Row 51) 24-02-2001 was downloaded from GLCF (Global Land Cover Facility) (<http://www.landcover.org/data/>). The Advanced Land Imager (ALI) satellite sensor was designed in part to provide future data continuity with the Landsat record (<http://eo1.usgs.gov/ali.php>). Although the EO-1 ALI swath width (37 km) is more restricted

than that of Landsat (185 km), and ALI acquisitions must be scheduled in advance, the ALI sensor is pintable. The spectral range and spatial resolution of bands for each sensor are given in Table 2. The ALI measures solar irradiance in 9 multispectral bands between 0.433 and 2.35 μm , providing 3 more multispectral bands than Landsat TM or ETM+. The spatial resolution of the panchromatic (PAN) band is 10 m, compared to the 15 m resolution of the ETM+ panchromatic band. Furthermore, ALI data are 16-bit rather than 8-bit, offering greater dynamic range. ALI data was downloaded from USGS earth explorer <http://edcsns17.cr.usgs.gov/EarthExplorer/>. Topographical data ASTER-DEM (30m) was downloaded from <http://www.gdem.aster.ersdac.or.jp/login.jsp>.

Band	EO-1 ALI		Landsat ETM+	
	Wave Length (μm)	Ground Resolution n (m)	Wave Length (μm)	Ground Resolution n (m)
1p	0.433-0.453	30	n/a	n/a
1	0.45-0.515	30	0.45-0.515	30
2	0.525-0.605	30	0.525-0.605	30
3	0.633-0.69	30	0.63-0.69	30
4	0.775-0.805	30	0.78-0.90	30
4p	0.845-0.89	30	n/a	n/a
5p	1.2-1.3	30	n/a	n/a
5	1.55-1.75	30	1.55-1.75	30
7	2.08-2.35	30	2.09-2.35	30
Pan	0.48-0.69	10	0.52-0.90	15

Table 2: Band Characteristics for LANDSAT ETM+ and EO-1 ALI sensors. n/a = "Not applicable"

5. METHODOLOGY

Data processing and interpretation for this work were performed at the Center for Remote Sensing and Geoinformatics at Sathyabama University Chennai, Tamilnadu. ERDAS IMAGINE 9.1 and ENVI 4.5 were the main software packages used for the image processing. The overall methodology for this study is presented in figure 4.

5.1. Data Fusion

For each sub scene, 30-m resolution Landsat 7 ETM+ Multispectral bands 1 to 5 and 7 were fused with the 15- m resolution panchromatic band figure 5. For 30-m resolution EO-1 ALI multispectral bands 2 to 9 were fused with 10-m resolution panchromatic band. The resulting fused bands were spatially enhanced while keeping the spectral characteristics close to the original Multispectral bands. Some qualitative and quantitative analyses were implemented to assess the spatial and spectral quality of the fused images. The results show that it was possible to carry out the fusion of a narrow-band Hyperspectral image and a high spatial resolution panchromatic image.

5.2 Optimum Band Selection

Once the training statistics were assembled from each band for each land cover, a decision must be made to determine the most suitable bands for discriminating the land cover classes in the imagery figure 6. For this purpose, the Principal Component Analysis (PCA) was performed to obtain new channels in the classification process.

The first four PCA channels of each date having total variance higher than 99% were used within the analysis. In addition to PCA channels, most effective bands were identified through examining class separability based on the divergence of the class signatures. As a result, a subset of best four bands was extracted for each scene.

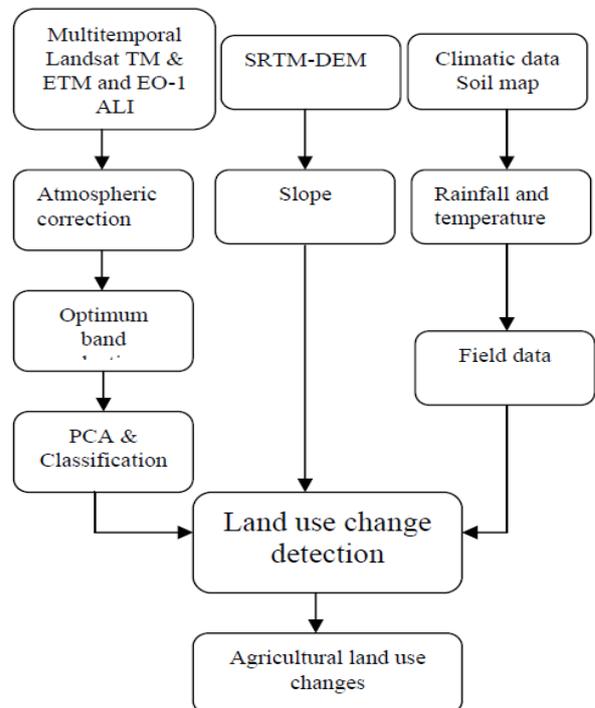


Figure 4. Flow Chart of the Different Methodological Steps in the Image Analysis Process

