Assessing spatial structure of vegetation patches at multi-spatial resolutions and studying effect of scale for analyzing spatial variation

PRIYANKA SHARMA
March, 2012

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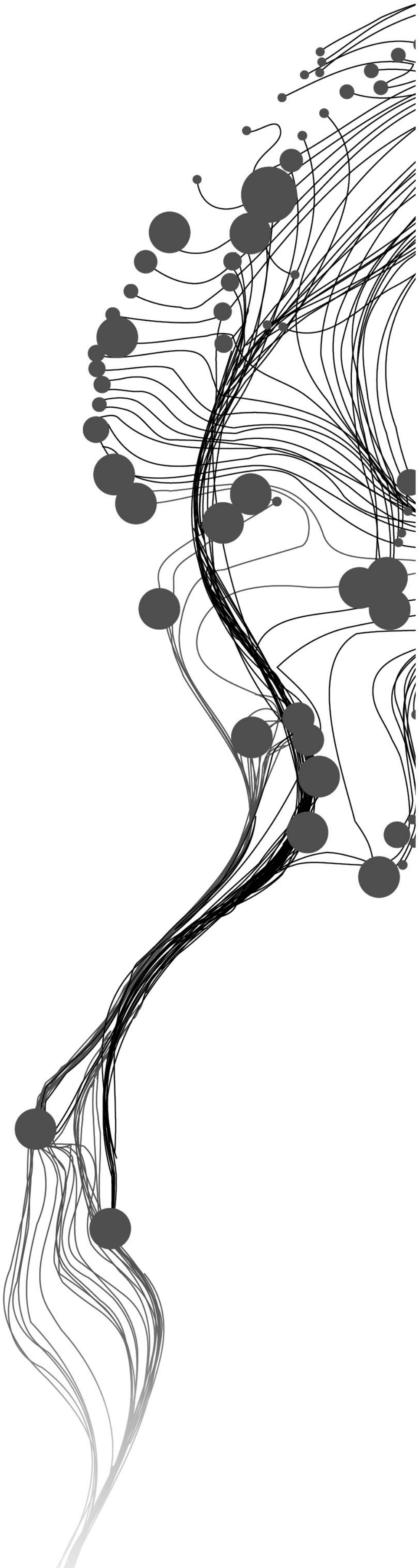

Assessing spatial structure of vegetation patches at multi-spatial resolutions and studying effect of scale for analyzing spatial variation

PRIYANKA SHARMA
Enschede, the Netherlands, March, 2012

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Geoinformatics

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ABSTRACT

With objective to explore potential of variogram analysis for analysing spatial structure of vegetation across scales, present study was an attempt to quantify spatial structure of vegetation patches at three different resolutions (LISS IV, LISS III and AWiFS) and to model it using variogram parameters (nugget, sill and range). Initially variogram analysis was carried out on subsets selected from different vegetation types(namely dense forest, open forest, agricultural land and mixed forest) taken from two study areas Dehradun & Haldwani (mainly Sal, Pine and Oak trees) to understand the spatial structure of these subsets at LISS IV resolution. It was found that variogram behaviour was almost similar for dense and open forest but variance was much higher for agricultural land and a patch present in urban areas. Four cases A, B, C and D were constructed to study the information associated with the patch boundary where Case A includes homogeneous vegetation patch, Case B includes non vegetation area present along the boundaries of a vegetation patch, Case C includes binary image having two classes i.e. vegetation (0) and non vegetation (1), and Case D includes the area after excluding a vegetation area (Case A). Variogram analysis across scales of homogeneous patches revealed the spatial structure of vegetation patches at different scales A change was observed in variogram parameters due to seasonal variation. Binary and non binary images have shown different variogram behaviour, smaller range in binary cases as compared to gray images represented in Case B. Also, the binary images had higher variance increasing exponentially as expected as binary cases represented indicator variogramps of presence/absence of vegetation patch. It was observed that homogeneity of a vegetation patch relates to variance and range of a variogram. Different variogram behaviours of simulated and original images reveal that seasonal and temporal factors associated with vegetation have a strong impact on variogram shape thus a change in spatial structure of the vegetation patches.

The study helped us to quantify spatial structure of vegetation patches considered and thus provided help to decide appropriate resolution of study for a particular type of vegetation. As spatial structures also indicates texture signature, outcome of this study can further be explored for its potential for a higher level of vegetation classification.

KEY WORDS Scale, Resolution, Vegetation Patches, Spatial Structure, Pattern, Shape, Boundary, NDVI, Variogram, Geostatistics, Transition Zones

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1. INTRODUCTION

1.1. Background

Vegetation communities present on the earth's surface play a significant role in studying and characterization of land surface. Vegetation is not just a source of consumption but, also have an important role in ecological and socio-economic context. Information extracted from the vegetation surface is an important indicator of land use and is highly useful for environmental applications and processes. Vegetation is one of the most important and vital resources present on the earth's surface but, at the same time, extensive deforestation, settlement of urban areas and development of land leads to severe environmental problems like soil erosion, global warming, biodiversity loss, vegetation health, land degradation and many more. There is an immense need to conserve these vegetation areas as they are not only important for environment and biodiversity but also an important source of fuel, wood and various other natural resources. In order to study the forest distribution, vegetation mapping, land use land cover mapping, various studies have been carried out so far.

Vegetation can be present in several forms like Dense forest, Open forest, National Parks, Orchards, Irrigation land etc. Studying the distribution and pattern of these forests present on the earth's surface can be an important aspect for ecological studies. Group of trees which are present on the earth's surface are also treated as vegetation patches and have an important aspect in socio economic context.

Vegetation patches can be in different forms like group of trees, trees along the road sides, group of trees, irrigation land, orchards, dense forests, open forests. Patches which are surrounded by urban areas, dense forests are very important for socio economic purposes (*Tyrvainen et al., 2005*).

Ground survey is one of the most popular methods to collect information of the vegetation spread across the area. However, there are several issues that are associated with ground surveys, they are time consuming, expensive in nature and can also damage the existing vegetation (*McCarthy, 1996*).It has been said that, out of several sensor systems and interpretation techniques, it is clear that remote sensing technologies are more powerful and economical to analyze the extent and health condition of the vegetation present on the earth's surface (*Hoffer et al., 1984*). For this reason, remote sensing was introduced for mapping and monitoring vegetation and its arrangement on the earth's surface. Several technologies are being used so far in studying vegetation communities present on the earth's surface like aerial photography, RADAR images, LIDAR technologies, image processing etc. Studied and analyzed several methods of studying the vegetation structure and mapping and it was also observed that LANDSAT gives comparatively better and economical methods to monitor vegetation. RADAR has a calibre to differentiate different vegetation species present in a particular area

1.2. Importance of vegetation mapping

Vegetation mapping not only deliver immense ground information but it also ensures the conservation of our ecosystem and wildlife. For the conservation of nature and enormous number of species present on the earth's surface, mapping of vegetation is an important need. Mapping of vegetation can be performed either with Ground surveys or using remote sensing imageries. Due to immense advancement in remote sensing technologies, vegetation mapping using remote sensing images is preferred. With remote sensing, vegetation mapping includes very large era of choices of images and technologies like image enhancement, image classification, image filtering and many other processing technologies. *Xie et al., 2008* reviewed several technologies for vegetation mapping and studied about an importance of vegetation mapping using remote sensing images. However, prime focus was on the comparisons of different sensors (SPOT, MODIS, Landsat TM and ETM+) for vegetation classification and different image processing methods. Vegetation mapping can also help in mapping major vegetation communities, formations, vegetation species, several ecosystems, environmental communities and water communities.

1.3. Motivation and Problem Statement

Describing the distribution and spatial structure of various vegetation entities present on the earth's surface is an important element of environment conservation. It was observed that studying the arrangement and distribution of vegetation patches present on the earth's surface can be important for the conservation of both wildlife habitat and wild plants *(Johnson et al., 2004*). In order to study deforestation in urban areas and analyzing the impact of human activities on vegetation land, there is a need to study and quantify the spatial structure of vegetation patches.

Spatial extent of vegetation patches is also one of the motivating factors behind this research. Vegetation patches are usually identified and reached through their boundaries and edges. In satellite imageries, they can be identified through their boundaries. Determination of boundaries and extent of vegetation patches can help in handling wildlife corridors, conservation of species and many other purposes. Fuzzy and vague boundaries associated with these vegetation patches lead to wrong interpretation of spatial extent of these patches which can generate severe issues to the problem of class (vegetation and non vegetation) and patch definition. Problem with class definition is one of the motivating factors behind this research. It is important to identify the correct spatial extent of these vegetation patches to avoid vague boundaries and confusion in defining transition zone of these patches. Several motivations are present to study the spatial analysis but common element behind all the motivations is the quantification and analysis of spatial pattern and their distributions.

In the recent past years, remote sensing technology has participated in the development of various technologies that are used for detecting patterns and spatial structure of these vegetation patches. Spatial structure helps in determining the distribution of pixels and their arrangement inside a patch which can be helpful in determining the heterogeneity level present inside a patch. Pattern present in these vegetation patches may reveal different tone and texture in satellite images. On the basis of these measures of texture of DN values, homogeneity and heterogeneity present in a patch can be determined

To study the spatial structure of geographic entities, variogram is a commonly used tool in geostatistics (*Isaaks and Srivastava, 1990*) and spatial structure which is present in vegetation patches can be quantified using variogram parameters like nugget, sill and range. Variogram calculation and estimation can be done to quantify the spatial structure of vegetation patches in order to determine the potential of variogram to study the spatial structure. It can be check with the help of this study that up to what extent variogram are appropriate in analyzing the spatial extent and spatial structure of patches.

Problem with class definition can be described using Binary images (0: vegetation and 1: non vegetation). NDVI images are gray tone images that explain the vegetation health in detail; their value lies between -1 and +1. It can be possible that, there could be some uncertainty along the vague boundaries of vegetation patches while classifying an image into vegetation and non vegetation, due to which, non vegetation class can come under vegetation and vice versa. It can be interesting to observe, whether this uncertainty can be quantified on comparing the variogram parameters of Binary and NDVI image and analyzing the difference between the corresponding variogram parameters. Further, existential and extensional uncertainty will be interesting to observe across the boundary of these vegetation patches where extensional uncertainty can help in analysing that up to what extent the vegetation patch exists while existential uncertainty helps in finding whether there is a patch present or not.

Spatial structure of vegetation patches contains some important indicators like shape, size, pattern, texture and tone. However, spatial structures of geographic entities like vegetation patches may vary at different resolutions i.e. the shape and pattern of these patches will be different at different scale (*Nayak, 2008*). In order to quantify the spatial variation and change in spatial structure of a patch on moving from high to low resolution, variogram modelling can be done. Change in resolution will also change variogram parameters and shape of a variogram, if it is possible to quantify this variation in vegetation patches, variogram modelling will be of much more importance. Shape of a patch will also change with the change in resolution and there is an immense need to check up to what extent variogram parameters can reveal some information about the shape of a patch or not.

Wallace et al., 2000 studied spatial structure of vegetation using variogram modelling of ground data and recommended to use low resolution satellite imageries to study the spatial structure of vegetation. In order to explore the suitability and potential of low resolution data set there is an immense need to characterize these vegetation patches at different resolutions datasets that are readily available in India at low cost. Studying the spatial structure of a vegetation patch can help in the forestation and wasteland developments but analyzing the spatial structure and distribution of these patches without having a proper knowledge of an appropriate resolution may lead to waste of the resources and money.

1.4. Research Objective

1.4.1. The main objective of the present study is:

To determine how the spatial structure of the vegetation patches varies at multiple spatial resolutions and to study the effect of resolution.
Spatial structure of a vegetation patch will be studied using variogram modelling of NDVI values at different resolutions (LISS IV, LISS III and AWiFS). Variation along the variogram parameters (nugget, sill and range) will be interpreted to quantify the spatial variation.

1.4.2. Specific Objectives

1. To study and quantify the spatial structure of vegetation patches at three different resolutions (LISS IV, LISS III and AWiFS) using variogram modelling.
2. To analyze the spatial variation in selected vegetation patches using variogram parameters across different resolutions.
3. To develop several scenarios to understand the relation between boundary of a patch and variogram parameters.
4. To find out the resolution of the data set that gives the highest and the lowest variance for these vegetation patches.

5. To compare and interpret the variogram estimations for both binary (0 and 1) and non-binary (NDVI) images generated from the data set at three different resolutions.

1.5. Research Questions

1. Is there any specific variogram model that fits for the selected vegetation patches? (RO:1)
2. Which resolution among the data set gives highest and lowest value of variance? Why? (RO:2)
3. Is it possible to quantify the change in the spatial structure of a vegetation patch using variogram parameters across different resolutions?
4. Is there any indication from variogram parameters on the shape and boundary of a vegetation patch? (RO:4)
5. Is there any information associated with the NDVI values to analyze the spatial structure of the vegetation patches as compared to the Binary images (0 and 1)? (RO: 4)

1.6. Research Outcome

This research will help in interpreting the spatial structure of the vegetation patches at different resolutions in order to determine the utility of variogram modelling in characterizing the structure of vegetation patches, to determine the uncertainty present along the vague boundaries of patch, to quantify the spatial variation on moving from LISS IV to AWiFS images.

Further, this research will help in analyzing the efficiency of low resolution data sets in characterizing the vegetation communities present on the earth's surface which can further help in forestry projects and monitoring vegetation changes.

1.7. Thesis Overview

Chapter 2 constitutes Literature review in which studies on spatial structure, Geostatistics, Scale and Resolution are discussed. Meaning of scale and resolution in different contexts are being discussed in detail in this chapter.

Chapter 3 includes Study area and Data processing, detailed description about the location of study area, vegetation species which are present in this area and specifications of remote sensing images are mentioned. This chapter also includes, purpose and observations gathered during field visit to the selected vegetation patches.

Chapter 4 includes detailed methodology which includes detailed description of different scenarios which are constructed for this study along with detailed description of respective steps present in the methodology section.

Chapter 5 includes variogram estimations and final results for the selected vegetation patches at different resolutions. Comparative analysis of results and their corresponding interpretation is present in chapter 5 of thesis.

Lastly, Chapter 6 includes Conclusions that are being achieved after comparative analysis and interpretation of variogram results and shape of a variogram.

2. LITERATURE REVIEW

Studies have been conducted over the last decade in ecology and landscape to explore the group of plantations, vegetation species, clusters of trees and their variation across scale. However, these vegetation patterns are proved to be useful at different range of resolution. Geostatistical techniques deal with the spatial variation and spatial structure of vegetation and they have wide range of applications so far. With respect to this study, there are number of studies that are performed so far to study the spatial structure and vegetation mapping.

2.1. Vegetation Patch and Spatial structure

Vegetation cover present in India, includes enormous and diverse amount of vegetation species. Being an agro-based country, agriculture has been a major source of income for more than half of the population of India. Agricultural lands, crop lands present near the roadsides, villages, rivers are important components of the vegetation cover present in India. Vegetation cover may include orchards, forestry plantations, plantations along rivers, canals etc. All these mentioned vegetation communities play an important role on the earth's surface and hence at the same time, it becomes important to monitor these vegetation communities. Studying vegetation pattern and distribution can be beneficial for agricultural development as it also adds efficient modelling and analysis for domains like crop management, biology, food production units, field measurement and sampling procedures.

Vegetation patches can be group of trees, clusters of vegetation in national parks, dense forests, open forests, irrigation land and there are several benefits and uses of such kind of vegetation patches. According to *Carolinian Boundary Delineation Guide*,

"A vegetation patch can be defined as an area that contains natural vegetation and associated features and functions, that is generally free of permanent disturbance and that can be distinguished from the surrounding land use."

Figure 1: Vegetation Patch (*Source: Google images*)

Fig. 1 represents a vegetation patch which clearly indicates that it is a non linear homogeneous area that has some continuous and crisp boundaries and can be differentiated from rest of the areas. Vegetation patch is an important ecological component and it has a major role in land use and ecological cycles and performances. *Liebhold et al., 2002* mentioned that, over the past 20 years, there is an important relationship in the spatial dependency of the biotic and ecological responses and examining spatial relationships became an important part in studying the spatial structure.

Properties of vegetation patches are very important in order to study the patch dynamics, patch type, spatial configuration of a patch, size of a patch and its boundaries. Size and spatial structure of a patch affects within patch processes and hence variability inside a patch. Further, these patches can be connecting other patches for animal movement, vegetation extent. Patch type can be identified by the components and properties of the entities present inside a vegetation patch and is also identified using the highest proportion of cover (*Wiens et al., 1993*).

2.2. Spatial structure of vegetation patches

Spatial structure refers to the distribution of components present inside a patch, which includes measure of randomness, richness and dispersion. Different analysis techniques like spatial point pattern analysis, spatial variation analysis, spatial association and analysis of spatial dependency among the components of patch are important to study vegetation structure. Spatial randomness present inside a patch can be a helpful component in studying the spatial structure of a patch which might help in understanding the distribution of trees, river, and homogeneity inside a patch Statistical analysis of vegetation need appropriate methods, out of which geostatistical modelling and point process analysis are frequently used methods (*Liebhold et al., 2002*).

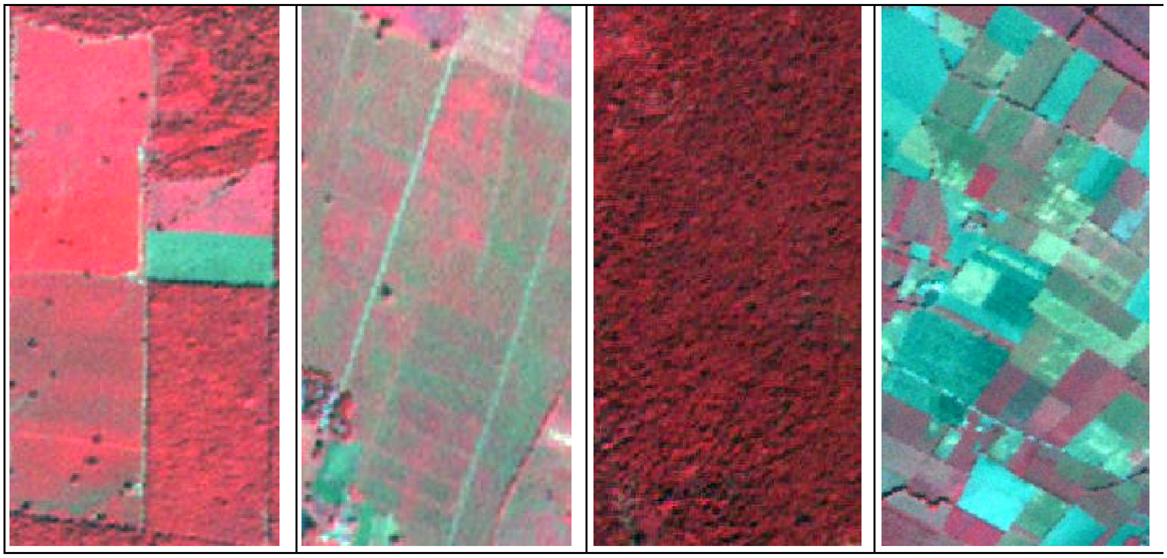

Figure 2: Spatial structure of vegetation

Wallace et al., 2000 undertook research in the Mojave Desert to characterize the spatial structure of vegetation communities using ground based data. Variogram analysis of different vegetation species was carried out using variogram parameters nugget, sill and range of estimated models. A plant width value of different vegetation data was calculated for various transects which helped in broad scale vegetation classification. It was concluded that the maximum variogram range was around 39m and patterns suggesting that transects should be 39 m long enough for a better classification of the vegetation species. Study has suggested using satellite images to study the spatial structure of different vegetation communities.

Busso et al., 2009 studied both quantitative and qualitative attributes of structure of vegetation patches and relationship between them. Greatest and lowest patch diameter was calculated and annual precipitation status was analyzed. Spatial dependency between height, diameters (largest and smallest), and maximum and minimum plant height was also interpreted using regression analysis. It was concluded that, vegetation patches present at high altitudes have large agricultural heterogeneity. Species were analyzed and their relationship with each other as per the proportional of the species was calculated. Shape of the vegetation patch was calculated as the difference between the largest and smallest diameter. For statistical analysis, techniques like histogram, Dendogram, correlation analysis between maximum plant height and distance to the next vegetation patch has been used so far. Finally, plant community was found to be homogeneous in nature as the structural characteristics was almost similar for the area (15 x 15 km). It was also observed that the greatest and smallest diameters of a vegetation patch are constant, for higher plants and the vegetation patch is thinner and for higher mound. Study recommends analyzing the structure of the vegetation patches for the conservation of ecological system and soil erosion.

Several studies reviewed the variation of spatial structure in biological communities and emphasizes on performing statistical analysis of ecological species and communities along with spatial autocorrelation. Methods like correlogram, multivariate mantel test, mantel correlogram and clustering methods have been used so far to determine the structure and variation present among the vegetation patterns.

Andersen et al., 2011 identified the spatial structure of peat land complex in Finland using variance analysis and spatial autocorrelation across different scales. Five types of spatial pattern (present in peat land) were identified in this forest area; minerotrophic – ombotrophic zone, dry and wet minerotrophic –

ombotrophic zone, open and shady areas, wet patches, dry patches It was observed that around 30% variability is present in plants and other vegetation communities which concluded that highest amount of variance was present in Sphagnum species present in peat land complex vegetation. This study also promotes and recommended to interpret spatial dependency between vegetation species as they have highest proportion of variance.

2.3. Role of Geostatistics in vegetation studies

Statistics is an important analysis tool for studying spatial variation and spatial structure of vegetation and Geostatistical modelling is an emerging area for spatial analysis and understanding spatial relationships. Variogram can be an important tool used for studying and understanding the spatial structure of vegetation patches. Within these vegetation patches, there can be a specific pattern and distribution which could be interpreted and quantified using variogram and its parameters.

Spatial statistics is one of the techniques which was developed and adapted in 1950s and gradually, with advancement in technologies in GIS and remote sensing, spatial statistics is now being used in number of applications of natural science like agriculture, environmental science, oil mining and ecology. Methods like correlogram, variogram, and point pattern analysis are available in Geostatistics to quantify the spatial structure of forest and to measure the degree of spatial correlation. Moreover, to understand the geographical and environmental models in a detailed way, spatial variation is an important part of all the ecological procedures that may exist. For this reason, to quantify the spatial pattern present in ecological domain, statistics can be applied *(Liebhold et al., 2002*). Variogram estimation is a part of spatial statistics where variogram is an important tool which is used to characterize the spatial variation for a specific area of interest. *Wallace et al., 2000* studied the spatial structure of different types of vegetation species using field data and variogram modelling was proved to be an efficient technology in quantifying the spatial structure of vegetation. Variogram uses theory of co regionalization that nearby locations are much more correlated and similar to each other as compared to the values that are further apart (fig. 3). On the basis of this theory of co regionalization, variogram depicts the spatial structure of vegetation patches. Spatial variability of any of the variables (ecological/geographical or environmental) can be efficiently described using variogram function. Spatial analysis techniques have several benefits in agricultural management (*Zhang et al., 2009)* and therefore, this method can be used to define the spatial variability and spatial pattern in well structured and quantified manner.

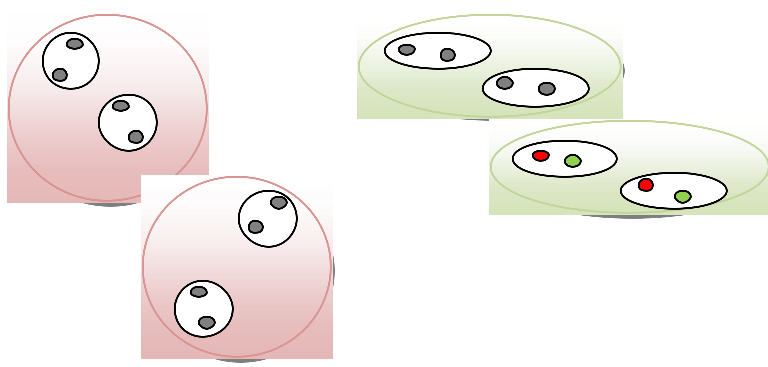

Figure 3: spatial correlation using variogram

2.3.1. Geostatistics and Spatial structure

Variogram function gives an important relation between spatial separations and provides unbiased description of scale, pattern and spatial variability (*Curran, 1988*). Satellite images and ground data, both can be used for variogram calculation. If a transcect is selected in a satellite image, where z is the DN value of pixels x, is extracted at regular interval, z(x), where x = 1, 2, 3 ...n.
Relation present between pair of pixels, distance between pair of pixels is h, which is called as lag distance (fig. 4).Variance present in these set of pixels will be calculated as:

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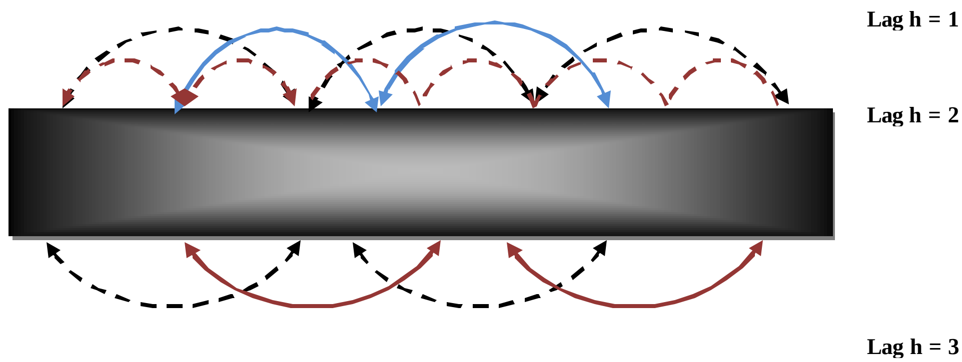


Figure 4: Lags long a transect of pixels

Variogram is described using its parameters i.e. nugget, sill and range where, nugget is a non spatial variation which is present within a pixel resolution, sill is the highest variance which is present in the transect of DN values and range can be describe as an extent up to which DN values are correlated to each other. Variogram also exhibits *anisotropic* behavior which means it also considers direction while calculating the variance (dissimilarity) with respect to the lag distance (h). Anisotropic behavior comes into the picture when the variable of interest varies in one particular direction than any other direction while omni-directional variogram considers average of all the directions. Fig. 5 represents a variogram with range, partial sill and nugget where, variance is present along y axis and lag distance is present at x axis.

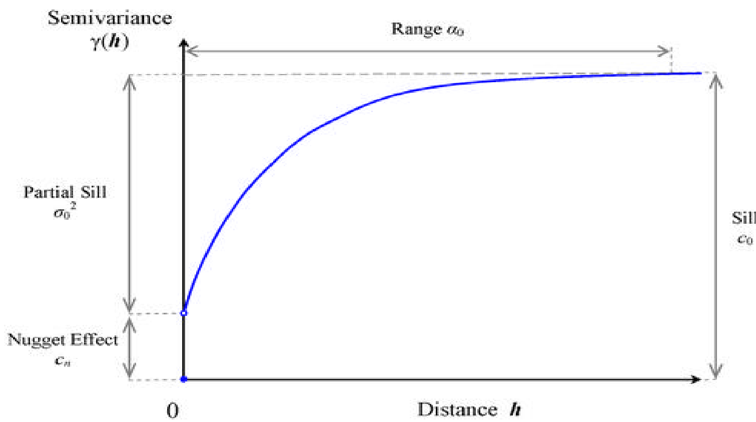


Figure 5: Variogram along with Lag distance (h)

Studies are being carried out so far to study the spatial structure and spatial variation in vegetation using variogram analysis. *Webster and Oliver, 2008* describes spatial scale estimation in environmental properties using variogram analysis. It explains the multivariate distribution of the different properties of the soil in the forest and then to create a classification result out of it using variogram analysis. Study was useful in determining the relation between soil and vegetation using variogram estimation.

Curran, 1988 estimated variogram for different types of vegetation and soil like bare soil, coniferous woodland vegetation, deciduous vegetation, Sea present near coastal areas agricultural land etc. Different type of areas revealed different shapes and parameters of variogram. It has been concluded that, accurate ground data should be used in order to calibrate satellite images as there can be several errors while sampling large areas in short interval of time. However, *Wallace et al., 2000* studied spatial structure using ground data to differentiate vegetation species using variogram calculation and estimation.

