Palestine Polytechnic University

College of Engineering
Civil & Architecture Engineering Department

Project Title

Mapping and Analysis of Land Cover in West Bank / Palestine using Landsat and Sentinel Multispectral Imagery

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Palestine

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By

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A PROJECT REPORT SUBMITTED IN PARTIAL FULFILLMENT OF THE

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Project Supervisor

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Prepared By:

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In accordance with the recommendations of the project supervisor, and the acceptance of all examining committee members, this project has been submitted to the Department of Civil and Architectural Engineering in the College of Engineering and Technology in partial fulfillment of the requirements of the department for the degree of Bachelor of Science in Engineering.

Project Supervisor **Department Chairman**

DEDICATION

Every challenging work needs self-efforts as well as guidance of elders especially those who were very close to our heart.

Our humble effort we dedicate to our sweet and loving

Families,

Whose affection, love, encouragement and prays of day and night made us able to get such success and honor,

Along with all hard working and respected

Teachers

ACKNOWLEDGEMENT

We would like to express our thanks and gratitude to Allah, the Most Beneficent, the most Merciful who granted us the ability and willing to start and complete this project. We pray to his greatness to inspire us the right path to his content and to enable us to continue the work started in this project to the benefits of our country.

We wish to express our deep and sincere thanks and gratitude to Palestine Polytechnic University, the Department of Civil & Architectural Engineering, and College of Engineering. We wish to express our thanks to Eng Nidal Aburajab, for a valuable help, encouragement, supervision and guidance in solving the problems that we faced from time to time during this project.

We can find no words to express our sincere, appreciation and gratitude to our parents, sisters and brothers, for their endless support and encouragement, we are deeply indebted to you and we hope that we may someday reciprocate it in some way.

Work Team

ABSTRACT

Mapping and Analysis of Land Cover in West Bank / Palestine using Landsat and Sentinel Multispectral Imagery

By

Basil K Foqha **Mohammad S Sawalhi** **Musab W Qasem**

Supervisor

Eng. Nidal ABURAJAB

In this study open source multispectral (Landsat, Sentinel) satellite imagery data are going to be used to compare regional Land-Cover in the (West Bank, Palestine) within different periods along the years 1984 to 2017, within analytical framework that included consistent reference data using Maximum Likelihood Classification method. Multispectral Satellite imagery provided by Landsat and Sentinel has the spatial resolution of 30 - 10 m. Using a special remote sensing software like ENVI along with using the ArcGIS software and some image processing tools, the images of both Landsat and Sentinel were analyzed, processed, checked and classified and a comparison between these images were made. The land-cover changes in the West Bank, and how those changes affected the natural cover, the economy, the agriculture, the environment and others were evaluated and statistically studied. Then it was linked to an official local data from PCBS (Palestinian Central Bureau of Statistics) in order to propose strategies and recommendations to get over the obstacles produced from those changes.

In this context, the primary objective of this study detected the changes regularly using Remote Sensing and GIS and provides an up-to-date information about the urban areas.

Table of Contents

Table of Figures

List of Tables

CHAPTER ONE

INTRODUCTION

1.1 General

1.2 Problem Definition

1.3 Study Area

1.4 Objectives

1.5 Time Table

1.6 Methodology

1.7 Scope of work

1.1 General

Regional and municipal planners require up-to-date information to effectively manage land development and plan for change. In the West Bank, particularly at the urban areas, this change is very rapid. As a result, it is difficult to maintain up-to-date information whether it is on vegetation or built up areas development.

Nowadays, the availability of satellite imagery and computer storage of information, and the uses of the modern technologies of remote sensing and geographic information systems has obviously developed. And one of the most important uses of these sciences is the production of land-cover maps, which made the planning and management of the land much easier than earlier times.

The land-cover map refers to the surface cover whether vegetation, water, soil, urban development or other. Land-cover map as a source of thematic information, it has been an important component for global monitoring studies, resource management and planning activities. Land cover maps derived from satellite imagery have a long and varied history of uses in planning science and management. The use of mid-scale digital resolution information (from 10 to 30 meters) is ideal for many applications from mapping and analysis of the open source data provided by the satellite imagery.

1.2 Definitions of Terms

Remote sensing: It is defined as any process whereby information is gathered about an object, area or phenomenon without being in contact with it. Given this rather general definition, the term has come to be associated more specifically with the gauging of interactions between earth surface materials and electromagnetic energy. On the other hand, it is the science of acquiring, processing and analyzing information.

The land cover pattern of a region is an outcome of natural and socio – economic factors and their utilization by man in time and space. Land is becoming a scarce resource due to immense agricultural and demographic pressure. Hence, information on land cover and possibilities for their optimal use is essential for the selection, planning and implementation of land use schemes to meet the increasing demands for basic human needs and welfare. Land cover change has become a central component in current strategies for managing natural resources and monitoring environmental changes. The advancement in the concept of vegetation mapping has greatly increased research on land cover change thus providing an accurate evaluation of the spread and health of the world's forest, grassland, and agricultural resources has become an important priority.

Viewing the Earth from space is now crucial to the understanding of the influence of man's activities on his natural resource base over time. In situations of rapid and often unrecorded land use change, observations of the earth from space provide objective information of human utilization of the landscape. Over the past years, data from Earth sensing satellites has become vital in mapping the Earth's features and infrastructures, managing natural resources and studying environmental change.

Land cover mapping serves as a basic inventory of land resource for all levels of government, environmental agencies and private industries throughout the world. Change detection in land cover can be performed on a temporal scale such as a decade to access landscape change caused due to anthropogenic activities on the land. Change detection in the land use/ land cover involves use of at least two period data sets .Change detected by post classification comparison is the most commonly used quantitative methods.

Remote Sensing (RS) and Geographic Information System (GIS) are now providing new tools for advanced ecosystem management. The collection of remotely sensed data facilitates the synoptic analyses of Earth - system function, patterning, and change at local, regional and global scales over time; such data also provide an important link between intensive, localized ecological research and regional, national and international conservation and management of biological diversity.

The present study describes the various land cover changes and categories of the study area. The present study has been taken up in order to understand the changes that have taken place in land cover in West-Bank district.

Figure 1. 1 Land use/cover map of West Bank in 2008 by (ARIJ Geo-information Department.

1.3 Study Area

The West Bank is the area that lies between the latitudes 31° 20' and 32° 38' N and between the longitudes 34° 53' and 35° 31' E. It extends along the River Jordan for about 70 km and for 40 km along the western shore of the Dead Sea.

While from the north, south and west it is bounded by the Jordan-Israeli Cease fire line of 1949. Although, the average width of the WB from east to west is about 40 km, it varies from one place to another. Its maximum length from north to south is around 130 km and its surface area including water of the Palestinian part of the Dead Sea is approximately 5877 km2.

The West Bank has an area of 5,628 km2, which comprises 21.2% of former Mandatory Palestine (excluding Jordan) and has generally rugged mountainous terrain. The total length of the land boundaries of the region are 404 kilometers. The terrain is mostly rugged dissected upland, some vegetation in the west, but somewhat barren in the east. The elevation span between the shoreline of the Dead Sea at −408 m to the highest point at Mount Nabi Yunis, at 1,030 m above sea level. The area of West Bank is landlocked; highlands are main recharge area for Israel's coastal aquifers.

There are few natural resources in the area except the highly arable land, which comprises 27% of the land area of the region. It is mostly used as permanent pastures (32% of arable land) and seasonal agricultural uses (40%). Forests and woodland comprise just 1%, with no permanent crops.

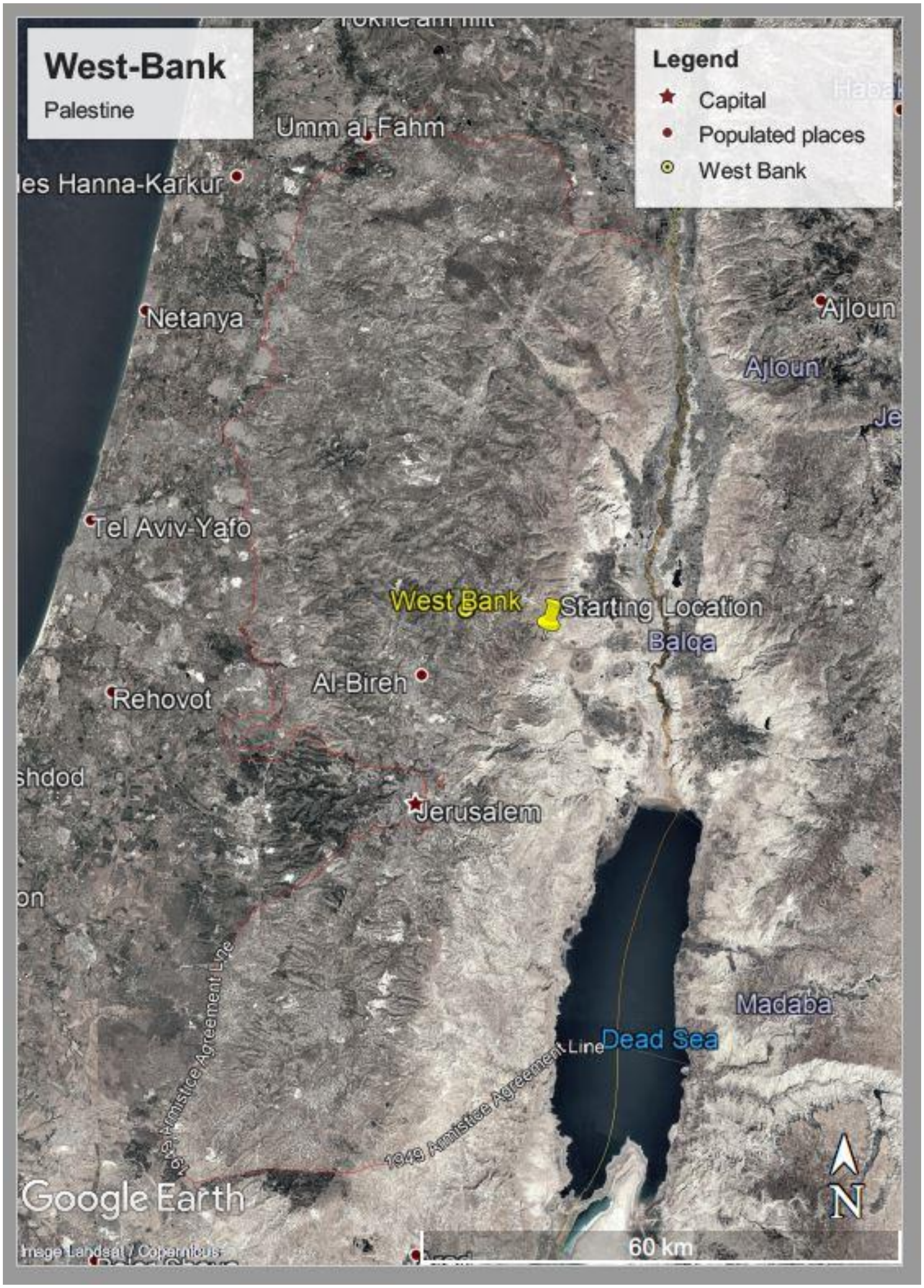


Figure 1. 2 West Bank Map from google maps.

1.4 Project Objectives

The objectives of this project are summarized below:

- To detect and determine the land-cover change rate using Landsat archives from 1984 to 2017.
- To detect and determine the land-cover change rate using Sentinel archives from 2015 to 2017.
- To compare the resolution and accuracy from both satellites Landsat and Sentinel.
- Provide an improved understanding of the process of changes in land-cover within the West Bank to develop strategies that can generate potential land-cover management practices.

1.5 Time Table

The time schedule shows the stages for achieving our work and the process of project growth that include choosing the project, problem definition, literature review, collecting data, office works, primary preparation of introduction and final preparation of project.

Table1 Time Table for The First Semester.

Week / Stage	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Choosing the project	■	■	■													
Problem Definition			■	■	■											
Collecting Data						■	■	■	■	■						
Office works										■	■	■	■			
Primary Report of introduction					■	■	■	■	■	■	■	■	■	■	■	
Final report of introduction													■	■	■	■

Table 2 Time Table for Second Semester.

Week Stage	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Classification of the images																
Generate confusion matrix																
Statistics of classification																
Map production																
Primary report of project																
Final report of project																

1.6 Methodology

The steps of this project are summarized below:

- Collecting and downloading the data from open source sites like the American governmental U.S Geological Surveys website: https://earthexplorer.usgs.gov/ and the European Space Agency website: https://scihub.copernicus.eu/dhus/
- Processing of images from satellites like mosaic, clip… etc.
- Classifying the data to make a good interpretation of the images.
- Start the mapping process to produce a land cover map for different Periods from different satellites.
- Analyzing the output and results to Work on applications.

1.7 Scope of Work

This project will presented in seven chapters:

- The first chapter entitled "Introduction" outlines the subject, definitions of terms, study area, objectives of project, and organization of the report.

- The second chapter entitled "Literature Review" provides an introduction to Remote Sensing, explains the electromagnetic spectrum and image resolutions, and the characteristics of Landsat and Sentinel imagery.

- The third chapter entitled "Methodology" describes in details the data collection, the satellite imagery characteristics, software package utilized, image classification and the change detection comparison.

- The fourth chapter entitled "Calculation and Analysis" outlines the whole process of the calculation, analysis and statistics of the image.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction to Remote Sensing

2.2 Electromagnetic Spectrum

2.3 Spatial radiometric spectral temporal resolution

2.4 Landsat series

2.5 Sentinel Satellite

2.1 Introduction to Remote Sensing

Remote sensing (RS), also called earth observation, refers to obtaining information about objects or areas at the Earth's surface without being in direct contact with the object or area. Humans accomplish this task with aid of eyes or by the sense of smell or hearing; so, remote sensing is day-today business for people. Reading the newspaper, watching cars driving in front of you are all remote sensing activities. Most sensing devices record information about an object by measuring an object's transmission of electromagnetic energy from reflecting and radiating surfaces.

Remote sensing techniques allow taking images of the earth surface in various wavelength region of the electromagnetic spectrum (EMS). One of the major characteristics of a remotely sensed image is the wavelength region it represents in the EMS. Some of the images represent reflected solar radiation in the visible and the near infrared regions of the electromagnetic spectrum, others are the measurements of the energy emitted by the earth surface itself i.e. in the thermal infrared wavelength region. The energy measured in the microwave region is the measure of relative return from the earth's surface, where the energy is transmitted from the vehicle itself. This is known as active remote sensing, since the energy source is provided by the remote sensing platform. Whereas the systems where the remote sensing measurements depend upon the external energy source, such as sun are referred to as passive remote sensing systems.

2.1.1 Principles of Remote Sensing

Detection and discrimination of objects or surface features means detecting and recording of radiant energy reflected or emitted by objects or surface material (Fig. 2.1). Different objects return different amount of energy in different bands of the electromagnetic spectrum, incident upon it. This depends on the property of material (structural, chemical, and physical), surface roughness, angle of incidence, intensity, and wavelength of radiant energy.

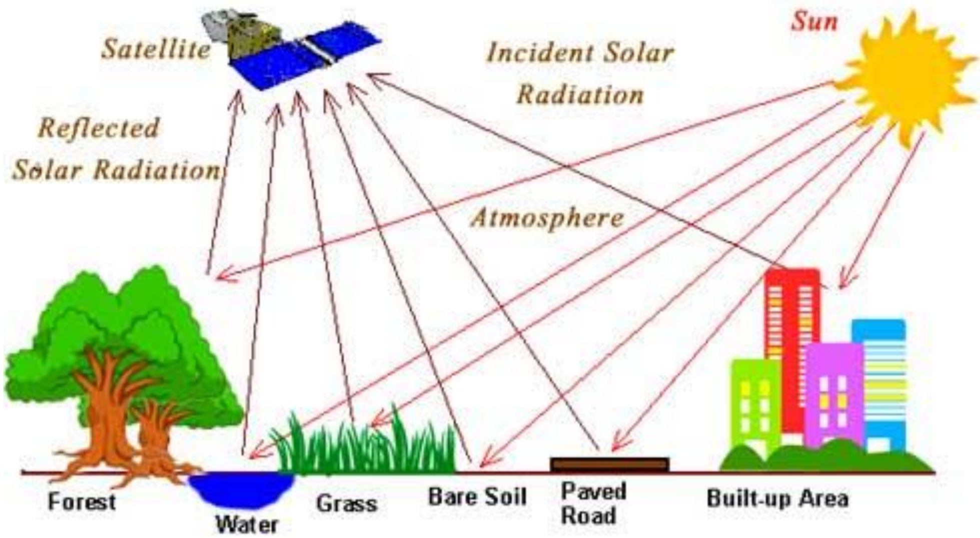


Figure 2. 1 Remote Sensing Process.

The Remote Sensing is basically a multi-disciplinary science which includes a combination of various disciplines such as optics, spectroscopy, photography, computer, electronics and telecommunication, satellite launching etc. All these technologies are integrated to act as one complete system in itself, known as Remote Sensing System. There are a number of stages in a Remote Sensing process, and each of them is important for successful operation.

2.1.2 Stages in Remote Sensing

- Emission of electromagnetic radiation, or EMR (sun/self- emission).
- Transmission of energy from the source to the surface of the earth, as well as absorption and scattering.
- Interaction of EMR with the earth's surface: reflection and emission.
- Transmission of energy from the surface to the remote sensor.
- Sensor data output.

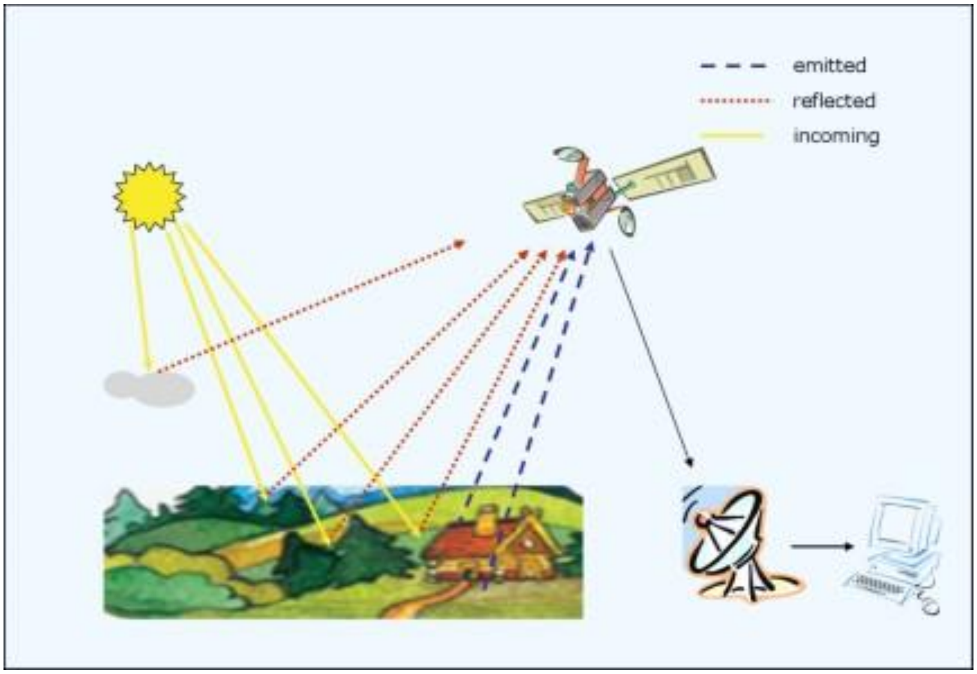


Figure 2. 2 Electromagnetic Remote Sensing of the Earth Surface.