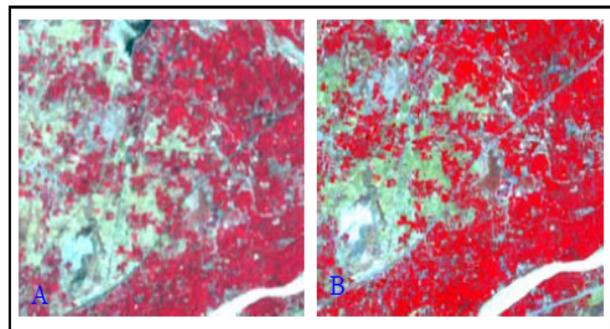


Figure 5. Resolution Merged ALI Data. A. 30-M Resolution Multispectral Data. B. 10-M PAN Merged Multispectral Data

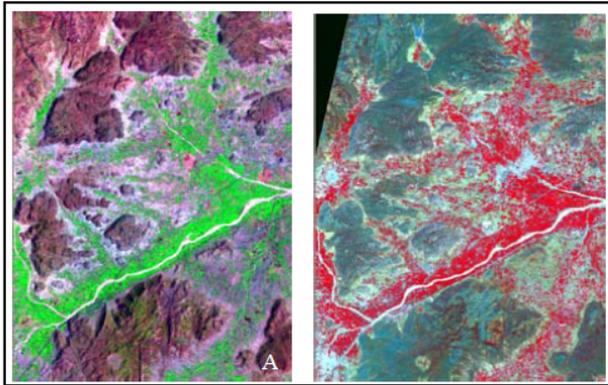


Figure 6. A. Lands at ETM + (7-4-3) B. EO-1 ALI (5-4-2)

5.3 Principle Component Analysis (PCA)

PCA can be applied to compact the redundant data into fewer layers and can be used to transform a set of image bands, as that the new layers (also called components) are not correlated with one another (Cees & Farifteh, 2001). High correlation between bands in multi spectral images such as Landsat image cause a lot of redundancy and finally give mixed pixels, which complicate classification. Principal Component Analysis is a statistical method used for compressing the original data set without losing too much information. A Principal Component Calculation is known as a method to extract or reduce the spectral noise/redundancy (Richards, 1993). Principal Component Analysis is collecting the information of the spectral bands used in a cloud of points in a multi dimensional space and calculates a new optimum set of axis through these cloud data points. The number of Principal Component equals the number of input bands. The first PC is defined by maximum variance of the original data set; the last PC defines the leftover variance (Janssen & Herwijnen, 1994).

- PC1: Useful for studies of the agricultural land and geology.
- PC3: Useful for studies of the bare soil.
- PC4: Useful for studies the agricultural lands.

5.4. Image Classification

Classifications procedures were applied on each Landsat and ALI scene separately by using different classification methods including supervised and unsupervised classification.

5.4.1. Unsupervised Classification: Unsupervised classification where the classification is based on the aggregation of the classes depending on the spectral reflectance. The iterative Self-Organizing Data Analysis Technique (ISODATA) was employed as a clustering algorithm.

5.4.2. Supervised Classification: Supervised classification where minimum distance to means, and maximum likelihood classifiers were run on the Landsat and EO-1 scenes (ALI & ETM). This approach is totally dependent on the spectral pattern recognition (Lillesand, 1994). The supervised classification technique is preferred, because the data of the study area is known and the prior

knowledge about the nature of the study area was available. Training areas were used for the supervised classification of each image. These training areas were delineated from a false color composite image. These training sites represent agricultural areas, semi natural areas and water bodies. To avoid misclassification, these training areas were homogeneous. Ancillary data such as aerial photos, ground truth points, and ETM & ALI were considered during the selection of training areas in order to obtain the test accuracy of the classification results. In the combination of multi-spectral bands, three bands including ETM4, 3 and 2 were used to supervise classification, which is based on ground data collected in the field, from training sample sites. Supervised classification is the procedure that user predefines spectral classes.

6. RESULTS AND DISCUSSION

6.1 Classification Results

The various landforms and its changes of the studied area were delineated by using the multitemporal Landsat TM & ETM+ and EO-1 ALI data, digital elevation model, and ground truth data. Both, the ETM+ and ALI supervised classification produced good results in discriminating between Agricultural land and bare soil and between cultural features and forest. When the spectral responses in all bands used were examined before the classification, ETM showed poor discrimination between bare soils and Agricultural field. However, it showed good results in discriminating ALI Spectral bands. Overall, the integration of the images into a GIS database, and the postclassification analysis were the key for the production of reliable results. In this study, totally, five LULC classes were established as agriculture, bare soil, pasture, rock outcrop, urban and water. Description of these land cover classes are presented in Table 3. Two dated Landsat TM & ETM and ALI images were compared supervised classification technique figure 7 & 8. Tables 4 portray the attributes and the areas derived from the supervised classified TM & ALI scenes.