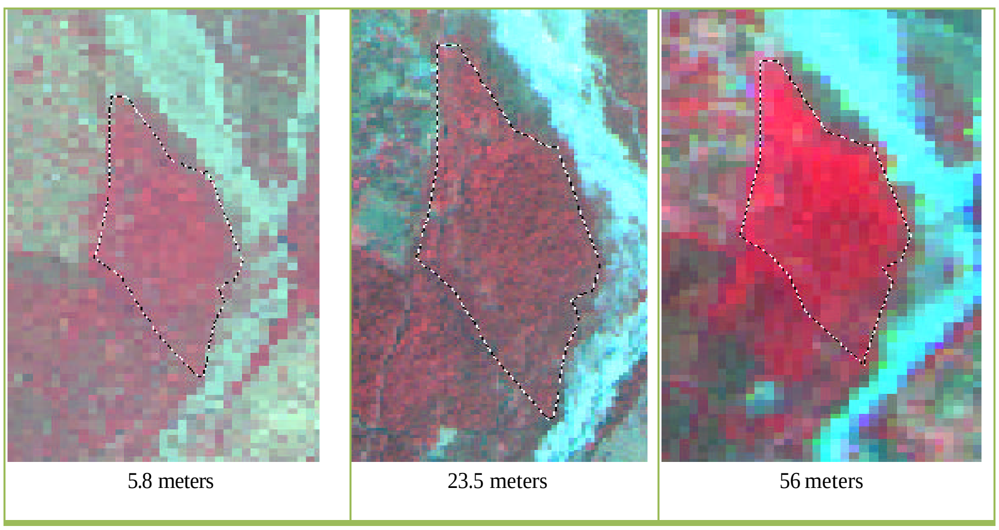
Atkinson et al, 2000 performed variogram modelling in soil survey and classification. This study has considered several methods to incorporate the spatial information in performing classification of remote sensing images. Main focus of this study was variogram modelling and using variogram as a measure of texture and smoothing function which can be useful in developing strategies for soil survey. Variogram modelling was proved to be an efficient method for geostatistical classification of remote sensing images. One more similar kind of study was performed by *Jakomulska et al., 2001* to apply geostatistical classification of different types of vegetation using textural parameters, shade and pattern of vegetation. Classification using variogram measures increases overall class specification accuracy. With an increase in resolution of imageries, more details will be revealed including shadow and pattern of vegetation present. However, it was concluded that this technique does not have a potential for discriminating different types of vegetation species on the basis of texture, some confusion between the classes is still present.

2.4. Boundaries of Vegetation Patches

Boundaries of vegetation patches are usually seen as constraints, barriers or some kind of limit for the movement of wild life and plants *(Fagan et al., 1999)* and they are important to study for both fine scale and broad scale images*(Fuentes et al., 2000; Belnap et al., 2003)*. Investigating and quantifying the boundaries of vegetation patches can be challenging for interpreting the quality of classification outcomes because several uncertainties can be associated along the vague and fuzzy boundaries of these vegetation patches. Several studies (*Stein et al., 2009., Zhao et al., 2010., Johnson et al., 2004)* are being carried out so far and it has been concluded that well defined boundaries are important to study the gradual changes in these vegetation entities, but there is a need to study the processes in a detailed way using geostatistics which could be helpful in analyzing the factors that are responsible for these uncertainties, procedures that are governing these changes along the boundaries. It is important to find out the potential of variogram modelling in studying and interpreting the reasons behind the gradual changes along the fuzzy boundaries of these vegetation patches.

Stein et al., 2009 indicated that most of the spatial objects that are present on satellite images have gradual transition zone due to scale of observation or due to poor definition of classes. Relationship between vegetation patch and its boundaries should be clearly understood in order to analyze how landscapes will respond to environmental and climate changes (*Karieva et al., 1995*). It can be observed from the three patches present at different scales (fig. 6), variation in the texture and tone along the edges of patch can be clearly seen in the figure shown below. Therefore, it is very important to interpret the boundaries and extent of real world entities represented on satellite imageries. This is one of the most important motivating factors behind analyzing the transition zone and boundaries of patches at different resolutions so that appropriate resolution can be find out for better understanding of extent of these vegetation patches. The basic idea behind this study is to quantify the uncertainties present along the boundaries of the vegetation patches at different resolutions using variogram modelling. Binary images (vegetation and non- vegetation) will be compare with NDVI images (gray tones) so that uncertainty along the boundaries can be observed on comparing the variogram parameters of both the images at different resolutions.

Figure 6: Change in Boundary at different resolutions



2.5. NDVI and Effect of Resolution

2.5.1. Meaning: Scale and Resolution

Scale and Resolution play an extensible role in studying the concepts of remote sensing and GIS. It has been noticed that scale and its effect on pattern is an important issue for various ecological and environmental modelling. In this regard, these effects of scale and resolution must be evaluated and studied. "Resolution is the building block of spatial data" (*Quattrochi et al., 1997*. Effect of scale can be explained as, scale change from a leaf, leaf to the tree, tree to the forest and gradually the vegetation covering changes with scale (*Quattrochi et al., 1997*). *Chhabra, 2004* studied spatial pattern and distribution of trees outside forest across different scales and analyzed the effect of change in resolution on classification

accuracy and area statistics and it was indicated that scale can be an important aspect to study the spatial structure of tree patches in order to determine minimum detectable patch from different scales. For this reason, scale could be an interesting area to study the spatial structure of geographic entities like vegetation patches. Resolutions helps in defining an extent of an area, higher the resolution, more detailed information will be present. Resolution gives the size of the smallest entity that can be distinguished from a spatial data (*Turner et al., 1989*).Grain and extent are the terms that are used to explain resolution in ecological studies.
Different types of resolution are explained in fig.7.

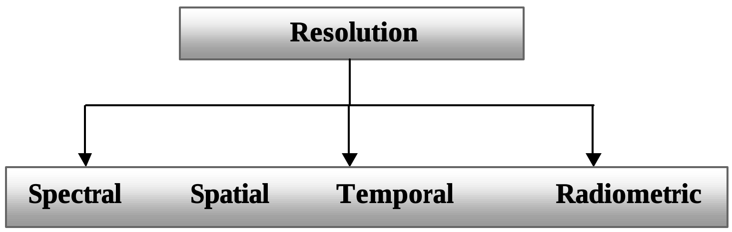


Figure 7: Types of Resolutions

NDVI is considered to be a very important parameter for analyzing vegetation coverage on earth's surface. Dense vegetation and area with no vegetation can be easily depicted using NDVI measures (Table. 1). It is completely based on ratio based indices and can be helpful in reducing noise influences and topographic effects while studying the vegetation patterns. As per (*Groten, S.M., 1993*), it can be used to assess vegetation coverage and productivity. Moreover, it can reduce the data like biomass, leaf area index, soil vegetation index etc. which multi dimensional characteristics.
Spatial variation of vegetation using variogram modelling of NDVI values can be helpful in interpreting the spatial structure of vegetation as NDVI has several advantages associated with vegetation. In order to study the spatial variation across different scale using NDVI, variogram modelling can be helpful in analyzing the spatial variation of vegetation. *Garrigues et al., 2006* characterize and quantified the spatial heterogeneity of vegetation cover using high spatial resolution and NDVI data. Sill value describes the heterogeneity present in the crop sites at landscape level.

Cover Type	**NDVI**
Dense vegetation	0.7
Dry Bare soil	0.025
Clouds	0.002
Snow and ice	-0.046
Water	-0.257

Table 1 NDVI values for various cover types (*Source: Holben, 1986*)

Mapping the variation of NDVI (Normalized Difference Vegetation Index) values is equally important and beneficial to analyze the variation in the boundary of the vegetation patches in order to retrieve extra information which can be associated with the grey tones of NDVI values. NDVI is mostly used for interpreting the health of the vegetation present on the earth's surface. It gives a measure of vegetation cover on the land surface. NDVI helps in differentiating dense vegetation, water, ice and other non vegetation areas.

Jin et al., 2010 used NDVI values to study temporal and spatial variations in Baikal Lake, China and it was mentioned that spatial variation of NDVI values can be an interesting part to study the gradual changes (gray tones) that can be associated along the boundaries of vegetation patches. In order to study the spatial structure of vegetation patches using NDVI values (between -1 and +1), variogram modelling can be done to quantify this variation.

2.5.2. Studies on Scale and Resolution

"Of all words that have some degree of specialized scientific meaning, scale is one of the most ambiguous and overworked" (*Quattrochi et al., 1992*). Scale is one of the most important and ambiguous domain present in remote Sensing and image processing. As the applications and meanings of scale are getting increased day by day, the remote sensing and GIS related studies are becoming data dependent, it is very important to develop and perform the studies that may help in the selection of suitable scale and resolution for several applications and may help in decision making processes. *Kotliar et al., 1990* studied the vegetation patches across a range of scales. Hierarchical model from high resolution to low resolution was constructed in order to understand the heterogeneity of patches over different spatial resolution. "Grain" was considered as the smallest scale and "Extent" was considered to be the largest scale of heterogeneity and on the basis of these two concepts, the model was implemented which was further implemented to get the prediction at different range of scales. For cartographic applications, scale can be the ratio between the distances on the map to the distance on the ground. Ex. Toposheet of 1:25,000 scales may not give detailed information as compared to the toposheet having 1:50,000 scale. At the same time, for ecological applications and purposes, scale can be used to study the variation in the size of the vegetation patches distributed into small habitats (*Quattrochi et al., 1992*). Concepts related to scale and resolutions are traditionally considered to be important issues to study in the field of geography and other relevant fields. In most of the studies, multi sensor data is often used for studying vegetation distribution and hence, these topics can further help in studying the effect of scale in various phenomenon.

Interpreting the boundaries of segmented objects can also be studied at different resolutions. Boundaries of segmented objects are studied but, studying variation along the boundary of a patch across a range of scale will be interesting to study. *Zhao et al., 2010* studied the uncertainty of segmented objects like vegetation patches present near Poyang Lake of China. In this study, it was concluded that random set can be useful information in analyzing the uncertainties of these patches and most of the geographic entities need to be extracted from satellite images for retrieving information.

3. STUDY AREA & DATA PROCESSING

3.1. Study Area

Vegetation communities present in Dehradun area comprise of several vegetation species like Sal forests, Pine trees etc. Detailed information about this vegetation is present in Table1.This study was carried out in Dehradun and its surrounding areas. Dehradun is located at **78°01.55.89'E** and **30°18.59.38'N** at an average elevation of **2123 ft.** It's a capital city of Uttarakhand which lies in the northern zone of India along with the Indo-Gangetic plain. Dehradun is surrounded by dense forests, open forests both. Several vegetation patches like Mohand Forest, Thano forest, Rajaji National Park and many more vegetation patches present near Haridwar bypass road, Barresi Road, Rampur road, Mossoro road etc. can be a part of this study. The study area has enormous and diverse vegetation patches in the form of road side plantations, group of trees, trees in the parks, trees in clusters, trees in the forests, agricultural land etc. Haldwani, is located at **79°31.145'E** and **29°13.182'N** with an average elevation of 424 meters. It has been mentioned in the source that the mountain Rivers present in this Indo-Gangetic plain go underground and they re-emerge later along the Indo-Gangetic plain.

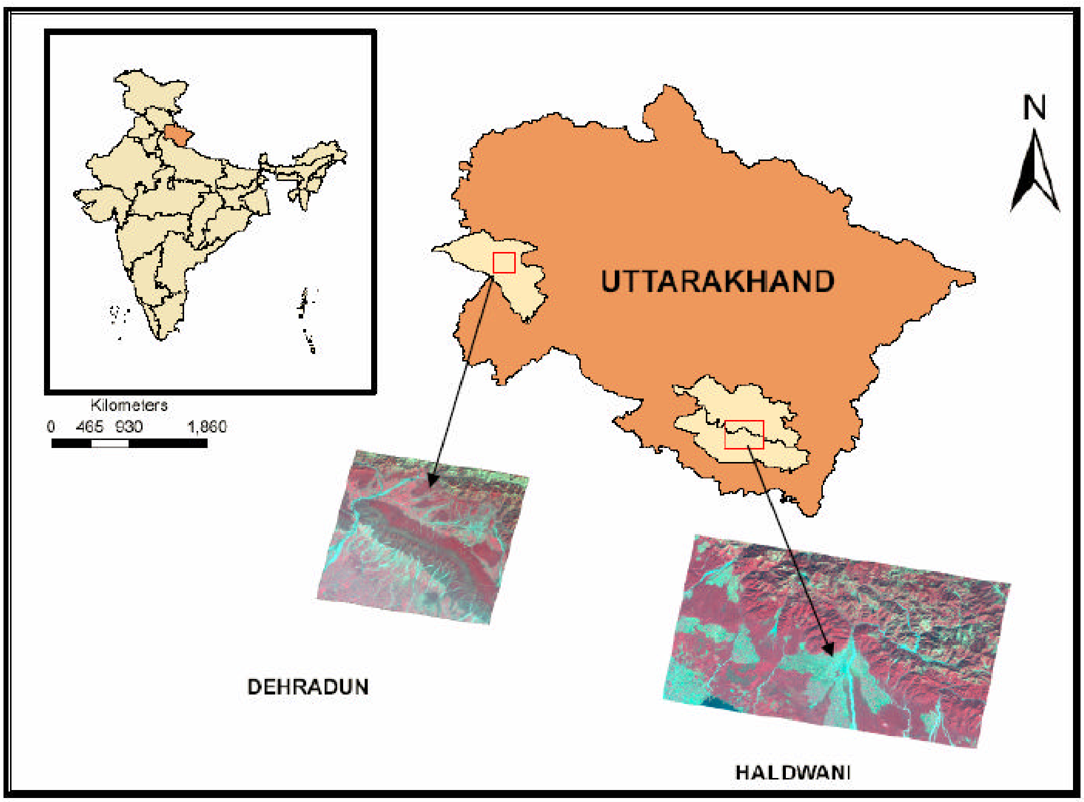


Figure 8: Study area: Dehradun and Haldwani

3.2. Vegetation present

S.No.	Forest type	Major Vegetation	Features
1	**Sub montane or sub-tropical region forests**	Sal (Shorea robusta) Pine (Pinus roxburghii)	Small medium sized tree, moderately developed crown, long leaves, Dark green and dense leaves, Flowering season: April and May Large sized tree. Not so developed crown, tree height: 30-35m, needle shaped leaves, Flowering season: February and April
2	**Montane-region forests**	Oak (Quercus leucotricophora)	Present at an elevation of 2000 meters. Medium to large sized trees Oblong leaves Flowering season: April to June

Table 2: detailed description of vegetation present in Dehradun

3.2.1. Satellite Images of Study Area (LISS IV, LISS III and AWiFS)

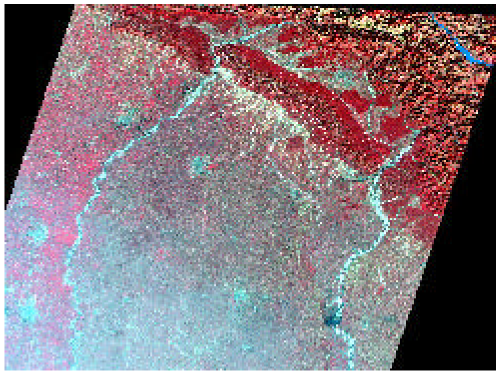
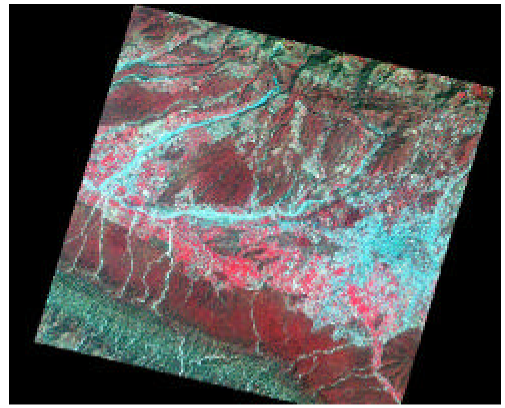
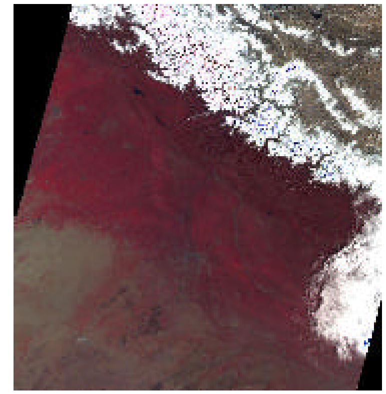
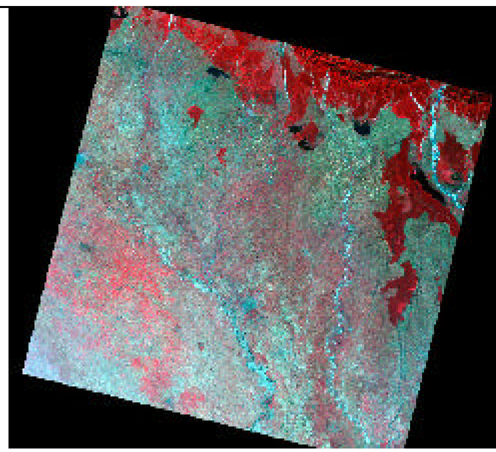
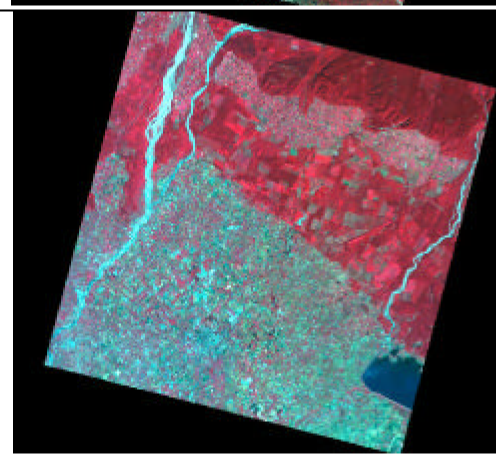
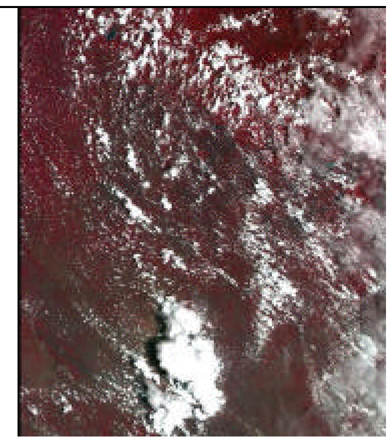
Study Area	Latitude	Longitude	LISS III (23.5m)	LISS IV (5.8m)	AWiFS (56m)
Dehradun	**30°19.292'**	**78°1.945'**			
Haldwani	**29°13.182'**	**79°31.145'**			

Figure 9: Satellite images of Dehradun and Haldwani area across resolutions (LISS IV, LISS III and AWiFS)

3.3. Field Investigation: Study area

Field investigation was done to interpret the overall structure of the vegetation patches selected in an image. Main purpose behind the field visit was to get detailed information about the vegetation patch that includes the type of species present in a patch, reasons that are causing the respective variogram parameters and its shape. Information from the field can be helpful in analysing structure and the variability with in a patch and also to interpret the results.

Boundary of a patch was analyzed during the field visit including a detailed analysis of a transition zone. Also, Shape of a vegetation patch was compared with the content of a vegetation patch which was done with the help of field visit. Careful observations were done while analyzing the boundary of a patch in order to explore and observe existential and extensional uncertainty associated with a patch. It was verified that, whether vegetation patches are present at the corresponding location or not and also, the extent of vegetation patch was also analysed. The basic purpose behind the field visit was to collect information about a selected vegetation patch. This information will be the type of vegetation present in a selected patch, the overall pattern of a patch (river flowing inside a patch, settlements etc) and other factors that can be related with the spatial structure of a patch and its variogram parameters.

3.3.1. Field visit and Extracted Information:

The basic purpose behind field visit was:

1. To understand the landscape and the general pattern of selected vegetation patches.
2. To observe the distribution of trees inside a patch and gather information that could be helpful in interpreting the variogram parameters of the corresponding patch. Example: High value of range and sill can be interpreted using the overall extent of a patch.
3. To interpret the transition zone of a patch in order to analyze the uncertainty associated across the boundary of a patch.

3.3.2. Indentifying a Vegetation Patch:

In order to analyze the pattern and distribution of vegetation patches located in Dehradun and its surrounding areas, some patches were identified and located on Google earth to get the directions to reach to a desired patch.

An example of Mohand forest in Google earth and LISS III image of Dehradun is shown below (fig. 10 a and 10b). In the same way, other vegetation patches were identified and located. Patches were selected in such a way that they can be easily accessible and easy to reach so that proper interpretation of the boundaries and distribution of the components of a patch can be studied. Google maps helped in determining the directions to reach respective patches and boundaries.

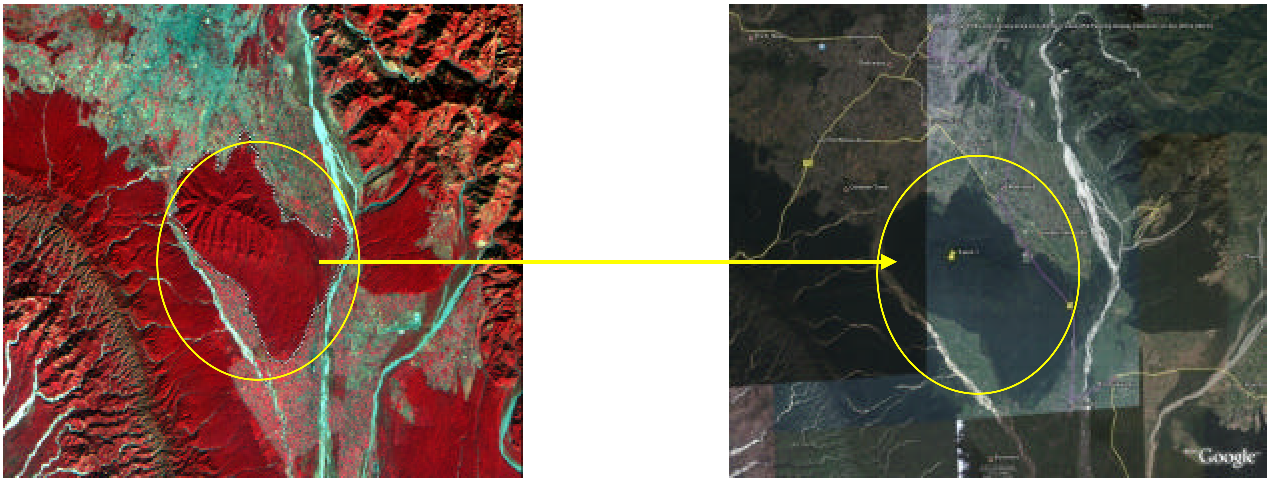


Figure 10 (a): Vegetation Patch LISS III Image, DDN **Figure 10 (b): Vegetation Patch Google Earth**

In total, seven vegetation patches (Appendix: 1) were selected from LISS IV, LISS III and AWiFS images of Dehradun area in order to study the spatial structure and pattern. Selected patches are identified using Google earth and it was found that these patches are present at Lachiwala, Mohand forest, Thano forest, Rajpur forest and some patches present are located near Haridwar area. All the seven selected patches are dense forest and major vegetation present in these patches is Sal.

4. METHODOLOGY

4.1. Methodology

Methodology adapted for this research work in order to achieve the research question is explained below (Fig. 11)

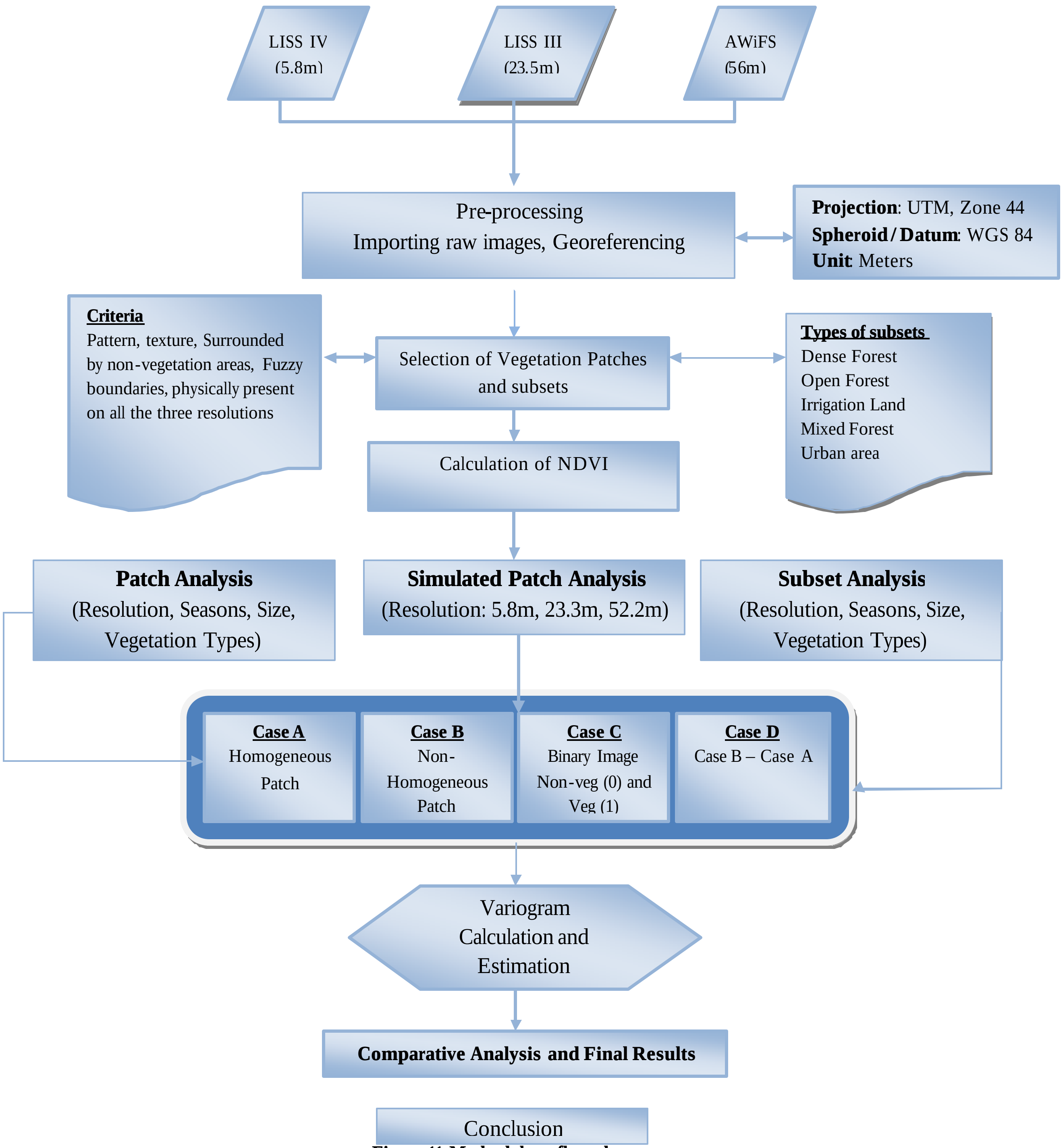


Figure 11: Methodology flow chart

Data Procurement and Preparation

Remote sensing imageries from all the three selected sensors (LISS IV, LISS III and AWiFS) were procured and analyzed in a detailed manner for this research. Being a multi-scale study, images are being procured so that there can be a sufficient variation in the resolution of images to interpret the vegetation patches in an efficient way. To find out the overlapped areas present in an available data set, several details are categorised i.e. Latitude (Minimum and Maximum), Longitude (Minimum and Maximum), zone and toposheet number for Dehradun and its surrounding areas.

Required toposheet number was recognized using the software called topotutor and finally, required toposheets for respective study areas were arranged from IIRS.

4.1.1. Pre processing of Data set

Pre-processing of data included importing raw images, Georeferencing, reprojection. Satellite data which was procured was not georeferenced and hence, it needs to be georeferenced using following methods:

4.1.1.1. Image to Image registration:

The Georeferenced LISS III image (December, 2010) as taken as a reference image to co register AWiFS (March, 2011). It was performed using Auto sync option present in ERDAS Imagine. Since it is a multiscalar study, Georeferencing was performed in such a way that there should a lowest error after co registration of an image. AOI (Area of Interest) comprised of a vegetation patch must be physically present on all the three resolution imageries. Therefore, it becomes important to perform georeferencing up to sub pixel level because same AOI should exist on all the three images (LISS IV, LISS III and AWiFS) in order to study the spatial variation and spatial structure.

4.1.1.2. Image to map registration

Toposheet from Survey of India for corresponding areas were collected and LISS IV images of Dehradun (June and March 2009) were georeferenced by taking toposheet as a reference image. To perform this task in an efficient manner, important features present like Crossing, Bridges, Barriers, Cross roads, edges etc. were used as GCP's (Ground Control Points) in such a way that these points are easy to locate on both toposheet and image which has to be georeferenced. Georeferencing was done with the help of Auto sync option present in ERDAS Imagine using WGS 84 Datum and Universal Transverse Mercator (UTM) and around 16 GCP's were taken to perform the Georeferencing in an efficient and accurate way. Dehradun area lies under Zone no. 44 and areas present near Saharanpur area lies under Zone no. 43.So, these areas were separated ac per their zones and projected accordingly to perform the Georeferencing in an accurate manner. Root mean squared error for this Georeferencing was calculated as 0.758 pixels.