2.2 Electromagnetic Spectrum

The electromagnetic spectrum is a continuum of all electromagnetic waves arranged according to frequency and wavelength. The sun, earth, and other bodies radiate electromagnetic energy of varying wavelengths. Electromagnetic energy passes through space at the speed of light in the form of sinusoidal waves. The wavelength is the distance from wave crest to wave crest.

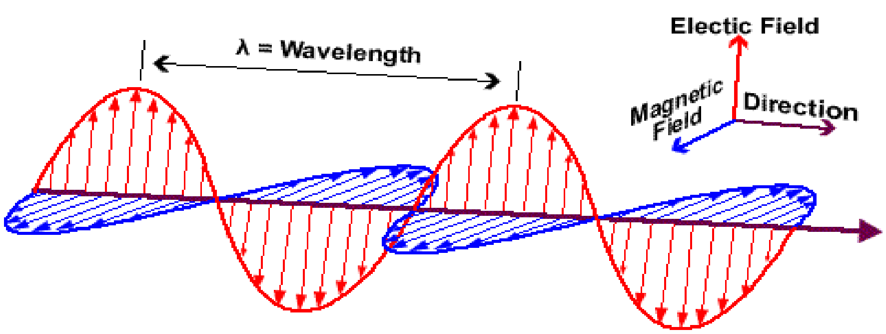


Figure 2. 3 Electromagnetic waves.

Light is a particular type of electromagnetic radiation that can be seen and sensed by the human eye, but this energy exists at a wide range of wavelengths. The micron is the basic unit for measuring the wavelength of electromagnetic waves. The spectrum of waves is divided into sections based on wavelength. The shortest waves are gamma rays, which have wavelengths of 10e-6 microns or less. The longest waves are radio waves, which have wavelengths of many kilometers. The range of visible consists of the narrow portion of the spectrum, from 0.4 microns (blue) to 0.7 microns (red).

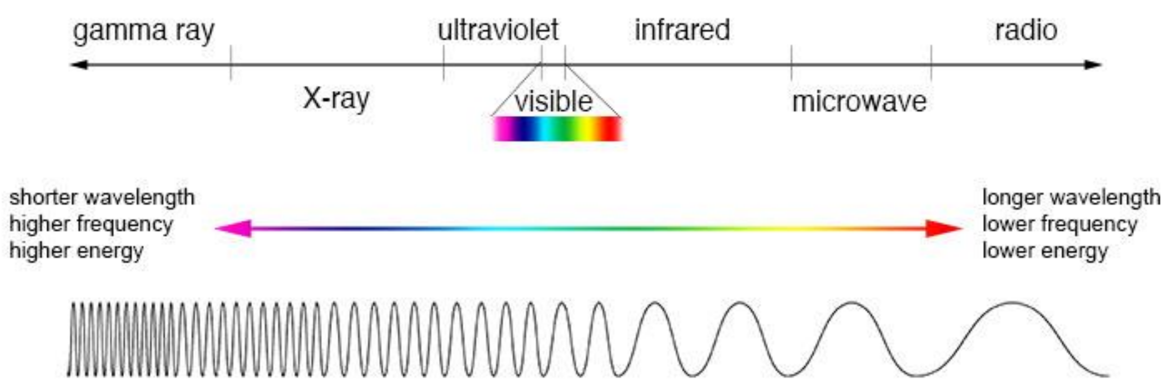


Figure 2. 4 Comparison of wavelength, frequency and energy for the electromagnetic spectrum. (Credit: NASA's Imagine the Universe.

Radio waves: If our eyes could see radio waves, we could (in theory) watch TV programs just by staring at the sky! Well not really, but it's a nice idea. Typical size: 30cm–500m. Radio waves cover a huge band of frequencies, and their wavelengths vary from tens of centimeters for high-frequency waves to hundreds of meters (the length of an athletics track) for lower-frequency ones. That's simply because any electromagnetic wave longer than a microwave is called a radio wave.

2.2.1 Types of Electromagnetic Radiations

Microwaves: Obviously used for cooking in microwave ovens, but also for transmitting information in radar equipment. It’s like short-wavelength radio waves. Typical size: 15cm (the length of a pencil).

Infrared: Just beyond the reddest light we can see, with a slightly shorter frequency, there's a kind of invisible "hot light" called infrared. Although we can't see it, we can feel it warming our skin when it hits our face—it's what we think of as radiated heat. If, like rattlesnakes, we could see infrared radiation, it would be a bit like having night vision lenses built into our heads. Typical size: 0.01mm (the length of a cell).

Visible light: The light we can actually see is just a tiny slice in the middle of the spectrum.

Ultraviolet: This is a kind of blue-ish light just beyond the highest-frequency violet light our eyes can detect. The Sun transmits powerful ultraviolet radiation that we can't see: that's why you can get sunburned even when you're swimming in the sea or on cloudy days—and why sunscreen is so important. Typical size: 500 nanometers (the width of typical bacteria).

X rays: A very useful type of high-energy wave widely used in medicine and security. Find out more in our main article on X rays. Typical size: 0.1 nanometers (the width of an atom).

Gamma rays: These are the most energetic and dangerous form of electromagnetic waves. Gamma rays are a type of harmful radiation. Typical size: 0.000001 nanometers (the width of an atomic nucleus).

Table 3 The different types of electromagnetic radiations.

Name	Wavelength (Ă)	Frequency (Hz)
Radio wave	$3\times10^{14}-3\times10^{7}$	$1\times10^{5}-1\times10^{9}$
Microwave	$3\times10^{7}-6\times10^{6}$	$1\times10^{9}-5\times10^{11}$
Infrared (IR)	$6\times10^{6}-7600$	$5\times10^{11}-3.95\times10^{16}$
Visible	$7600-3800$	$3.95\times10^{16}-7.9\times10^{14}$
Ultraviolet (UV)	$3800-150$	$7.9\times10^{14}-2\times10^{16}$
X-Rays	$150-0.1$	$2\times10^{16}-3\times10^{19}$
γ- Rays	$0.1-0.01$	$3\times10^{19}-3\times10^{20}$
Cosmic Rays	0.01- zero	3×10^{20} –infinity

2.3 Image Resolutions

Satellite remote sensing data with multi-temporal resolution has become a crucial tool for monitoring land use/cover change. Satellite-based land observation sensors offer reliable and consistent digital data with different ranges of spectral, spatial radiometric and temporal resolutions.

Spatial resolution refers to the capability of the sensor to depict, measure, and record objects on the ground. The spatial resolution varies among sensors and satellites. The smaller the spatial resolution the greater the detail in the satellite image.

2.3.1 Spatial Resolution and Pixel Size

The image resolution and pixel size are often used interchangeably. In reality, they are not equivalent. An image sampled at a small pixel size does not necessarily has a high resolution. The following three images illustrate this point. The first image is a SPOT image of 10 m pixel size. It was derived by merging a SPOT panchromatic image of 10 m resolution with a SPOT multispectral image of 20 m resolution. The effective resolution is thus determined by the resolution of the panchromatic image, which is 10 m. This image is further processed to degrade the resolution while maintaining the same pixel size. The next two images are the blurred versions of the image with larger resolution size, but still digitized at the same pixel size of 10 m. Even though they have the same pixel size as the first image, they do not have the same resolution.

Figure 2. 5 Differences between coarse and fine resolutions credit by Sayed Abulhasan Quadri, Research Associate at CEDEC, USM, Malaysia.

The detail discernible in an image is dependent on the spatial resolution of the sensor and refers to the size of the smallest possible feature that can be detected. Spatial resolution of passive sensors (we will look at the special case of active microwave sensors later) depends primarily on their Instantaneous Field of View (IFOV). The IFOV is the angular cone of visibility of the sensor (A) and determines the area on the Earth's surface which is "seen" from a given altitude at one particular moment in time (B). The size of the area viewed is determined by multiplying the IFOV by the distance from the ground to the sensor (C). This area on the ground is called the resolution cell and determines a sensor's maximum spatial resolution. For a homogeneous feature to be detected, its size generally has to be equal to or larger than the resolution cell. If the feature is smaller than this, it may not be detectable as the average brightness of all features in that resolution cell will be recorded. However, smaller features may sometimes be detectable if their reflectance dominates within an articular resolution cell allowing sub-pixel or resolution cell detection.

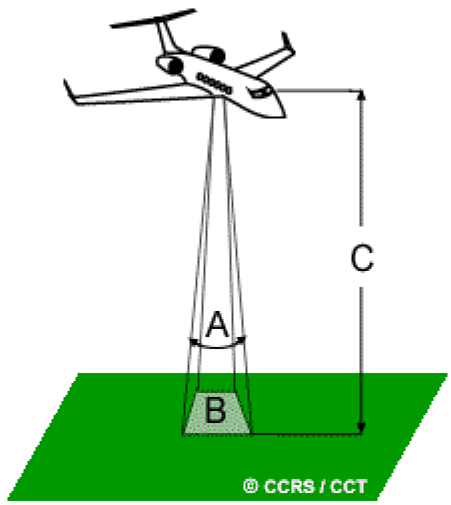


Figure 2. 6 IFOV determination.

Most remote sensing images are composed of a matrix of picture elements, or pixels, which are the smallest units of an image. Image pixels are normally square and represent a certain area on an image. It is important to distinguish between pixel size and spatial resolution - they are not interchangeable. If a sensor has a spatial resolution of 20 meters and an image from that sensor is displayed at full resolution, each pixel represents an area of 20m x 20m on the ground. In this case the pixel size and resolution are the same. However, it is possible to display an image with a pixel size different than the resolution. Many posters of satellite images of the Earth have their pixels averaged to represent larger areas, although the original spatial resolution of the sensor that collected the imagery remains the same.

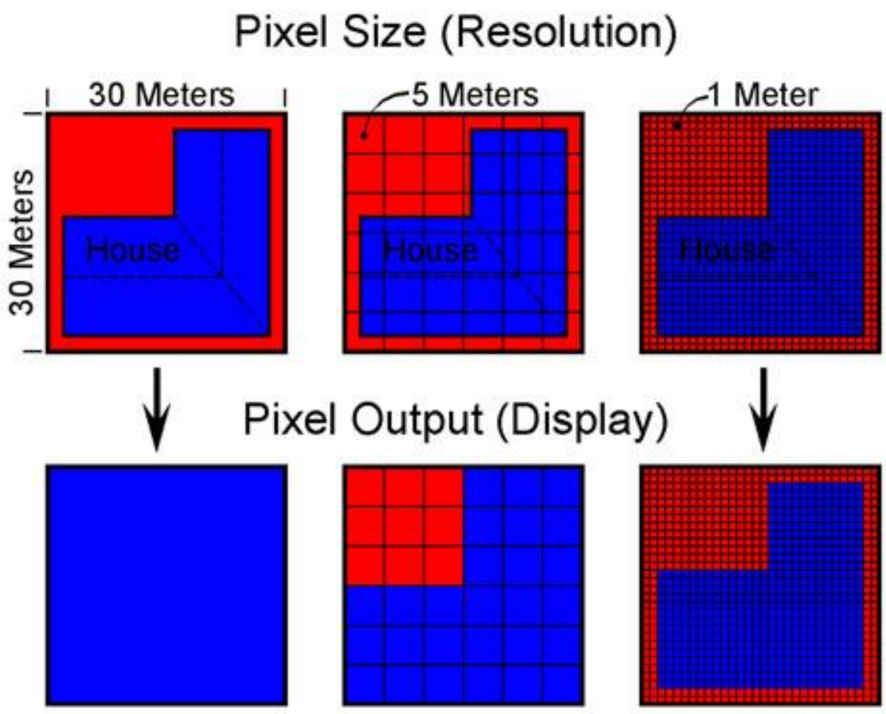


Figure 2. 7 Pixel size and its effects on spatial resolution.

High spatial resolution: 0.41 - 4 m

Low spatial resolution: 30 - > 1000 m

2.3.2 Spectral resolution

The spectral resolution is defined as the number and spectral width of the bands in the electromagnetic spectrum of a satellite sensor. A band is composed of pixels, and each pixel has a digital number (DN) or brightness value (BV). DN or BV is the relative reflectance of the electromagnetic spectrum for the target area or foot print.

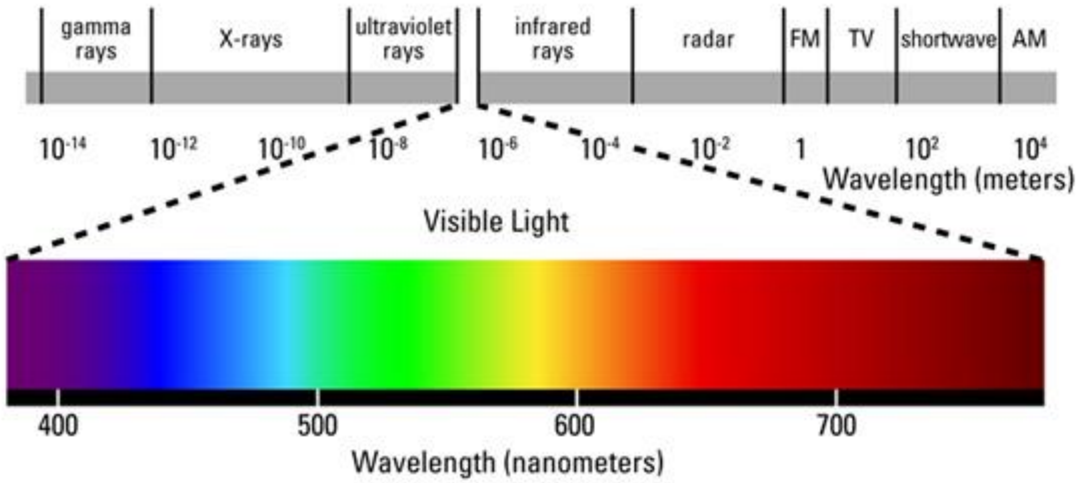


Figure 2. 8 Electromagnetic spectrum.

Electromagnetic energy reaching the earth's surface from the Sun is reflected, transmitted or absorbed. A basic assumption made in remote sensing is that specific targets (soils of differed types, water with varying degrees of impurities, rocks of differing lithologies, or vegetation of various species) have an individual and characteristic manner of interacting with incident radiation that is described by the spectral response of that target.

The spectral response of a target also depends upon such factors as the orientation of the Sun, the height of the Sun in the sky (solar elevation angle), direction in which the sensor is pointing relative to nadir (the look angle), the topographic position of the target in terms of slope orientation, the state of health of vegetation if that is the target, and the state of the atmosphere. The spectral reflectance curve is affected by factors such as soil nutrient status, the growth stage of the vegetation, the color of the soil (which may be affected by recent weather conditions).

In some instances, the nature of the interaction between incident radiation and earth's surface materials will vary from time to time during the year, such as might be expected in the case of vegetation as it develops from the leafing stage, through growth to maturity and, finally to senescence. The term 'spectral signature' is sometimes used to describe the spectral response curve for a target.

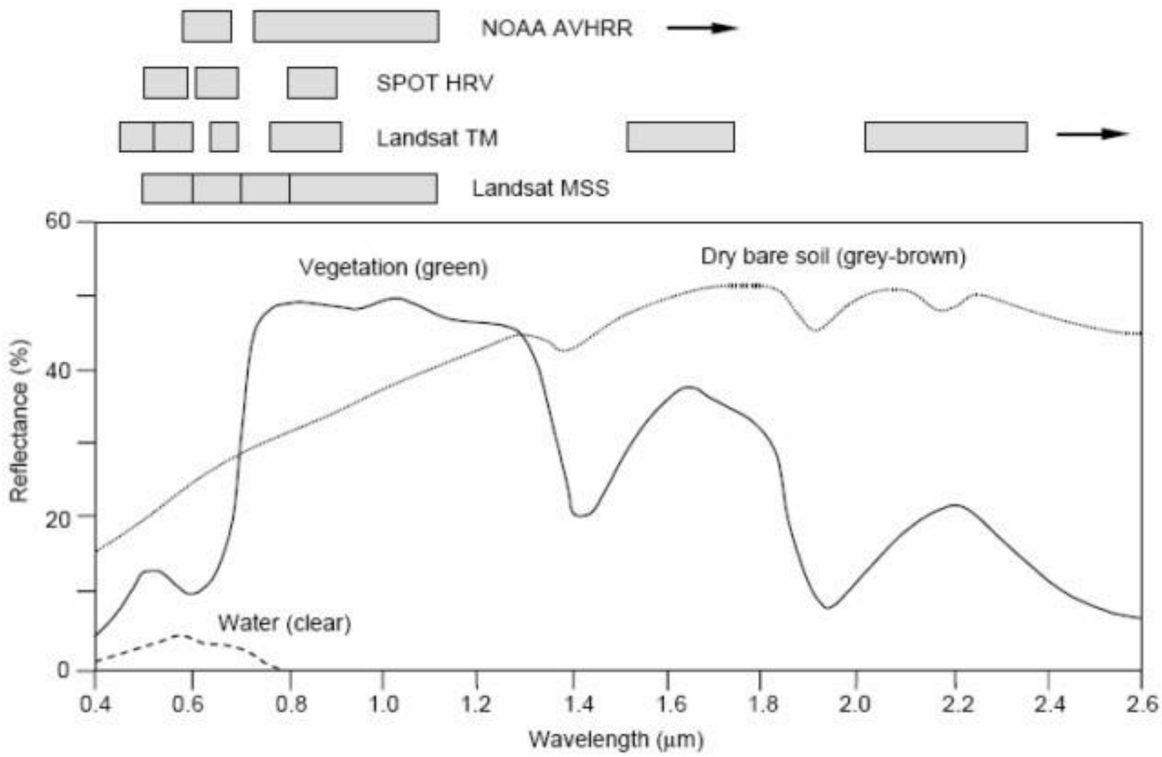


Figure 2. 9 Typical spectral reflectance curves of common earth surface materials in the visible and near to mid-infrared range. The positions of spectral bands for some remote sensors are also indicated.