Land Cover Classes	Description
Pasture	Areas consisting of arid lands with short vegetations
Bare Soil	Areas with no vegetation covers, stock quarry, stony areas, uncultivated agricultural lands
Water	Tanks
Urban	Residential,
Agriculture	Almost all are green cultivated area

Table 3. Major Land Covers Features Identified in the Study Area

Chart 3 shows different land use land cover feature percents in result of supervised classified Landsat and ALI data. Here it shows clearly topographically the study area increased agriculture in some parts but due to insufficient rainfall and groundwater lowering the agricultural activities is decreased in some of the places in study area. In other land cover features like rock outcrops and pastures are decreased due to deforestation in semiarid terrain.

6.2. Land Cover Changes

Differences between each land cover through time were computed, based on the change detection technique explained previously, for each time-period. Arc GIS 9.2, in conjunction with the change masks produced in ERDAS, were used to generate the output raster maps showing the changes. The new maps were developed representing all combinations of category values resulting from the cross tabulation of the input maps. A reclassification was then used to obtain the final map showing the changes that occurred in the area. Field visits to the areas that showed greatest change, and work with ancillary photographs and archives for the early years were undertaken in order to evaluate the reliability of the change-maps.

S.no	Landuse /Landcover	TM 1991 (km ²)	ALI 2004 (km ²)	Changes (km ²)
1.	Agriculture	93.14	118.06	+24.92
2.	Rocky outcrops	527.97	452.77	-75.2
3.	Pasture Lands	152.16	151.72	-0.44
4.	Bare Soils	53.38	89.18	+35.8

Table 4. The Attribute Data Derived from the Supervised Classification of Landsat TM (1991) and ALI (2004) Scenes.

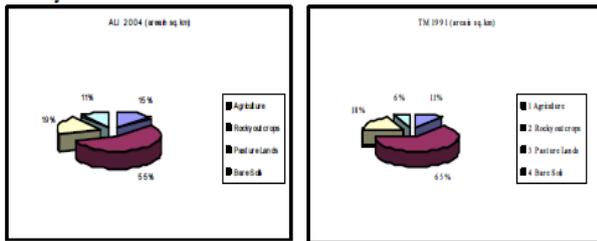


Chart 1. Land Cover Statistics Derived from Using Supervised Classification of Landsat TM (1991) and EO-ALI (2004) of the Study Area

Results from the analysis indicated that significant differences in land cover classes were observed between ETM & ALI images. The land classifications were greatly influenced by season or the time of the image was taken with respect to the annual cycle, as well as weather conditions preceding collection of the data. In this image a more diversified classification over agricultural cultivation fields appear by the fully growing summer season. As expected the classifications will also be limited by the image resolution. For these particular images, with a 10-m pixel resolution, the classification procedure generated a great deal of mixed classes especially over narrow concrete or asphalt tar paved roads, highways and small buildings with various neighboring surfaces. The ALI classification was also sensitive to moisture content, illustrated by the even differentiation within the same crop field. The additional bands ms1' at 0.433 μm, ms4' at 0.845 μm, and ms5' at 1.200 μm included in ALI data, can be beneficial for detecting crop growth condition, inland water quality and more detailed soil differentiation in crop fields. Both Landsat and ALI data can be used effectively for land cover classification, however the higher resolution of ALI data does provide better separation for many of the classes. Figure 8 shows a subset of the ALI 04-03-

2004 classification image and the Landsat 7 TM image acquired on 10-04- 1991(Figure 7).

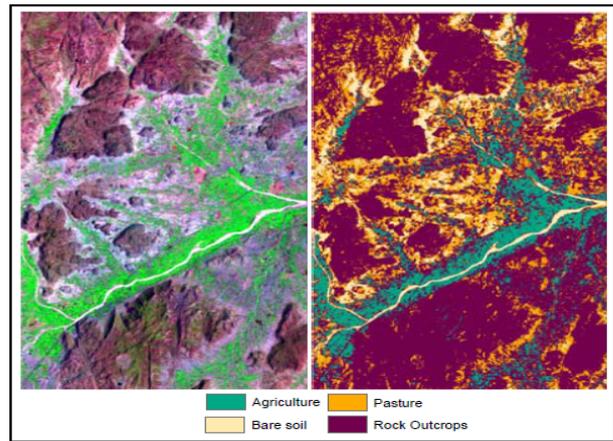


Figure 7. Landsat TM (1991) Scene on the Left Side and the Derived Thematic Data of the Supervised Classification on the Right Side