4.1.2. Selection of vegetation patches

Vegetation patches were selected on Dehradun areas for all the three resolutions (LISS IV, LISS III and AWiFS). Firstly, a vegetation patch was selected using AOI (Area of Interest) on LISS IV (5.8m) image of Dehradun area and later the same AOI was selected on the other two images as well i.e. LISS III (23.5m) and AWiFS (56m). Selected patches (fig. 12) physically cover the same area on all the three images of Dehradun area. Patches were selected using several criteria's which are as follows:

1. Patch should be homogeneous.
2. Patch should be selected in such a way that they have some crisp, irregular and fuzzy boundary.
3. Patch should be taken in such a way that it should be differentiated easily from rest of the areas.
4. Patch selected should be surrounded by non vegetation areas i.e. urban area and other non vegetative zones because it will help in interpreting the binary images (O (Non-vegetation) and 1(vegetation)) for analyzing the change in the boundary of a vegetation patch.
5. Most importantly, patch selected should be physically present on all the three images (LISS IV, LISS III and AWiFS) of Dehradun areas so that spatial variation can be analysed appropriately.
6. Patches selected must be easily accessible so that field visit can be preformed to implement the results and to understand the reason behind the value of the variogram parameters (nugget, sill and range) and also the shape of the variogram.

Different set of vegetation patches for all the three resolutions were selected for all the four cases (Case A, Case B, Case C and Case D). In total, more than seven set of vegetation patches were selected for all the possible cases to interpret and perform the quantitative analysis.

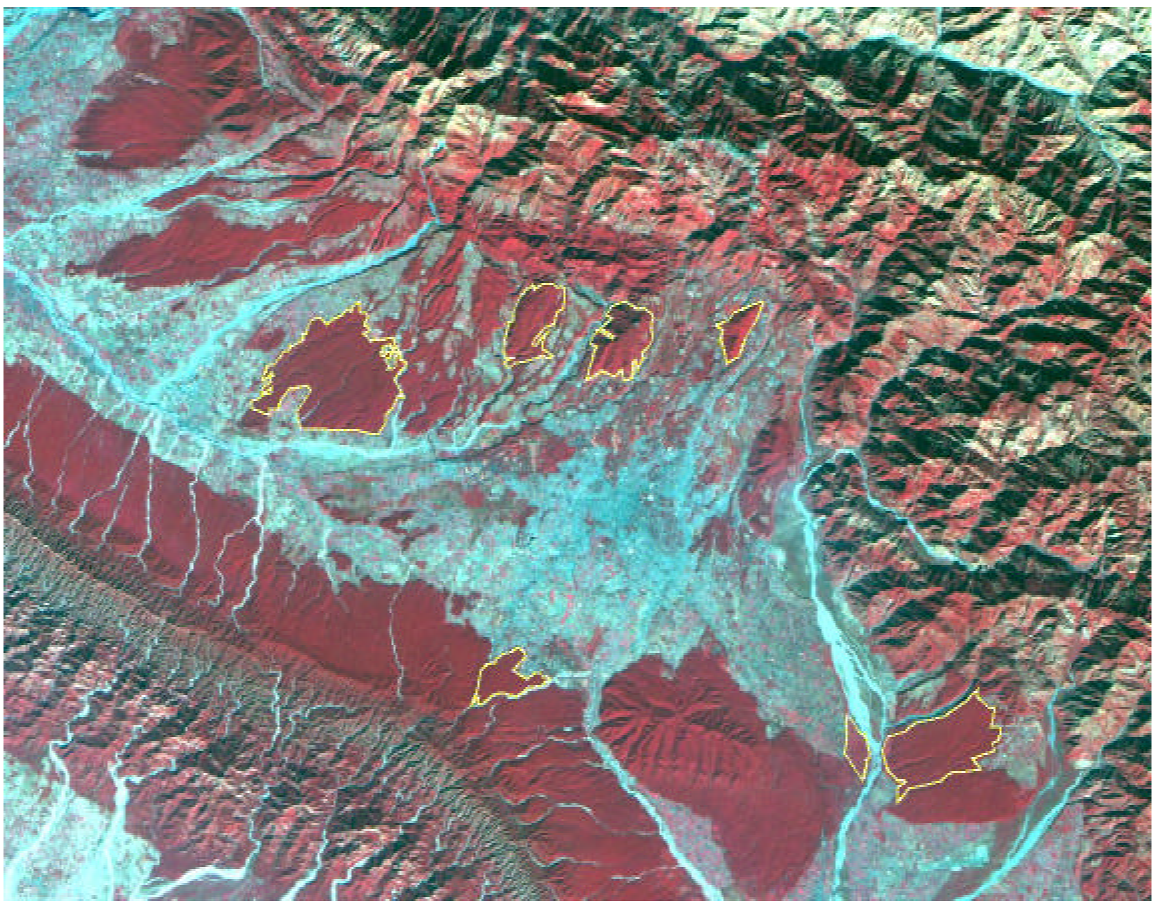


Figure 12: Selected vegetation patches in Dehradun area

4.1.3. Calculation of NDVI

NDVI was calculated using Red and infrared bands. For LISS III, LISS IV and AWiFS, all the three images NIR is the third band and Red is the second band. NDVI was calculated using programming language R using the mathematical function:

$$NDVI = (Band\ 3 - Band\ 2) / (Band\ 3 + Band\ 2)$$

So, for all the three set of images, i.e. LISS IV, LISS III and AWiFS,

Where, NIR and R stands for reflectance measurements captured in Near Infra red and Red bands of LISS IV, LISS III and AWiFS images respectively.

4.1.4. Selection of different scenarios (Case A, B, C and D)

For a given set of a patch, four types of scenarios or cases were selected to analyze the spatial structure of the vegetation patches, to analyse the change in the boundary of vegetation patch and the role of NDVI in spatial structure and boundary interpretation. For a given set of a vegetation patch, four different scenarios are explained here:

a) Case A (Pure homogeneous vegetation patch): A vegetation patch that comprises of purely vegetation and that does not include any neighbouring pixels along the boundaries. This one is a reduced vegetation patch as compared to the Non-homogenous patch.

b) Case B (Non-homogeneous vegetation patch): A vegetation patch that includes pixels from the neighbouring patches along the borders.

c) Case C (Binary vegetation patch) generated from image present in Case B (Patch + Non vegetation area) using hard Classification: 0/1 where 0 means non-vegetation and 1 means vegetation. (Unsupervised – Using ISODATA Classification algorithm). Case D (Case B- Case A): This case will include the difference between the NDVI values for Case A and Case B). Each case revealed some important information for the structure and the shape of a patch. Case D helped in analyzing the variation in the shape of a vegetation patch. Comparison of variogram parameters for Case A and Case D will help in analyzing the data quality and many more interpretation (Discussed in Results and Discussion section). On comparing Case A and Case B, for a same vegetation patch, there is a difference in the shape of their relevant variogram. For a homogeneous vegetation patch, the values are much more correlated and give a better spatial structure as compared to the non-homogeneous vegetation patch. However, on comparing the results of same vegetation patch for all the four cases, information related to shape of a patch was revealed and also parameters like sill and range helped in interpretation of a structure of a patch. Sill indicated about the highest variability present within a patch also for black and white images. Comparison between Binary and NDVI images helped in the interpreting the vagueness present along the boundary of a patch.

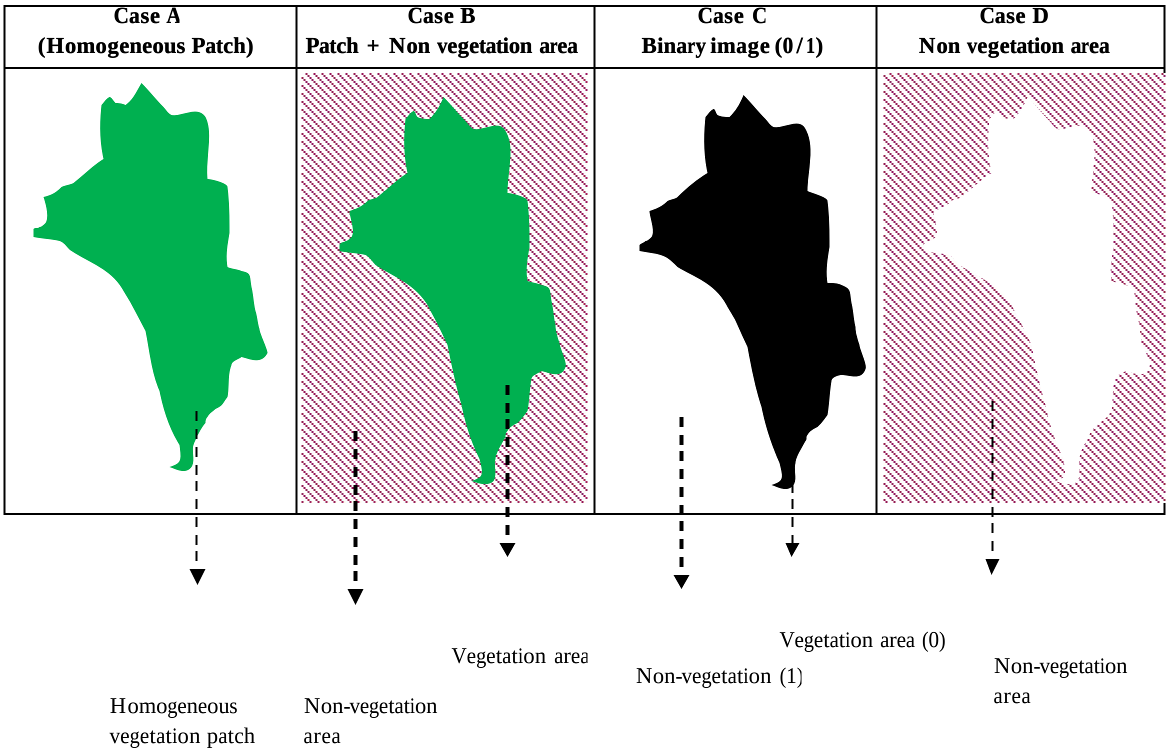


Figure 13: Explanation of different scenarios (Case A, B, C and D)

4.1.5. Variogram Calculation and Estimation

Variograms were calculated and estimated for seven different set of vegetation patches across all the three resolutions (LISS IV, LISS III and AWiFS) using R software. One set of vegetation patch includes, calculated and estimated variogram for all the four scenarios (Case A, Case B, Case C and Case D) (Appendix 2-A)

Packages present in R like RGDAL, raster, Gstat, spat stat, fields, lattice, and map tools were used to perform variogram modelling and displaying the corresponding results. Variograms were calculated for different cut-offs and bin width and in most of the cases cut off was taken as one third of the total lag distance. However, variogram calculation was done for full length of a patch, ½ of the total lag distance and 1/3rd of the total lag distance (Appendix 3-A). In most of the cases, variogram calculated for 1/3rd of the total lag distance was selected so that sufficient number of point pairs can be present to calculate the variogram and the shape of a variogram can be interpreted in an efficient way.

4.1.6. Comparison of Results and Analysis

Variogram parameters for homogeneous patch were calculated and analyzed at three different resolutions. With the change in these parameters (nugget, sill and range), spatial variation among the vegetation patch was observed and interpreted. Sill helped in finding the highest and lowest variance present among all the resolutions while range gives an idea about the extent of spatial dependency.

Comparison of variogram parameters of Binary and NDVI images helped in interpreting the uncertainty that is present across the boundary of a patch. It helped in observing the class definitions while defining non vegetation and vegetation classes. Results are present and discussed in section 5 in a detailed way.

4.2. Classification of Images

4.2.1. Unsupervised Classification

Unsupervised classification algorithm deals with grouping of pixels that have same spectral values and each group is called as spectral class. Unsupervised classification classifies data into various spectral classes on the basis of natural groupings present in the image gray values. Binary images generated in this study were generated using ISODATA (Iterative self organizing data analysis) classification algorithm present in unsupervised classification. While classifying two classes were selected Vegetation and non vegetation. Since, there is a very high chance of merging of spectral classes, 7-8 initial spectral classes were selected with a convergence threshold of 15 iterations. Finally, spectral classes were merged into vegetation and non vegetation.

Present study adopted isodata classification algorithm because of several advantages like unsupervised classification is useful for spectrally complex classes, they require only minimal initial input and spectral classes can also be merged later and it is iterative in nature but it does not considers spatial homogeneity (*Chhabra, 2004*).

5. RESULTS

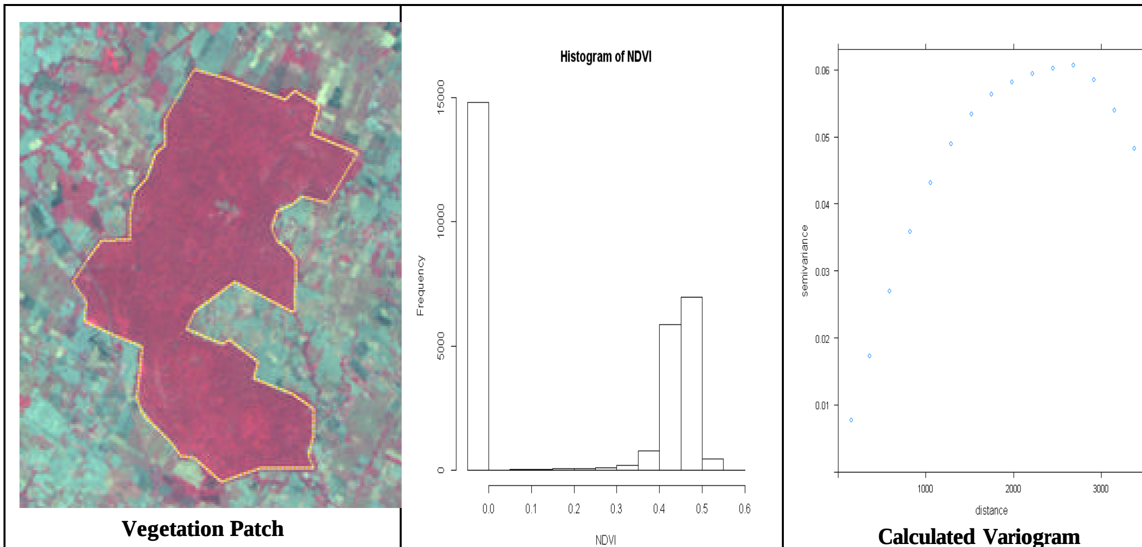
This chapter is divided into nine sections. First section explains spatial structure of vegetation patches using variogram analysis and spatial variation at different resolutions. This section also includes spatial variation of NDVI values across resolution.

Second section studied and interpreted the effect of including non vegetation areas across the boundary of a patch selected in section A and also this effect was observed while changing the spatial resolution in Section three. Section four explains transition zone of a patch using variogram analysis. Section five includes comparison of binary and non binary images to study the uncertainty associated with the boundary of a patch. Section six addresses shape of a patch using variogram analysis across resolution. Section seven studied and compared variogram for small and large sized vegetation patches located at two different resolutions. Section eight explains effect of shadow on the spatial structure of vegetation patch using variogram analysis. Section nine explains spatial structure and variograms for different types of vegetation patches (open forest, dense forest, irrigation land) selected from LISS IV image of Dehradun area while Section ten explains the spatial structure of vegetation subsets present in LISS III image of Haldwani area. Lastly, Section eleven explains the effect of change in season on the spatial structure of a same vegetation patch present in LISS IV images of Dehradun area.

5.1.1. Spatial structure: Homogeneous patch

In order to study the spatial structure of a vegetation patch, a homogeneous vegetation patch was selected from LISS III image of Haldwani area. NDVI was calculated for this selected vegetation patch and Omni -directional variogram was calculated for the whole patch for full length of a patch (3500 meters). On observing the histogram calculated for NDVI values present in this selected patch, it was found that most of the NDVI values are positive in nature and there is no negative NDVI value inside this selected vegetation patch which means that patch is purely a vegetation patch.

On observing the variogram of a patch, it can be seen that there is a clear spatial structure present inside this patch. Variance is continuously increasing up to a distance of 2500 meters (approx.) and then, there is a sudden dip in the shape of a variogram after 2500 meters i.e. variance started decreasing with distance which means that at 2500 meters, there is a sudden change in the NDVI values. Highest variance present in this patch is 0.06 approximately.



Vegetation Patch
Haldwani (LISS III: 23.5 meters)
195 rows x 151 columns
4582 x 3548 meters

Calculated Variogram
Cut off: 3500 meters

Figure 14: Spatial Structure of a vegetation patch using variogram analysis (Case A)

5.1.2. Spatial Structure across different Resolutions (LISS IV, LISS III and AWiFS)

In order to study spatial structure of selected vegetation patches across resolutions, variogram analysis was performed. Case A was designed to study spatial structure of a homogeneous vegetation patch at three different resolutions (LISS IV, LISS III and AWiFS). Patches are selected in such a way so that, they physically covers the same area on all the resolutions so that omni-directional variograms can be compared and analysed thoroughly across resolutions. One of these selected patches is located near Mohand Forest, Dehradun and it is surrounded by non vegetation area towards north- east direction and north- west direction (Figure 13). Spatial structure of this selected vegetation patch at three different resolutions is explained below:

5.1.2.1. Vegetation Patch (LISS IV)

Size of a patch selected in LISS IV image is 2709 x 1090 meters and omni directional variogram was calculated for the whole patch with a cut off of 1000 meters. It can be seen from the histogram distribution that, NDVI value varies from -0.3030 to 0.2592. While observing the calculated variogram, it was observed that, variance present in this patch continuously increases till 800 meters and highest variance present in this patch is 0.005 approximately. Spherical model was found to be a best fitted model for this selected patch and after fitting a model to a variogram, it was found that sill (highest variance) is 0.0047 and range present in this vegetation patch after fitting a variogram found to be 932 meters. Nugget was found to be 0.0009 which means non spatial variation present in this vegetation patch is almost negligible (Table 3).

5.1.2.2. Vegetation patch (LISS III)

In case of LISS III image, NDVI values varies between -0.0642 to 0.5201. Variogram analysis of this patch revealed that, variance is continuously increasing and there is a slight bend in the variogram curve after 800 meter (approx.) which means there is some kind of dissimilarity among the NDVI values and spatial variation is associated till 800 meters. In this case also, Spherical model was found to be a best fitted model and after fitting a model to the variogram, it was noticed that highest variance (sill) present in this patch is 0.0380 and range up to which NDVI values are spatially dependent on each other found to be 832 meters. Nugget present in this vegetation patch was found to be 0.0006 which is also negligible in this image (Table 3).

5.1.2.3. Vegetation patch (AWiFS)

It was noticed that, vegetation patch selected in AWiFS image has clear spatial structure and the spatial association exhibits till 812 meters and variance is continuously increasing and it can be observed from variogram analysis that highest dissimilarity present in a patch is 0.10 approximately. On fitting a spherical model to a variogram, it was noticed that, Nugget value was found to be 0.0009 and sill was 0.098 which means that highest amount of variance present in this patch is 0.098. Range of this vegetation patch was 812 meters. Highest variance present in this image was found to be 0.098. Range present in this patch was calculated as 812 meters that shows NDVI values are dependent on each other up to 812 meters.

5.1.3. Effect of change in Spatial Resolution

In order to determine the spatial variation of NDVI values across different spatial resolutions, variogram parameters of vegetation patches present in LISS IV, LISS III and AWiFS images (Figure 13) can be compared and interpreted. On moving from higher resolution to lower resolution (Table.2), it was observed that:

a) Range decreases. LISS IV has highest value of range (932 meters) as compared to LISS III (832 meters) and AWiFS (812 meters). Sill value increases. Highest sill (0.0987) was found to be for AWiFS image, which shows that highest variability is present among the AWiFS pixels as compared to LISS IV and LISS III images. It shows that, there is more heterogeneity within AWiFS patch as compared to the patch present in LISS IV and LISS III images. It can be concluded that, variability i.e. the dissimilarity between the pixels increases as we move from high resolution to low resolution. However, nugget was found to be negligible for all the three images (LISS IV (0.0002), LISS III (0.0006) and AWiFS (0.0987)).

b) Sill increases. It can be observed that, lowest sill is present in LISS IV image (0.0047) as compared to LISS III(0.0380) and AWiFS (0.0987) image which means, AWiFS image has highest variance among the NDVI values is present in AWiFS image as compared to other two images (LISS IV and LISS III). Several factors like phenological reasons, different seasons can be responsible behind these values (refer to Discussion section).

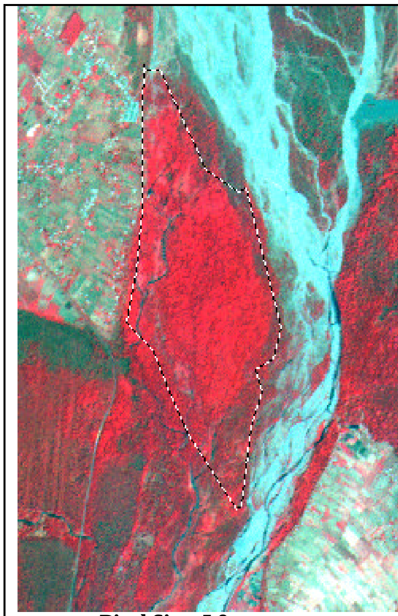
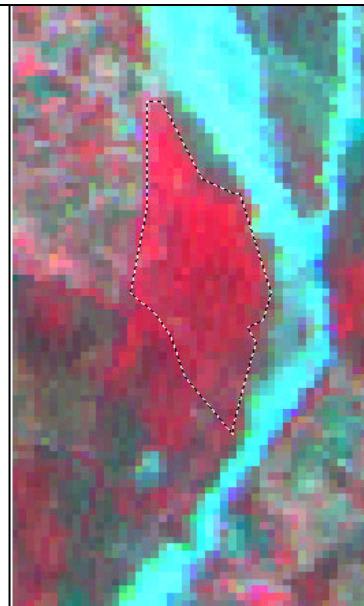
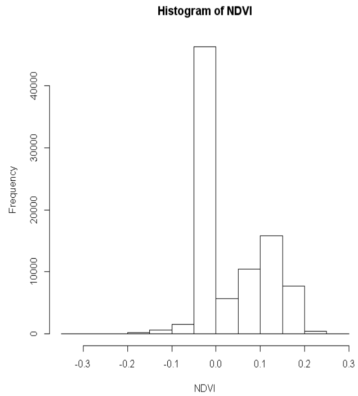
		
Pixel Size: 5.8 meters **Patch1_Case A_LISSIV_June2009** **Patch Size: 470 rows x 189 columns** **(2709 x 1090 meters)**	**Pixel Size: 23.5 meters** **Patch1_CaseA_LISSIII_Dec_2010** **Patch Size: 110 rows x 45 columns** **(2585 x 1057 meters)**	**Pixel Size: 56 meters** **Patch1_CaseA_AWiFS_Mar_2011** **Patch Size: 49 rows x 21 columns** **(2744 x 1176 meters)**

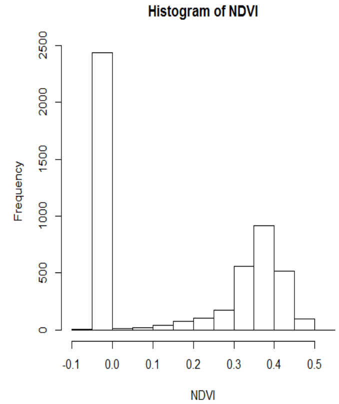
Figure15: Selected homogeneous vegetation patch (Case A) across different resolutions



Patch Size: 467 rows x 188columns (2708 x 1096 meters)

Min: -0.3030, Max: 0.2592

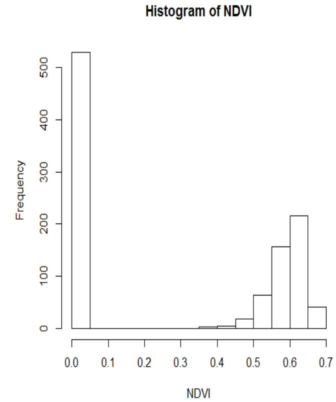
LISS IV (5.8 meters)



Patch Size:110 rows x 45 columns (2585 x 1056 meters)

Min: -0.0642, Max: 0.52 01

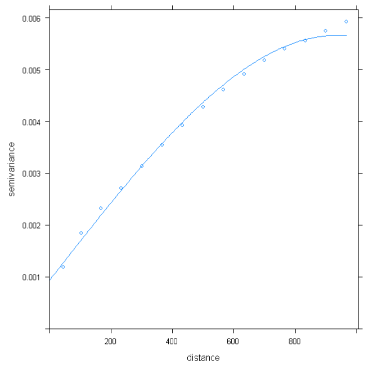
LISS III (5.8 meters)



Patch Size:49 rows x 21 columns (2744 x 1176 meters)

Min: 0, Max: 0.6734

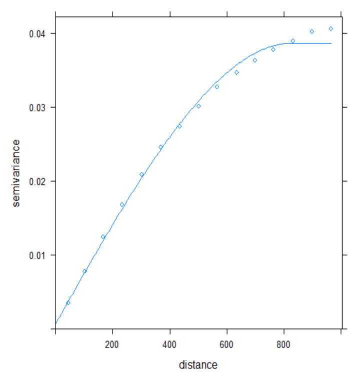
AWiFS (56m)



nugget: 0.0009,partial sill: 0.0047,

range: 932m, (cut off: 1000m)

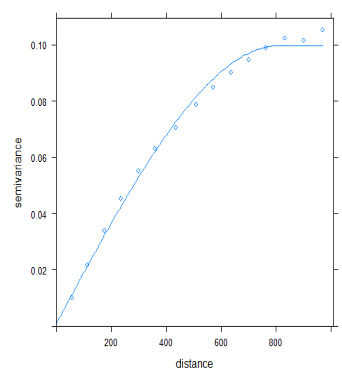
Best fitted model: Spherical



nugget: 0.0006,partial sill: 0.0380,

range:832m, (cut off: 1000m)

Best fitted model: Spherical



nugget: 0.0009,partial sill: 0.0987,

range: 812 m, (cut off: 1000m)

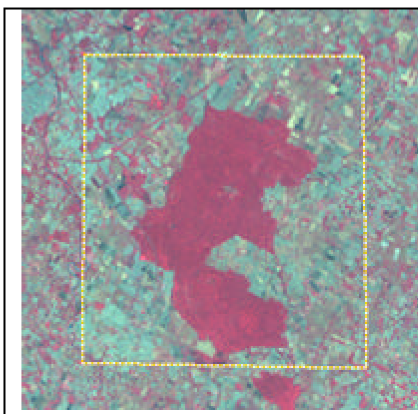
Best fitted model: Spherical

Table 3: Histogram and Variogram estimation for a homogeneous patch (Case A) across different resolutions

5.2. Effect of including non vegetation areas

In order to study the effect of non vegetation areas on omni directional variogram, vegetation patch (Figure 15) along with non vegetation areas was selected from LISS III image of Haldwani area for variogram analysis. Non vegetation area around the vegetation patch selected in first section was taken for variogram analysis. It can be seen from the histogram of NDVI values, that NDVI values varies from negative to positive (-0.2 to 0.6).Negative NDVI values are present in the histogram due to the presence of non vegetation areas in this selected vegetation patch.

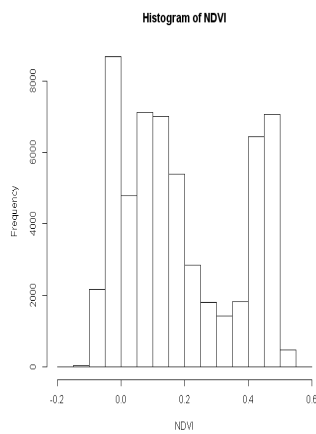
Total size of a vegetation patch was 5457 x 5475 meters and omni-directional variogram was calculated for the whole patch with a cut off of 5000 meters. It can be clearly seen from the variogram (Figure 16), that two type of spatial structure are present inside this patch. First type of spatial structure present in the variogram indicates that, variance is increasing with the distance i.e. dissimilarity between the point pairs of NDVI values increases up to a distance of 3000 meters (approximately) and then there is a sudden dip in the shape of a variogram. Highest variance present in this patch with non vegetation area is approximately 0.04. After 3000 meters, variance started decreasing which means NDVI values are coming out to be similar in nature. Two kind of spatial structure can be present due to the presence of both vegetation and non vegetation areas. On comparing the shapes of variograms calculated for vegetation patch and after including non vegetation areas (Figure 14 and Figure 16), it was observed that after including a non vegetation area, sill value decreases from 0.06 (Figure 14) to 0.04 (Figure 16) and the distance up to which NDVI values are spatially dependent on each other are almost same for both the patches (before and after including non vegetation areas).