The earth surface materials that are considered here are vegetation, soil, bare rock and water. In principle, a material can be identified from its spectral reflectance signature if the sensing system has sufficient spectral resolution to distinguish its spectrum from those of other materials. This premise provides the basis for multispectral remote sensing.

The fundamental approach in remote sensing is to investigate the spectral signature before a correct image interpretation may be achieved. The variety of earth's surface materials is enormous, and therefore the recording of their spectral signatures (also known as spectral library) requires substantial financial and time investments. For years, efforts have been made to establish such datasets and pool them for general use through what are known as spectral libraries. Such spectral libraries are maintained by many organizations including the Johns Hopkins University (JHU), the Jet Propulsion Laboratory (JPL), and the United States Geological Survey (USGS). Many of these datasets are made available with commercial remote sensing image processing software packages. A typical spectral reflectance curve of the most common earth surface materials viz., water and vegetation is shown in Fig 2.10.

Spectral reflectance of common land covers

Vegetation has a unique spectral signature which enables it to be distinguished readily from other types of land cover in an optical/near-infrared image. The reflectance is low in both the blue and red regions of the spectrum, due to absorption by chlorophyll for photosynthesis. It has a peak at the green region. In the near infrared (NIR) region, the reflectance is much higher than that in the visible band due to the cellular structure in the leaves. Hence, vegetation can be identified by the high NIR but generally low visible reflectance. This property has been used in early reconnaissance missions during war times for "camouflage detection".

The reflectance of bare soil generally depends on its composition. In the spectral reflectance curves shown in Figs 5 and 6, the reflectance increases with increasing wavelength. The reflectance of clear water is generally low. However, the reflectance is maximum at the blue end of the spectrum and decreases as wavelength increases. Hence, clear water appears dark-bluish. Turbid water has some sediment suspension which increases the reflectance in the red end of the spectrum, accounting for its brownish appearance.

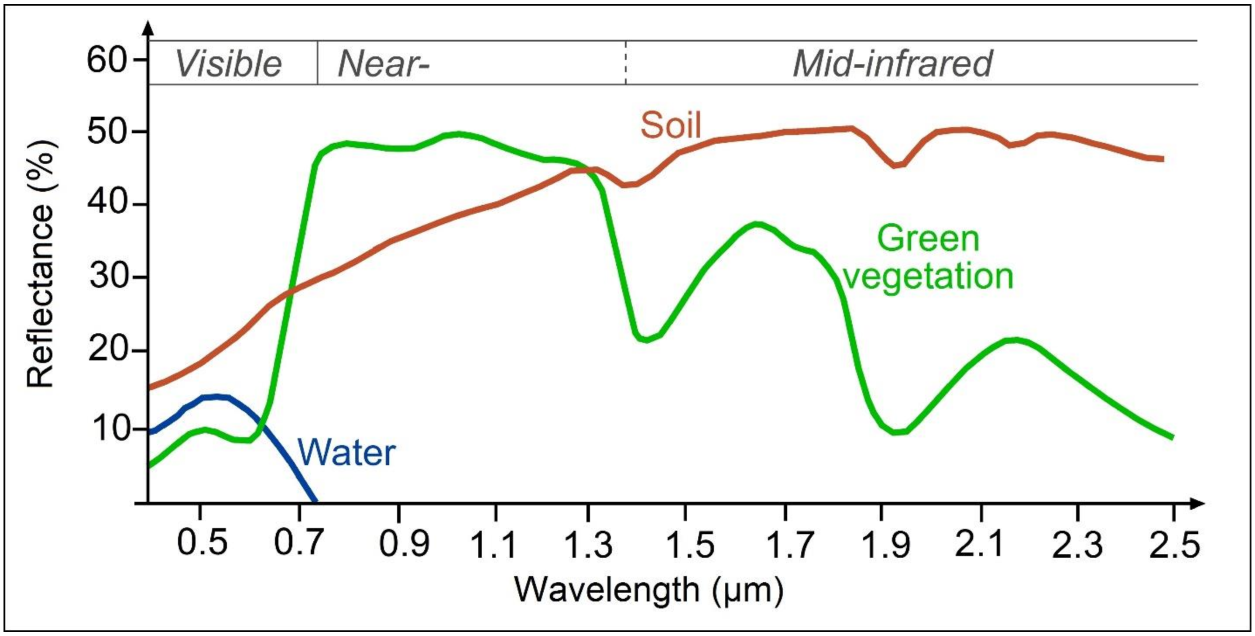


Figure 2. 10 Reflectance of water, soil and vegetation at different wavelengths.

High spectral resolution: - 220 bands
Medium spectral resolution: 3 - 15 bands
Low spectral resolution: - 3 bands

2.3.3 Radiometric resolution

The radiometric resolution specifies how well the differences in brightness in an image can be perceived; this is measured through the number of the grey value levels. The maximum number of values is defined by the number of bits (binary numbers). An 8 bit representation has 256 grey values, a 16 bit (ERS satellites) representation 65.536 grey values.

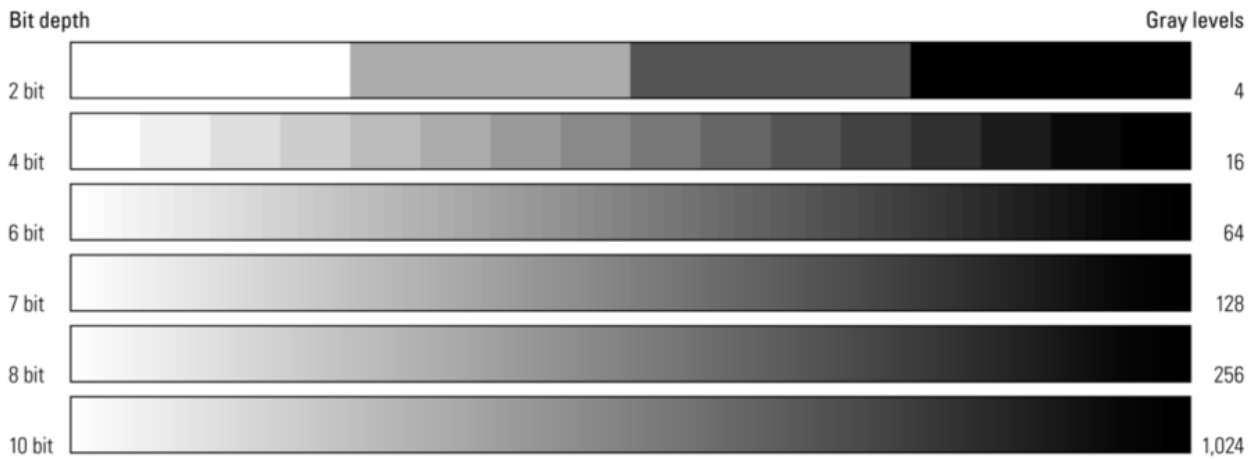


Figure 2. 11 The relationship between Bit depth and Grey levels.

The finer or the higher the radiometric resolution is, the better small differences in reflected or emitted radiation can be measured, and the larger the volume of measured data will be (compare with the image on the right).

The advantage of a higher radiometric resolution is rather small - when comparing LANDSAT-MSS (6 bits) and TM (8 bits) the improvement is in the order of 2-3%.

Radiometric resolution depends on the wavelengths and the type of the spectrometer:

- LANDSAT-MSS (from LANDSAT 1-3): 6 bits (64 grey values).
- IRS-LISS I-III: 7 bits (128 grey values).
- LANDSAT-TM (from LANDSAT 4-5) & SPOT-HRV: 8 bits (256 grey values)
- LANDSAT-ETM & ETM+ (from LANDSAT 6-7): 9 bits (only 8 bits are transmitted).
- IRS-LISS IV: 10 bits (only 7 bits are transmitted).
- IKONOS & QuickBird: 11 bits.

Figure 2. 12 An example showing a comparison of different radiometric resolutions for the same image.

2.3.4 Temporal Resolution

Remote sensed data represents a snap shot in time. Temporal resolution is the time between two subsequent data acquisitions for an area. This is also known as the "return time". The temporal resolution depends primarily on the platform, so instance satellites usually have set return times and while sensors mounted on aircraft have more varied return time. For satellite the return time depends on the orbital characteristics (low vs high orbit), the swath width and whether or not there is an ability to point the sensor. For example Landsat has a return time of approximately 16 days, while other sensor like MODIS have nearly daily return times.

Table 4 Temporal Resolutions for Some Common Sensors.

TEMPORAL RESOLUTIONS	
Remote Sensing Instrument	**Temporal Resolution**
Landsat 1,2, and 3 (Both TM and MSS)	18 Days (Every 251 Orbits)
Landsat 4,5, and 6 (Both TM and MSS)	16 Days (Every 233 Orbits)
Landsat 7 and 8 (ETM+, TIRS and OLI)	16 Days (Every 233 Orbits)
Sentinel 1A and 1B	12 days (Every 175 Orbits)
Sentinel 2A and 2B	10 days with one satellite and 5 days with 2 satellites.

High temporal resolution: < 24 hours - 3 days
Medium temporal resolution: 4 - 16 days
Low temporal resolution: > 16 days

2.3.5 Resolution Trade-Off

The different spatial, temporal and spectral resolutions are the limiting factor for the utilization of the satellite image data for different applications.

Unfortunately, because of technical constraints, satellite remote sensing systems can only offer the following relationship between spatial and spectral resolution: a high spatial resolution is associated with a low spectral resolution and vice versa.

That means that a system with a high spectral resolution can only offer a medium or low spatial resolution.

Therefore, it is either necessary to find compromises between the different resolutions according to the individual application or to utilize alternative methods of data acquisition.

The trade-off may result in two different solutions:

- To lay emphasis upon the most important resolution, in direct dependency to the application, with the acceptance of low attendant resolutions at the same time, or
- To lay no emphasis on one specific resolution and at the same time the acceptance of a medium spectral, temporal and spatial resolution.

2.4 Landsat Satellite Imagery

The Landsat program is a joint USGS and NASA led enterprise for Earth Observation that represents the world's longest running system of satellites for moderate-resolution optical remote sensing for land, coastal areas and shallow waters.

Since 1972, Landsat satellites have provided EO data to support work in agriculture, geology, forestry, education, mapping, emergency response and disaster relief, as well as providing a long-term record of natural and human-induced changes to the Earth.

Landsat's Global Survey Mission is to establish and execute a data acquisition strategy that ensures repetitive acquisition of observations over the Earth's land mass, coastal boundaries, and coral reefs and consists of a series of eight satellites, the fourth, fifth and eighth of which are presented here.

2.4.1 Landsat-1

Figure 2. 13 Landsat-1 Satellite.

Participants

- NASA.
- Department of the Interior (DOI) U.S. Geological Survey (USGS).
- Manufacturer: General Electric's (GE's) Space Division in Valley Forge, Pennsylvania.

Launch

- Date: July 23, 1972.
- Vehicle: Delta 900.
- Launched by: NASA.
- Site: Vandenberg Air Force Base, California.

Spacecraft

- Weight: approximately 953 kg (2,100 lbs.).
- Overall height: 3 m (10 ft.).
- Diameter: 1.5 m (5 ft.).
- Solar array paddles extend out to a total of 4 m (13 ft.).
- 3-axis stabilized using 4 wheels to +/-0.7° attitude control.
- Twin solar array paddles (single-axis articulation).
- S-Band and Very High Frequency (VHF) communications.
- Hydrazine propulsion system with 3 thrusters.

Communications

- Direct downlink from 2, 30 minute wide-band video tape recorders.
- Data rate: 15 Mbps.
- Quantization: 6 bit (64 levels).

Orbit

- Worldwide Reference System-1 (WRS-1) path/row system.
- Sun-synchronous, near-polar orbit at an altitude of 917 km (570 mi).
- Inclined at 99.2°.
- Circled the Earth every 103.34 minutes.
- Completed 14 orbits per day.
- Repeat cycle: 18 days.
- Swath width: 185 km (115 mi).
- Equatorial crossing time: 9:30 a.m. +/- 15 minutes.
- Swath overlap (or side lap) varied from 14 percent at the Equator to a maximum of approximately 85 percent at 81° north or south latitude.

Sensors

Return Beam Videocon (RBV)

- Operated from July 23, 1972 to August 5, 1972, recording only 1692 images.
- 80 meter-ground resolutions.
- Data: 3.5 MHz FM video.
- Three cameras operating in the following spectral bands:
    1. Band 1 Visible blue-green (475-575 nm).
    2. Band 2 Visible orange-red (580-680 nm).
    3. Band 3 Visible red to Near-Infrared (690-830 nm).

Multispectral Scanner (MSS)

- 80-meter ground resolution in four spectral bands:
    1. Band 4 Visible green (0.5 to 0.6 µm).
    2. Band 5 Visible red (0.6 to 0.7 µm).
    3. Band 6 Near-Infrared (0.7 to 0.8 µm).
    4. Band 7 Near-Infrared (0.8 to 1.1 µm).
- Six detectors for each spectral band provided six scan lines on each active scan.
- Ground Sampling Interval (pixel size): 57 x 79 m.

Other Characteristics

- Scene size: 170 km x 185 km (106 mi x 115 mi).
- Originally named ERTS-A (Earth Resources Technology Satellite); also known as ERTS-1 and Landsat-1.
- Program renamed Landsat in 1975.
- Design Life: Minimum of 1 year.

2.4.2 Landsat-2

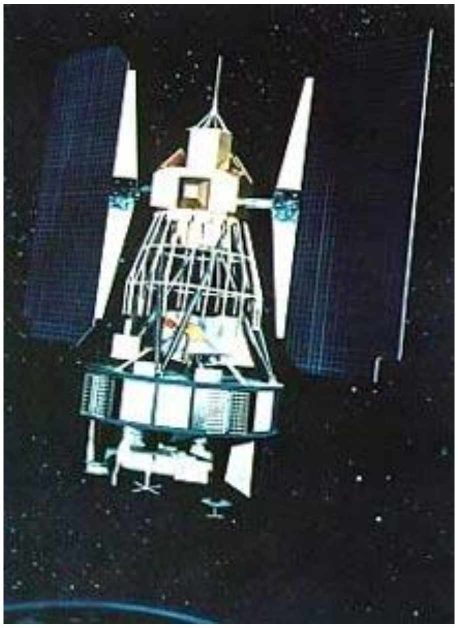


Figure 2. 14 Landsat-2 Satellite.

Participants

- NASA.
- Department of the Interior (DOI) .U.S.Geological Survey (USGS).
- Manufacturer: General Electric's (GE's) Space .Division in Valley Forge, Pennsylvania.

Launch

- Date: January 22, 1975.
- Vehicle: Delta 2910.
- Launched by: NASA.

- Site: Vandenberg Air Force Base, California.

Spacecraft

- Weight: approximately 953 kg (2,100 lbs).
- Overall height: 3 m (10 ft.).
- Diameter: 1.5 m (5 ft).
- Solar array paddles extend out to a total of 4 m (13 ft).
- 3-axis stabilized using 4 wheels to +/-0.7° attitude control.
- Twin solar array paddles (single-axis articulation).
- S-Band and Very High Frequency (VHF) communications.
- Hydrazine propulsion system with 3 thrusters.

Communications

- Direct downlink from 2, 30 minute wide-band video tape recorders.
- Data rate: 15 Mbps.
- Quantization: 6 bit (64 levels).

Orbit

- Worldwide Reference System-1 (WRS-1) path/row system.
- Sun-synchronous, near-polar orbit at an altitude of 917 km (570 mi).
- Inclined at 99.2°.
- Circled the Earth every 103 minutes.
- Completed 14 orbits a day.
- Repeat cycle: 18 days.
- Swath width: 185 km (115 mi).
- Equatorial crossing time: 9:30 a.m. +/- 15 minutes.
- Swath overlap (or side lap) varied from 14 percent at the Equator to a maximum of approximately 85 percent at 81° north or south latitude.

Sensors

Return Beam Vidicon (RBV)

- The RBV system on Landsat 2 was operated primarily for engineering evaluation purposes and only occasional RBV imagery was obtained, primarily for cartographic uses in remote areas.
- 80 m resolution in the multispectral band.
- Three cameras that operate in the following spectral bands:
    1. Visible blue-green (475-575 nm).

2. Visible orange-red (580-680 nm).
3. Visible red to Near-Infrared (690-830 nm).

- Data: 3.5 MHz video.

Multispectral Scanner (MSS)

- Four spectral bands:
  1. Band 4 Visible green (0.5 to 0.6 µm).
  2. Band 5 Visible red (0.6 to 0.7 µm).
  3. Band 6 Near-Infrared (0.7 to 0.8 µm).
  4. Band 7 Near-Infrared (0.8 to 1.1 µm).
- Six detectors for each spectral band provided six scan lines on each active scan.
- Ground Sampling Interval (pixel size): 57 x 79 m.

Other Characteristics

- Scene size: 170 km x 185 km (106 mi x 115 mi).
- Originally designated ERTS-B (Earth Resources Technology Satellite-B), then named Landsat-2 prior to launch.
- Design Life: Minimum of 1 year.

2.4.3 Landsat-3

Figure 2. 15 Landsat-3 Satellite.

Participants

- NASA.
- Department of the Interior (DOI) U.S. Geological Survey (USGS).
- Manufacturer: General Electric (GE) Astrospace.

Launch

- Date: March 5, 1978.
- Vehicle: Delta 2910.
- Launched by: NASA.
- Site: Vandenberg Air Force Base, California.

Spacecraft

- Weight: approximately 953 kg (2,100 lbs).
- Overall height: 3 m (10 ft).
- Diameter: 1.5 m (5 ft).
- Solar array paddles extend out to a total of 4 m (13 ft).
- 3-axis stabilized using 4 wheels to +/-0.7° attitude control.
- Twin solar array paddles (single-axis articulation).
- S-Band and Very High Frequency (VHF) communications.
- Hydrazine propulsion system with 3 thrusters.

Communications

- Direct downlink from 2, 30 minute wide-band video tape recorders.
- Data rate: 15 Mbps.
- Quantization: 6 bit (64 levels).