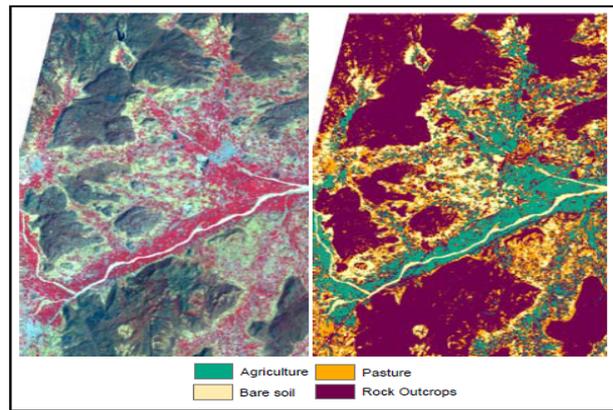


Figure 8. EO-1 ALI (2004) Scene on the Left Side and the Derived Thematic Data of the Supervised Classification on the Right Side

6.3. Agricultural Land Cover Changes According to Climate and Topography

The relationship between Agricultural land cover and topography, in the time period of 1991-2004, was analyzed by using multitemporal Satellite data and Digital Elevation Model (DEM). Before all else, how land use/land cover was changed in the course of time was determined according to elevation and climatic variability. The results of analysis of land cover in performed according to topography and rainfall are given in Figure 9 &10. Agricultural lands were mostly located in the region with 250-400 m of altitude and a decrease occurred in agricultural area with the increase in altitude. Since the mountains start right after the sea coast, there are forest areas in the coastal region in study area. As these areas are mostly rugged, they can be used as neither residential nor agricultural areas. The forest areas are densely located in the regions with 1000 m of altitude in the study area, and the forest area is more than the other kinds of lands in places with high altitude.

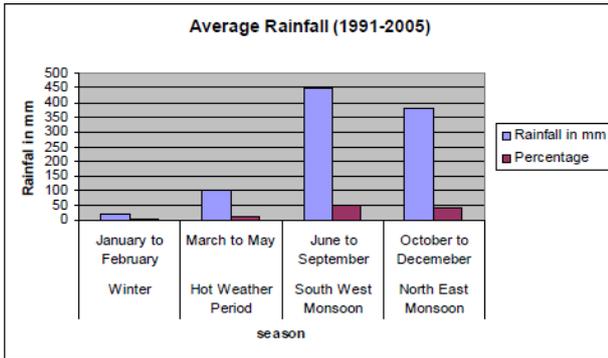


Figure 9. Average Rainfall in Gudiyatham and Ambur Stations From 1991 – 2005

CONCLUSION

This paper aims investigating agricultural land use changes occurred in arid region between 1991 and 2004 using Landsat TM, ETM+ and EO-ALI remote sensing data and GIS. The LULC changes were analyzed according to climate and topographical variability. The main change observed for the time period of 1991-2004 was that the area of agriculture was increased in some part and decreased in most of the part in study area. Some difficulties faced in determining LULC using remotely sensed data in the study area. The mountainous and sloping topographic structure of the region and complex vegetation of the area and negative climate conditions are the essential reasons for those difficulties. For this reason, it was quite hard to find usable satellite images. There were also some other problems that had stemmed from using different sensor technologies (spatial resolution and spectral resolution) in comparing Landsat ETM+ and ALI data, and in determination of land cover. These problems were tried to be eliminated by independently applying supervised classification change detection technique to both images. Compared to Landsat data, it provides nine observation bands between visible and short wave infrared. Since it includes one additional blue range wavelength, one more in the near infrared, and the other in the short wave infrared, it shows great sensitivity over water bodies and vegetated regions. It also gives a better spatial resolution. ALI data can be easily generated to 10 meters resolution using its panchromatic band.

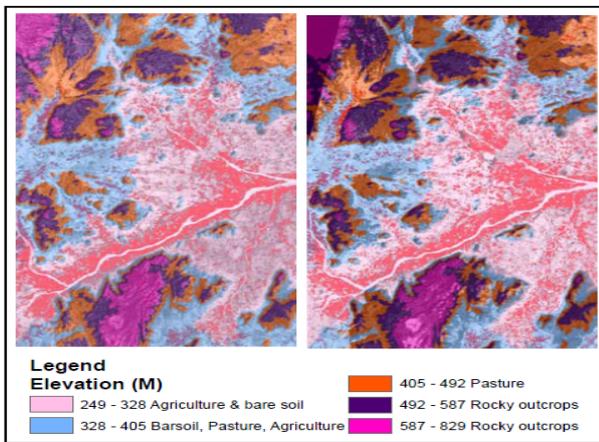


Figure 10. Example of Land Use \ Land Cover Map With Elevation. A) Landsat TM 1991, B) EO-1 ALI 2004