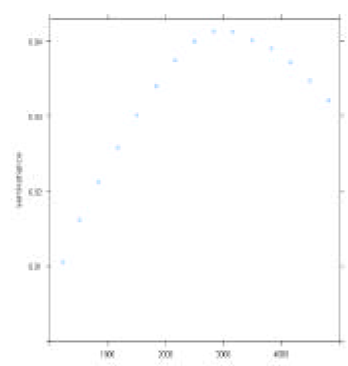


Vegetation Patch

Haldwani (LISS III: 23.5 meters)
245 rows x 233 columns

5757 x 5475 meters



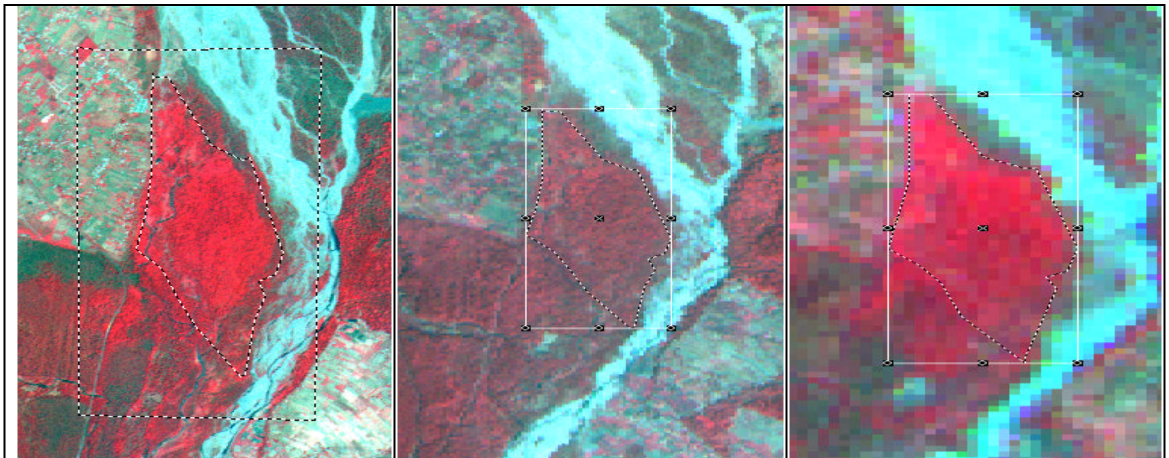


Calculated Variogram
Cut off: 5000 meters

Figure 16: Variogram analysis of a vegetation patch on including non vegetation areas (Case B)

5.3. Spatial variation after including Non vegetation areas

To quantify the effect of including non vegetation areas along the boundaries of a selected vegetation patch across different spatial resolutions, variogram analysis was performed for one set of patch. Summarized results (Figure 17) of compared variogram parameters (Nugget, Sill and Range) are explained below:



Pixel Size: 5.8 meters Patch1_Case B_LISSIV_June2009 Patch Size: 561 rows x 325 columns (3523 x 1885 meters)	Pixel Size: 23.5 meters Patch1_CaseB_LISSIII_Dec_2010 Patch Size:144 rows x 87 columns (3384 x 2044 meters)	Pixel Size: 56 meters Patch1_CaseB_AWiFS_March_2011 Patch Size:58 rows x 21 columns (3248 x 1176 meters)

Figure 17: Selected vegetation patches with non vegetation areas along the boundaries across different spatial resolutions (Case B)

5.3.1. Homogeneous and Non- homogeneous vegetation patches (LISS IV):

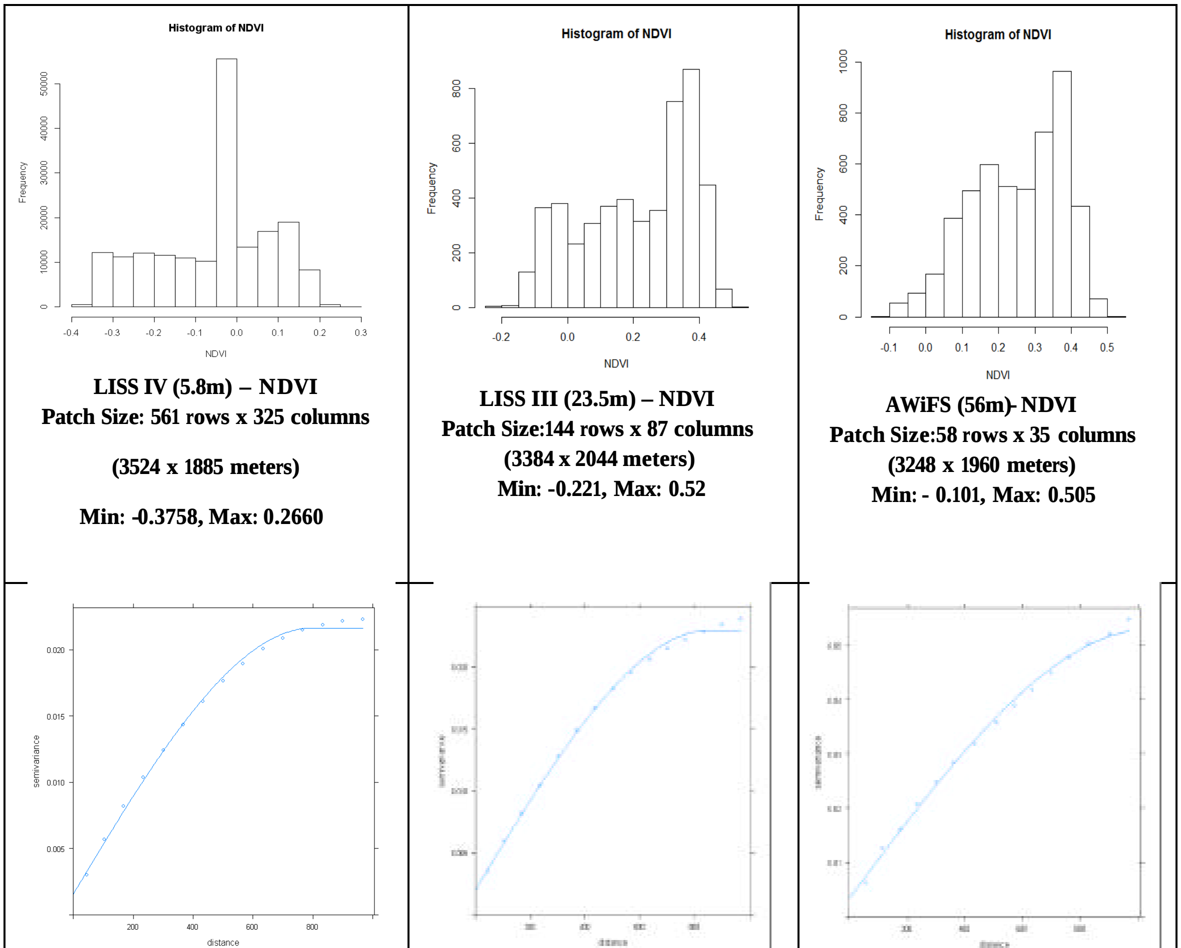
On comparing the range estimated variograms of both homogeneous and non homogeneous patches present in LISS IV image, it was found that range of a vegetation patch decreases after including non vegetation areas across the boundary of a patch. Initially, for a pure vegetation patch present in LISS IV image (figure 15(a)), range was found to be 932 meters but after including non vegetation areas across the boundary of a patch, range decreases to 799 meters. It was also noticed that non homogeneous patch (Case B) has higher value of sill (0.0026) as compared to homogeneous vegetation patches (0.0047), which is logical because the variability of NDVI values used to compute the variogram is larger and this larger variability lead to larger variance and hence larger value of sill in Case B as compared to Case A.

5.3.2. Homogeneous and Non- homogeneous vegetation patches (LISS III):

For LISS III image, it was observed that, range of a non homogeneous vegetation patch (856 meters)is larger than that of pure homogeneous vegetation patch (833 meters). However, sill value for non homogeneous vegetation patch (0.0209) is lower than sill present in homogeneous vegetation patch (0.0380). Nugget was found to be 0.0006 for Case A and 0.0020 for Case B.

5.3.3. Homogeneous and Non- homogeneous vegetation patches (AWiFS):

For AWiFS image, Case B (1045 meters) has larger range as compared to Case A (812 meters) but, sill is lower in Case B (0.0496) as compared to Case A (0.0987). Nugget was found to be 0.0009 for Case A and 0.0034 for Case B.



LISS IV (5.8m) – NDVI
Patch Size: 561 rows x 325 columns
(3524 x 1885 meters)
Min: -0.3758, Max: 0.2660

LISS III (23.5m) – NDVI
Patch Size:144 rows x 87 columns
(3384 x 2044 meters)
Min: -0.221, Max: 0.52

AWiFS (56m)- NDVI
Patch Size:58 rows x 35 columns
(3248 x 1960 meters)
Min: - 0.101, Max: 0.505

Nugget: 0.0015,Sill: 0.0200,
Range: 799m, (cut off: 1000m)
Best fitted model: Spherical

nugget: 0.0020,partial sill: 0.0209,
range: 856 meters, (cut off: 1000m)
Best fitted model: Spherical

nugget: 0.0034, partial sill: 0.0496,
range: 1045 meters, (cut off: 1000m)
Best fitted model: Spherical

Figure 18: Histogram and Variogram estimation for a non-homogeneous patch (Case B) across different resolutions

5.4. Transition Zone and Variogram Analysis

It has been mentioned earlier that, main objective behind this research is to study the potential of variogram analysis to study the spatial structure of vegetation patches. In order to explore the spatial structure of different patches associated with different scenarios, variogram analysis was carried out (Figure 19). Vegetation patches which are shown below are taken from LISS III image of Haldwani area.

First vegetation patch (figure 19(a)) represents an irrigation land present inside a dense forest patch. On analysing the calculated variogram for this selected patch, it can be seen that, clear spatial structure is present in a variogram. Variance among the NDVI values increases up to a distance of 1000 meters and goes up to 0.06 (approx). After crossing a distance of 1000 meters, variance is moving periodically which could be due to the presence of variation of vegetation inside this selected patch (figure 19(a)) which might lead to such type of variation in the NDVI values. Another vegetation patch (fig. 19(b)) present in Haldwani area has a transition from irrigation land to dense forest towards north direction. Variogram analysis revealed two types of variations in this patch which can be due to the presence of transition present on moving from south to north direction. Shape of a variogram has a slight change at 1100 meters (approx.) which means variance reaches up to 0.025 and then there is a change in the shape of a variogram. Vegetation patch present in fig. 18 (c), shows that there is a gradual change in the transition across the boundary present at eastern direction. It can be clearly seen that, on moving towards eastern direction irrigation land changes to aquatic vegetation and then it changes to urban areas. Variogram analysis for this vegetation patch revealed that, highest variance present in this vegetation patch is 0.04 and variance is continuously increasing with distance. Change in the shape of a variogram can be clearly seen at a distance of 1500 meters approximately.

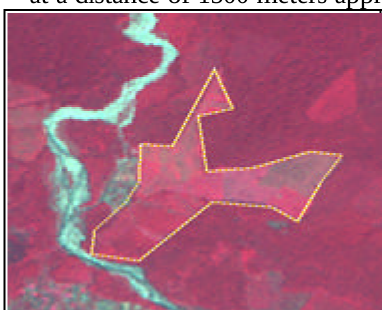


Figure 19 (a)
109 rows x 97 columns
2561 x 2280 meters

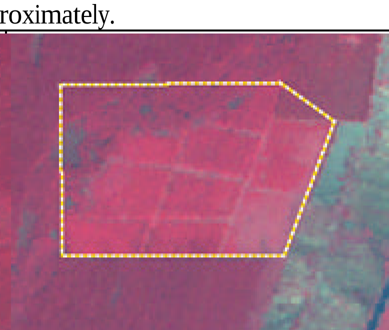


Figure 19 (b)
53 rows x 87 columns
1246 x 2045 meters

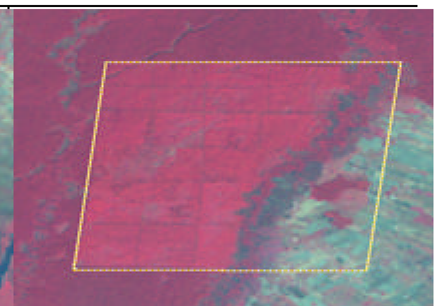
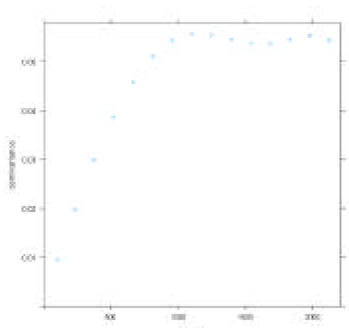
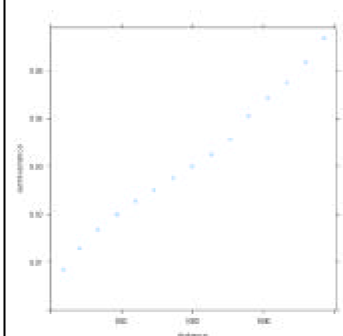


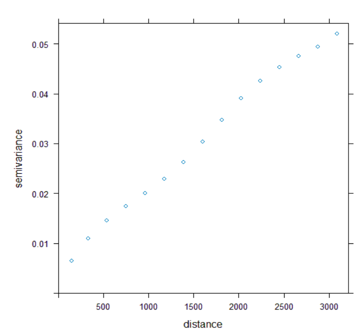
Figure 19 (c)
137 rows x 136 columns
3219 x 3196 meters



Calculated Variogram
Cut off: 2200 meters



Calculated Variogram
Cut off: 2000 meters



Calculated Variogram
Cut off: 3000 meters

Figure 19: Variogram analysis for vegetation patches having fuzzy and crisp boundaries (Haldwani, LISS III image)

5.5. Binary and Non- Binary Images: Comparison

Case C was designed for variogram calculation and estimation in order to analyze the spatial structure of binary images generated from Case B. Binary images present across all the three resolutions shows clear spatial structure. It can be seen that (Table. 6), AWiFS image has highest value of sill (0.554) and LISS III has lowest amount of sill (0.1407). Also, AWiFS has largest range (524 meters) and LISS III has lowest range (214 meters). Nugget value is almost similar for all the three resolutions (LISS IV: 0.2006, LISS III: 0.0362, AWiFS: 0.0350) in binary images.

Variogram parameters and shape of a variogram are compared with each other to analyze the difference between binary and NDVI (gray toned) images (Table. 6). It was observed that, binary images have smaller range as compared to non-binary images (NDVI). For LISS IV, range present in binary image was 374 meters while in case of non binary image it was 799 meters. Similarly, for LISS III and AWiFS images, range is very small in binary images as compared to non binary images.

Exponential model was found to be a best fitted model for binary images while Spherical model was found to a best fit for non binary images because in case of binary images, variance present in the NDVI values increases exponentially unlike non binary images. On the other hand, sill value was found to be higher in case of binary images, for LISS IV, sill present in binary image was 0.2006 and in non binary image, sill was 0.0200. Similarly, for LISS III, sill present in binary image was 0.1407 and non binary image was 0.0209 and for AWiFS image, sill present in binary image was very high (0.5543) as compared to non binary image (0.0496). Due to very high value of sill present in binary images, variance is very high and hence, exponential model was found to be a best fitted model for binary images at all the three resolutions.

However, observing the shape of a variogram for binary images in LISS IV image (fig. (20.a)), it can be seen that variance is increasing exponentially and highest variance present in 0.4 approximately at a distance of around 400 meters but after fitting a model to a variogram it was found that highest sill present is 0.2006 and range is 374 meters. This indicates that, after crossing a distance of 400 meters, there is a change in the structure of a variogram which could be due to change in the NDVI values while moving from vegetation to non vegetation area. Similarly, for LISS III image highest variance present is 0.15 (approx.) and distance up to which NDVI values are dependent on each other is around 600 meters but, after fitting an exponential model to the variogram, the value of range decreases to 216 meters and sill is almost similar. In AWiFS image, spatial structure is bit different as compared to LISS IV and LISS III images. It can be observed from fig. (20.c) that, variance increases and then there is a slight dip in the variogram shape and then again variance started increasing which means there is transition from vegetation to non vegetation class due to which variance increases but this sudden change in the shape of a variogram indicates that there can be some vegetation area outside a vegetation patch due to which variance decreases at a distance of 550 meters.

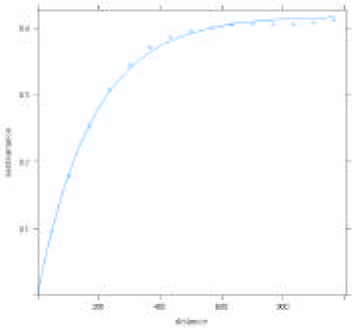


Fig. (20.a) Binary image: LISS IV (5.8m)

nugget: 0.0338,partial sill: 0.2006,

range: 374 m, cut off: 1000 m

561 rows x 325 columns

Best fitted model: Exponential

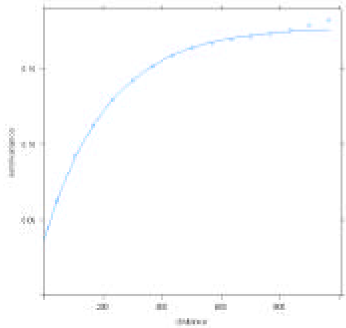


Fig. (20.b) Binary image: LISS III (23.5m)

nugget: 0.0362,partial sill: 0.1407,

range: 216 m, cut off: 1000 m

144 rows x 87 columns
Best fitted model: Exponential

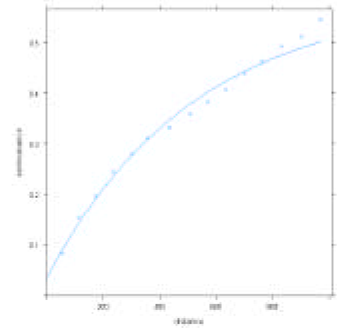


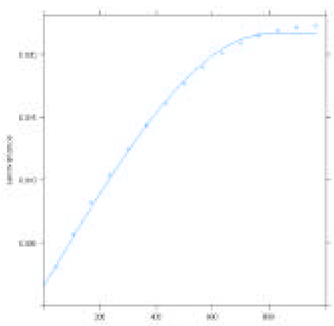
Fig. (20.c) Binary image: AWiFS (56m)

nugget: 0.0350,partial sill: 0.5541,

range: 524 m, cut off: 1000 m

58 rows x 35 columns

Best fitted model: Exponential



Non binary image:

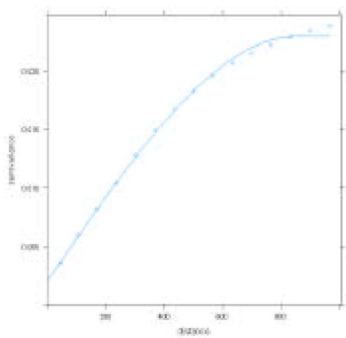
LISS IV (5.8 meters)

nugget: 0.0015,partial sill: 0.0200,

range: 799 m, cut off: 1000m

561 rows x 325 columns

Best fitted model: Spherical



Non binary image:

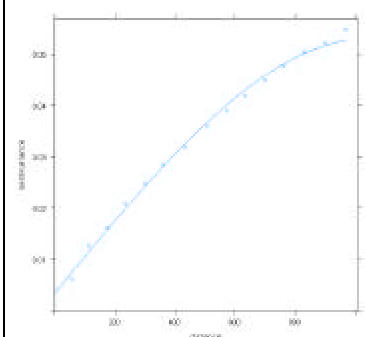
LISS III (23.5 meters)

nugget: 0.0020, partial sill: 0.0209,

range: 856 m, cut off: 1000 m

144 rows x 87 columns

Best fitted model: Spherical



Non binary image:

AWiFS (56 meters)

nugget: 0.0034, partial sill: 0.0496,

range: 1045 m, Cut off: 1000 m

58 rows x 35 columns

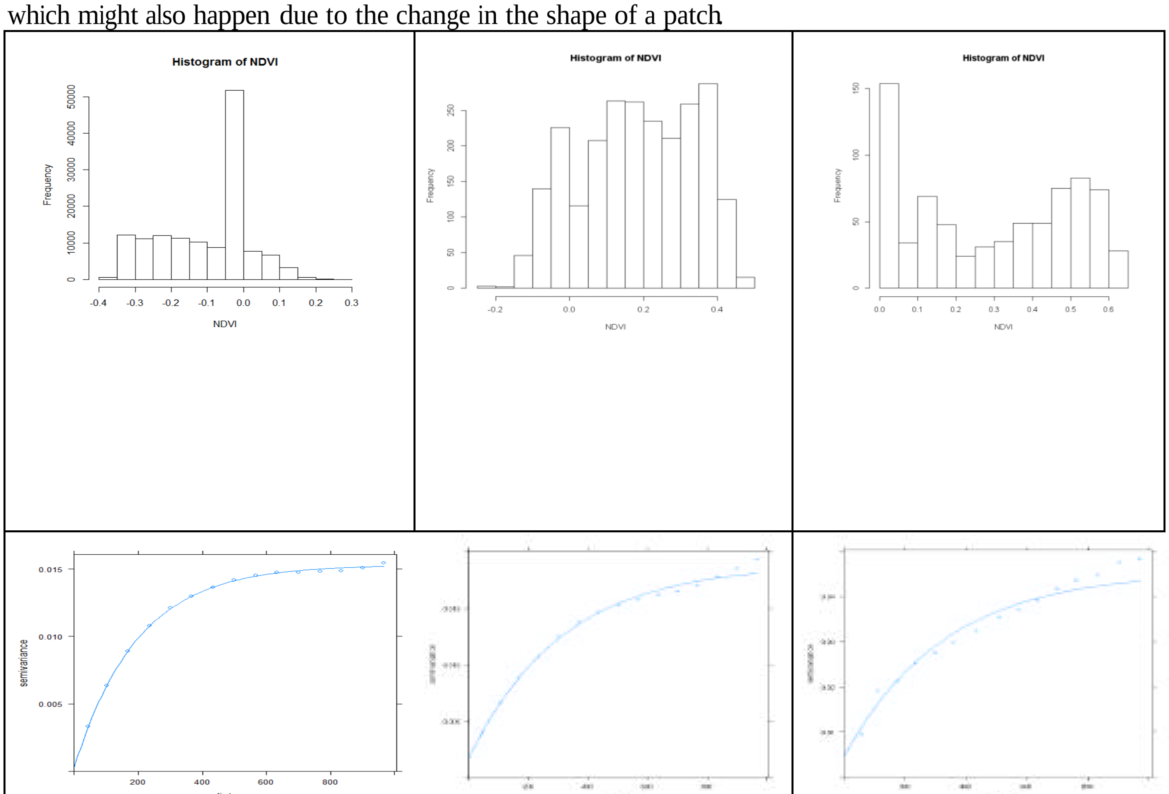
Best fitted model: Spherical

Figure 20: Comparison of variogram estimation for binary (Case C) and non binary images (Case B) at different resolutions

5.6. Variogram and shape of a patch

In order to study and analyze the shape of a vegetation patch and to study the spatial structure present in an area which we get after excluding a vegetation patch in Case A from an image present in Case B, variogram calculation and estimation was done for Case D. Variogram analysis was performed after excluding NDVI values of a homogeneous patch i.e. Case B – Case A and it was observed from the histograms of all the three images (fig. (21)) that for LISS IV image, most of the NDVI values are 0 which can be clearly justified because the area present in Case D has non vegetation area and hence, most of the NDVI values are 0. Case D has only non vegetated area and it shows clear evidence of spatial structure, but it does not have a clear shape.

Variogram analysis and comparison across spatial resolution indicate that, highest sill (0.0409) is present in AWiFS image and lowest sill (0.0017) is present in LISS III image. However, longest range was found to be 329 meters for AWiFS image and smallest range (196 meters) is present in LISS IV image. Exponential model was found to be the best fitted model for all the three images (Case D). It can be seen that for LISS IV image and there is a slight bend in a variogram curve at a distance of around 400 meters. This indicates that, there is a sudden change in the NDVI values and spatial continuity breaks at a distance of around 400 meters approximately. It can be due to the reason that there may be some change in the shape of a patch where the discontinuity breaks and NDVI values are no more correlated. From these observations, it can be interpreted as bend in the shape of a variogram curve leads to sudden change in the NDVI values, which might also happen due to the change in the shape of a patch.



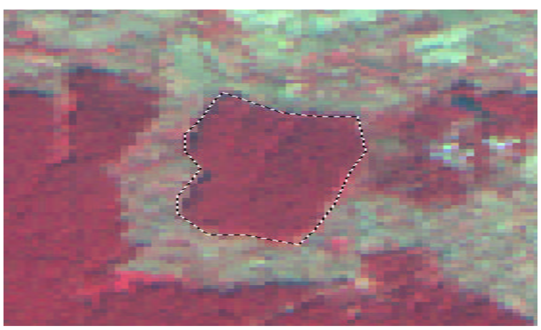
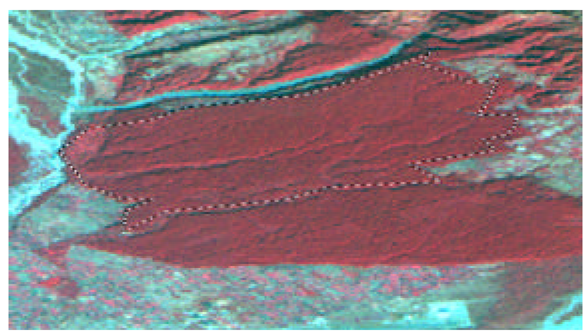
nugget:0.0002,partial sill: 0.0150, range:196 meters,	**nugget: 0.0004,partial sill: 0.0017, range:312 meters,**	**nugget: 0.0045,partial sill: 0.0409, range: 329 meters,**

Figure 21: Histogram and Variogram estimations after excluding vegetation patch from NDVI image CaseD

5.7. Variogram and Size of a Patch

Vegetation patches of two different sizes (Small and Large size) were selected to study the difference between their variogram parameters. Variogram was calculated and estimated for the two selected patches located at Lachiwala and Thano forest, Dehradun (fig. (22)). Selected patches which are shown below are taken from LISS III image. Variogram calculation was done on full length of a patch in order to acquire detailed information about a patch. On comparing the variogram parameters of both the patches, it was noticed that, range present in a large sized vegetation patch (3182 meters) is very high as compared to small sized patch (448 meters). However, sill present in a small sized patch (0.0382) is higher as compared to large sized vegetation patch (0.0004). Spherical model was found to be a best fitted model for both the vegetation patches. On observing the shape of a variogram, it was noticed that variance is increasing with the distance and NDVI values are spatially dependent on each other up to distance of 1200 meters (approx.) and highest variance which can be present in this vegetation is 0.008 (approx.) but on fitting a spherical model to this variogram, range decreases to 448 meters and sill also decreases to 0.0382.