Orbit

- Worldwide Reference System-1 (WRS-1) path/row system.
- Sun-synchronous, near-polar orbit at an altitude of 917 km (570 mi).
- Inclined at 99.1°.
- Circled the Earth every 103 minutes.
- Completed 14 orbits a day.
- Repeat cycle: 18 days.
- Swath width: 185 km (115 mi).
- Equatorial crossing time: 9:30 a.m. +/- 15 minutes.

- Swath overlap (or side lap) varied from 14 percent at the Equator to a maximum of approximately 85 percent at 81° north or south latitude.

Sensor

Return Beam Vidicon (RBV)

- The RBV system on Landsat 3 used two cameras, mounted side-by-side, with panchromatic spectral response and higher spatial resolution (40 m) to complement the multispectral coverage provided by the Multispectral Scanner (MSS). Each of the cameras produced a swath of about 90 km (for a total swath of 180 km).
- 40 m resolution from 2, 80 m resolution cameras.
- Two cameras with a panchromatic spectral response.
- Data: 3.5 MHz video.

Multispectral Scanner (MSS)

- Five spectral bands, including a thermal band:
    1. Band 4 Visible (0.5 to 0.6 µm).
    2. Band 5 Visible (0.6 to 0.7 µm).
    3. Band 6 Near-Infrared (0.7 to 0.8 µm).
    4. Band 7 Near-Infrared (0.8 to 1.1 µm).
    5. Band 8 Thermal (10.4 to 12.6 µm).
- Data: 100 kHz digital.
- Six detectors for each reflective band provided six scan lines on each active scan.
- Ground Sampling Interval (pixel size): 57 x 79 m.

Other Characteristics

- Scene size: 170 km x 185 km (106 mi x 115 mi).
- Originally designated Landsat 3; also known as Landsat C.
- Design Life: Minimum of 1 year

2.4.4 Landsat-4

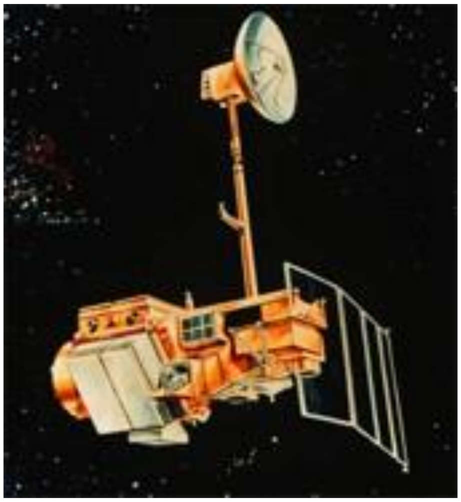


Figure 2. 16 Landsat-4 Satellite.

Participants

- NASA.
- National Oceanic and Atmospheric Administration (NOAA).
- Earth Observation Satellite Company (EOSAT).
- Department of the Interior (DOI) U.S. Geological Survey (USGS).

Launch

- Date: July 16, 1982.
- Vehicle: Delta 3920.
- Launched by: NASA.
- Site: Vandenberg Air Force Base, California.

Spacecraft

- 3-axis stabilized, zero momentum with control of 0.01 deg using reaction wheels.
- Aluminum with graphite struts.
- Hydrazine propulsion system.
- Single solar array with 1-axis articulation.
- Three Nickel Cadmium (NiCd) batteries provide 100 Ampere-Hour (AHr) total

- Retractable boom (4 m long) with 2 powered joints supports the articulated High Gain Antenna, which downlinked data via the Tracking and Data Relay Satellite System (TDRSS).
- Weight: approximately 4,300 lbs. (1,942 kg).

Communications

- Direct downlink with TDRSS.
- Data rate: 85 Mbps.
- Communications system uses S, X, L, and Ku Bands.
- Quantization: 8 bit (256 levels).

Orbit

- Worldwide References System-2 (WRS-2) path/row system.
- Circular, sun-synchronous, near-polar orbit at an altitude of 705 km (438 mi).
- Inclined at 98.2°.
- Circled the Earth every 99 minutes.
- Repeat cycle: 16 days.
- Equatorial crossing time: 9:45 a.m. +/- 15 minutes.
- Swath width: 185 km (115 mi).

Sensors

Multispectral Scanner (MSS)

- Four spectral bands (identical to Landsat 1 and 2):
    1. Band 4 Visible (0.5 to 0.6 µm).
    2. Band 5 Visible (0.6 to 0.7 µm).
    3. Band 6 Near-Infrared (0.7 to 0.8 µm).
    4. Band 7 Near-Infrared (0.8 to 1.1 µm).
- Data: 100 kHz digital.
- Six detectors for each reflective band provided six scan lines on each active scan.
- Ground Sampling Interval (pixel size): 57 x 79 m.

Thematic Mapper (TM)

- Added the mid-range infrared to the data.
- Seven spectral bands, including a thermal band:
    1. Band 1 Visible (0.45 - 0.52 µm) 30 m.
    2. Band 2 Visible (0.52 - 0.60 µm) 30 m.
    3. Band 3 Visible (0.63 - 0.69 µm) 30 m.

4. Band 4 Near-Infrared (0.76 - 0.90 µm) 30 m.
5. Band 5 Near-Infrared (1.55 - 1.75 µm) 30 m.
6. Band 6 Thermal (10.40 - 12.50 µm) 120 m.
7. Band 7 Mid-Infrared (IR) (2.08 - 2.35 µm) 30 m.

- Ground Sampling Interval (pixel size): 30 m reflective, 120 m thermal.

Other Characteristics

- Scene size: 170 km x 185 km (106 mi x 115 mi).
- Design Life: Minimum of 3 years.

2.4.5 Landsat-5

Figure 2. 17 Landsat-5 Satellite.

Participants

- NASA.
- National Oceanic and Atmospheric Administration (NOAA).
- Earth Observation Satellite Company (EOSAT).
- Department of the Interior (DOI) U.S. Geological Survey (USGS).

- Manufacturers: General Electric (GE) Astrospace and Hughes Santa Barbara Remote Sensing.

Launch

- Date: March 1, 1984.
- Vehicle: Delta 3920.
- Launched by: NASA.
- Site: Vandenberg Air Force Base, California.

Spacecraft

- 3-axis stabilized, zero momentum with control of 0.01 deg using reaction wheels.
- Aluminum with graphite struts.
- Hydrazine propulsion system.
- Single solar array with 1-axis articulation.
- Three Nickel Cadmium (NiCd) batteries provide 100 Ampere-Hour (AHr) total.
- Retractable boom (4 m long) with 2 powered joints supports the articulated High Gain Antenna, which downlinks data via Tracking and Data Relay SatelliteSystem (TDRSS).
- Communications system uses S,X,L, and Ku Bands.
- Weight: approximately 4,800 lbs (2,200 kg).

Communications

- Direct downlink with TDRSS.
- Data rate: 85 Mbps.
- Quantisation: 8 bit (256 levels).

Orbit

- Worldwide Reference System-2 (WRS-2) path/row system.
- Circular, sun-synchronous, near-polar orbit at an altitude of 705 km (438 mi).
- Inclined at 98.2°.
- Repeat cycle: 16 days.
- Swath width: 185 km (115 mi).
- Equatorial crossing time: 9:45 a.m. +/- 15 minutes.

Sensors

Multispectral Scanner (MSS)

- Acquisitions of Landsat 5 MSS data over the United States ceased in 1992; global acquisitions ended in 1999. Limited acquisitions were made from June 2012 through January 2013, after the loss of the TM sensor on the satellite.
- Four spectral bands (identical to Landsat 1 and 2):
    1. Band 4 Visible green (0.5 to 0.6 µm).
    2. Band 5 Visible red (0.6 to 0.7 µm).
    3. Band 6 Near-Infrared (0.7 to 0.8 µm).
    4. Band 7 Near-Infrared (0.8 to 1.1 µm).
- Six detectors for each spectral band provided six scan lines on each active scan.
- Ground Sampling Interval (pixel size): 57 x 79 m.

Thematic Mapper (TM)

- Added the mid-range infrared to the data.
- Seven spectral bands, including a thermal band:
    1. Band 1 Visible (0.45 - 0.52 µm) 30 m.
    2. Band 2 Visible (0.52 - 0.60 µm) 30 m.
    3. Band 3 Visible (0.63 - 0.69 µm) 30 m.
    4. Band 4 Near-Infrared (0.76 - 0.90 µm) 30 m.
    5. Band 5 Near-Infrared (1.55 - 1.75 µm) 30 m.
    6. Band 6 Thermal (10.40 - 12.50 µm) 120 m.
    7. Band 7 Mid-Infrared (2.08 - 2.35 µm) 30 m.
- Ground Sampling Interval (pixel size): 30 m reflective, 120 m thermal.

Other Characteristics

- Also known as Landsat-D.
- Scene size: 170 km x 185 km (106 mi x 115 mi).
- Design Life: Minimum of 3 year.

2.4.6 Landsat-6

Figure 2. 18 Landsat-6 Satellite.

Participants

- NASA.
- National Oceanic and Atmospheric Administration (NOAA).
- Department of the Interior (DOI) U.S. Geological Survey (USGS).
- Spacecraft bus: Lockheed Martin Missiles & Space.
- Enhanced Thematic Mapper (ETM): Hughes Santa Barbara Research Center.

Launch

- Date: October 5, 1993.
- Vehicle: Titan II.
- Launched by: NASA.
- Site: Western Test Range at Vandenberg Air Force Base, California.

Spacecraft

- Power provided by a single sun-tracking solar array and two 50 Ampere-Hour (AHr), Nickel Cadmium (NiCd) batteries.
- Attitude control provided through four reaction wheels (pitch, yaw, roll, and skew); three 2-channel gyros with celestial drift updating; a static Earth sensor; a 1750 processor; and torque rods and magnetometers for momentum uploading.
- Orbit control and backup momentum unloading provided through a blow-down monopropellant hydrazine system with a single tank containing 270 pounds of hydrazine, associated plumbing, and twelve 1-pound-thrust jets.
- Weight: approx. 4,800 lbs (2,200 kg).

- Length: 4.3 m (14 ft).
- Diameter: 2.8 m (9 ft).

Communications

- Direct downlink with solid state recorders capable of storing 380 gigabits of data (100 scenes).
- Data rate: 85 Mbps.

Orbit (if obtained)

- Worldwide Reference System-2 (WRS-2) path/row system.
- Sun-synchronous orbit at an altitude of 705 km (438 mi).
- Inclined 98.2° (slightly retrograde).
- Repeat cycle: 16 days.
- Equatorial crossing time: 10:00 a.m. +/- 15 minutes.

Sensors

Enhanced Thematic Mapper (ETM)

- Eight spectral bands, including a pan and thermal band:
    1. Band 1 Visible (0.45 - 0.52 µm) 30 m.
    2. Band 2 Visible (0.52 - 0.60 µm) 30 m.
    3. Band 3 Visible (0.63 - 0.69 µm) 30 m.
    4. Band 4 Near-Infrared (0.76 - 0.90 µm) 30 m.
    5. Band 5 Near-Infrared (1.55 - 1.75 µm) 30 m.
    6. Band 6 Thermal (10.40 - 12.50 µm) 120 m.
    7. Band 7 Mid-Infrared (2.08 - 2.35 µm) 30 m.
    8. Band 8 Panchromatic (PAN) (0.52 - 0.90 µm) 15 m.
- Ground Sampling Interval (pixel size): 30 m reflective, 120 m thermal.

Other Characteristics

- Scene size: 170 km x 185 km (106 mi x 115 mi).

2.4.7 Landsat-7

Figure 2. 19 Landsat-7 Satellite.

Participants

- NASA.
- National Oceanic and Atmospheric Administration (NOAA) (initial participant).
- Department of the Interior (DOI) U.S. Geological Survey (USGS).
- Spacecraft bus: Lockheed Martin Missiles & Space.
- Enhanced Thematic Mapper Plus (ETM+): Hughes Santa Barbara Remote Sensing.

Launch

- Date: April 15, 1999.
- Vehicle: Delta II.
- Launched by: NASA.
- Site: Western Test Range at Vandenberg Air Force Base, California.

Spacecraft

- Power provided by a single Sun-tracking solar array and two 50 Ampere-Hour (AHr), Nickel Cadmium (NiCd) batteries.

- Attitude control provided through four reaction wheels (pitch, yaw, roll, and skew); three 2-channel gyros with celestial drift updating; a static Earth sensor; a 1750 processor; and torque rods and magnetometers for momentum uploading.
- Orbit control and backup momentum unloading provided through a blow-down monopropellant hydrazine system with a single tank containing 270 pounds of hydrazine, associated plumbing, and twelve 1-pound-thrust jets.
- Weight: approx. 4,800 lbs (2,200 kg).
- Length: 4.3 m (14 ft).
- Diameter: 2.8 m (9 ft).

Communications

- Direct Downlink with Solid State Recorders (SSR).
- Data rate: 150 Mbps.

Orbit

- Worldwide Reference System-2 (WRS-2) path/row system.
- Sun-synchronous orbit at an altitude of 705 km (438 mi).
- 233 orbit cycle; covers the entire globe every 16 days (except for the highest polar latitudes).
- Inclined 98.2° (slightly retrograde).
- Circles the Earth every 98.9 minutes.
- Equatorial crossing time: 10:00 a.m. +/- 15 minutes.

Sensors

Enhanced Thematic Mapper Plus (ETM+)

- Eight spectral bands, including a pan and thermal band:
    1. Band 1 Visible (0.45 - 0.52 µm) 30 m.
    2. Band 2 Visible (0.52 - 0.60 µm) 30 m.
    3. Band 3 Visible (0.63 - 0.69 µm) 30 m.
    4. Band 4 Near-Infrared (0.77 - 0.90 µm) 30 m.
    5. Band 5 Near-Infrared (1.55 - 1.75 µm) 30 m.
    6. Band 6 Thermal (10.40 - 12.50 µm) 60 m Low Gain / High Gain.
    7. Band 7 Mid-Infrared (2.08 - 2.35 µm) 30 m.
    8. Band 8 Panchromatic (PAN) (0.52 - 0.90 µm) 15 m.
- Ground Sampling Interval (pixel size): 30 m reflective, 60 m thermal.
- Added the Band 6 Low and High gain 60 m thermal bands.

- On-board calibration was added to Landsat 7: a Full Aperture Solar Calibrator (FASC) and a Partial Aperture Solar Calibrator (PASC), in addition to the 2 calibration lamps.

Other Characteristics

- Scene size: 170 km x 185 km (106 mi x 115 mi).
- Design Life: Minimum of 5 years.

2.4.8 Landsat-8

Figure 2. 20 Landsat-8 Satellite.

Participants

- NASA.
- Department of the Interior (DOI) U.S. Geological Survey (USGS).
- Spacecraft bus: Orbital Science Corp.
- Operational Land Imager Sensor: Ball Aerospace & Technologies Corp.
- Thermal Infrared Sensors: NASA Goddard Space Flight Center.

Launch

- Date: February 11, 2013.
- Vehicle: Atlas-V rocket.
- Launched by: NASA.
- Site: Vandenberg Air Force Base, California.

Spacecraft

- 3.14 terabit solid-state data recorder.
- Power provided by a single 9 x 0.4 meter solar array and one 125 Ampere-Hour (AHr), Nickel-Hydrogen (NiH2) battery.
- Weight: 2,071 kg (4,566 lbs) fully loaded with fuel (without instruments)
- Length: 3 m (9.8 ft).
- Diameter: 2.4 m (7.9 ft).

Communications

- Direct Downlink with Solid State Recorders (SSR).
- Data rate: 384 Mbps on X-band frequency; 260.92 Mbps on S-band frequency.

Orbit

- Worldwide Reference System-2 (WRS-2) path/row system.
- Sun-synchronous orbit at an altitude of 705 km (438 mi).
- 233 orbit cycle; covers the entire globe every 16 days (except for the highest polar latitudes).
- Inclined 98.2° (slightly retrograde).
- Circles the Earth every 98.9 minutes.
- Equatorial crossing time: 10:00 a.m. +/- 15 minutes.

Sensors

Operational Land Imager (OLI)

- Nine spectral bands, including a pan band:
  1. Band 1 Visible (0.43 - 0.45 µm) 30 m.
  2. Band 2 Visible (0.450 - 0.51 µm) 30 m.
  3. Band 3 Visible (0.53 - 0.59 µm) 30 m.
  4. Band 4 Red (0.64 - 0.67 µm) 30 m.
  5. Band 5 Near-Infrared (0.85 - 0.88 µm) 30 m.
  6. Band 6 SWIR 1(1.57 - 1.65 µm) 30 m.
  7. Band 7 SWIR 2 (2.11 - 2.29 µm) 30 m.
  8. Band 8 Panchromatic (PAN) (0.50 - 0.68 µm) 15 m.
  9. Band 9 Cirrus (1.36 - 1.38 µm) 30 m.

Thermal Infrared Sensor (TIRS)

- Two spectral bands:
  1. Band 10 TIRS 1 (10.6 - 11.19 µm) 100 m.

2. Band 11 TIRS 2 (11.5 - 12.51 µm) 100 m.

Other Characteristics

- Scene size: 170 km x 185 km (106 mi x 115 mi).
- Design Life: Minimum of 5 years.

2.5 Sentinel Satellite Imagery

Sentinel is a multispectral operational imaging mission within the Global Monitoring for Environment and Security program, jointly implemented by the European Commission and European Space Agency for global land observation (data on vegetation, soil and water cover for land, inland waterways and coastal areas, and also provide atmospheric absorption and distortion data corrections) at high resolution with high revisit capability.

2.5.1 Sentinel-1

Figure 2. 21 Sentinel-1 Satellite.

Sentinel-1 is a two satellite constellation with the prime objectives of Land and Ocean monitoring. The goal of the mission is to provide C-Band SAR data continuity following the retirement of ERS-2 and the end of the Envisat mission.

To accomplish this satellites carry a C-SAR sensor, this offers medium and high resolution imaging in all-weather conditions. The C-SAR is capable of obtaining night imagery and detecting small movement on the ground, which makes it useful for land and sea.

Launch

- Sentinel-1A - 03 April 2014.
- Sentinel-1B - 25 April 2016.
- Operational lifespan: 7 years (With consumables for 12).

Mission Objectives

- Land monitoring of forests, water, soil and agriculture.
- Emergency mapping support in the event of natural disasters.
- Marine monitoring of the maritime environment.
- Sea ice observations and iceberg monitoring.
- Production of high resolution ice charts.
- Forecasting ice conditions at sea.
- Mapping oil spills.
- Sea vessel detection.
- Climate change monitoring.

Orbit

- Orbit Type: Sun-synchronous, near-polar, circular.
- Orbit Height: 693 km.
- Inclination: 98.18°.
- Repeat Cycle: 175 orbits in 12 days.

Payload

- C-SAR (C-band Synthetic Aperture Radar).

Resolution and Swath Width (Four modes)

- Strip Map Mode: 80 km Swath, 5 x 5 m spatial resolution.
- Interferometric Wide Swath: 250 km Swath, 5x20 m spatial resolution.
- Extra-Wide Swath Mode: 400 km Swath, 25 x 100 m spatial resolution.
- Wave-Mode: 20 km x 20 km, 5 x 20 m spatial resolution.

Configuration

- With the single C-SAR payload, the spacecraft carries a deployable solar array, and large data storage. The mission is expected to provide data quickly, in the event of disaster monitoring, and will utilize an X-band downlink to accomplish this. The dimensions of the craft are: 3.9 x 2.6 x 2.5 m with a weight (at time of launch) of 2300 KG.

2.5.2 Sentinel-2

Figure 2. 22 Sentinel-2 Satellite.

The Sentinel-2 mission is a land monitoring constellation of two satellites that provide high resolution optical imagery and provide continuity for the current SPOT and Landsat missions.

The mission provides a global coverage of the Earth's land surface every 10 days with one satellite and 5 days with 2 satellites, making the data of great use in on-going studies.

The satellites are equipped with the state-of-the-art MSI (Multispectral Imager) instrument that offers high-resolution optical imagery.

Launch

- Sentinel-2A - 23 June 2015.
- Sentinel-2B - 07 March 2017.

- Operational lifespan: 7.25 years (with consumables for 12).

Mission Objectives

- Land observation, including: Vegetation, soil and water cover, inland waterways and coastal areas.
- Land use and change detection maps.
- Providing support in generating land cover.
- Disaster relief support.
- Climate change monitoring.

Orbit

- Orbit Height: 786 km.
- Orbit Type: Sun-synchronous.
- Inclination: 98.5o.
- Repeat cycle: 10 days with one satellite and 5 days with 2 satellites.

Payload

- MSI (Multispectral Imager) Resolution and Swath Width: 290 km - 10 m, 20 m and 60 m spatial resolution.

Configuration

- The spacecraft is equipped with a deployable solar array and the dimensions of the craft are: 3.4 m x 1.8 m x 2.35 m with a weight (at time of launch) of 1100 kg.

CHAPTER THREE

METHODOLOGY

3.1 Data Collection

3.2 Image Stacking

3.3 Image Clipping

3.4 Image Classification

3.5 Raster to Vector

3.6 Confusion Matrix

3.1 Data Collection

The first step of the project is to obtain the multispectral images for the study area, open source data will be used from both Landsat and Sentinel, and the following sections will describe the process of obtaining the images.

3.1.1 Landsat Imagery Collection

Landsat images are obtained from the United States Geological Survey website, as shown in the steps below:

- Opening the earth explorer website (https://earthexplorer.usgs.gov/).
- A registration is required, if already registered then login, if not, click on register and follow the steps of identity confirmation.

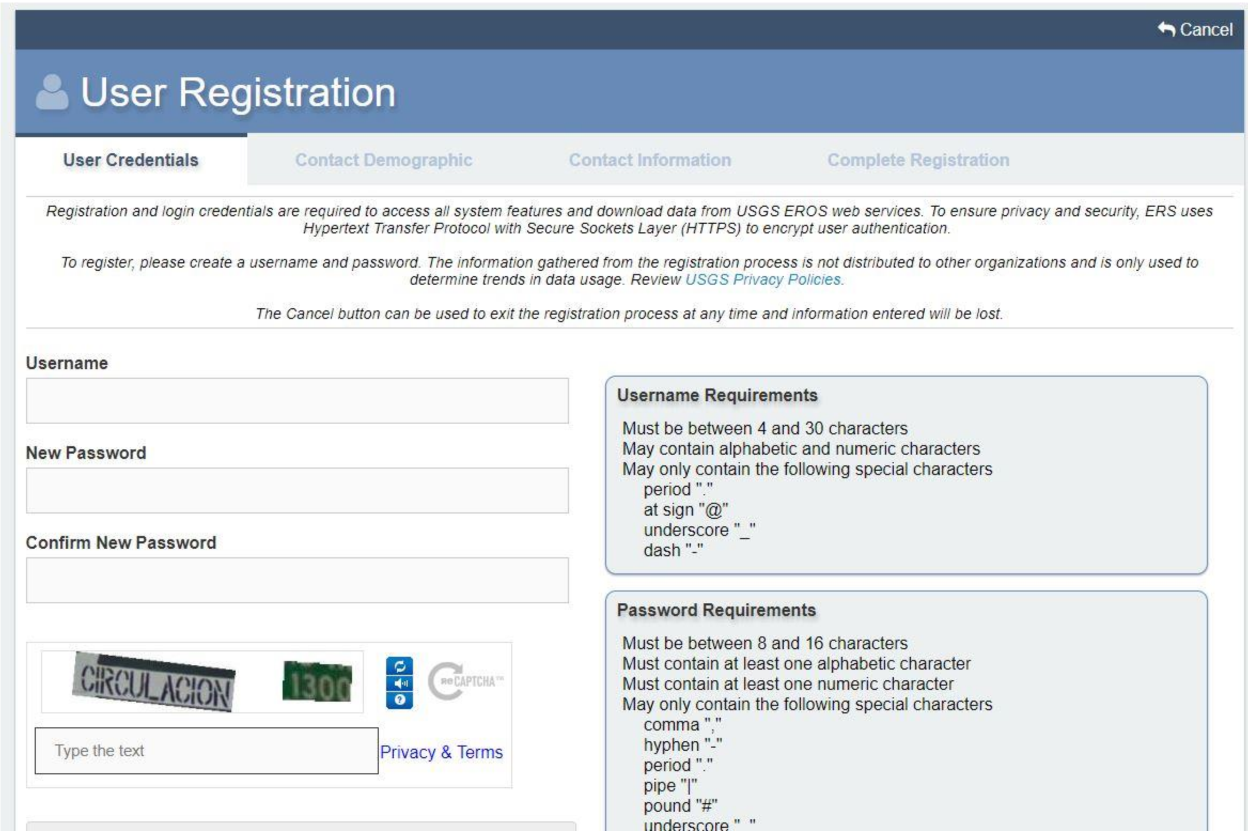


Figure 3. 1 User Registration for Earth Explorer.

- After signing in, go to the search criteria and type the path/raw or name of the location.

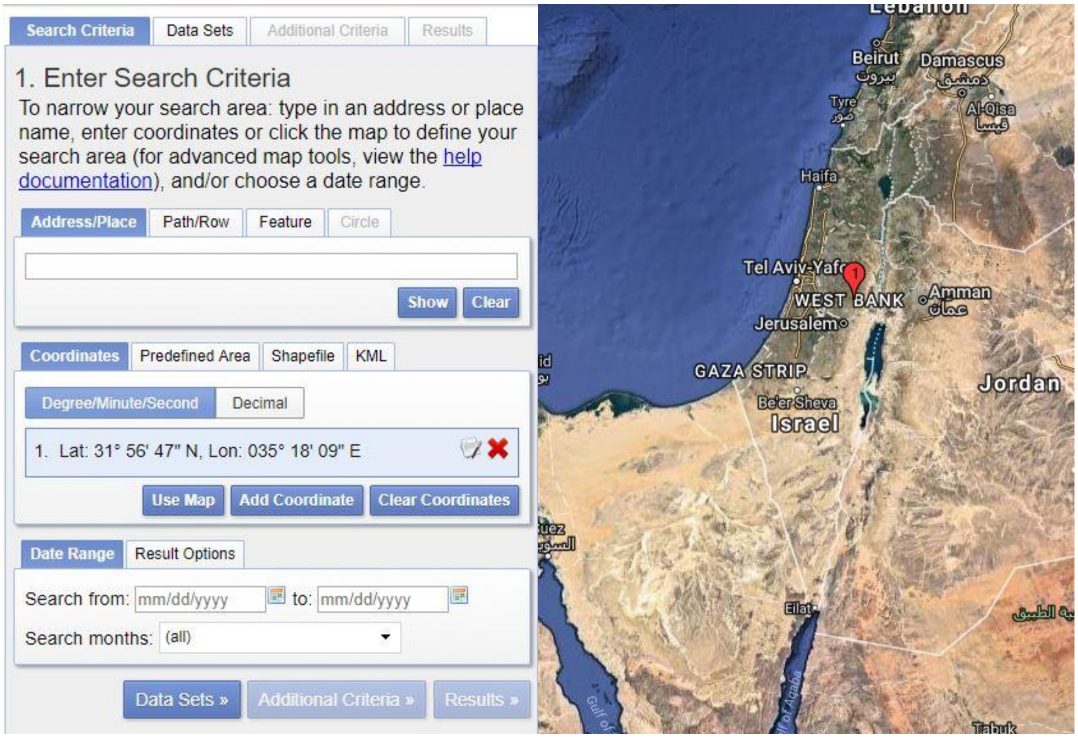


Figure 3. 2 Finding the study area.

- Then specify the Data sets you need to use, in this projects case (Landsat).

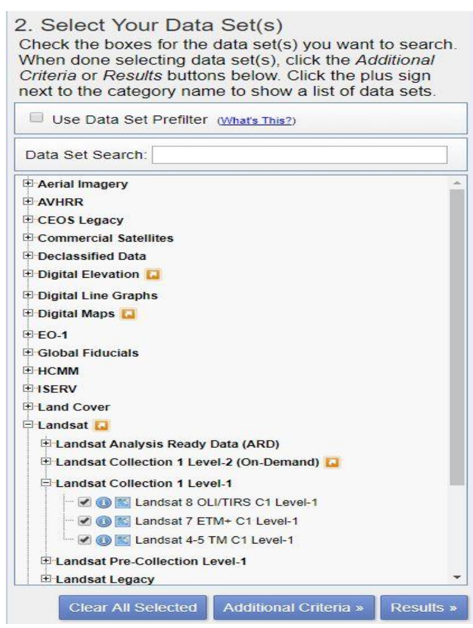


Figure 3. 3 Specifying the data sets.

- Then specify the additional criteria, such as the cloud coverage and Day/Night indicator.

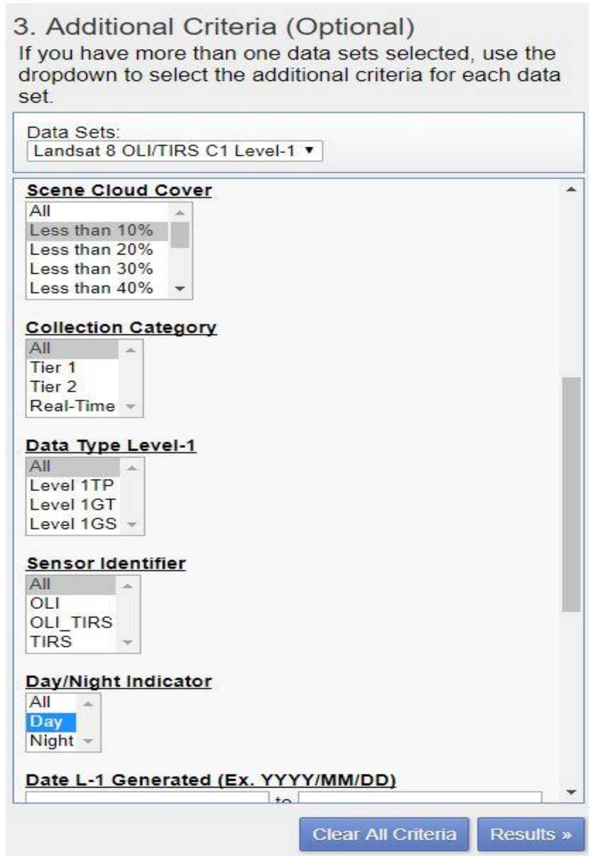


Figure 3. 4 Specifying the additional criteria.

- Choosing the image to be downloaded according to the date acquired and the image characteristics.

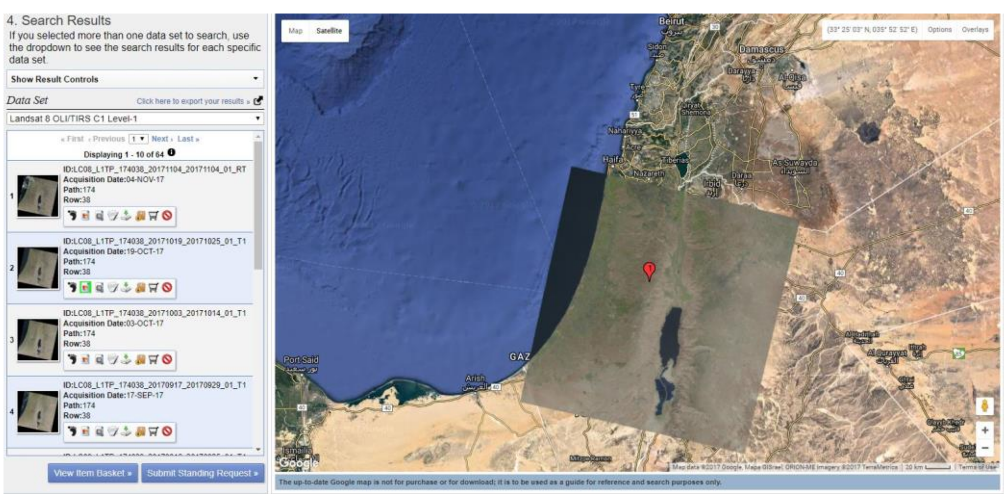


Figure 3. 5 The search result.

- Choosing the download option, in this projects case (Level-1 GeoTIFF Data Product).

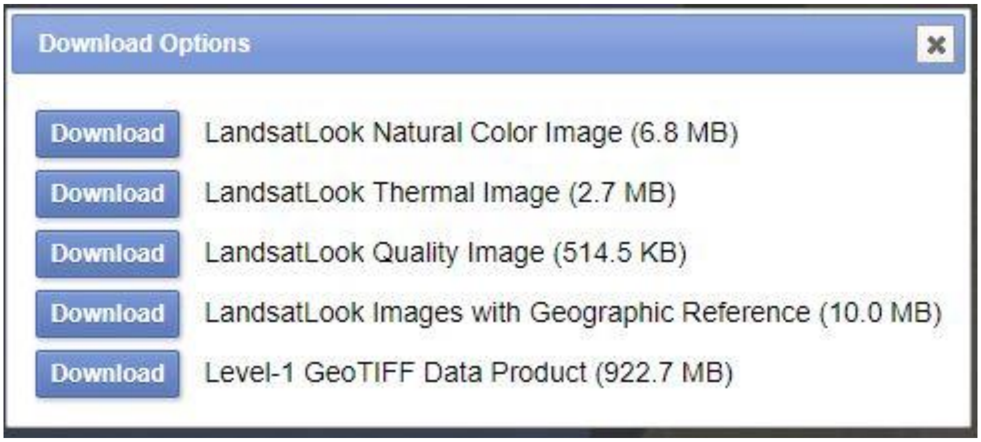


Figure 3. 6 Earth Explorer download options.

- The image downloaded consists from several separated bands (Red, Green, Blue, Near-IR…etc.).

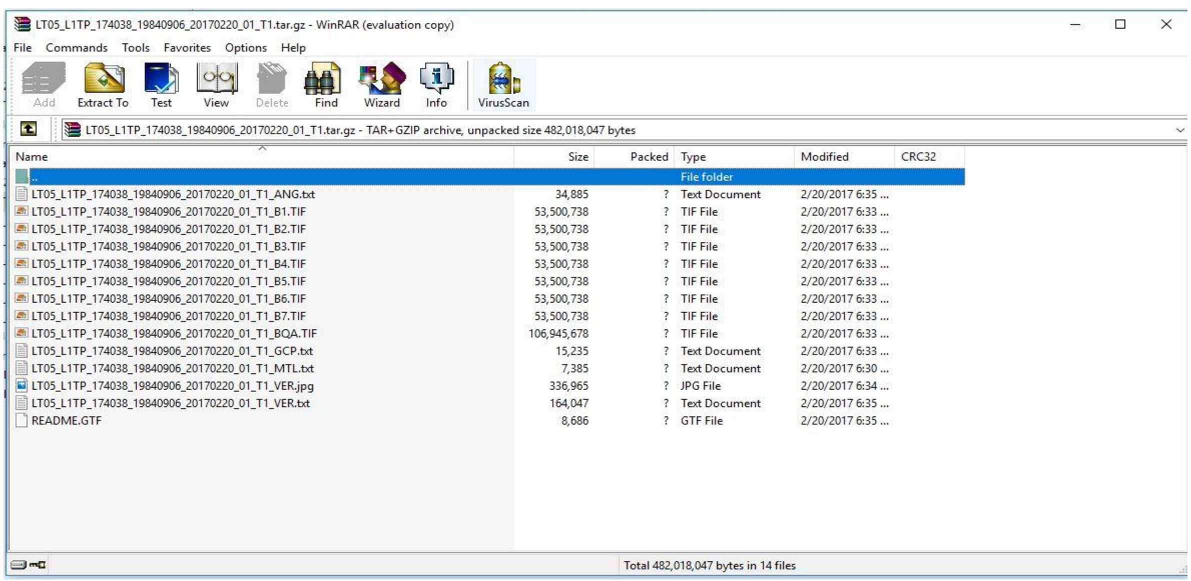


Figure 3. 7 Image archive content.

3.1.2 Sentinel Image Collection

Sentinel images are obtained from the European Space Agency, from the Copernicus Open Access Hub website, as shown in the steps below:

- Opening the earth explorer website (https://scihub.copernicus.eu/dhus/).

- A registration is required, if already registered then login, if not, click on sign up and follow the steps of identity confirmation.