For a large sized patch (fig. (22.b)), shape of a variogram indicate that, spatial dependency of NDVI values exists up to a distance of 2500 meters (approx.) and highest variance present in this patch is 0.0009 but on fitting a spherical model to this variogram it was found that range is 3182 meters and sill value is less than nugget itself (0.0004)

Small Sized Patch (LISS III-23.5 m)	Large Sized Patch (LISS III-23.5 m)
	
Patch size : 46 rows x 27 columns, (1081 x 634m), Location: Lachiwala, Dehradun	**Patch size : 186 rows x 195 columns, (4371 x 4582 m), Location: Thano Forest, Dehradun**

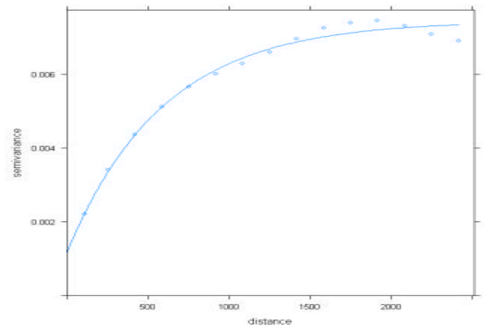


Fig.(22. a) nugget: 0.0016, partial sill: 0.0382, range: 448 m

(Cut off: 700 m)

Best fitted model: Spherical model

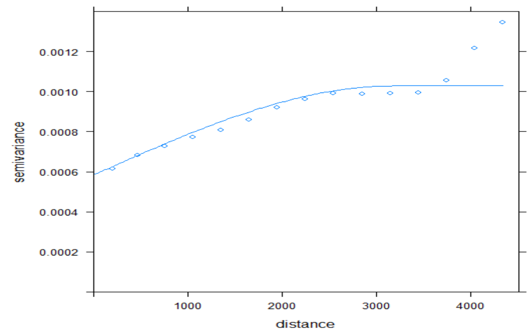


Fig. (22.b) nugget: 0.0005,partial sill: 0.0004, range: 3182m,

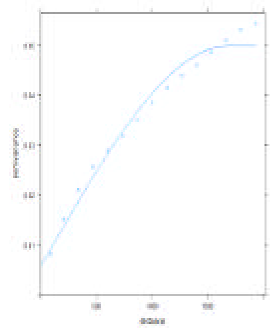
(Cut off: 4500m)

Best fitted model: Spherical

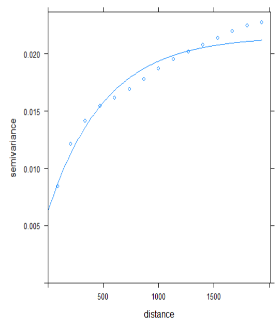
Figure 22: Comparison of variogram parameters for small and large size homogeneous vegetation patch (Case A)

5.8. Effect of Shadow on Variogram

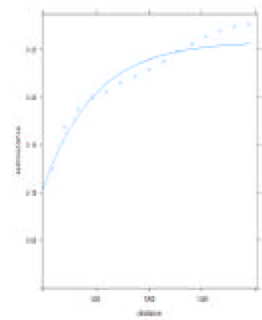
Vegetation patch which is located at an elevation was selected for variogram analysis. Selected patch is located near Mussorie diversion road at an elevation of 3114 ft. It can be seen from an image (Fig. 24), that selected patch has shadows which indicates about the presence of elevation.



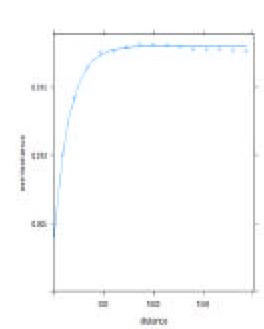
Patch size:
135 rows x 112 columns
(3172 x 2632 meters)
Spherical model,
Cut off: 2000m
nugget: 0.0057, partial sill:
0.0441, range:1691m
Case A



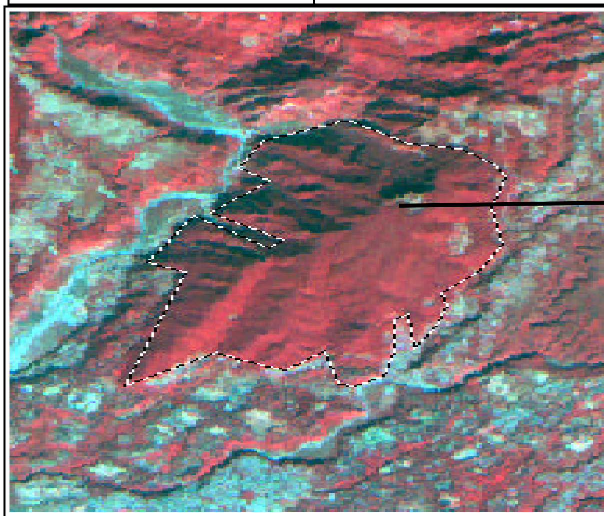
Patch size:
186 rows x 145 columns
(4371 x 3407 meters)
Exponential model,
Cut off: 2000m
nugget: 0.0062,partial sill:
0.0152, range: 513 m
Case B



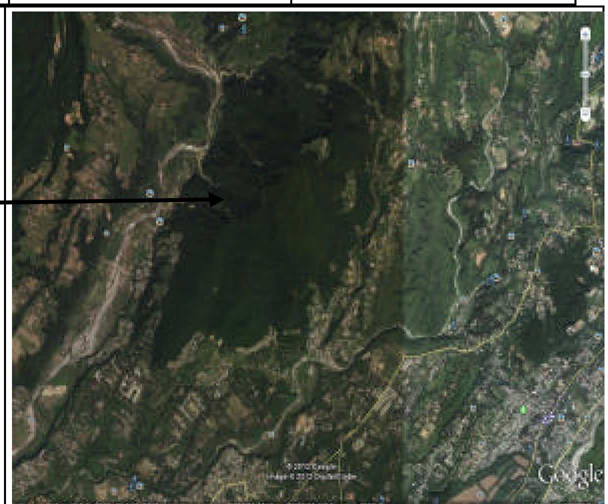
Patch size:
186 rows x 145 columns
(4371 x 3407 meters)
Exponential model,
Cut off: 2000m
nugget: 0.1024 ,partial sill:
0.1564, range:479 m
Case C



Patch size:
186 rows x 145 columns
(4371 x 3407 meters)
Exponential model,
Cut off: 2000m
nugget: 0.0036,partial sill:
0.0143,range:155 m
Case D



Patch at an elevation: LISS III, DDN
Location: Dhamma Salila, Dehradun



Google earth image
Elevation: 3029 ft.

Figure 23 and Figure 24 representing variogram analysis for a patch located at an elevation of 3029 ft. in Dehradun area

Variogram analysis was done for four different scenarios for the selected patch (fig. 23). It can be observed that, for a pure homogeneous vegetation patch (Case A), variogram shows a clear spatial structure and spherical model was found to be a best fitted model. Total length of a patch was around 2632 meters and variogram was calculated for around one third of it i.e. 2000 meters. Sill calculated for this homogeneous vegetation was 0.0441 and range was found to be 1691 meters. This indicates that, NDVI values are correlated to each other up to 1691 meters which is very near to the full length of a patch. Nugget present in this patch was 0.0057.

For Case B, i.e. after including non vegetation areas along the boundaries of a vegetation patch, it was observed that, range of patch decreases (513 meters), which means local dependency between the NDVI values decreases which is evident because of the presence of non vegetation areas. However, exponential model was found to be a best fit for Case B and for Case A, it was spherical model. Nugget value for Case B was found to be 0.0062 and sill was 0.0152. For binary image, range decreases (479 meters) and sill increases (0.1564) as compared to homogeneous vegetation patch (Case A). It can be clearly justified range decreases because degree of correlation decreases as there are only two classes' vegetation and non vegetation in binary images and there will be a sudden change in the variance which gives a high sill. Case D which has only non vegetation area has lowest value of range (155 meters)among all the four cases because it has only non vegetation area due to which there will be more heterogeneity among the NDVI values.

On comparing the variogram parameters of a patch which is located at a plain area (Table. 8) with the parameters of a patch located at some elevation (Table. 10), it was observed that, patch which is located at some elevation has higher sill (0.0441) as compared to the sill present in a patch at plain area (0.0015). It can be due to the presence of shadow present in a patch at an elevation. It was also noticed that, patch present at an elevation has longer range (1691 meters) while, patch present at a plain area has 939 meters.

5.9. Different types of vegetation patches

In order to study the spatial structure of different types of vegetation patches and to find out the potential of variogram in differentiating these patches, variogram analysis was performed. Different types of patches were selected from LISS IV image of Dehradun area and Omni directional variogram was calculated for NDVI values of these selected vegetation patches.

5.9.1. Dense Forest, Open Forest and Agricultural Land

Figure 25.a represents dense forest patch, in which variogram was calculated for full length of a patch and 1/3rd length of a patch to understand the spatial structure of a patch in an efficient way. Variogram analysis for dense forest patch indicated that, variance increases up to a distance of 600 meters (approx.) and then it started decreasing (fig. 25.b). Highest variance which can be present in this patch is 0.0020 approximately.

Figure 25.b represents open forest patch, in which variogram calculated for full length of a patch indicated that, variance of a patch is varying periodically in variogram. Highest variance which can be present in this patch will be around 0.0018.

Figure 25.c represents an agricultural land patch with crisp boundaries. On observing the variogram for this patch, it was found that sill value increases up to a distance of 400 meters and then there is a sudden dip in the shape of a variogram which means that NDVI values are no more dissimilar. Highest variance which can be present in this vegetation patch will be 0.008 approximately.

On comparing the variogram shape of three different types of patches, it was observed that highest variance is present in open forest patch because it is more heterogeneous in nature as compared to dense forest and agricultural land. Lowest variance was found to be for agricultural patch because it seems to be a smooth patch as compared to open forest patch. It was also noticed that variogram reveals different shape for different length of a patch. Shape of a variogram calculated for full length of a patch is completely different from the shape of a variogram calculated for half length of a patch.

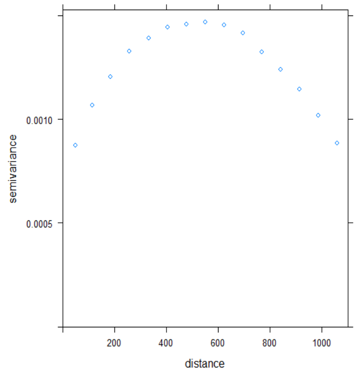
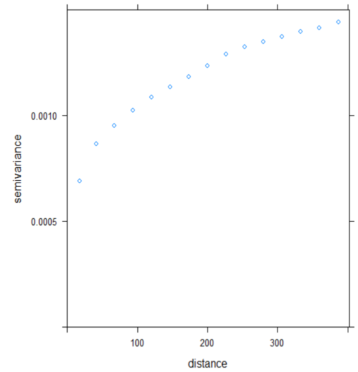
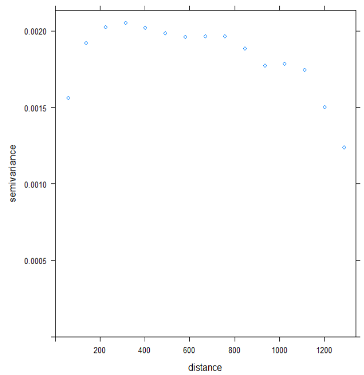
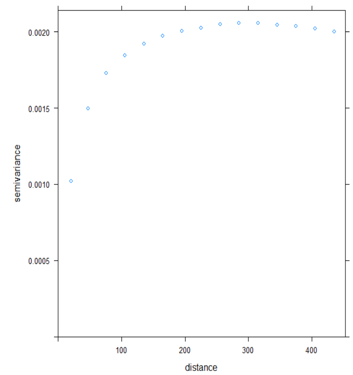
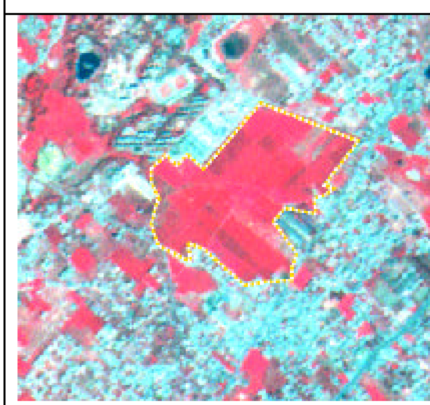
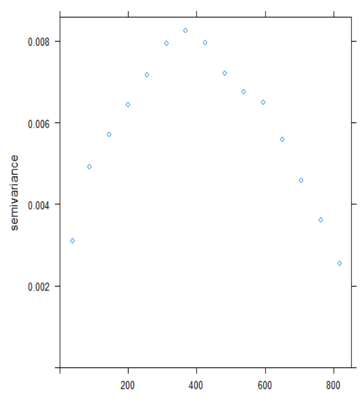
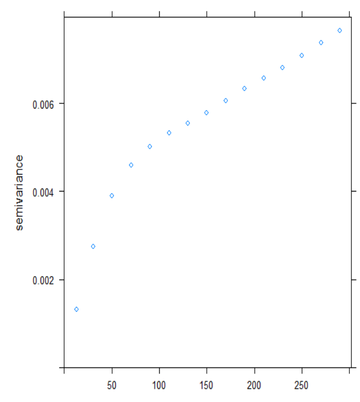
Patch Type	Variogram: Full length of a patch	Variogram: 1/3rd length of a patch
 Fig.25.a Dense Forest Patch Location: Lachiwala, Dehradun 147 rows x 185 columns 853 x 1073 meters	 Fig. B Cut off: 1100 meters	 Cut off: 350 meters
 Fig.25.b Open Forest Patch Location: IMA, Dehradun 179 rows x 231 columns 1038 x 1340 meters	 Cut off: 1340 meters	 Cut off: 450 meters
 Fig.25.c Agricultural Land Patch Location: Ballupur, Dehradun 120 rows x 150 columns	 Cut off: 850 meters	 Cut off: 300 meters

Figure 25 Variogram calculation for dense forest, open forest and agricultural land present in LISS IV, Dehradun area

5.10. Spatial Structure of different types of vegetation subsets

To address the spatial structure of different types of subsets selected in Haldwani area (fig. 26), variogram calculation was performed. Variogram results for selected subsets are summarized here:

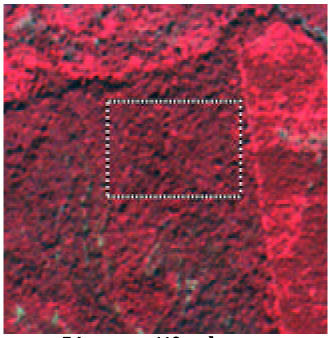
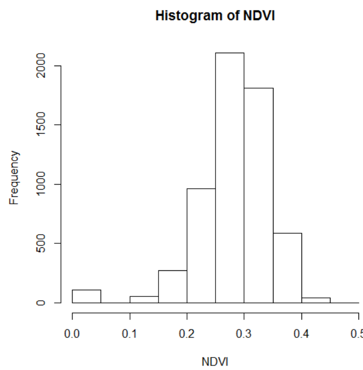
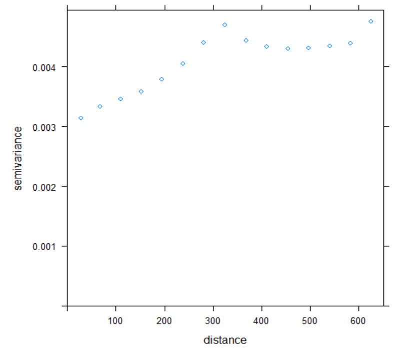
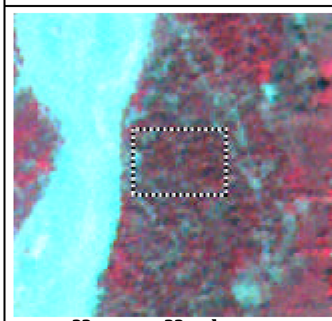
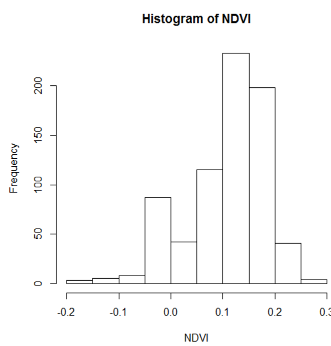
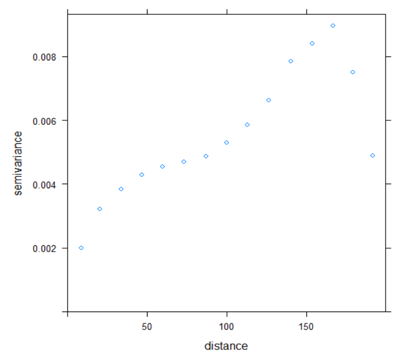
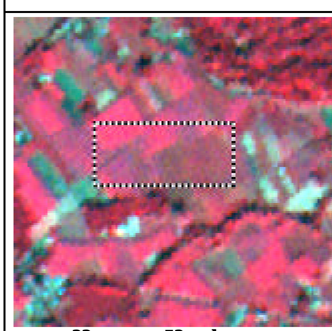
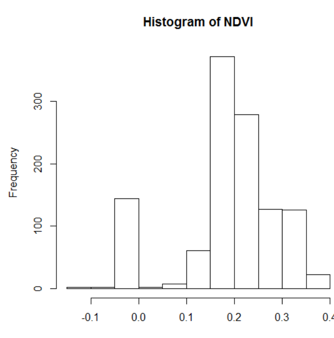
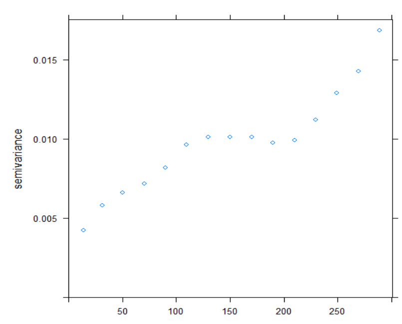
 54 rows x 110 columns 313 x 638 meters Dense Forest		 Calculated Variogram Cut off: 600 meters
 23 rows x 32 columns 133 x 186 meters Mixed Forest		 Calculated Variogram Cut off: 180 meters
 22 rows x 52 columns 128 x 302 meters Irrigation Land		 Calculated Variogram Cut off: 300 meters

Figure 26 Variogram calculations for selected subsets of different vegetation types present in LISS IV, Haldwani area

Analyzing the variogram shape of different types of subsets of vegetation patches, it was noticed that spatial structure present in dense forest subset is much clear as compared to the mixed vegetation and agricultural land subset. Mixed vegetation subset is the most heterogeneous subset among three types of vegetation subsets which means variance should be highest in case of mixed subset as compared to dense forest and agricultural land. It can be clearly justified after observing the calculated variogram that variance is highest for mixed subset. In case of mixed subset, there is a variation in the variance of a subset due to the dissimilarity among the NDVI values inside a subset.

5.11. Effect of Change in Season on Spatial structure of Vegetation Patch

Same dense forest patch was selected on LISS IV image of two different seasons. March and June are the two different seasons and to study the effect of change in spatial structure of a patch, variogram analysis was performed. On observing the histogram of NDVI values calculated for the selected patches, it was observed that during March season, most of the NDVI values varies between -0.1 and 0.0 but during June season, most of the NDVI values varies between 0.0 and 0.1 which means there is more healthier and dense vegetation in June as compared to March. Since, March is an extremely cold season for Dehradun area and there will not be any new vegetation during this season which might lead to negative NDVI values. However, shape of a variogram calculated for a patch during March season indicated that variance is increasing and highest variance which can be present in this patch can be 0.0016 approximately which in case of variogram calculated for June season, it was observed that highest variance could be around 0.0014 (approx.).

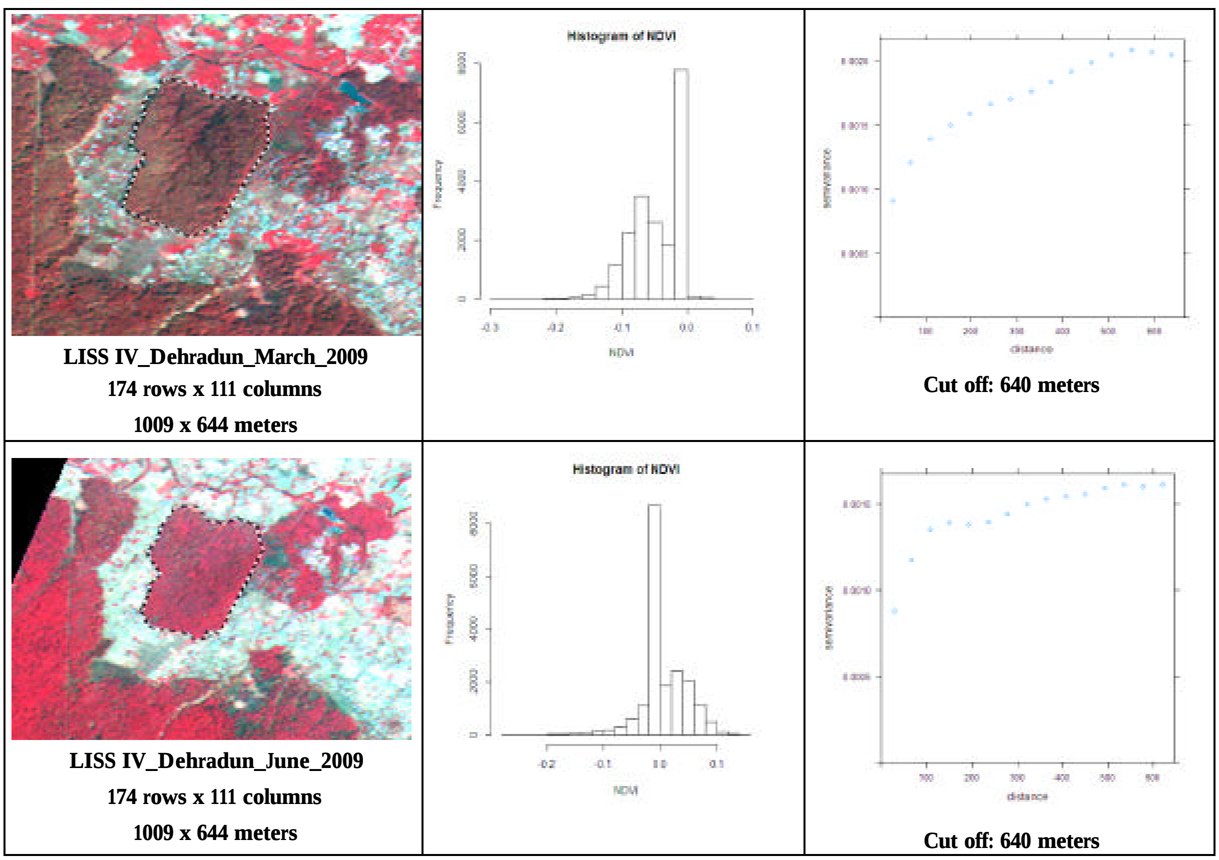


Figure 27 Variogram calculations for same vegetation patch during two different seasons (March and June)

5.12. Simulated patches across resolution

As three selected patches across different resolutions (fig. 15) are taken from different seasons (L4: June,2009, L3: Dec,2010 and March,2011) due to which AWiFS image has highest variance and LISS IV has lowest variance. Different seasons of these images had a strong impact of the variogram of these selected patches. To avoid the biasness of the seasonal effect, we took LISS IV image (5.8m) and simulated to make it equal to LISS III (23.5m) and AWiFS (56m) approximately Upscaling of LISS IV image by a factor of 4 and 9 to make it closer to LISS III and AWiFS resolution (explained below)

5.8 x 4 = 23.2 meters (almost equivalent to LISS III (23.5 meters)

5.8 x 9 = 52.2 meters (almost equivalent to AWiFS (56 meters)

Observing the variogram of simulated images (fig. 28), for a selected vegetation patch it can be seen that highest variance (0.006 approx.)is present original LISS IV image and lowest variance (0.006 approx.) is present in simulated image of resolution 52.2m which is completely different for the variance present in original images. For original images, highest sill was present in AWiFS image and lowest in LISS IV image.

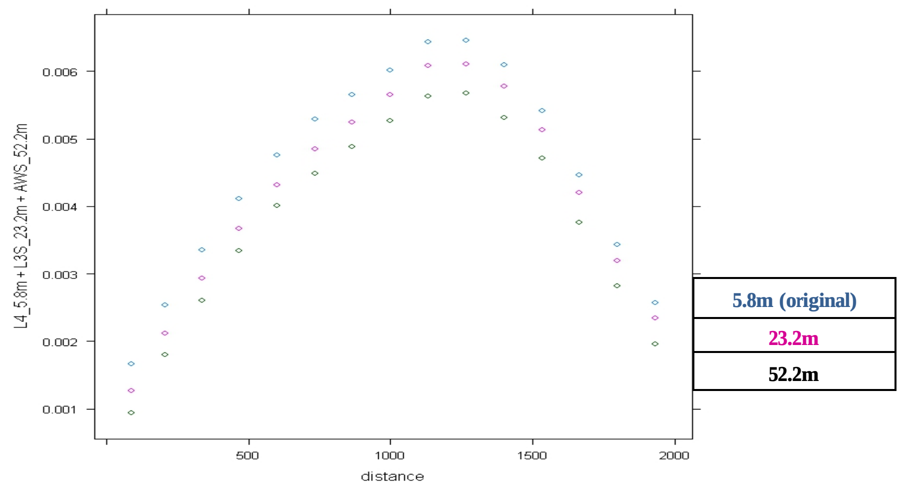


Figure 28 Variogram calculation s for LISS IV (5.8m) and two simulated images (52.2m and 23.2m)

6. DISCUSSION

To decide how to use this NDVI information for studying spatial structure and the shape of vegetation patch this study has proposed a variogram based methodology based on computing omni directional variogram for whole vegetation patch. Analysis of auto correlation of NDVI values present in a vegetation patch indicated the presence of clear spatial structure in vegetation patches. Variogram analysis of different vegetation patches concluded that it is possible to consider this complementary information associated with NDVI values for studying pattern of vegetation patches. Both NDVI variance and lag distance present in a variogram were tested and studied accordingly and it would be interesting in a future to apply this geostatistical method to study spatial structure of vegetation patches.

Spatial structure at different resolutions was studied to analyze the spatial variation and to analyze the difference between the patterns of a patch. Spherical model was found to be an appropriate model to study the structure of homogeneous vegetation patches. For all the selected vegetation patches, variance increases with the lag distance and indicated a clear spatial structure.

6.1. Variogram Analysis of different types of vegetation patches

Section 1.9.1 explains spatial structure of different types of vegetation patches present in LISS IV image of Dehradun area. Different types of vegetation patches were analyzed to verify that each type of a patch shows a different spatial variability. Section 1.9.1 illustrates the omni directional variogram for different types of vegetation. Dense forest, open forest and irrigation land reveal different spatial behaviours'. Spatial correlation (range parameter) for dense forest exhibits up to 600 meters, 400 meters for open forest and 300 meters for agricultural land. There is a noteworthy similarity between the spatial correlation pattern of open forest and dense forest (Fig.), probably due to a presence of certain homogeneity in the spatial distribution of the vegetation, although their variances are different and allowed us to distinguish them. Agricultural land has lower sill as compared to open forest and dense forest patches. It has been said that, each land cover class presents in an image reveal different spatial variability pattern (Miranda et al., cited in (*Chica-Olmo et al., 2000*)) which can be clearly justified after observing different shapes of variogram for different types of vegetation.

Moreover, it can be possible that longer range can be due to the larger size of patch. It can be explained as due to a large size of a vegetation patch, NDVI values can be correlated and spatially dependent on each other up to a longer extent as compared to a small sized vegetation patch. Degree of local spatial dependency in large sized patch will be much higher as compared to small sized patch and it can also be seen from images of both large sized and small sized patch that extent of homogeneity is somehow related to the value of range due to which large size patch has longer extent (range) as compared to small sized patch. It was noticed that range parameter is longer for large sized patch and smaller for small sized vegetation patch which means spatial autocorrelation exhibits up to a longer distance in large sized patch as compared to small sized vegetation patch.

In addition to this, two types of agricultural vegetation patches were selected (Table. 10) to explore the spatial structure of these selected vegetation patches using variogram parameters. One of them is bit homogeneous in nature (Patch 1 in Table. 10) and another one is bit heterogeneous in nature (Patch 3 in Table. 10). It was observed that, agricultural land which is homogeneous in nature gives very high value of range (1829 meters) as compared to other patch (592 meters) which is heterogeneous in nature. Moreover, due to the presence of heterogeneity among NDVI values inside a patch (Patch 3), sill value is very high as compared to homogeneous patch. Smooth texture can be clearly seen from an image of homogeneous patch while a patch which is heterogeneous in nature has rough texture and colour is completely different from homogeneous agricultural patch. For all these reasons, exponential model was found to be a best fit for a patch which is heterogeneous in nature because variance increases exponentially, while spherical model was a best fitted model for homogeneous patch because it gives a clear spatial structure.

6.2. NDVI measures of spatial variability

Omni directional variograms across different spatial resolutions (represented in Results section) considered different parameters such as direction, maximum distance of a patch and lag distance. It was observed that variograms have different behaviours for different resolutions which can be due to the variations in the structure and correlation patterns of the NDVI values. Texture of a vegetation patch changes on moving from higher to lower resolution and it can be clearly seen from an image that pattern and structure of a patch changes with resolution. Variograms have different behaviours and shapes for LISS IV, LISS III and AWiFS and it was observed that, on moving from higher to lower resolution, range decreases and variance (sill) in a selected patch increases. It could be due to the phenological reasons associated with a selected patch (section 2.4) and local variability present at different resolution due to different pixel sizes (5.8 m, 23.5m and 56m).

Some patches are selected in such a way that they are located at an elevation of 3200 ft approximately. It has been mentioned in Literature review section that vegetation patches present at high altitudes have high agricultural heterogeneity *(Burso et al., 2009).* In the present study, vegetation patch located at an elevation (3200 ft) clearly reflects the presence of shadow zones. Its variogram shows that NDVI values present high heterogeneity (variance: 0.0057), due to the differences between the NDVI values of shadow zones and plain areas. On comparing the variance present in the patch at a plain area (elevation: 1107 ft.), it was observed that, variogram has a much lower variance (0.0047) in plain areas due to lighter shadow effect.