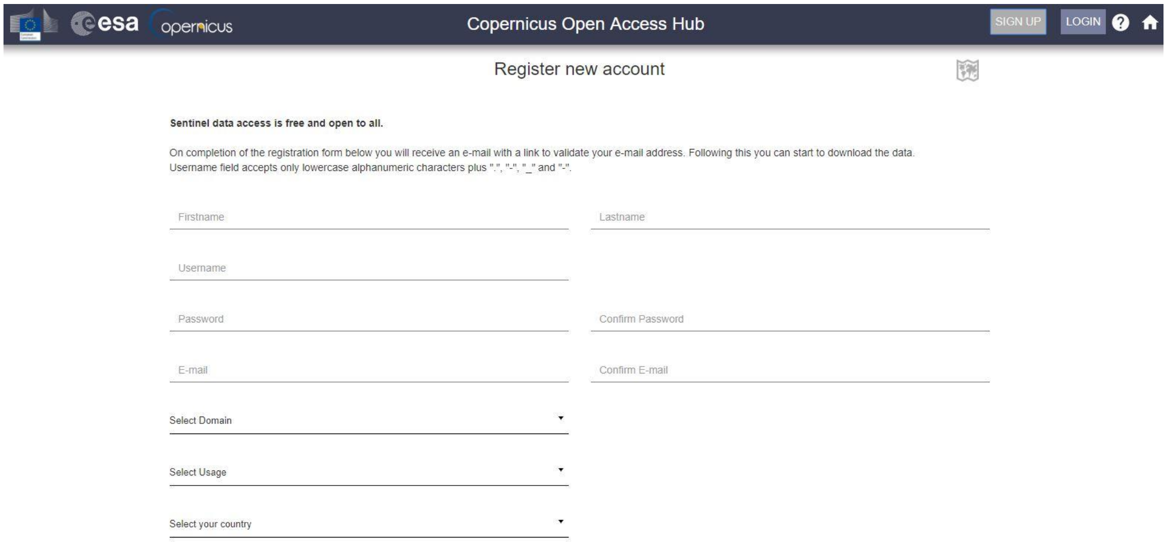


Figure 3. 8 User registration for Copernicus Open Access Hub.

- After signing in, draw a box on the study area.

Figure 3. 9 Specifying the study area on the website.

- After drawing the box, specify the search criteria, the data sets to be used and date of image.

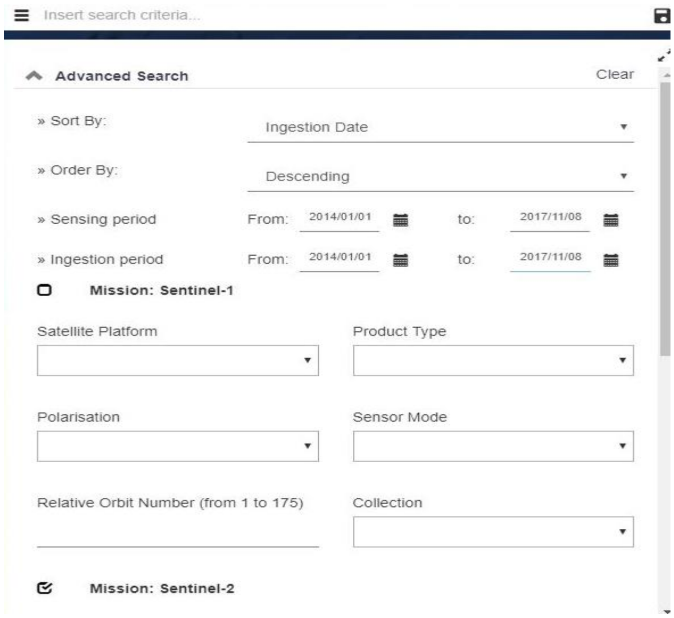


Figure 3. 10 Specifying the search criteria and data sets.

- Choosing the image to be downloaded according to the date acquired and the image characteristics.

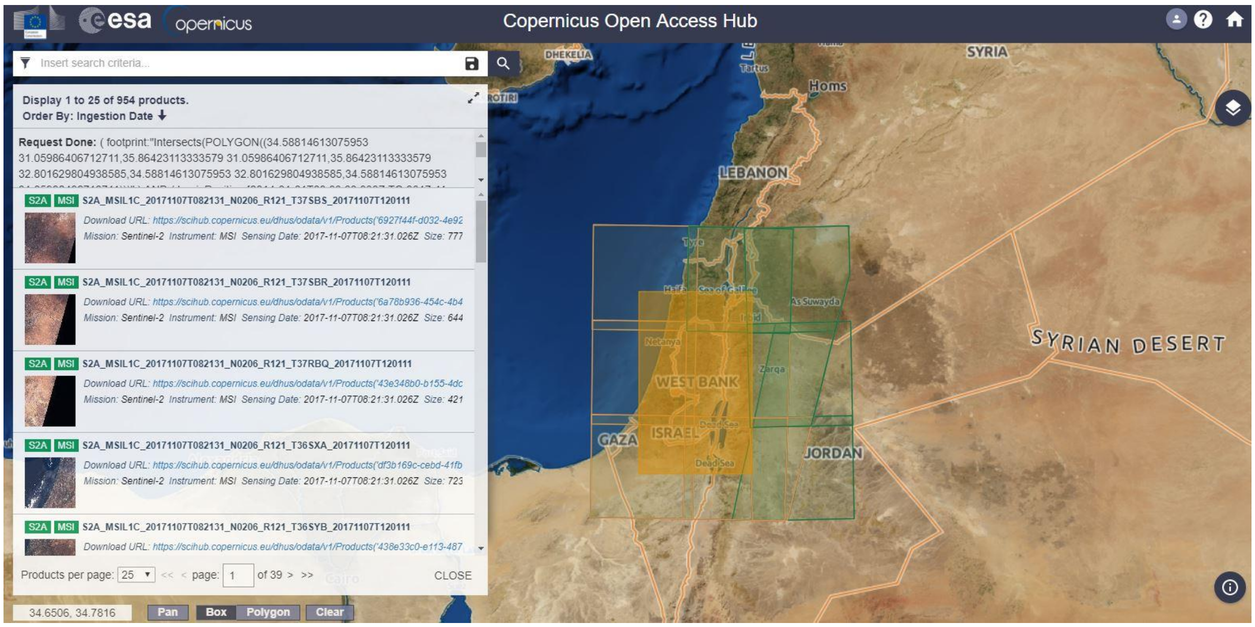


Figure 3. 11 The search result.

- Click on the download button as below.

Figure 3. 12 Downloading the selected image.

- The image downloaded consists from several separated bands (Red, Green, Blue, Near-IR…etc.).

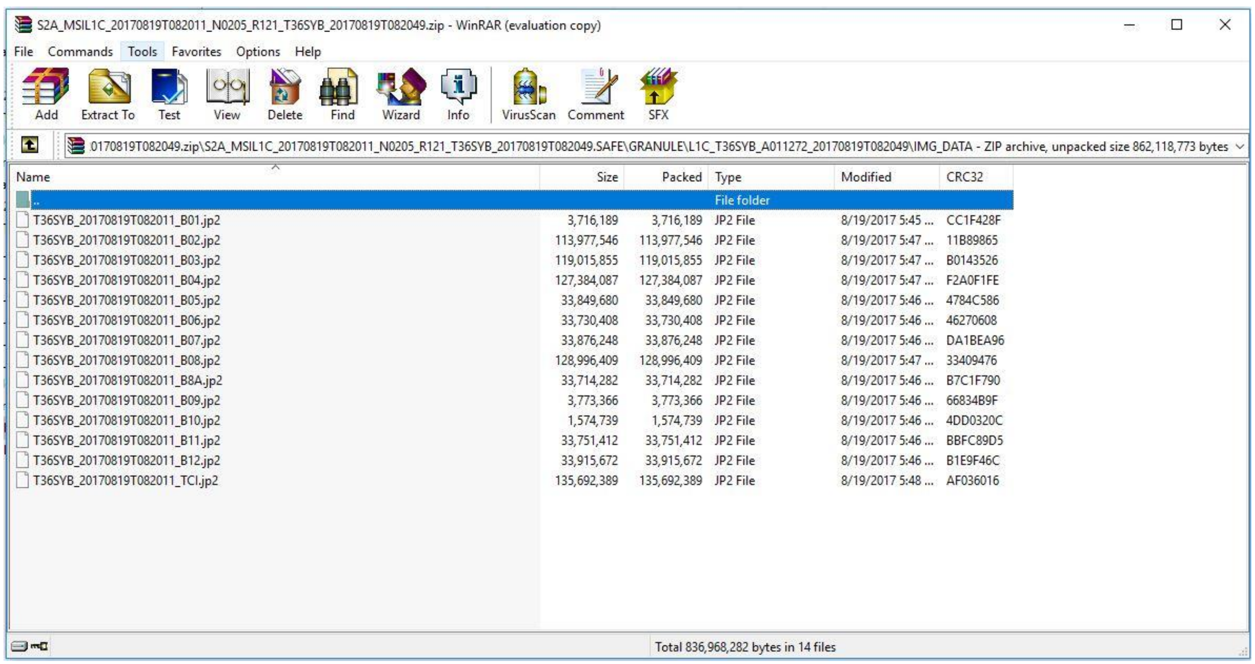


Figure 3. 13 Image archive content.

3.2 Image Stacking

The images downloaded from the open sources mentioned before consists of an archive of separated bands. In order to make a multi-band file the process of image stacking should be used, as shown in the steps below:

- Open the Envi software and insert the image bands to be used in the classification.

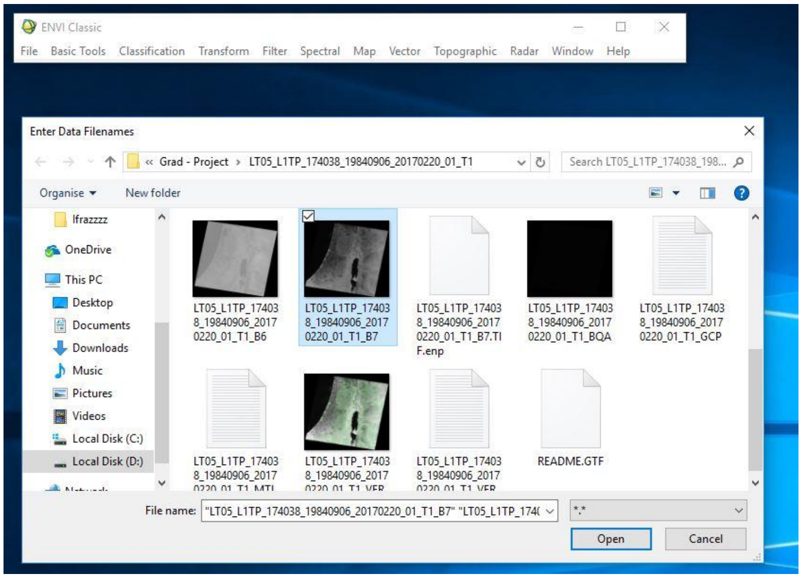


Figure 3. 14 Inseting image bands.

- From Basic Tools panel, click on the “Layer Stacking” option.

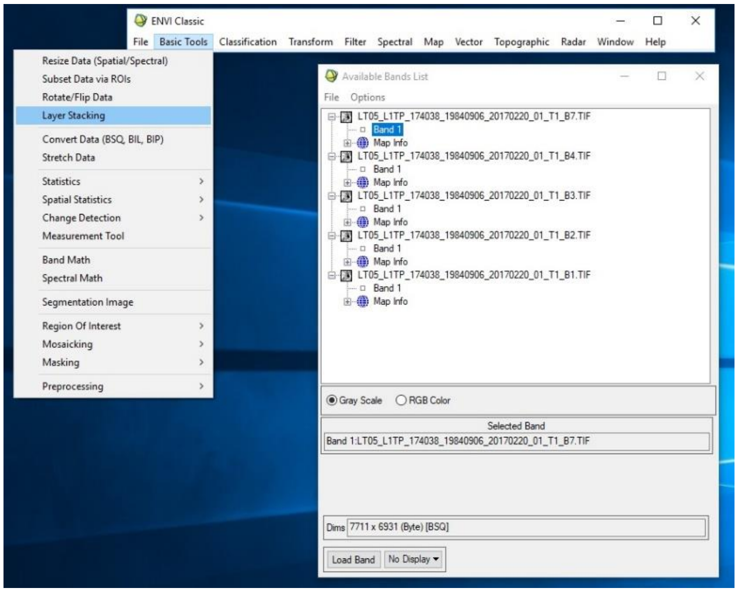


Figure 3. 15 Layer Stacking.

- Select the bands to be stacked.

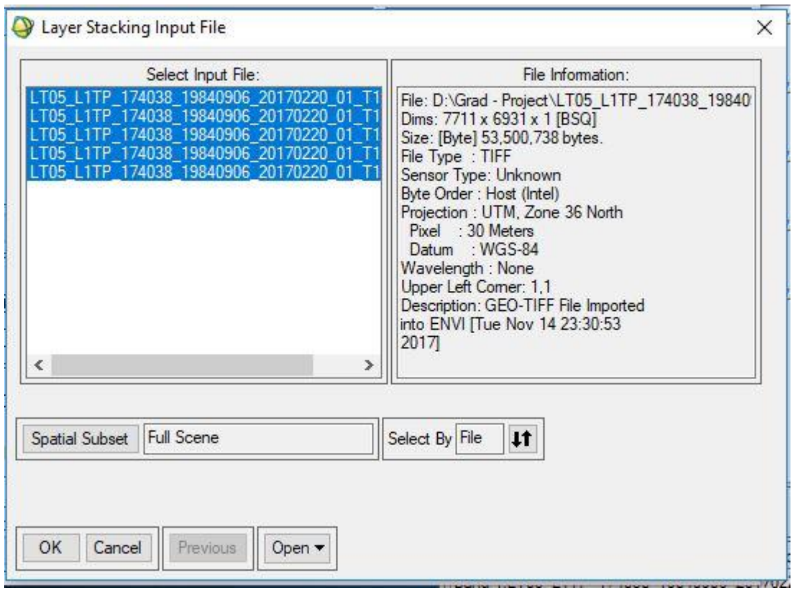


Figure 3. 16 Bands selection.

- Specify the stack parameters, projection and the output file name and location.

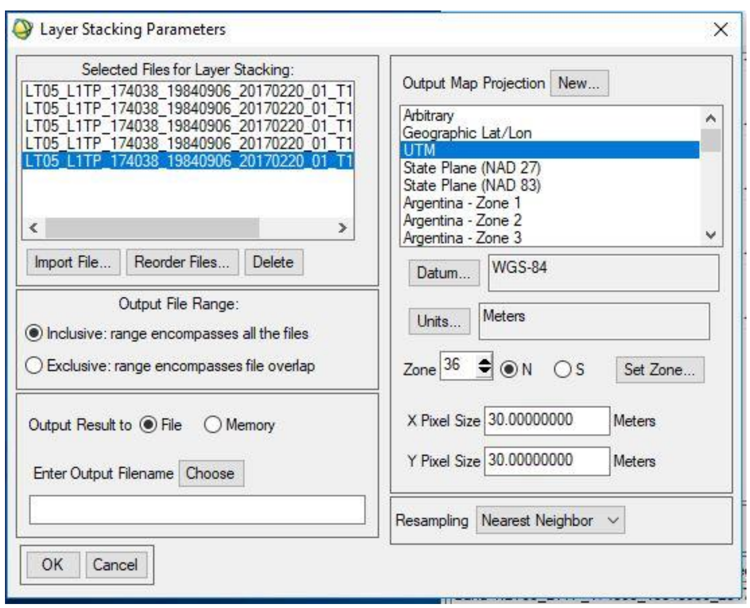


Figure 3. 17 Layer Stacking parameters.

- All selected bands now are gathered into one stack/file.

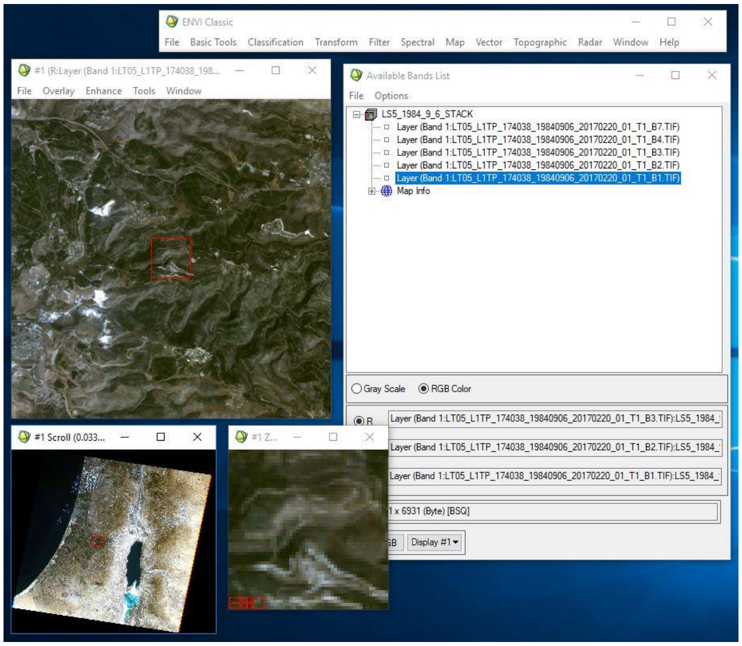


Figure 3. 18 Stacked bands.

3.3 Image Clipping

In order to use a specified study area of the image downloaded, a clipping of the image should be done, as shown in steps below:

- Run the "Envi Classic" software and open the image.