6.2.1. Shape of a Patch

Case D was constructed to study the shape of a vegetation patch (Case B - Case A). When homogeneous vegetation patch (present in Case A) is excluded from an image present in Case B, area left should be non vegetation area. Variogram was calculated was done in order to check whether there is any indication about shape of a patch or not. Variogram calculation was done for area left after excluding homogeneous patch from NDVI image and it was noticed that, for LISS IV and LISS III images, there are some negative NDVI values which indicate that there is a presence of non vegetation area in these two patches but this does not hold true for AWiFS image as there are no negative NDVI values in AWiFS image, which means this left over area has also vegetation which could be newly grown small plants and other vegetation. March is a favourable season for newly grown small vegetation and since, AWiFS image was taken on March, 2011; it can be possible that due to the presence of small vegetation across the boundary of a patch, NDVI values are coming out to be positive.

6.3. Effect of including non vegetation areas

It was observed that, exponential model is a best fit for patches which are bit heterogeneous in nature and spherical model is a best fitted model for pure homogeneous vegetation patches. Range (spatial dependency) is higher for homogeneous patch and it decreases as the heterogeneity inside a patch increases.

On including the non vegetation area along the boundaries of homogeneous vegetation patch (Case B), it was observed that for LISS IV image, sill increases from 0.0015 to 0.0026 which can be clearly justified due to the increase in dissimilarity (variance) among the NDVI values due to the presence of non vegetation area. However, in case of LISS III and AWiFS images, sill value decreases after introducing non vegetation areas with a pure homogeneous vegetation patch which can happen due to other phenological factors associated with these selected vegetation patches present in LISS III and AWiFS image.

6.4. Spatial structure and Phenology

Satellite images used in this study area of three different dates and seasons (LISS IV: June, 2009, LISS III: December, 2010, AWiFS: March, 2011). It is possible that NDVI values for selected vegetation patch may vary considerably between these dates and can be affected by several factors like vegetation growth, seasonality, environmental conditions, meteorological conditions etc. It has been seen that, variogram behaviour changes with the change in (*Nayak, 2008*). Variation in NDVI values can be related to the phenological character of a vegetation patch which can further influence sill and range parameter of a patch.

It was observed that, vegetation patch present in AWiFS image (March, 2011) has highest value of sill (0.0987) and LISS IV (June, 2009) has lowest value of sill (0.0015). It can happen due to phenological factors associated with this Sal dominant vegetation patch. AWiFS image was captured on March, 2011 and it has been said that High heterogeneity among NDVI values lead to high variance and therefore high value of sill in AWiFS image.

Similarly, AWiFS image (March, 2011) has smallest range. Range can be affected by two factors; firstly, it can be small due to the presence of heterogeneity among the NDVI values, NDVI values are dependent on each other up to a shorter distance as compared to the patch present in other two images (LISS IV and LISS III). Secondly, range can be shorter because AWiFS image was captured on 2011 and other two images (LISS IV and LISS III) were taken on 2009 and 2010. It could be possible that, there could be deforestation or cutting of trees and land cover change during this interval of time i.e. June,2009 to March,2011 which can further lead to decrease in the value of range (939 meters to 812 meters). It was observed from all the three images (Table. 4), that there is a difference in the texture of all the three images. AWiFS image has comparatively lighter texture and colour as compared to other two images (LISS IV and LISS III) which lead to different variogram parameters like sill and range.

6.5. Comparative Analysis of Binary and Gray tone images

Variogram parameters generated for binary (Case C) and Non binary images (Case B) produced some interesting and defining results. It has been already mentioned before that, binary images are generated from classification of a NDVI image present in Case B. On interpreting and comparing the variogram parameters of both binary and non binary images, it was noticed that there is a difference between their corresponding variogram parameters for all the three resolutions. For binary image, exponential model was found to be a best fitted model while for non binary image; spherical model was a best fit. It can be due to the fact that with binary images there is a sudden change in the NDVI values while moving from vegetation (0) to non vegetation class (1) but, in case of non binary (gray tone) images, there will be a gradual variation in the NDVI values across the boundary of a vegetation patch. NDVI values will vary from -1 to +1 in gray image but in case of binary it will be either 0 or 1 which lead to an exponential increase in variance in case of binary images. Binary images have shorter range as compared to non binary images (Table. 6) because spatial dependency exists up to a shorter distance in case of binary images. Somehow, it also gives an idea about the uncertainty associated along the boundary of a vegetation patch while defining the class (vegetation and non vegetation) in binary images. Larger range in NDVI image indicate that, spatial dependency in NDVI values (vegetation) exhibits up to a longer distance as compared to binary images. It was also observed that, sill present in binary images is comparatively very high to that of non binary image, which means that, there is very less amount of dissimilarity present in a non binary image as compared to binary images.

6.6. Original and Simulated Images: Variogram analysis

To overcome the seasonal effect on variogram parameters, LISS IV image was simulated to a pixel size (23.2m and 52.2m) which is almost equal to LISS III and AWiFS images. It was found that, variogram behaviour of a simulated image is completely different from original image.

Comparing the variogram parameters of original and simulated images across resolutions reveal that, for original image, AWiFS has highest variance and LISS IV has lowest variance but in case of simulated images, LISS IV has highest variance and AWiFS has lowest which is completely different. This indicates that, variogram behaviour is affected due to different seasons and phenological effect present in original images but in case of simulated images, there is no impact of season and temporal variation which leads to different parameters (sill and range).

7. CONCLUSION & RECOMMENDATIONS

Finally, the proposed methodology used in this research study proved to be efficient strategy to study the shape and structure of a patch. It can be concluded that variogram analysis using NDVI values can give detailed information about the vegetation structure and seasonal information about the images. Information about the spatial structure of vegetation coverage on earth's surface is an important aspect in remote sensing and Geostatistical techniques are proved to effective in studying the spatial structure of vegetation patches, in analyzing the uncertainty associated while defining the classes as vegetation and non vegetation, in exploring the extra information that can be associated with the NDVI values, in studying the effect of resolution the spatial structure of vegetation, in charactering the phenological aspects that are associated with different seasons of LISS IV, LISS III and AWiFS images.
In this chapter, first section concluded the importance of NDVI after observing the variogram results. Second section explains about the relevance of this study for studying the spatial structure of different types of vegetation patches. It explains the importance of range and sill parameters for discriminating different vegetation types.

7.1. NDVI – An Important Indicator

A straightforward conclusion is apparent, that variogram analysis using NDVI can be a useful geostatistical approach for studying the spatial structure of vegetation. NDVI is proved to be an efficient vegetation index to study the spatial structure as it helps in providing information about the vegetation status (rich vegetation or poor vegetation). Minimum and maximum NDVI values were calculated in order to determine the variation of vegetation health inside a patch. In some of the cases, it was observed that some non vegetation areas are also present inside a selected homogeneous vegetation as some of the NDVI values are negative in nature (less than zero).On comparing and observing the variogram shape and parameters of binary and gray images, it can also be concluded that, NDVI values can be an appropriate parameters for defining vegetation and non vegetation classes as compared to binary images. Variogram shape and parameters are able to analyze the uncertainty which is associated with class definition of binary images. Third section explains the role of variogram analysis in interpreting the transition zone and boundary of a patch.

7.2. Spatial structure of vegetation patches

Selected vegetation patches in this study exhibits different pattern and spatial structure. With the change in resolution, the pattern and of these patches also changes with the change in resolution. The study explored the potential of variogram modelling in studying the spatial structure of vegetation patches across resolutions. Extent of heterogeneity and homogeneity present inside a patch can be clearly understood from the behaviour of a variogram.

7.2.1. Range of a variogram

It is interesting to note that; range can be a useful parameter for describing both local and global correlation of vegetation coverage. Range was found to be fairly smaller for mixed vegetation subsets as compared to rich dense forest subsets. However, open forest and dense forest shows almost similar variogram behaviour. Homogeneous patches have longer range as compared to heterogeneous patches, for example, patches present in urban areas have smaller range as compared to the patches present in dense forest. From all these observations, it can be concluded that range can be appropriate variogram parameter to analyze the extent of spatial dependency among the NDVI values and up to some extent; range parameters could be helpful in analyzing the homogeneity of a patch. Further, we can clearly identify small and large sized vegetation patch using range parameter of a variogram. Range was found to be larger for large areas which have rich and dense vegetation than for smaller areas present in urban areas with mixed components having poor vegetation.

7.2.2. Appropriate spatial resolution

It has been mentioned above that range parameter is a useful parameter to study the spatial structure of vegetation patches. After analyzing the spatial structure of most of the vegetation patches, it can be concluded that appropriate resolution for studying the spatial structure of vegetation patches is almost half of the total range of variogram which means if a range of a variogram is 70 meters then, appropriate resolution to study the spatial structure of that vegetation patch will be 35 meters approximately. It can be due to the fact that range is gives an idea about the spatial autocorrelation of NDVI values and it is an extent up to which NDVI values are spatially dependent on each other. It was concluded after observing the variogram behaviour of different patches that clear spatial structure can be seen at a resolution which is half of the total range present.

7.2.3. Simulated and Original Image

Simulated and original images have shown different variogram behaviour across different resolutions and it can be concluded that there is a strong impact of seasons, phenology, vegetation type and other factors on variogram behaviour and they strongly effect variance and spatial auto correlation present inside a image.

7.2.4. Shape of a variogram

Variogram interpretation was usually focused on analyzing range and sill parameters. However, variogram behaviour for different types of vegetation and scenarios is equally important for analyzing the variation and phenomenon associated with a vegetation patch. It can be seen from results calculated after including non vegetation areas across the boundary of a patch (section 1.2) that there is a sudden change in the shape of a variogram after reaching a specific variance (sill) and then shape of a variogram changes. It was due to the presence of both vegetation and non vegetation areas due to which the variogram behaviour exhibits sudden change. However, there are several other factors like phenological reasons, discussed earlier which are responsible for different variations of NDVI values. Images selected for this study were captured on different dates and seasons (LISS IV: June, 2009, LISS III: December, 2010 and AWiFS: March, 2011). Temporal differences present between these three images also play a major role behind different variogram behaviours.

7.3. Transition zone across different resolutions

Variogram parameters were compared and differences between the variogram parameters indicated that there is some uncertainty present while defining the classes (vegetation and non vegetation) to generate a binary image (0/1).Uncertainty of these patches is realized by interpreting the variogram parameters at different resolutions. It was observed that sill and range values for binary and non binary images are different from each other. Different values of range indicate that the distance up to which NDVI values are spatially dependent on each other are different in case of binary images as compared to non binary image.

In almost all the cases, binary images have low value of range as compared to non binary images. This clearly indicates some uncertainty in class definition of binary images.

Moreover, sill value is different for Binary images and Gray tone images (NDVI) which reflects that classified results of vegetation and non vegetation can be different and non- vegetation classes can also be a part of vegetation class. However, there are many more reasons behind different sill values of binary and non binary images like threshold selection for generating binary images was arbitrary. Putting a different threshold to generate a binary image may give different sill value and range value thus obtaining completely different spatial structure and variogram parameters of a patch selected.

Several decision makers and organisations working for vegetation patches and their extent to study wild life corridors are concerned about ecological changes and variations in the shape of such type of patches. These conclusions and results can be useful in interpreting the distribution of vegetation and its spatial structure. Organisations which are working for the conservation of these patches like Thano forest, Rajaji national park may be interested in such kind of spatial structure information while making National highways, roads etc. This information will be a helpful tool for these organisations to interpret the extent and transition zones of these patches and also, with the help of spatial structure of a patch, the distribution of species and variability within a patch can also be interpreted. Thus, variogram modelling can also be an efficient process to monitor these segmented patches and can be used instead of basic image processing technologies.

7.4. Variogram analysis in differentiating vegetation type

It has been concluded that texture of an image is one of the most important indicator of smoothness and coarseness present in an image (*Lillesland and Kiefer, 1994*). Present study concluded that different types of vegetation patches reveal different texture information. It was observed that, homogeneous dense forest patches have smooth texture while patches present in urban areas or poor vegetation have rough texture. It reveals important information about the structural arrangements of the components of a patch and hence it provides important discriminating characteristics related to variability pattern of different land cover classes and classification (*Chica-Olmo et al., 2000*). It has been already concluded in one of the studies (*Chica-Olmo et al., 2000*)) that texture signature can also be used in discriminating land cover classes.

Present study has selected different subsets and vegetation patches (Dense forest, Open forest, Agricultural land, urban areas) and it was observed that range and sill parameters are different for different vegetation types. It can be also concluded that, variogram analysis can be an effective tool to discriminate different types of vegetation and classes because each land cover class reveals a different spatial variability pattern.

7.5. Answers to Research Questions

The following research questions were answered to meet the objective of this research study:

Is there any specific variogram model that fits for the selected vegetation patches? (RO: 1)

Variogram calculation and estimation was performed in order to study the spatial structure of vegetation patches including homogeneous patches, binary images and non homogeneous patches (vegetation + non vegetation). It was observed that, for homogeneous vegetation patches Spherical model was found to be a best fitted model because they exhibit clear spatial structure.

On the other hand, binary images having only two classes either vegetation (0) or non vegetation (1), Exponential model was found to be a best fitted model because in binary images, variance increases very frequently as compared to gray images (NDVI). Binary image exhibits higher variance because there is a sudden change in the pixel values of a patch. DN value changes from 0 to 1 and vice versa which leads to high value of variance as compared to NDVI images.

Due to sudden increase in variance, exponential model was the best fit. However, for Case D, which has only non vegetation area, fitting any specific variogram model was bit difficult as it was more heterogeneous in nature as compared to other cases but, exponential model was fitted for Case D as well.

In most of the cases, Spherical and Exponential model was found to be the best fitted model for variogram estimation. Spherical Variograms was found to be best fitted model for most of the vegetation patches. On the other hand, for binary images (Indicator variogram), Exponential model was found to be a best fitted model (Case D). It can be due to the fact that, in case of binary images, variance increases very frequently as compared to non binary images.

Which resolution among the data set gives highest and lowest value of variance? Why? (RO: 2)

In principle, coarser resolution should have lowest sill value as compared to higher resolution because of the presence of large pixel size in coarser resolution; variance between the pixels will be smaller as compared to the pixels present in high resolution. This means in this study, LISS IV should have highest sill value and AWiFS should have lowest value of sill but, on comparing the variogram parameters of same homogeneous vegetation patch across different resolutions (LISS IV, LISS III and AWiFS), it was observed that vegetation patch present in AWiFS image has highest value of sill and LISS IV image has lowest sill. However, there are several factors like phenological reasons and environmental conditions are responsible for high value of sill in AWiFS image (discussed above). Phenological reasons are one of the important reasons behind high sill in AWiFS image. AWiFS image was taken on March, 2011 and March is a season of undergrowth small vegetation which might lead to heterogeneity among the NDVI values inside a patch which lead to higher value of sill as compared to other images (June, 2009 and December, 2010). Hence, it can be concluded that, most of the spectral characteristics of vegetation changes with time and season and due to the phenology associated with different vegetation, morphological characters also changes which indicate that change in spectral reflectance and change in season has a direct effect on variogram parameters.

What is the effect of changing resolution on the spatial structure of a vegetation patch?

The main objective of present study was to find out the potential of variogram modeling to study the spatial structure of vegetation patches. With this study, it was possible to quantify the structure of a patch, distribution of patch components. For most of the selected vegetation patches, variogram shows a definite trend and variation.

On moving from higher to lower resolution, it was found that range decreases and sill increases. It can be due to the Sill helped in interpreting and quantifying the heterogeneity inside a patch. Range was able to quantify the extent of spatial dependency among the NDVI values inside a patch and it was also observed that small sized patch usually have smaller range as compared to large sized patches. It was also concluded that, range and sill parameter can be useful in differentiating binary and non binary images because binary images have smaller range as compared to gray (NDVI) images.

Is there any indication from variogram parameters on the shape and boundary of a vegetation patch? (RO: 4)

Variogram calculation has shown its usefulness and appropriateness in characterizing the spatial structure of vegetation patches. Case D was constructed to analyze the shape of a patch however, observing the shape of a variogram indicated some information about the shape of a patch. It was observed that, shape has some effect on variogram parameters but it was difficult to model the shape of a patch using variogram. It requires more information and understanding to model the shape of a patch using variogram parameters.

Is there any information associated with the NDVI values to analyze the spatial structure of the vegetation patches as compared to the Binary images (0 and 1)? (RO: 4)

Yes, NDVI has been proved to be useful in providing information about the vegetation status of selected patches in several aspects. Firstly, distribution of NDVI values (Histogram) revealed detailed information about the vegetation coverage and also overall vegetation status inside a patch which helped in analyzing variogram parameters in an efficient way. Secondly, as discussed above, comparison of binary image (0/1) and NDVI image (gray) indicated important information regarding the uncertainty which is associated with defining classes (vegetation and non vegetation) while generating binary images. For this study, NDVI was proved to be an efficient index for studying spatial structure of vegetation patches.

7.6. Limitations of the Study

This study has few limitations which had some impact on variogram analysis. Since, it was a multi resolution study; we should have an image of same area for all the three spatial resolutions (LISS IV, LISS III and AWiFS). To serve this purpose, we have taken images of same area but from different dates and seasons. Phenological reasons and different dates had a strong impact on variogram analysis. Satellite images of same area, same data for different resolutions could have given better results. It is advisable to use this methodology (fig.) after atmospheric correction and radiometric enhancement of the vegetation present in satellite images so that more clear spatial structure can be seen for different vegetation patches.

7.7. Recommendations

- This study has calculated Isotropic variogram but spatial structure can be different in different directions. For this reason, directional variogram and Correlogram can also be calculated for vegetation patches at multiple resolutions.
- Variation of texture indices can be interpreted using variogram analysis.

- Spatial structure of vegetation can also be studied using other vegetation indices instead of NDVI.
- Different types of vegetation can be differentiated with the help of variogram calculation and then to compare the results with the some classification strategy in order to check the efficiency of Geostatistical classification.
- Kriging and cokriging could be done in order to study and explore the spatial extent of vegetation coverage.

LIST OF REFERENCES

Wallace, C. S. A., J.M. Watts and S.R. Yool. 2000. Characterizing the spatial structure of vegetation communities in the Mojave Desert using geostatistical techniques. Computer and Geosciences 26: 397-410.

Guo, Y. H. X. and B.C. Si. 2007. Detecting grassland spatial variation by a wavelet approach. International Journal of Rempte Sensing. 28: 1527-1545.

Nayak, C. 2008. Comparing fractal models for analyzing vegetation cover types at different resolutions with the change in Altitude and Season. M.Sc. thesis. International Institute of Geo-Information Science and Earth Observation.

Tate, N. J. and P.M. Atkinson. 2001. Modelling Scale in Geographical Information Science. Wiley: England.

Chhabra, S. S. 2004. Modelling the effects of Scale on Mapping Trees outside Forests. M.Sc. thesis. International Institute of Geo-Information Science and Earth Observation.

Brunsell, N. A. and M.C. Andersen. 2011. Characterizing the multi-scale spatial structure of land-atmosphere interactions with information theory. Bio geosciences Dsicussions. 14: 3435-3462.

Kerry, R. and M.A. Oliver. 2011. Soil geomorphology: Identifying relations between the scale of spatial variation and soil processes using the variogram. Geomorphology 130: 40-54.

Kotliar, N. B. and J.A. Weins. 1990. Multiple scales of patchiness and patch structure: a hierarchical framework for the study of heterogeneity. Oikon 59:253-260.

Isaaks, E. H. and R. M. Srivastava. 1990. An Introduction to Applied Geostatistics. Oxford University Press: U.S.A.

Webster, R. and M. Oliver. 2008. Geostatistics for Environmental Scientists. Wiley.

Johnson, C.J. , M.S. Boyce, R. Mulders, A. Gunn, R.J. Gau, H. D. Cluff and R. L. Case. 2004. Quantifying patch distribution at multiple scales: applications to wildlife-habitat models. Landscape Ecology 2004: 869-882.

Johansen, K. and S. Phinn. 2006. Linking riparian vegetation spatial structure in Australian tropical savannas to ecosystem health indicators: semi-variogram analysis of high spatial resolution Satellite imagery. Canadian Journal of Remote Sensing 32: 228-243.

Tyryainen, L., S. Pauleit, K. Seeland and S. D. Vries. 2005. Benefits and Uses of Urban Forests and Trees. Springer.

J. L. Dungan et al. 2002. A balanced view of scale in spatial statistical Analysis. Ecography 25: 626-640.

McCarthy, L. E. 1996. Impact of military maneuvers on Mojave Desert surfaces: a multiscale

Analysis. Ph.D. dissertation, Department of Geography and Regional Development,University of Arizona.

Quattrochi, D. A., N.S.-N. Lam, H.-l. Qiu, and W. Zhao. 1997. Scale in Remote Sensing and GIS.

Curran, P.J. 1988. The semivariogram in remote sensing: An introduction. Remote Sensing of Environment 24(3):493-507.

Atkinson, P.M. and D.R. Emery. 1999. Exploring the relation between spatial structure and wavelength: Implications for sampling reflectance in the field. International Journal of Remote Sensing 20: 2663-2678.

Zhang, H., Y. Lan, R.E. Lacey, Y. Huong, W.C. Hoffmann, D. Marting and G.C. Bora. 2009. Analysis of variograms with various sample sizes from a multispectral image. International Journal of Agricultural and Biological engineering 62(2):4.

Atkinson, P.M. 1993. The effect of spatial resolution on the experimental variogram of airborne MSS imagery. International Journal of Remote Sensing 14(5):1005-1011.

Atkinson, P.M. and P. Lewis. 2000. Geostatistical classification for remote sensing: an introduction. Computers and Geosciences 26:361-371.

Jakomulska, A. and K.C. Clarke. 2001. Variogram- Derived measures of textural image classification: Application to large scale vegetation mapping. Geostatistics for Environmental Applications 23: 345-355.

Levin, S.A. 1992. The Problem of Pattern and Scale in Ecology. Ecology 73(6):1943-1967.

Matheron, G. 1963. Principles of Geostatistics. Economic Geology 58: 1246-1266.

Andersen, R., M. Poulin, D. Borcard, R. Laiho, J. Laine, H. Vasander, E. T. Tuittila. 2011. Environmental control and spatial structures in peatland vegetation. Journal of Vegetation Science 1-3.

Busso, C.A. and G.L. Bonvissuto. 2009. Structure of vegetation patches in northwestern Patagonia, Argentina. Biodiversity Conservation 18:3017-3041.

Zhao, X., A. Stein and X. Chen. 2010. Application of random sets to model uncertainties of natural entities extracted from remote sensing images. Springer 24: 713-723.

Xie, Y., Z. Sha and M. Yu. 2008. Remote Sensing imagery in vegetation mapping: a review. Journal of Plant Ecology 1: 9-23.

Carolinian Canada Draft Boundary Delineation Guide, "Guidelines for assessing ecological boundaries of vegetation patches", *www.carolinian.org*. [Online] Available: www.carolinian.org/Publications/eis_D.pdf [Accessed: 20-Oct-2012].

Liebhold, A.M. and J. Gurevitch. 2002. Integrating the statistical analysis of spatial data in ecology. Ecography 25: 553-557.

Kareiva, P. and U. Wennergren. 1995. Connecting landscape patterns to ecosystem and population processes. Nature 373: 299-302.

Fagan, W.F., R.S. Cantrell and C. Cosner. 1999. How habitat edges change species interactions. Am. Nat 153: 165-182.

Belnap, J., C.V. Hawkes and M.K. Firestone. 2003. Boundaries in miniature: two examples from soil. Biosciences 53: 739-749.

Weins, J.A., N.C. Stenseth, B. Van Home and R.A. Ims. 1993. Ecological mechanisms and landscape ecology. Oikos 66: 369-380.

Garrigues, S., D. Allard, F. Baret and M. Weiss. 2006. Quantifying spatial heterogeneity at the landscape scale using variogram models. Remote Sensing of Environment 103: 81-96.

Appendix 1: Glossary

Patch: Patch can be defined as a homogeneous area that has crisp or vague boundary and which can be differentiated from rest of the area. Boundary of a patch can be irregular in nature.

Spectral: Spectral resolution is determined using different wavelength intervals on which satellite can capture the data. High spectral resolution is generated from band widths which provide accurate spectral signatures for crisp entities. A spectral resolution is sensitive to remote sensing instrument that captures the band widths or wavelength intervals.

Spatial: Spatial resolution refers to the smallest object that can be depicted on the ground. In case of satellite images, this smallest object can't be smaller that the pixel size. Spatial resolution must be appropriate enough in order to interpret well. High resolution image refers to small pixel size and vice versa. LISS IV (5.8m) is high resolution imagery while AWiFS (56m) is a small resolution image.

Temporal: Temporal resolution can be explain as image recording frequency i.e. the speed at which images of specific area are getting captured from a sensor. More frequency means better and finer temporal resolution.

Radiometric: Radiometric resolution can be explain as the sensitivity of a remote sensing sensor to differentiate various signal strength. It records the radiance which is reflected from the terrain. It also indicates about change in range and number of data files values that can be possible in each band. It can be explained as the smallest change in intensity level that can be detected by a sensor. It depends upon signal to noise ratio and consider quantization levels which are used to discriminate between objects.

Isotropic: Isotropic is a greek word where, *Iso* means equal and *tropos* refer to direction. A phenomenon is said to be isotropic in nature if it is uniform in all the directions and not dependent on directions or angles.

Anisotropic: Phenomenon which is used to describe several situations, where results vary systematically and results are completely dependent on directions. Anisotropic variogram means, variogram is calculated for different directions.

Kriging: Kriging can be explained as a phenomenon which is used to predict or interpolate the values of random fields like landscape, elevation and other geographic locations at unobserved locations. In simple words, it's a process of predicting unobserved values on the basis of values present at nearby locations.

Nugget: The amount of discontinuity present near the origin of a variogram is called as nugget. The variogram may exhibit an apparent discontinuity at the origin. The magnitude of the discontinuity is called the nugget. It is also called as non-zero variance and it can be describe as discontinuity present at the origin of a variogram.

Random Function: A random function may be seen in two different forms; it may be thought of as a collection of dependent random variables with one for each possible sample location. Alternatively it may be thought of as a "random variable" whose values are functions rather than numbers.

Range: Range can be explained as an extent up to which sample points are spatially dependent on each other. It usually represents the extent of correlation between the sample points. In variogram, range can be explained as a distance at which variogram becomes constant, which indicates that the sample points are no more spatially dependent on each other.

Sill: Sill present in a variogram can be defined as the highest variance present in a variogram. Power model does not have any sill value. Sill value can be seen beyond the range of a variogram.

Omni directional variogram: Omnidirectional means all the possible directions are present in variogram. It combines all directional variograms into a single variogram and it can be explained as an average of all possible directional variogram.However, the calculation of Omni directional variogram does not indicated that spatial continuity is the same in all the directions. They have more than one structure in each direction. It has been said that the total sill of an Omni directional variogram gives an approximate idea of the total sill present in directional variogram. The main purpose behind using omni-directional Variogram is that it gives a clear structure for overall spatial continuity. Omni directional variogram contains more number of pairs than any other directional Variogram and hence it deals with very less discontinuity.

Variogram (semi-variogram): Variogram can be defined as a function which describes the degree of spatial dependency of several available stochastic processes. According to *Cressie, 1993*, variogram is a representation of the difference between the variance values at two different locations.

Correlation: It can be explained as a statistical representation which explains how closely the two variables are varying with each other and how they are spatially dependent on each other. In simple words, it can be called as the relation between two or more than two variables which gives an idea about the spatial dependency between the two variables.

Trend surface: Trend surfaces are generated using fitting of low order polynomial functions of the locations variables. It helps in interpreting and studying the results over point grids. Order of the polynomial functions controls the smoothness of the output surface.

Trend analysis: Trend analysis is used for extraction of pattern present in a particular area on analysing the behaviour of the points. Trend can be partly present or sometimes it can be hidden by the noise present in a data.

Lag distance: Lag distance can be explained as grouping of distance interval (present along the x axis) into different classes in order to get maximum number of sample points inside one distance class. It is represented by h.

Regression: Regression can be explained as a statistical measure that determines the relationship between one variable (Dependent) and other set of changing variables (Independent).

Geostatistics: It is a branch of statistics that deals with spatial data sets. It is concerned with the collection and interpretation of quantitative data to determine the parameters of earth employing probability theory

Appendix 2: Specifications of Remote Sensing images

Satellite imageries of Dehradun area for different resolutions were selected. Since, this was a multiscalar study; resolutions were selected in such a way that vegetation patches can be interpreted across a wide range of scale i.e. from 5.8 meters to 56 meters.