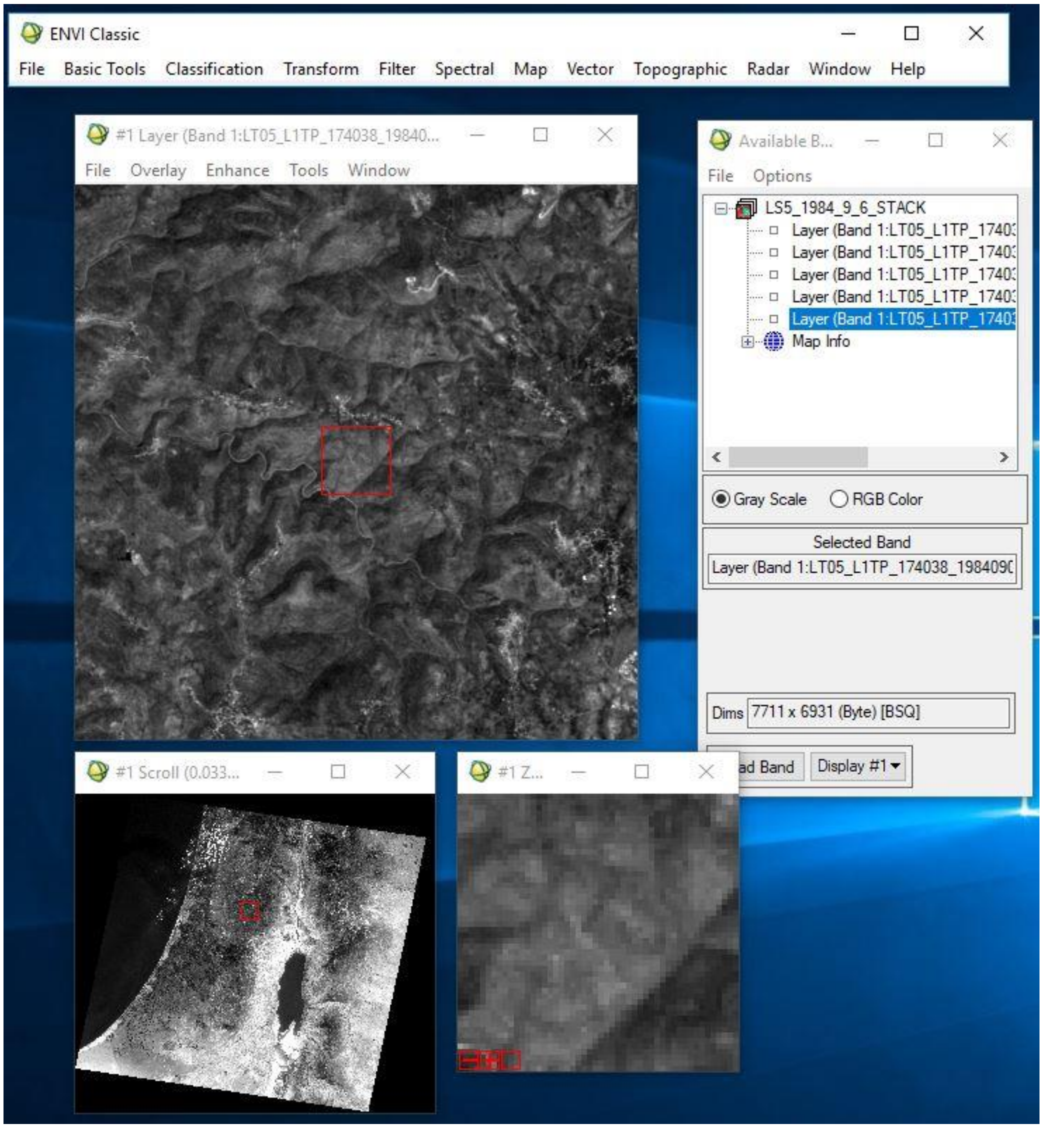


Figure 3. 19 Image to be clipped.

- Open a boundary shape file to use for clipping tool.

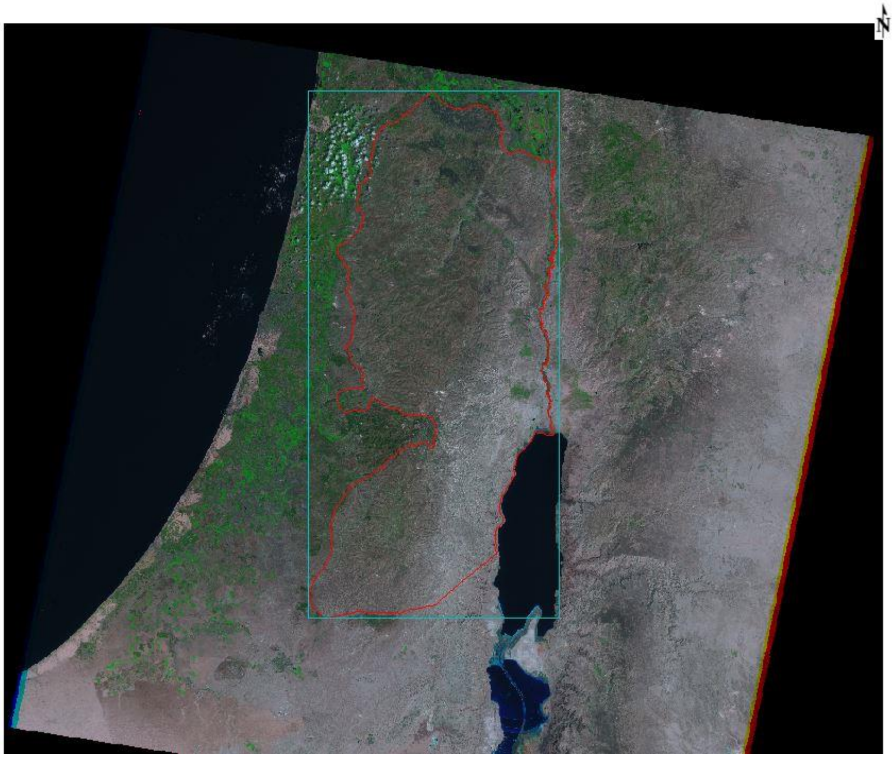


Figure 3. 20 Shapefile of study area.

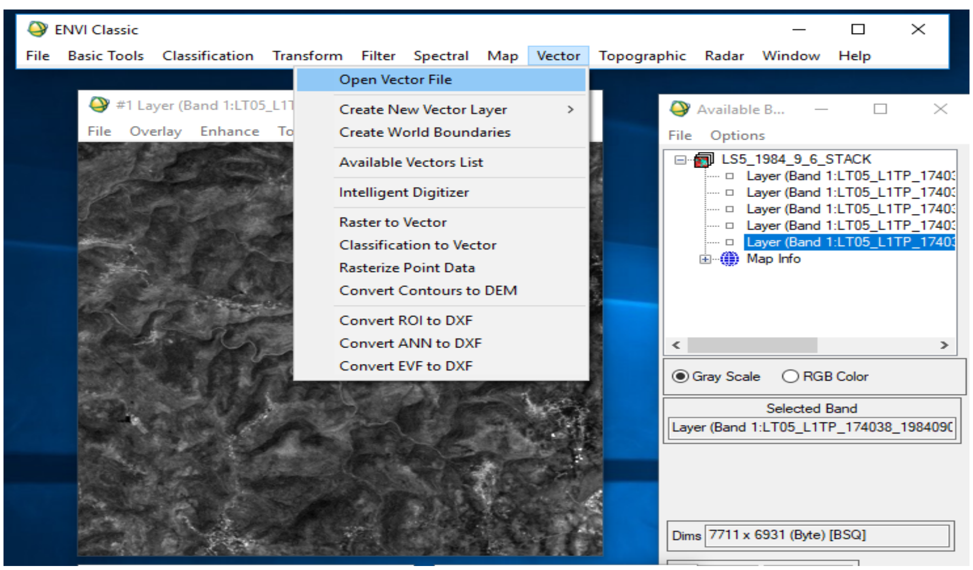


Figure 3. 21 Opening the shapefile in ENVI program.

- Identify the vector parameters (datum, units…etc.).

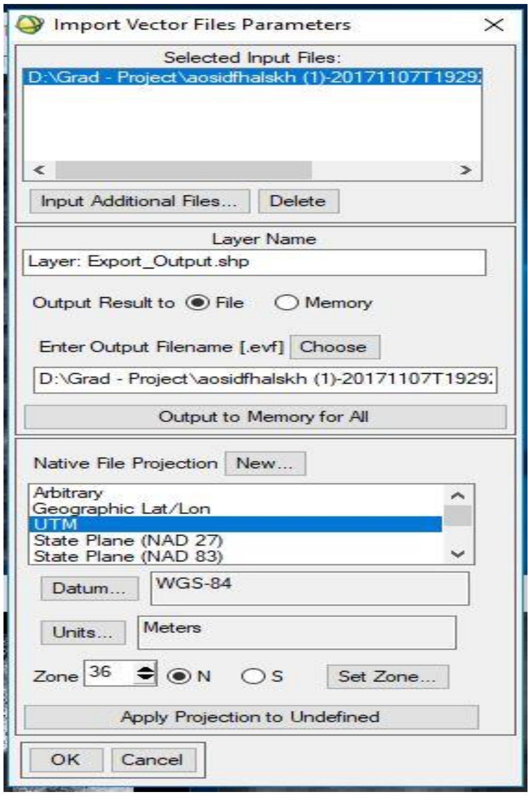


Figure 3. 22 Import vector parameters.

- Apply the mask input file and choose the masked band.

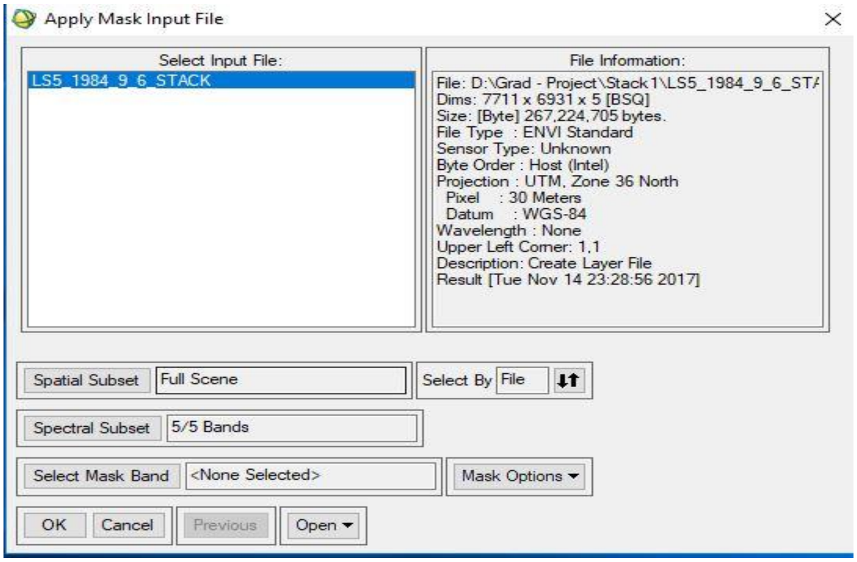


Figure 3. 23 Apply mask file.

- Define the mask file and mask definition input EVF.

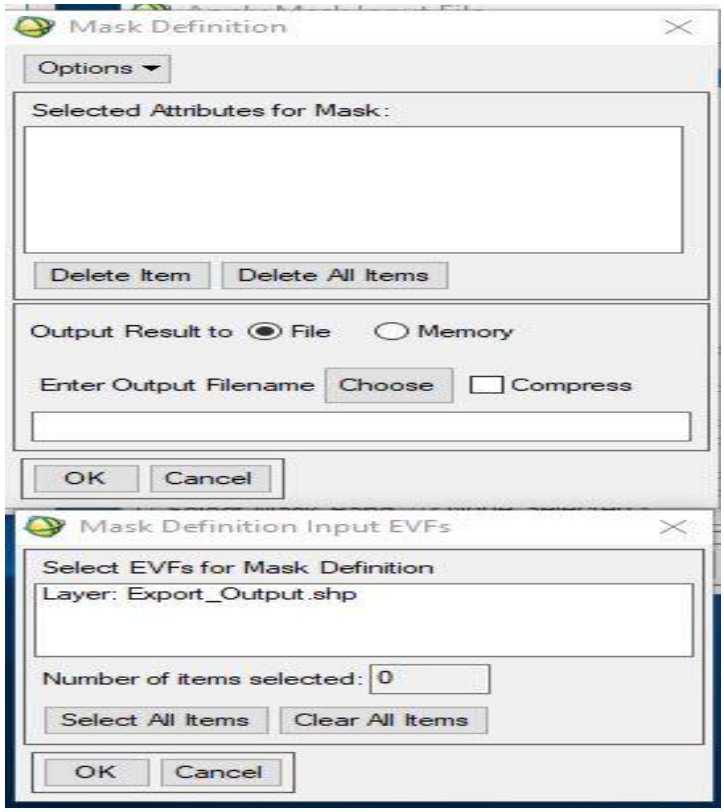


Figure 3. 24 Mask Definition.

- Select the stacked image that associated with the mask file (EVF file).

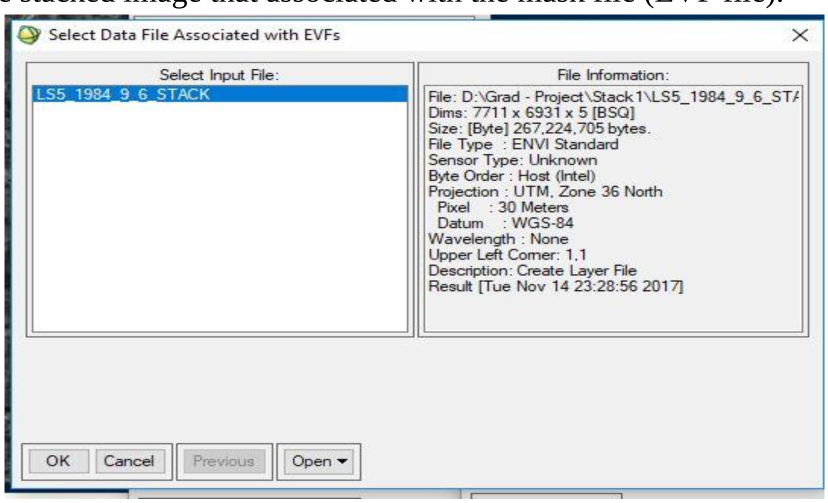


Figure 3. 25 Select data file associated with EVFs.

- The stack is now clipped as required according to the study area.

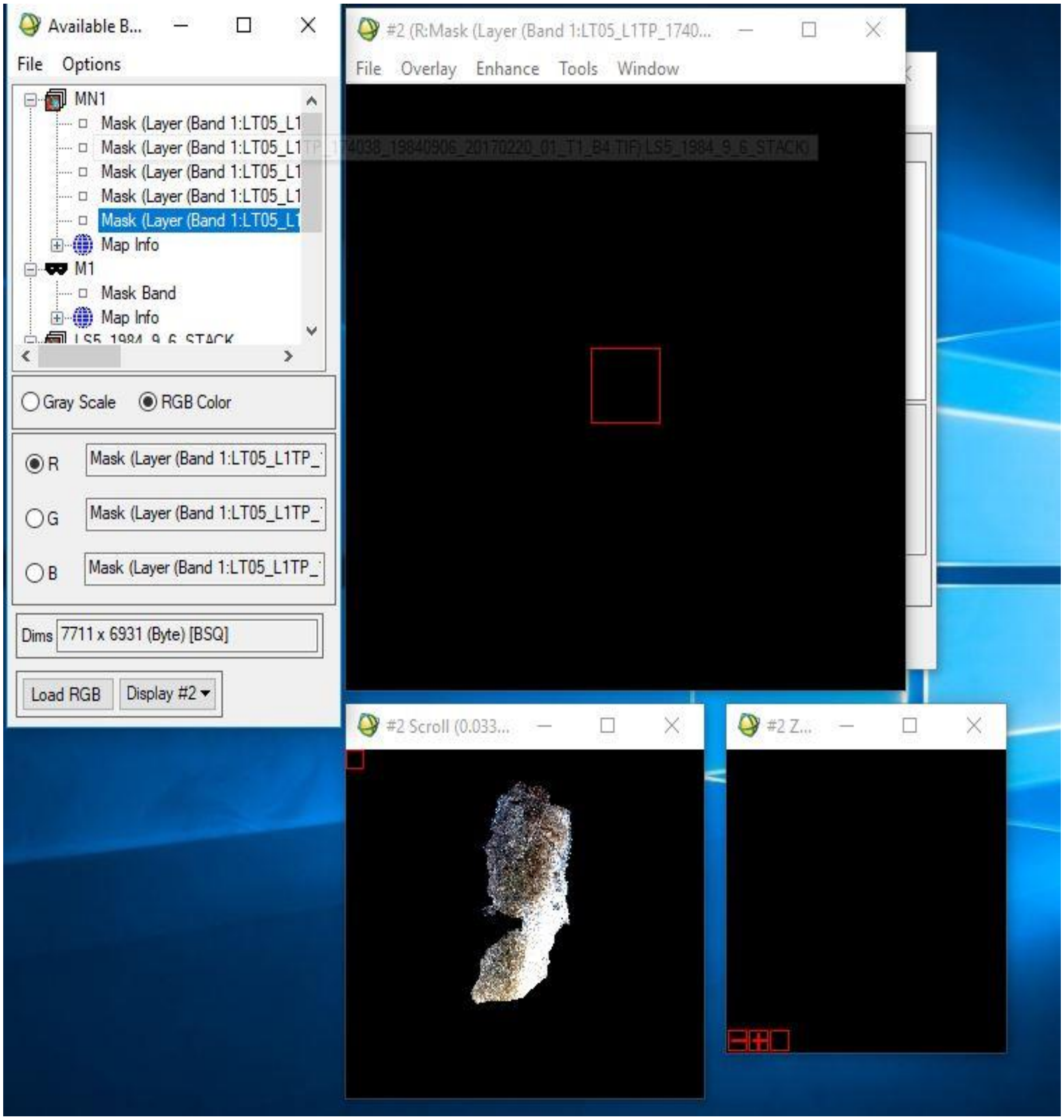


Figure 3. 26 The final result of clipping process.

3.4 Image Classification

To classify each pattern in the image supervised classification will be used. With supervised classification, the analyst develops the spectral responses of known categories, such as urban, forest, water (training site development) and then the software assigns each pixel in the image to the cover type to which its spectral response is most similar.

In this projects case CORINE level 1 classification will be used in the training/check parcels.

Level 1	Level 2	Level 3
1 Artificial surfaces	11 Urban fabric	111 Continuous urban fabric
		112 Discontinuous urban fabric
	12 Industrial, commercial and transport units	121 Industrial or commercial units
		122 Road and rail networks and associated land
		123 Port areas
		124 Airports
	13 Mine, dump and construction sites	131 Mineral extraction sites
		132 Dump sites
		133 Construction sites
	14 Artificial, non-agricultural vegetated areas	141 Green urban areas
		142 Sport and leisure facilities
2 Agricultural areas	21 Arable land	211 Non-irrigated arable land
		212 Permanently irrigated land
		213 Rice fields
	22 Permanent crops	221 Vineyards
		222 Fruit trees and berry plantations
		223 Olive groves
	23 Pastures	231 Pastures
	24 Heterogeneous agricultural areas	241 Annual crops associated with permanent crops
		242 Complex cultivation patterns
		243 Land principally occupied by agriculture, with significant areas of natural vegetation
		244 Agro-forestry areas
3 Forest and semi natural areas	31 Forests	311 Broad-leaved forest
		312 Coniferous forest
		313 Mixed forest
	32 Scrub and/or herbaceous vegetation associations	321 Natural grasslands
		322 Moors and heathland
		323 Sclerophyllous vegetation
		324 Transitional woodland-shrub
	33 Open spaces with little or no vegetation	331 Beaches, dunes, sands
		332 Bare rocks
		333 Sparsely vegetated areas
		334 Burnt areas
		335 Glaciers and perpetual snow
4 Wetlands	41 Inland wetlands	411 Inland marshes
		412 Peat bogs
	42 Maritime wetlands	421 Salt marshes
		422 Salines
		423 Intertidal flats
5 Water bodies	51 Inland waters	511 Water courses
		512 Water bodies
	52 Marine waters	521 Coastal lagoons
		522 Estuaries
		523 Sea and ocean

Figure 3. 27 CORINE Land Cover (CLC) nomenclature

(Source: http://www.igeo.pt/gdr/pdf/CLC2006_nomenclature_addendum.pdf).