LISS IV (5.8m)

BAND	WAVELENGTH	RESOLUTION	SWATH WIDTH	REVISIT TIME
1(Green)	0.52 ?m to 0.59 ?m	5.8 m	23.9 km	5 Days
2(Red)	0.62 ?m to 0.68 ?m	5.8 m	23.9 km	5 Days
3(NIR)	0.77 ?m to 0.86 ?m	5.8 m	23.9Km	5 Days

LISS III (23.5m)

BAND	WAVELENGTH	RESOLUTION	SWATH WIDTH	REVISIT TIME
1(Green)	0.52 ?m to 0.59 ?m	23.5 m	140 km	24 Days
2(Red)	0.62 ?m to 0.68 ?m	23.5 m	140 km	24 Days
3(NIR)	0.77 ?m to 0.86 ?m	23.5 m	140 km	24 Days
4 (SWIR)	1.55 ?m to 1.70 ?m	23.5 m	140 km	24 Days

AWiFS (56m)

BAND	WAVELENGTH	RESOLUTION	SWATH WIDTH	REVISIT TIME
1(Green)	0.52 ?m to 0.59 ?m	56m	741 km	24 Days
2(Red)	0.62 ?m to 0.68 ?m	56m	741 km	24 Days
3(NIR)	0.77 ?m to 0.86 ?m	56m	741 km	24 Days
4 (SWIR)	1.55 ?m to 1.70 ?m	56m	741 Km	24 Days

Appendix 3: Variogram calculation for fuzzy and crisp boundaries

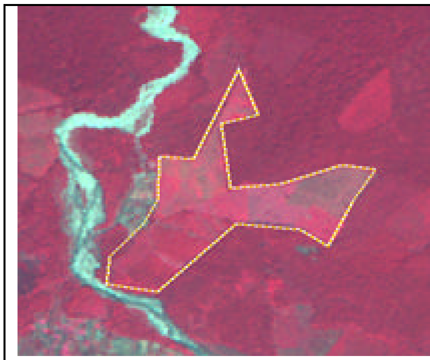
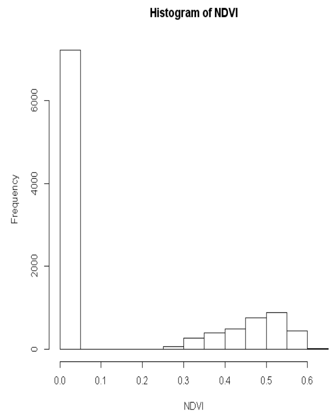
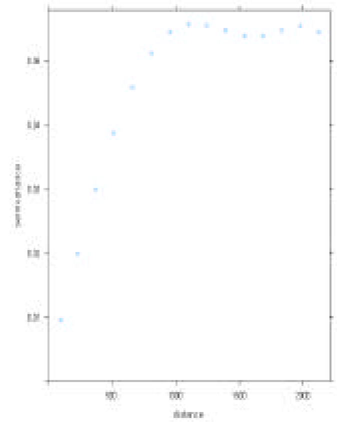


Figure 28 (a)
109 rows x 97 columns
2561 x 2280 meters
Cut off: 2200 meters





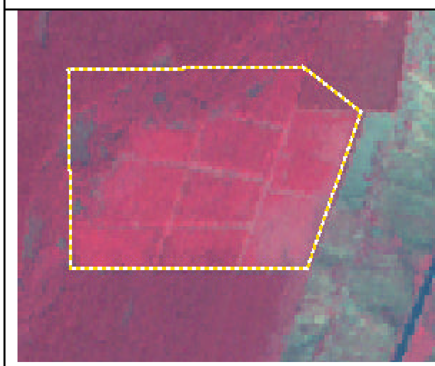
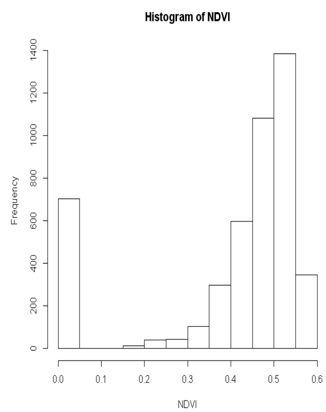
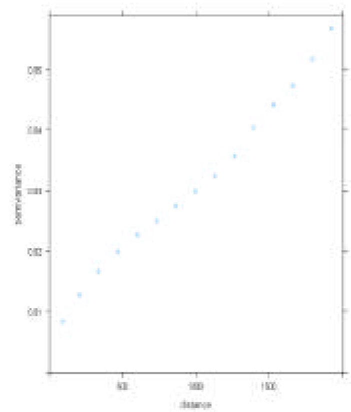


Figure 28 (b): P1_ag_df_hald_l3.aoi
53 rows x 87 columns
1246 x 2045 meters
Cut off: 2000 meters





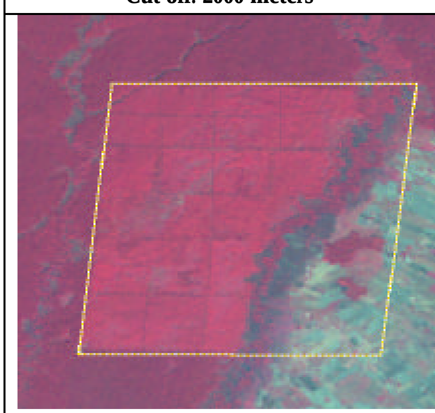
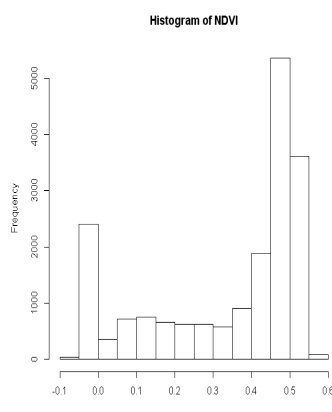
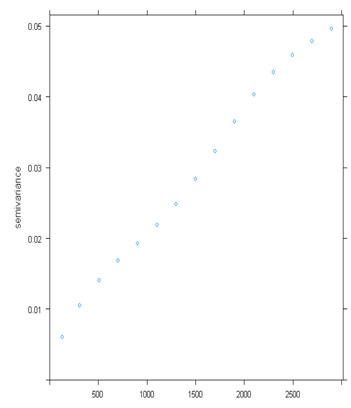
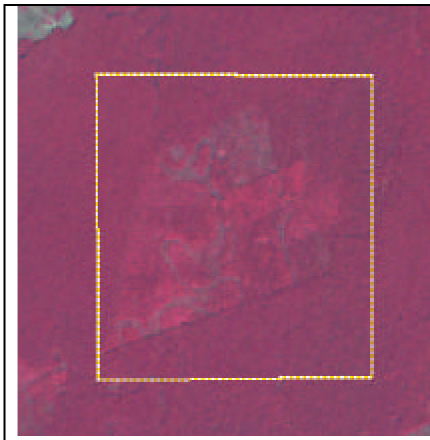
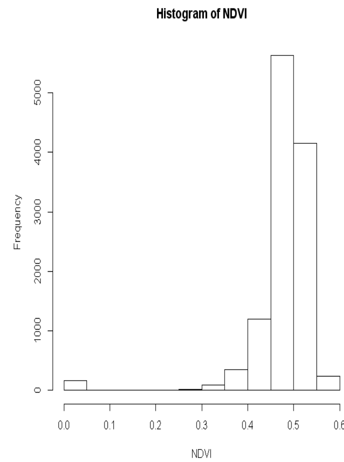


Figure 28 (c): P2_ag_u_hald_l3.aoi
137 rows x 136 columns
3219 x 3196 meters
Cut off: 3000 meters









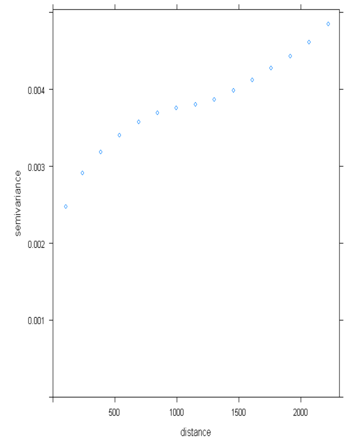
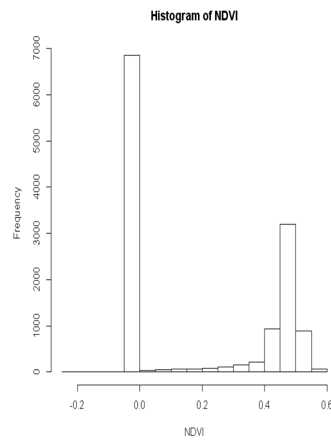


Figure 28 (d): p3_ag_df_hald_l3

116 rows x 102 columns

2726 x 2397 meters

Cut off: 2300 meters



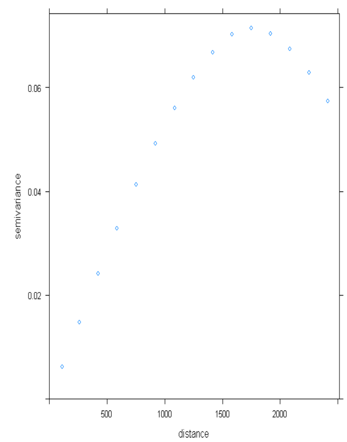
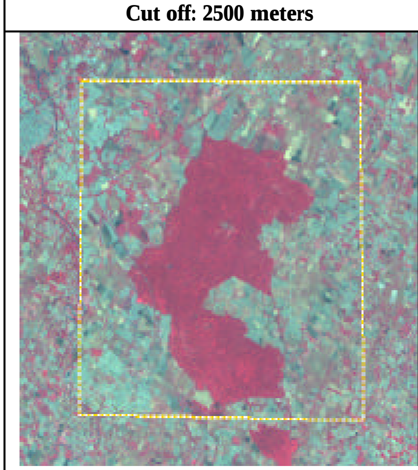


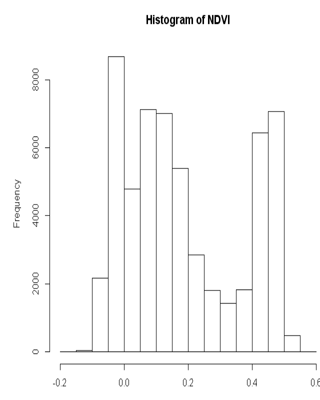
Figure 28 (e): p4_of_df_hald_l3.aoi

118 rows x 108 columns

2773 x 2538 meters

Cut off: 2500 meters





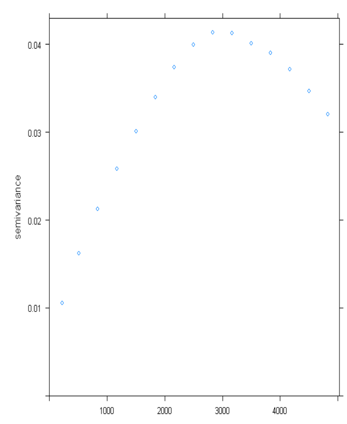


Figure 28 (f): p6_u_forest_hal_l3

245 rows x 233 columns

5757 x 5475 meters

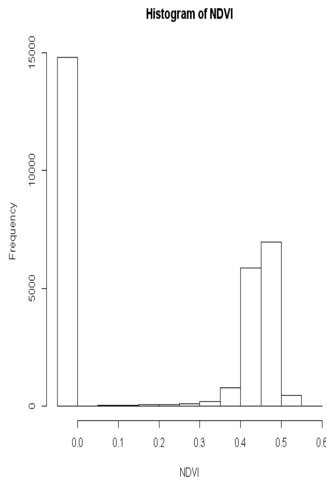
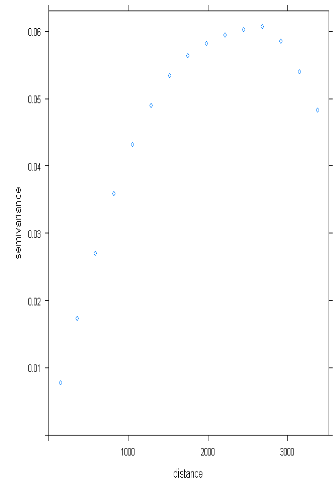
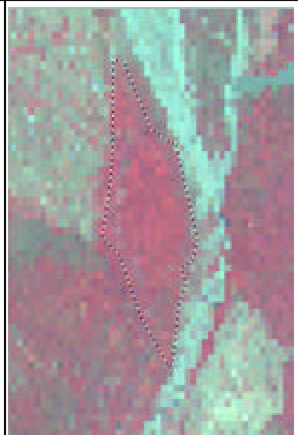
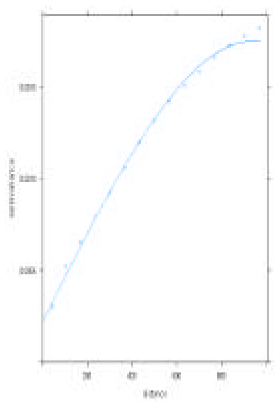
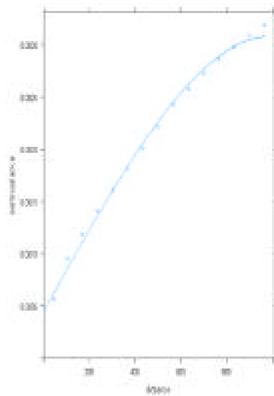
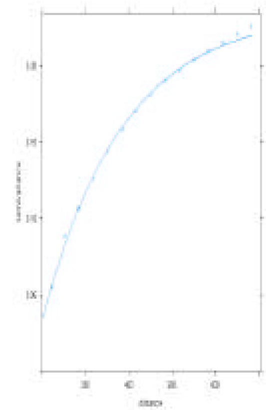
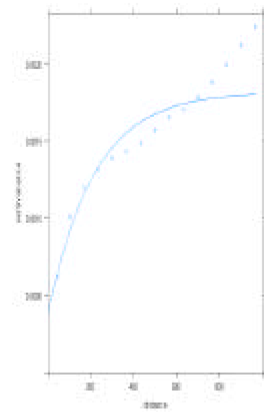
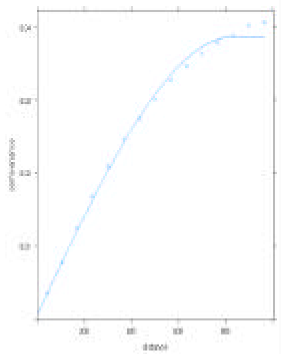
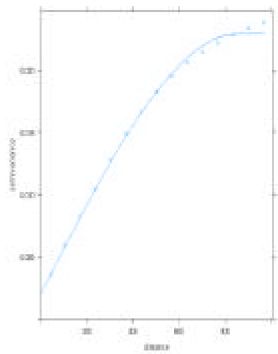
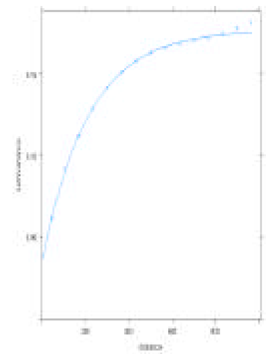
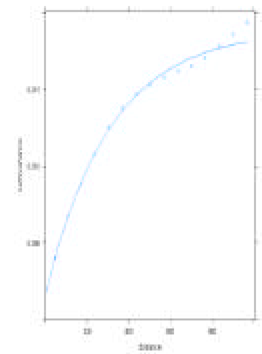
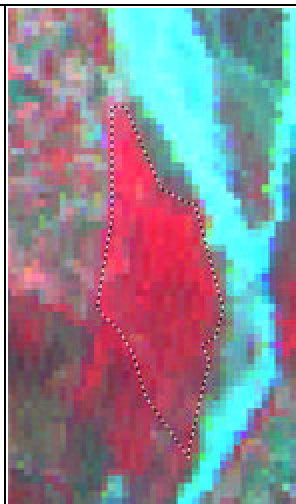
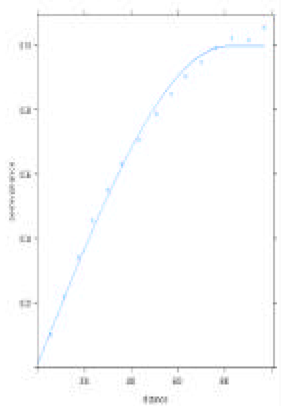
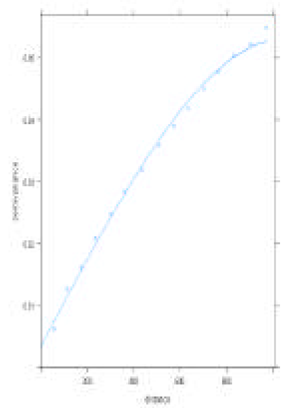
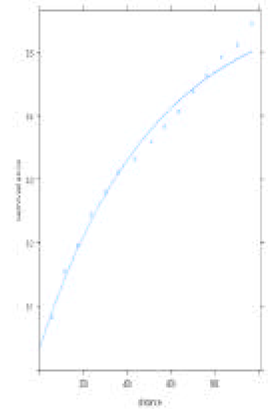
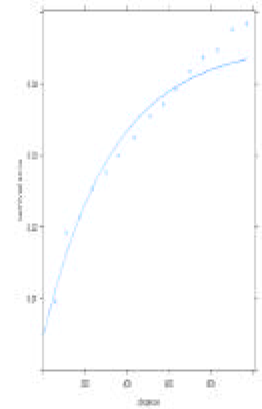
Cut off: 5000 meters	
  **Figure 28 (g): P7_u_forest_hal_l3** **195 rows x 151 columns** **4582 x 3548 meters** **Cut off: 3500 meters**	

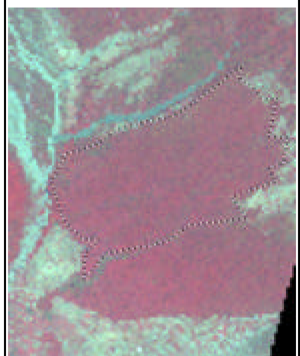
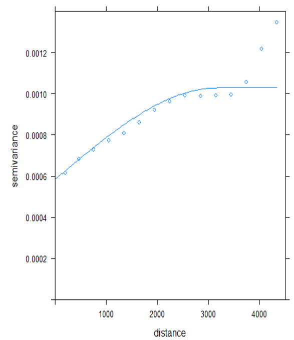
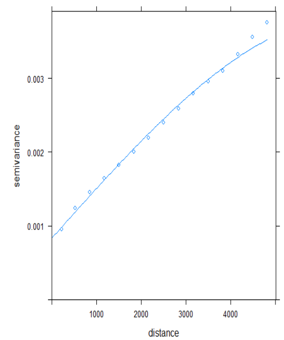
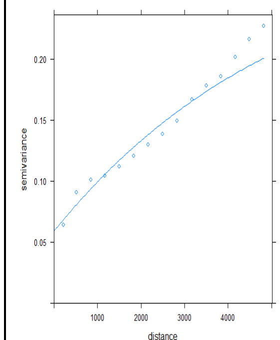
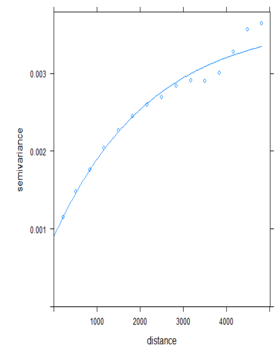
Figure 28: Variogram calculation for different types of subsets selected in Haldwani: LISS III (October, 2009)

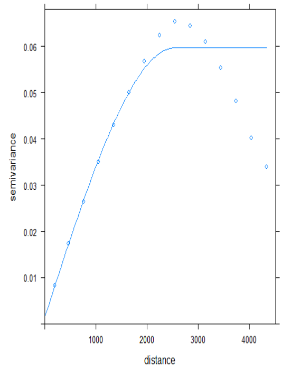
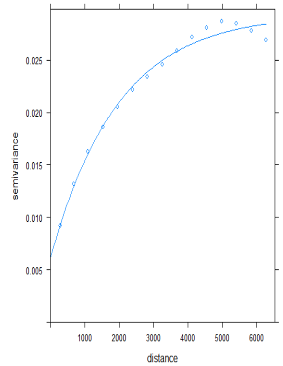
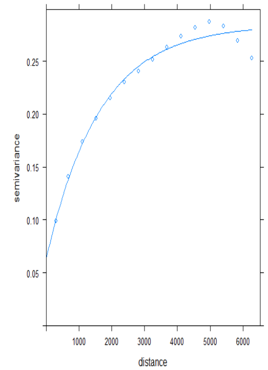
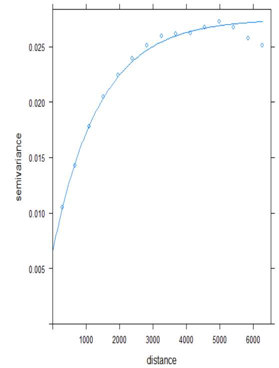
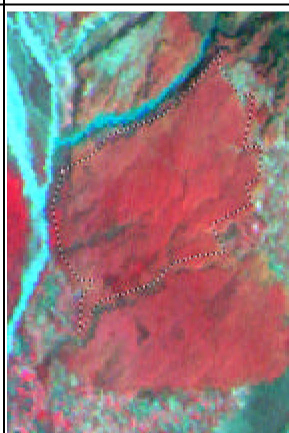
Appendix 4: Variogram calculations and Estimations

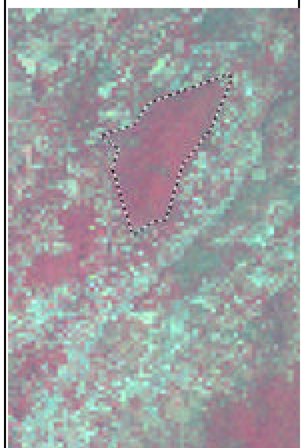
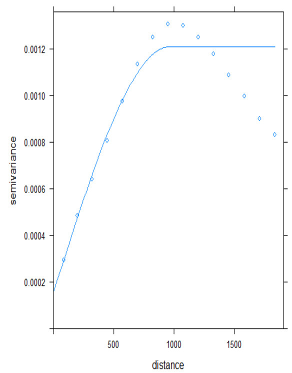
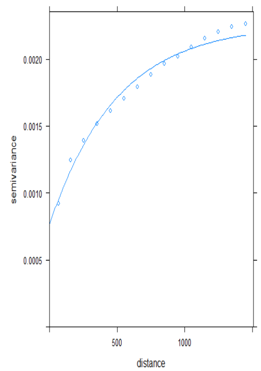
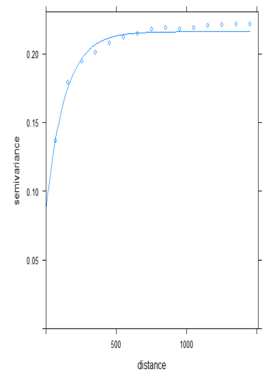
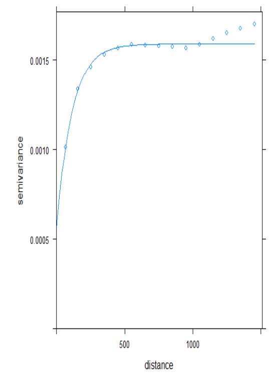
Resolution	PATCH:1 Patch Image	Case A (homogeneous patch)	Case B (Patch + non vegetation area)	Case C (Binary Image)	Case D (Case B - Case A)
LISS IV		 Nugget: 0.0002,Sill: 0.0015, Range:939m, cut off: 1000m Spherical 467 rows x 188 columns (2708 x 1090 meters)	 Nugget: 0.0004,Sill: 0.0026, Range: 997m, cut off: 1000m Spherical 579 rows x 277 columns **(3358 x 1606 meters)**	 Nugget: 0.0338,Sill: 0.2006, Range: 374 m, cutoff:1000m Exponential 579 rows x 277 columns **(3358 x 1606 meters)**	 Nugget:0.0003,Sill:0.0014, Range: 218 m, cut off:1000m Exponential

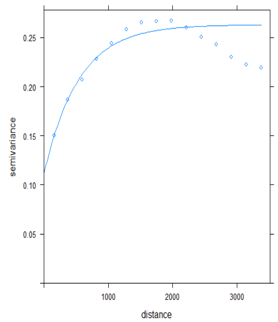
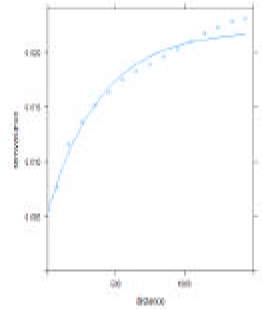
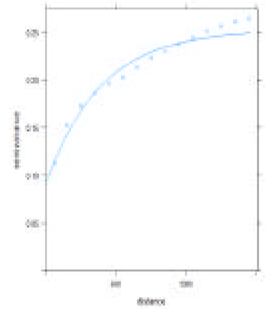
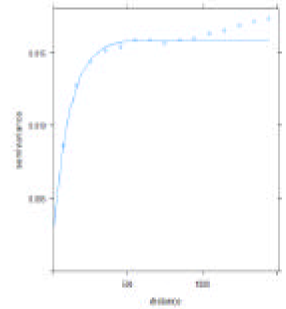
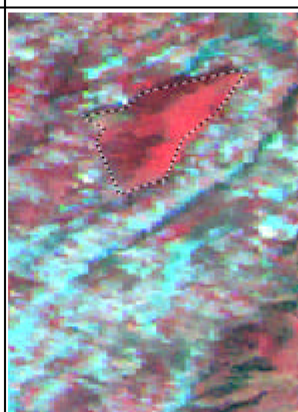
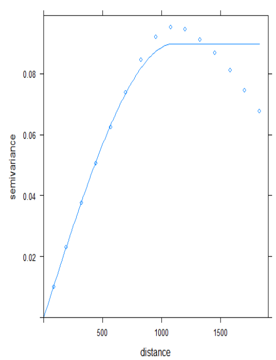
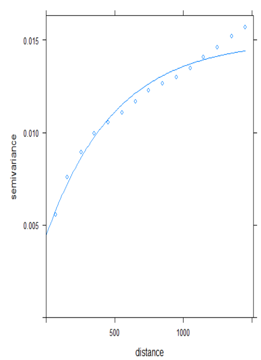
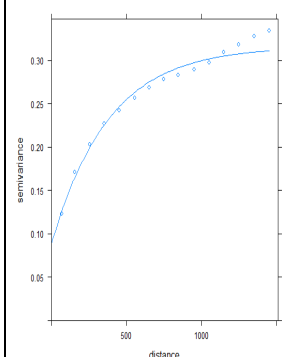
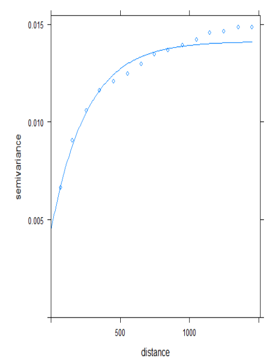
LISS III		 Nugget: 0.0006,Sill: 0.0380, Range:833m, cut off: 1000m Spherical 110 rows x 45 columns	 Nugget: 0.0020,Sill: 0.0209, Range: 856m, cut off: 1000m Spherical 144 rows x 87 columns	 Nugget: 0.0362,Sill: 0.1407, Range:216m, cut off: 1000m Exponential 144 rows x 87 columns	 Nugget: 0.0017,Sill:0.0171, Range:312 m, cut off: 1000m Exponential

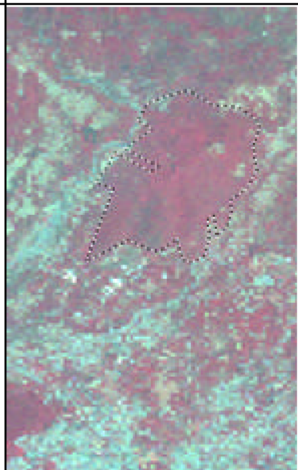
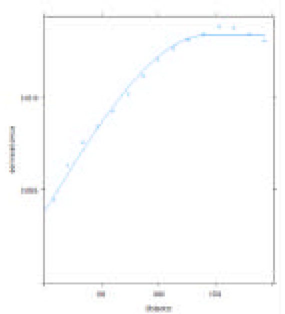
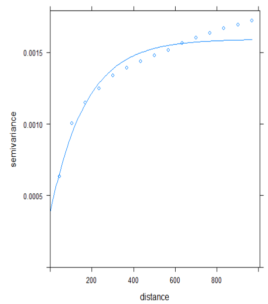
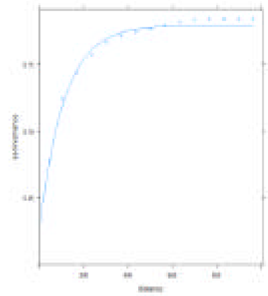
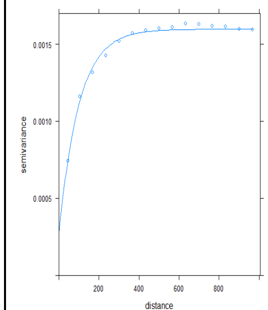
AWiFS		 Nugget: 0.0009,Sill: 0.0987, Range: 812 m, cut off: 1000m Spherical 49 rows x 21 columns	 Nugget: 0.0034,Sill: 0.0496, Range: 1045 m, cut off: 1000m Spherical **58 rows x 22 columns**	 Nugget: 0.0350,Sill: 0.554, Range:524m, cut off:1000 m **Exponential** 58 rows x 22 columns	 Nugget: 0.0045,Sill: 0.0409, **Range:329m, cut off:1000m** Exponential

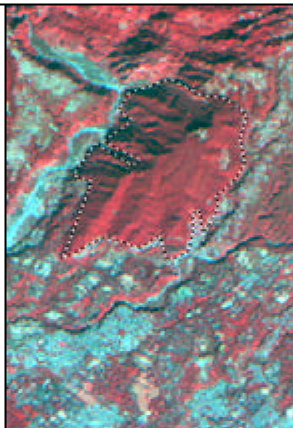
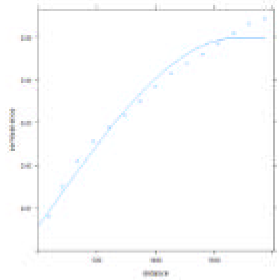
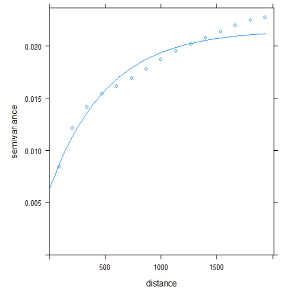
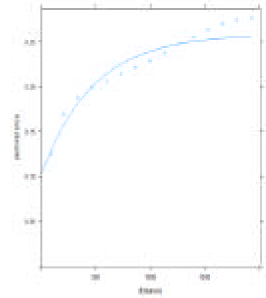
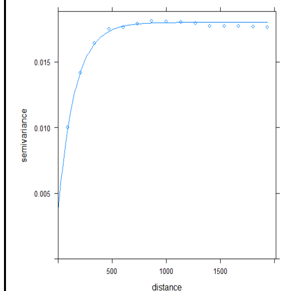
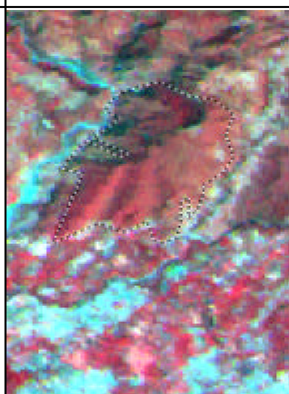
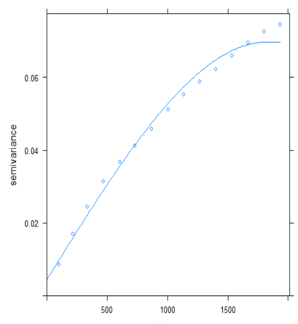
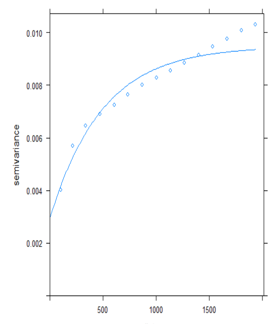
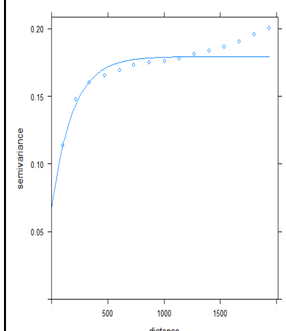
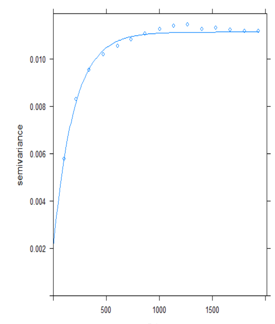
Resolution	**PATCH:2** **Patch Image**	**Case A** **(homogeneous patch)**	**Case B** **(Patch + non vegetation area)**	**Case C** **(Binary Image)**	**Case D** **(Case B - Case A)**
LISS IV		 **Nugget: 0.0002,Sill: 0.0015,** Range:939m, cut off: 1000m Spherical 467 rows x 188 columns (2708 x 1090 meters)	 Nugget: 0.0004,Sill: 0.0026, Range: 997m, cut off: 1000m Spherical 579 rows x 277 columns **(3358 x 1606 meters)**	 **Nugget: 0.0338,Sill: 0.2006,** Range: 374 m, cutoff:1000m Exponential 579 rows x 277 columns **(3358 x 1606 meters)**	 Nugget:0.0003,Sill:0.0014, Range: 218 m, cut off:1000m Exponential

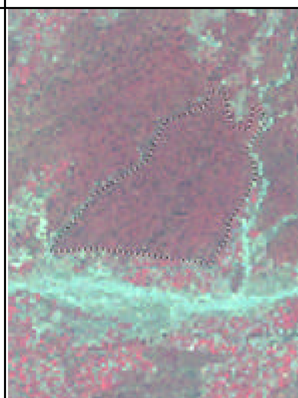
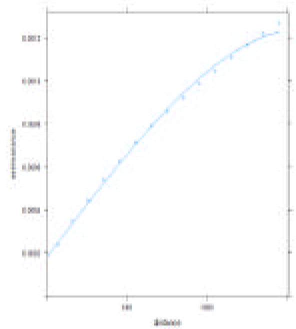
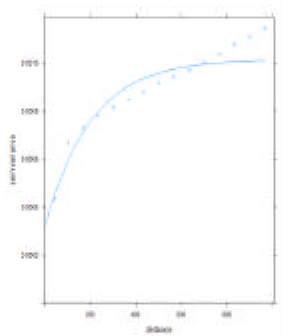
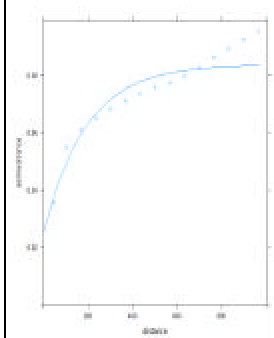
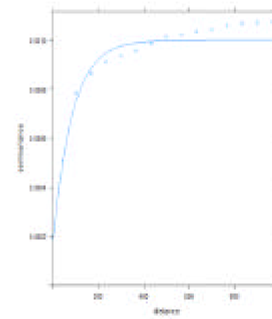
LISS III		 Nugget: 0.0006,Sill: 0.0380, Range:833m, cut off: 1000m Spherical 110 rows x 45 columns	 Nugget: 0.0020,Sill: 0.0209, Range: 856m, cut off: 1000m Spherical 144 rows x 87 columns	 Nugget: 0.0362,Sill: 0.1407, Range:216m, cut off: 1000m Exponential 144 rows x 87 columns	 Nugget: 0.0017,Sill:0.0171, Range:312 m, cut off: 1000m Exponential
AWiFS					

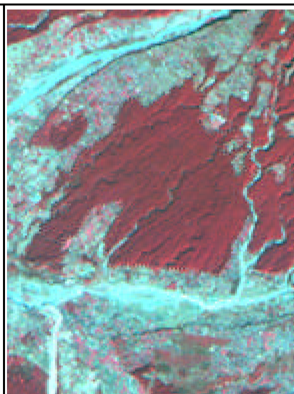
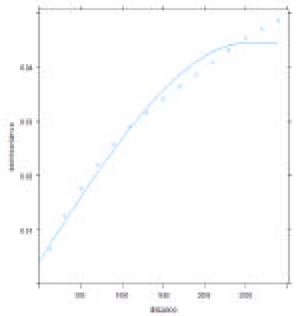
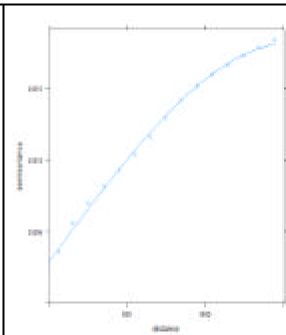
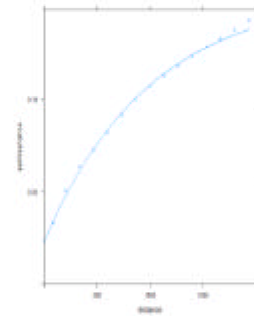
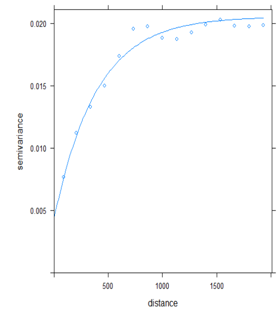
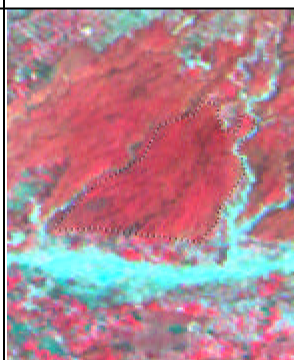
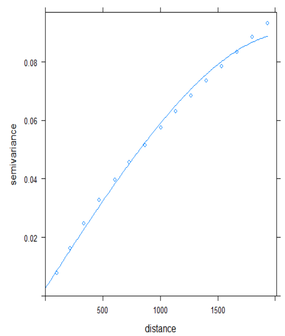
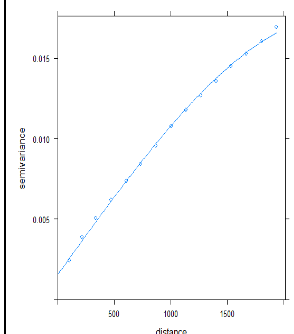
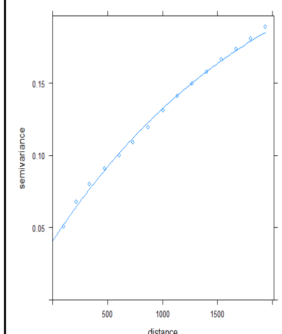
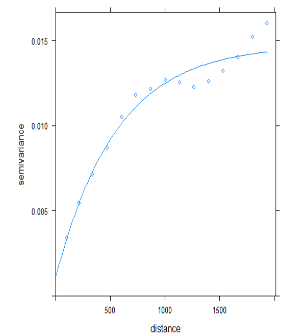
Resolution	**PATCH:3** **Patch Image**	**Case A** **(homogeneous patch)**	**Case B** **(Patch + non vegetation area)**	**Case C** **(Binary Image)**	**Case D** **(Case B - Case A)**
LISS IV		 Nugget: 0.0001,Sill: 0.0010, Range: 966 m, cut off: 1900m Spherical 446 rows x 330 columns (2587 x 1914 meters)	 Nugget: 0.0007,Sill: 0.0014, Range: 496 m, cut off: 1500m Exponential 672 rows x 561 columns **(3898 x 3254 meters)**	 Nugget: 0.0867,Sill: 0.1294, Range: 134 m, cutoff:1500m Exponential 672 rows x 561 columns **(3898 x 3254 meters)**	 Nugget: 0.0005,Sill: 0.0010, Range: 114 m, cut off:1500m Exponential

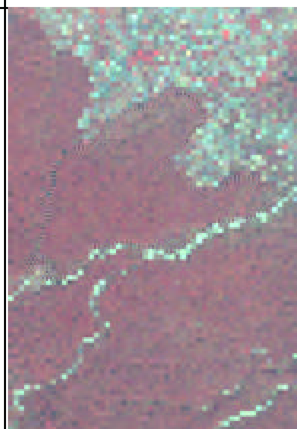
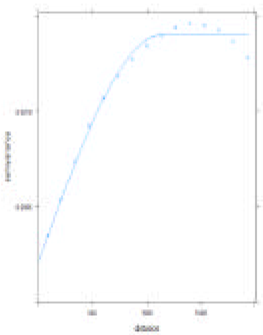
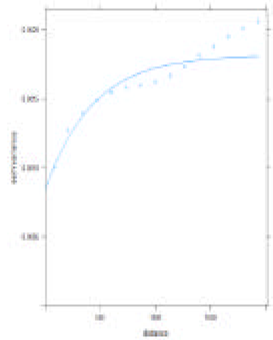
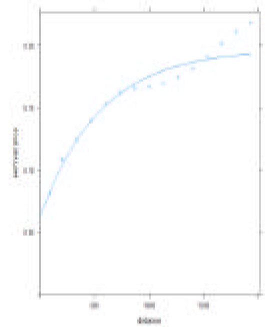
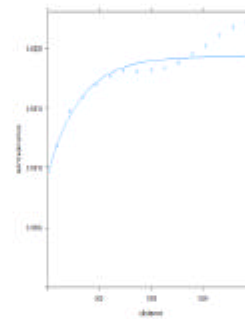
LISS III		 Nugget: 0.0002,Sill: 0.0380, Range:833m, cut off: 3000m Spherical 105 rows x 79 columns **(2467 x 1856 meters)**	 Nugget: 0.0054, Sill: 0.0166, range: 389 meters, cut off: 1500m **Exponential** 158 rows x 132 columns (3713 x 3102 meters)	 Nugget: 0.0917, Sill: 0.1611, range: 393 meters, cut off: 1500m Exponential 158 rows x 132 columns (3713 x 3102 meters)	 Nugget: 0.0028, Sill 0.0130, range: 112 meters, cut off: 1000m **Exponential** 158 rows x 132 columns (3713 x 3102 meters)
AWiFS		 Nugget: 0.000,Sill: 0.0898,Range: 1108 m, cut off: 1900m	 nugget: 0.0044, sill: 0.0105, range: 499 meters ,Cut off: 1500 m, Exponential	 nugget: 0.0887, sill: 0.2272, range: 381 meters Cut off: 1500 m, Exponential	 nugget: 0.0044, sill: 0.0096, range: 260 meters, Cut off: 1500 m, Exponential

Resolution	PATCH: 4 Patch Image	Case A (homogeneous patch)	Case B (Patch + non vegetation area)	Case C (Binary Image)	Case D (Case B - Case A)
LISS IV		 **Nugget: 0.00038 sill: 0.00094 Range:1427, Spherical model, cutoff: 2000m** **574 rows x 477 columns** **3329 x 2767 meters**	 **Nugget: 0.00038,sill: 0.0012,Range:171m** , cut off: 1000m Exponential **794 rows x 618 columns** **4605 x 3584 meters**	 **Nugget: 0.0307, sill: 0.1485,Range:113m** , cut off: 1000m Exponential **794 rows x 618 columns** 4605 x 3584 meters	 **Nugget: 0.00027, sill: 0.00132,Range:100m** , cut off: 1000m Exponential **794 rows x 618 columns** 4605 x 3584 meters

LISS III		 Nugget: 0.0057sill: 0.0441,Range:1691 m, cut off: 2000m Spherical **135 rows x 112 columns** **3172 x 2632 meters**	 Nugget: 0.0062,sill: 0.0152,Range: 513 m, cut off: 2000m **Exponential** **186 rows x 145 columns** **4371 x 3407 meters**	 Nugget: 0.1024, Sill: 0.1564, range: 479meters, cut off: 2000m Exponential **186 rows x 145 columns** **4371 x 3407 meters**	 Nugget: 0.0036, Sill 0.0143, range: 155 meters, cut off: 2000m **Exponential** **186 rows x 145 columns** **4371 x 3407 meters**
AWiFS		 Nugget: 0.0044,Sill: 0.0652,Range: 1828 m, cut off: 2000m, Spherical	 Nugget:0.0029, Sill:0.0065, Range: 493m, cut off: 2000m,Exponential	 **Nugget: 0.0667, sill: 0.1127,Range:187 m, Exponential**	 Nugget: 0.0020, sill: 0.0090, Range: 191 m,**Exponential**

Resolution	PATCH: 5 Patch Image	Case A (homogeneous patch)	Case B (Patch + non vegetation area)	Case C (Binary Image)	Case D (Case B - Case A)
LISS IV		 **Nugget: 0.0001, sill: 0.0010 Range:1622, Spherical model, cutoff: 1500m**	 **Nugget: 0.0003,sill: 0.0006,Range:202m** , cut off: 1000m	 **Nugget: 0.0251, sill: 0.0584,Range:191 m** , cut off: 1000m	 **Nugget: 0.00017, sill: 0.00082,Range:85m** , cut off: 1000m

LISS III		 Nugget: 0.0042, sill: 0.0403,Range:2544 m, cut off: 2000m	 Nugget: 0.0029,sill: 0.0152,Range: 1556 m, cut off: 2000m	 Nugget: 0.0226, Sill: 0.1339, range: 993 m, cut off: 2000m	 Nugget: 0.0043, Sill 0.0161, range: 393 m, cut off: 2000m
AWiFS		 Nugget: 0.0026,Sill: 0.0876, Range: 2168 m, cut off: 2000m	 Nugget:0.0015, Sill:0.0159, Range: 2458m, cut off: 2000m	 **Nugget: 0.0407, sill: 0.2328,Range:1999 m,** cut off: 2000m	 Nugget: 0.0011, sill: 0.0136, Range: 557 m,

Resolution	PATCH: 6 Patch Image	Case A (homogeneous patch)	Case B (Patch + non vegetation area)	Case C (Binary Image)	Case D (Case B - Case A)
LISS IV		 Nugget: 0.0002, sill: 0.0011 Range:1138, Spherical model, cutoff: 2000m 408 rows x 545 columns 2366 x 3161 meters	 Nugget: 0.0008,sill: 0.0009,Range:429 m , cut off: 2000m Exponential 528 rows x 563 columns 3381 x 3265 meters	 Nugget: 0.0626, sill: 0.1347,Range:556 m , cut off: 2000m Exponential 528 rows x 563 columns 3381 x 3265 meters	 Nugget: 0.0009, sill: 0.0009,Range:312m , cut off: 2000m Exponential 528 rows x 563 columns 3381 x 3265 meters

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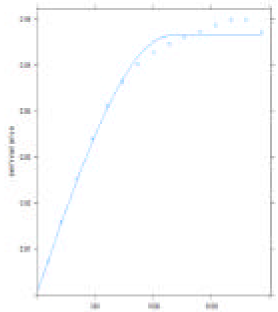
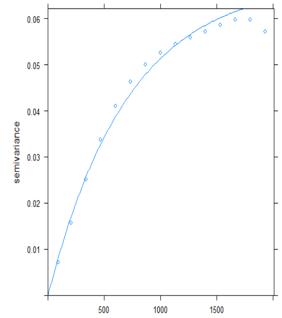
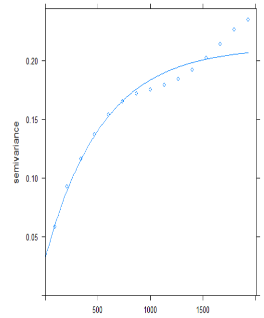
<td>

Nugget: 0.0007, sill: 0.0554,Range:1144 m, cut off: 2000m

Spherical

96 rows x 128 columns
2256 x 3008 meters</td>
<td>

Nugget: 0.0000,sill: 0.0681,Range: 715 m, cut off: 2000m

Exponential
124 rows x 132 columns
2914 x 3102 meters</td>
<td>

Nugget: 0.0320, Sill: 0.1795, range: 541 m, cut off: 2000m

Exponential

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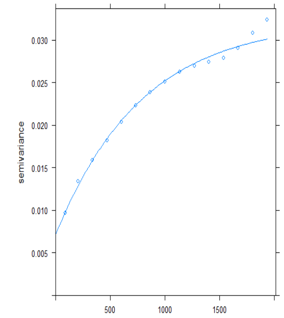
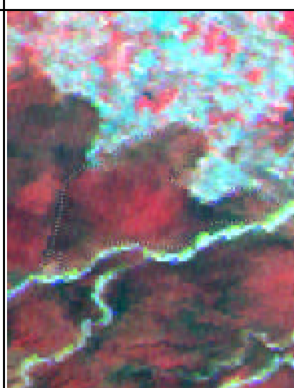
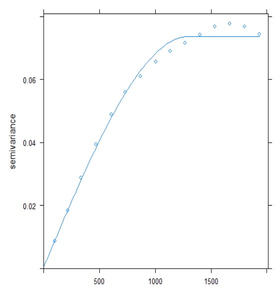
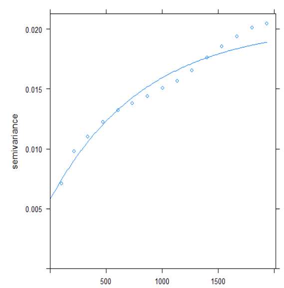
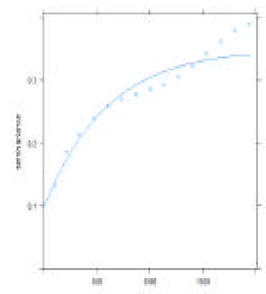
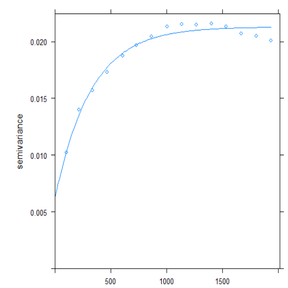
2914 x 3102 meters</td>
<td>

Nugget: 0.0043, Sill 0.0161, range: 393 m, cut off: 2000m

Exponential
124 rows x 132 columns
2914 x 3102 meters</td>
</tr>
<tr>
<td>AWiFS</td>
<td></td>
<td>

Nugget: 0.0004,Sill: 0.0732,

Range:1302 m , cut off: 2000m</td>
<td>

Nugget: 0.0057, Sill: 0.0145, Range: 839m, cut off: 2000m</td>
<td>
Nugget: 0.0968, sill: 0.2537,Range: 591 m, cut off: 2000m</td>
<td>

Nugget: 0.0062, sill: 0.0150, Range: 324 m, cut off: 2000m</td>
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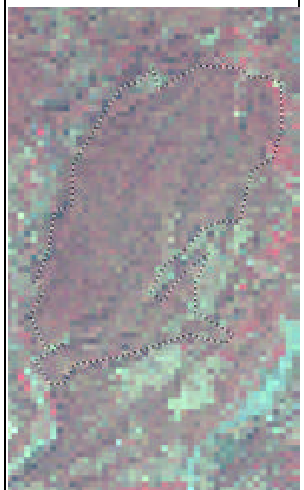
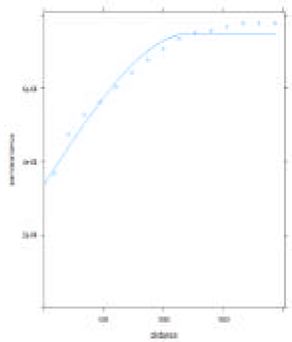
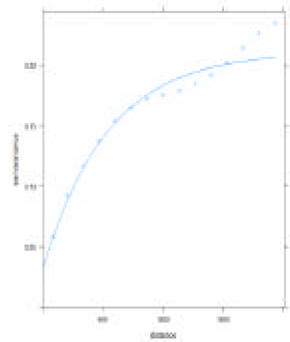
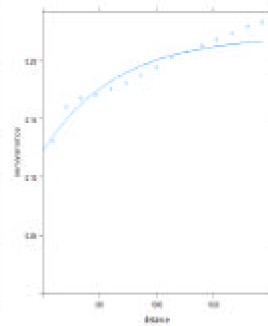
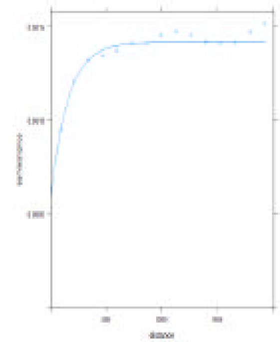
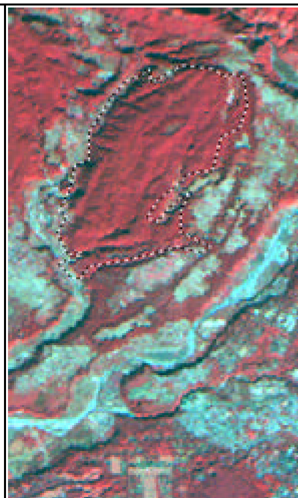
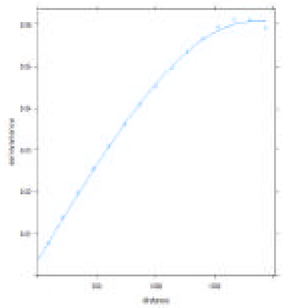
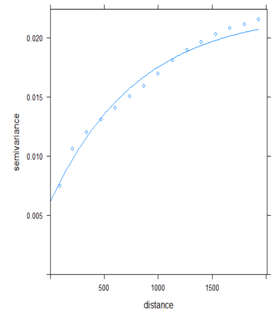
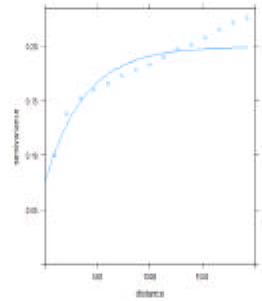
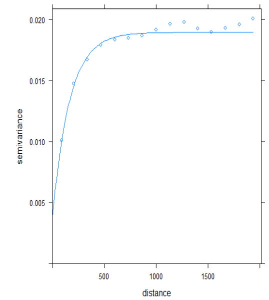
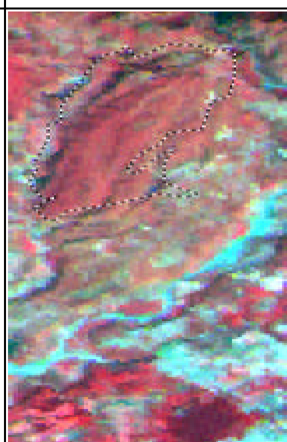
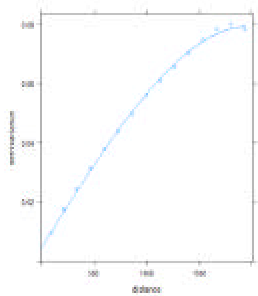
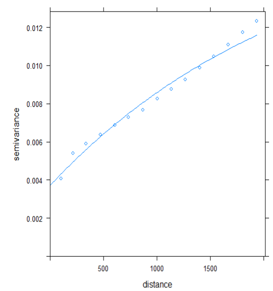
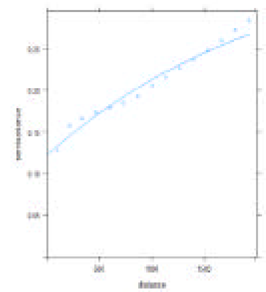
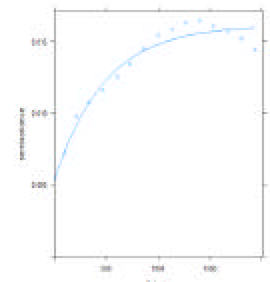
Resolution	**PATCH: 7** **Patch Image**	**Case A** **(homogeneous patch)**	**Case B** **(Patch + non vegetation area)**	**Case C** **(Binary Image)**	**Case D** **(Case B - Case A)**
LISS IV		 **Nugget: 0.0003, sill: 0.00041, Range:1224, Spherical model, cutoff: 2000m** 605 rows x 437 columns 3509 x 2535 meters	 **Nugget: 0.0320,sill: 0.01795,Range:541 m** , cut off: 2000m Exponential **712 rows x 458 columns** 4130 x 2656 meters	 **Nugget: 0.1224, sill: 0.0993,Range:643 m** , cut off: 2000m Exponential **712 rows x 458 columns** 4130 x 2656 meters	 **Nugget: 0.00059, sill: 0.0008,Range:158m** , cut off: 2000m Exponential **712 rows x 458 columns** 4130 x 2656 meters

LISS III		 Nugget: 0.0037, sill: 0.0569,Range:1828 m, cut off: 2000m Spherical **141 rows x 102 columns** **3313 x 2397 meters**	 Nugget: 0.0061,sill: 0.0160,Range: 811 m, cut off: 2000m **Exponential** **167 rows x 107 columns** **3924 x 2514 meters**	 Nugget: 0.0760, Sill: 0.1236, range: 378 m, cut off: 2000m Exponential **167 rows x 107 columns** **3924 x 2514 meters**	 Nugget: 0.0037, Sill: 0.0151, range: 166 m, cut off: 2000m **Exponential** **167 rows x 107 columns** **3924 x 2514 meters**
AWiFS		 Nugget: : 0.0043,Sill: 0.0750, Range: 1972 m, cut off: 2000m **3528 x 2576 m**	 Nugget: 0.0037, Sill: 0.0139, Range: 2333, cut off: 2000m Exponential	 **Nugget: 0.1226, sill: 0.2525,Range: 2262 m,** **Exponential** **4144 x 2688 m**	 Nugget: 0.0053, sill: 0.0108, Range: 482 m, **Exponential** **4144 x 2688 m**