- First of all a region of interest should be done. Using ENVI software from the "Basic Tools" panel go to "Region of Interest" then click on "ROI Tool".

*Regions of Interest (ROIs) are selected samples of a raster, such as areas of water, that are identified for a particular purpose

- Then, new window appears, choose the region name, click "New Region" to add new classes for the classification, and start drawing the training parcels.

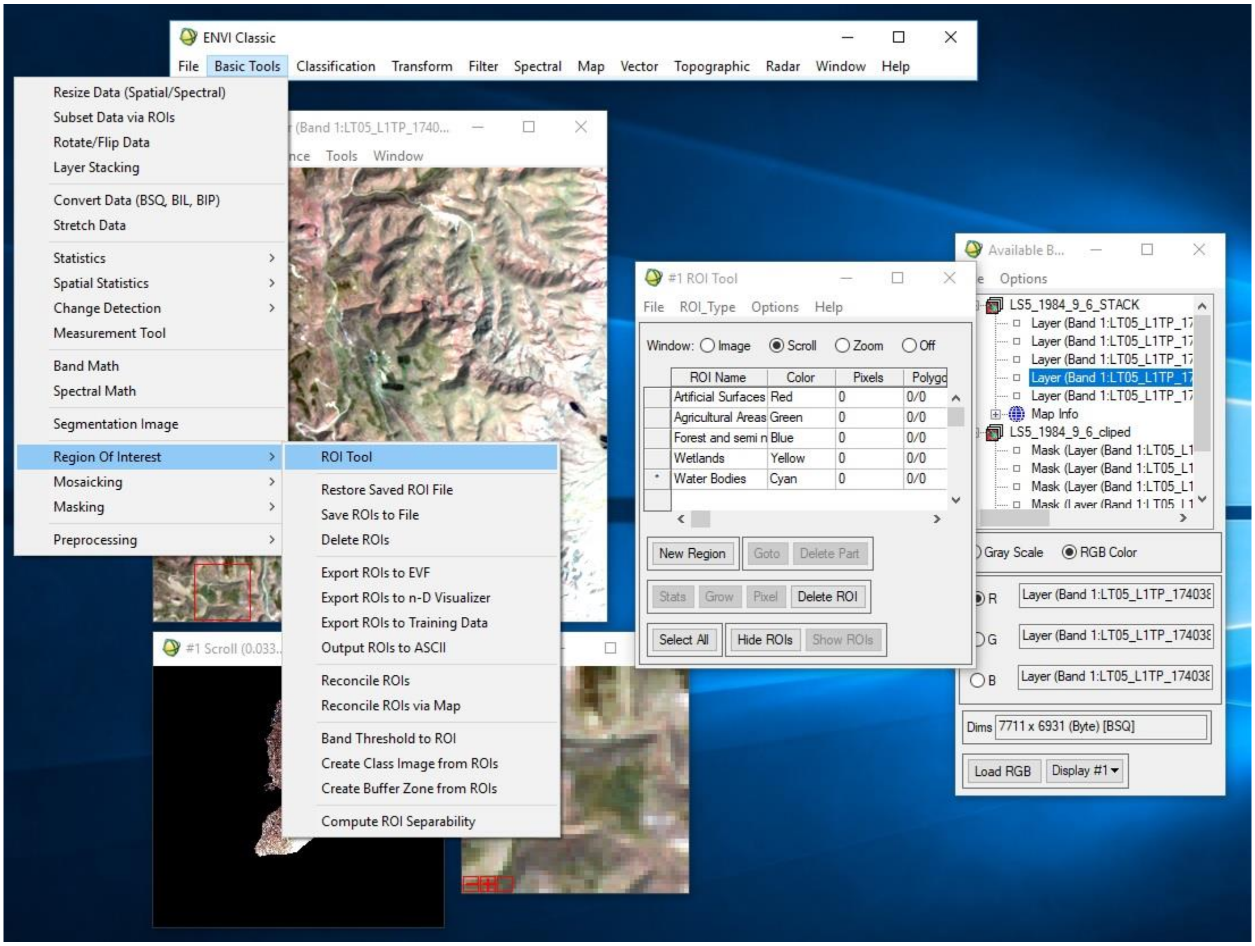


Figure 3. 28 Region of Interest.

- After making drawing the reference polygons in the region of interest, from the "Classification" panel, go to "Supervised" then "Maximum Likelihood".

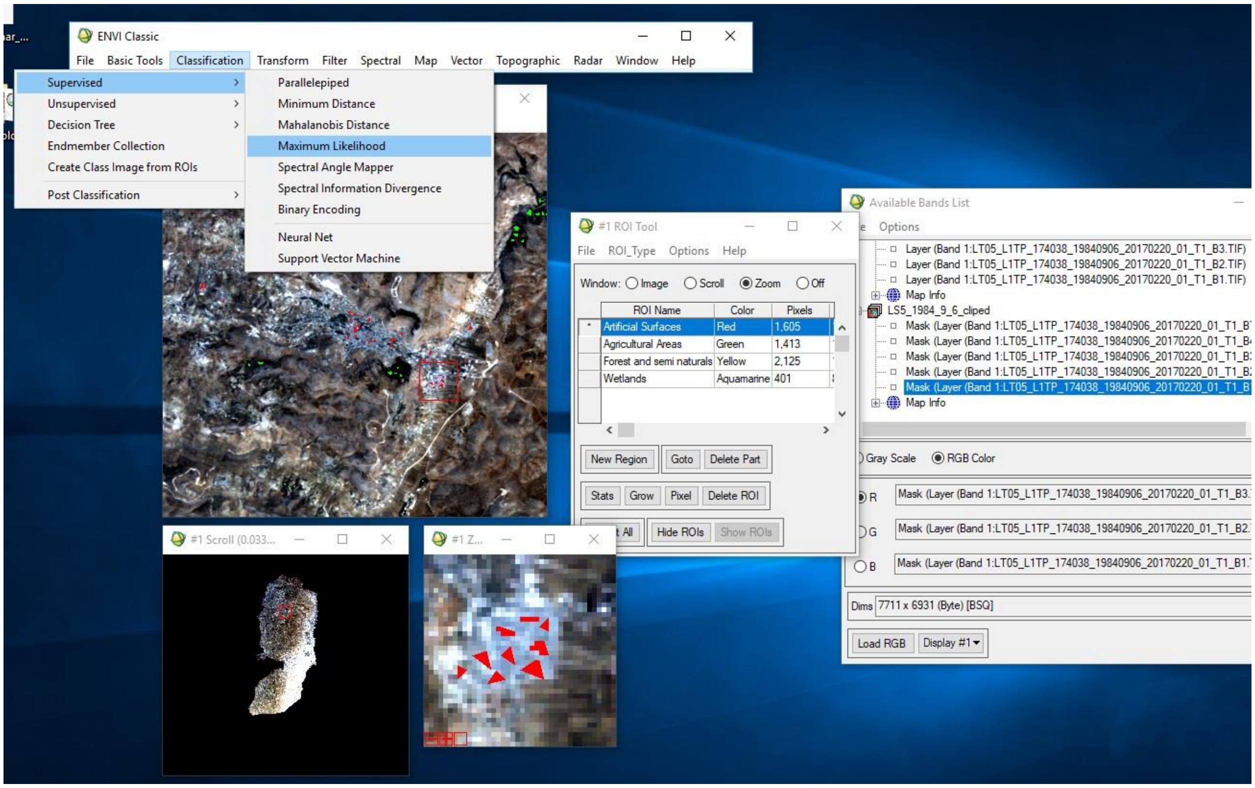


Figure 3. 29 Classification Process.

- Choose the classes required for the classification and the output file location.

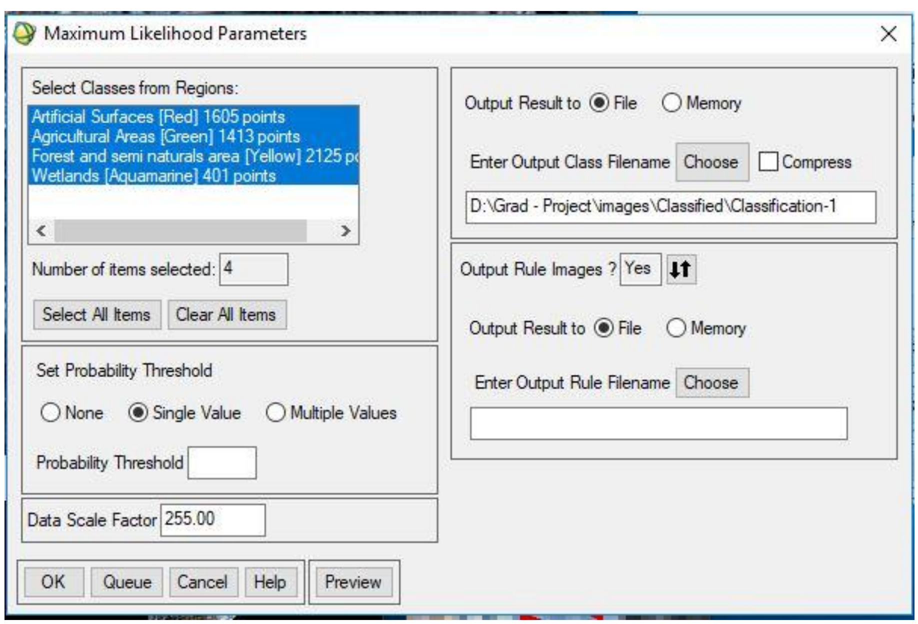


Figure 3. 30 Maximum Likelihood Parameters.

3.5 Raster to Vector

In order to make the analysis and calculations on the image using ArcMap software, the data provided from ENVI has to be converted from Raster to Vector.

- Once the classification is done, convert the classification from raster to vector; by going to the panel "Vector", then click on "Raster to Vector".

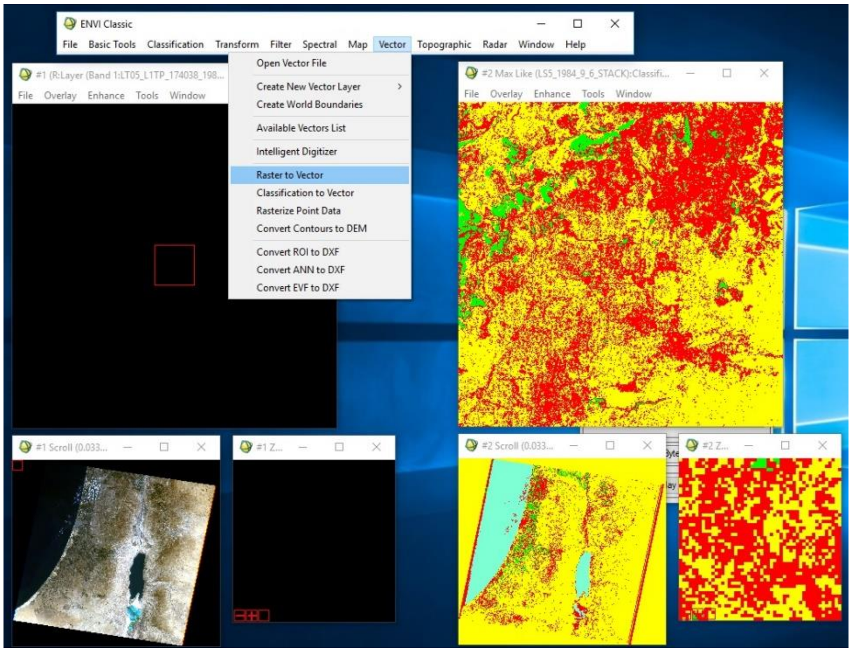


Figure 3. 31 Raster to Vector.

3.6 Confusion Matrix

The most common tool used for the classification accuracy assessment is the confusion matrix (or error matrix). A confusion matrix is a square array of dimension (P*P), where p is the number of classes. The matrix shows the relationship between two samples of measurements taken from the area that has been classified. The first set represents training parcels or check parcels (both together reference parcels) that have been collected via field observation, inspection of agricultural records, air photo interpretation, or other similar means. The second sample composed of labels of the pixels, allocated by the classifier, that correspond to the training or checking parcels point.

The essence of the assessment the classification depend on the parameters derived from the confusion matrix, the derivation of the confusion matrix is an easy process using ENVI software, but the derived confusion matrix from ENVI is a text file, where most of its parameters aren't understandable. To provide a better understanding of the confusion matrix, a reformation had been developed, in order to transform the text file into an excel template designed with colors, labels and comments that is more convenient and easy to understand.

The final form of the confusion matrix shows some useful information added on the matrix, like the name of the classification, image used to run the classification, minimum area of each class and the version of the ROIs used because it is important to keep track to the classification parameters.

Classification name : West Bank & DeadSea 1998

Input image stack	:	LT05_1998_Classified-05
Number of features B	:	5 (B1+B2+B3+B4+B7)
Minimum area of each class	:	5x 30 = 150
Training parcels	:	roi-03.roi
Mask	:	

General statistics						
Overall accuracy	=	102363	/	110413	=	92.71%
Mean accuracy	=				=	76.70%
Kappa coefficient	=	0.871556				

Figure 3. 32 Useful information added to the confusion matrix.

Confusion matrix parameters

There reference parcels have to be divided upon certain criteria into training and check parcels, as a result a confusion matrix for training and another for check have to be derived. Those are the definitions of each term used in the equations.

Table 5 Definitions for the terms used in the equations.

Cij	Number of pixels of training parcel i that have been classified as j in the output image.
Cii	Number of pixels of well classified pixels (diagonal value in the pixel matrix).
Ci.	Total number of pixels in the class i training parcels in input.
C.j	Total number of pixels classified as class j in the output image.
n	Total number of pixels in all the training parcels in input.
p	Total number of classes.
Ci./n	Percentage of class i over all training parcels

Where,

$(Ci. = \sum_{j=1}^{c} Cij \quad)$ Eqn. (1).

$(C.j = \sum_{i=1}^{c} Cij \quad)$ Eqn. (2).

$(n = \sum_{i=1}^{p} . \sum_{j=1}^{p} Cij \ )$ Eqn. (3).

Reference or ground truth classes i (pixels)

The Confusion matrix is calculated by comparing the location and class of each training parcel pixel with the corresponding location and class in the classification image. Each column of the confusion matrix represents a training parcel class and the values in the column correspond to the classification image's labelling of the training parcels pixels.

Reference or ground truth classes i (percent)

The reference or ground truth classes i (percent) table shows the distribution in percent for each training parcel class. The values are calculated by dividing the pixel counts in each training parcel column by the total number of pixels in a given training parcel class.

Minimum area of each class

As a rule of thumb that the number of training parcels to derive a valid confusion matrix should be at least 30 times the number of features (number of spectral bands).

Overall Accuracy

The overall accuracy is calculated by summing the number of pixels classified correctly and dividing by the total number of pixels. The pixels classified correctly are found along the diagonal of the confusion matrix table which lists the number of pixels that were classified into the correct training parcel class. The total number of pixels is the sum of all the pixels in all the training parcel classes.

$$\left(Ao = \frac{\sum_{i=1}^{c} Cii}{Pc} \right) \quad \text{Eqn. (4).}$$

Kappa Coefficient

The kappa coefficient K ˆ takes not just the principal diagonal entries but also the off-diagonal entries into consideration. The higher the value of kappa, the better the classification performance. If all information classes are correctly identified, kappa takes the value 1. As the values of off-diagonal entries increase, the value of kappa decreases.

It is calculated by dividing the total sum of the confusion matrix diagonals on total number of pixels in all the training parcels in input (n), subtracting from the sum of total number of pixels in the class i training parcels in input multiply by total number of pixels classified as class j in the output image, and dividing by the total number of pixels in all the training parcels squared. The previous terms divided on one subtracting from the sum of total number of pixels in the class i training parcels in input multiply by total number of pixels classified as class j in the output image, and dividing by the total number of pixels in all the training parcels squared.

$$\left(K = \frac{\sum_{\iota=1}^{c} C\iota\iota/\widehat{pc - \sum_{\iota=\jmath=1}^{C}} C\iota.*C.\jmath/pc^2}{1-\sum_{\iota=\jmath=1}^{c} C\iota.*C.\jmath/pc^2} \right) \quad \text{Eqn. (5).}$$

Mean accuracy

The summation of all calculated producer accuracies values (proportion of pixels in the training parcel set that are correctly recognized by the classifier) for all training parcels divided by the total numbers of training parcels.

$$(\mathrm{A}m = \frac{\sum_{i=1}^{c} \frac{Cii}{Ci.}}{c}) \qquad \text{Eqn. (6).}$$

Commission

Errors of commission represent pixels that belong to another training parcel that are labelled as belonging to the training parcel of interest. The errors of commission are shown in the rows of the confusion matrix. It is calculated for each training parcel by subtracting the number of pixels classified as class j in the output image for the class from Number of pixels of well classified pixels (diagonal value in the pixel matrix) for the same class divided by total number of pixels classified as class j in the output image for the same class.

$$(Ci = \frac{C.j - Cii}{C.j}) \qquad \text{Eqn. (7).}$$

Omission

Errors of omission represent pixels that belong to the training parcel class but the classification technique has failed to classify them into the proper class. The errors of omission are shown in the columns of the confusion matrix. It is calculated for each class by subtracting number of pixels in the class i training parcels in input for the class from the number of pixels of well classified pixels (diagonal value in the pixel matrix) for the same class divided by the total number of pixels in the class i training parcels in input for the same class.

$$(\mathrm{Oi} = \frac{Ci. - Cii}{Ci.}) \qquad \text{Eqn. (8).}$$

Producer accuracy

The proportions of pixels in training parcel set that are correctly recognized by the classifier. This calculated by dividing Number of pixels of well classified pixels (diagonal value in the pixel matrix) on the total number of pixels in the class i training parcels in input.

$$(Ai = \frac{Cii}{Ci.}) \qquad \text{Eqn. (9).}$$

User accuracy

Measures the proportion of pixels identified by the classifier as belonging to class i that agree with the training parcel. This calculated by dividing Number of pixels of well classified pixels (diagonal value in the pixel matrix) on total number of pixels classified as class j in the output image.

$$(Ui= \frac{Cii}{C.j}) \qquad \text{Eqn. (10).}$$

These steps show the procedure of generating the confusion matrix as a text file using ENVI software:

- To obtain the confusion matrix from the software "ENVI", go to "Classification" then "Post Classification" then "Confusion Matrix" and click on "Using Ground Truth ROIs".

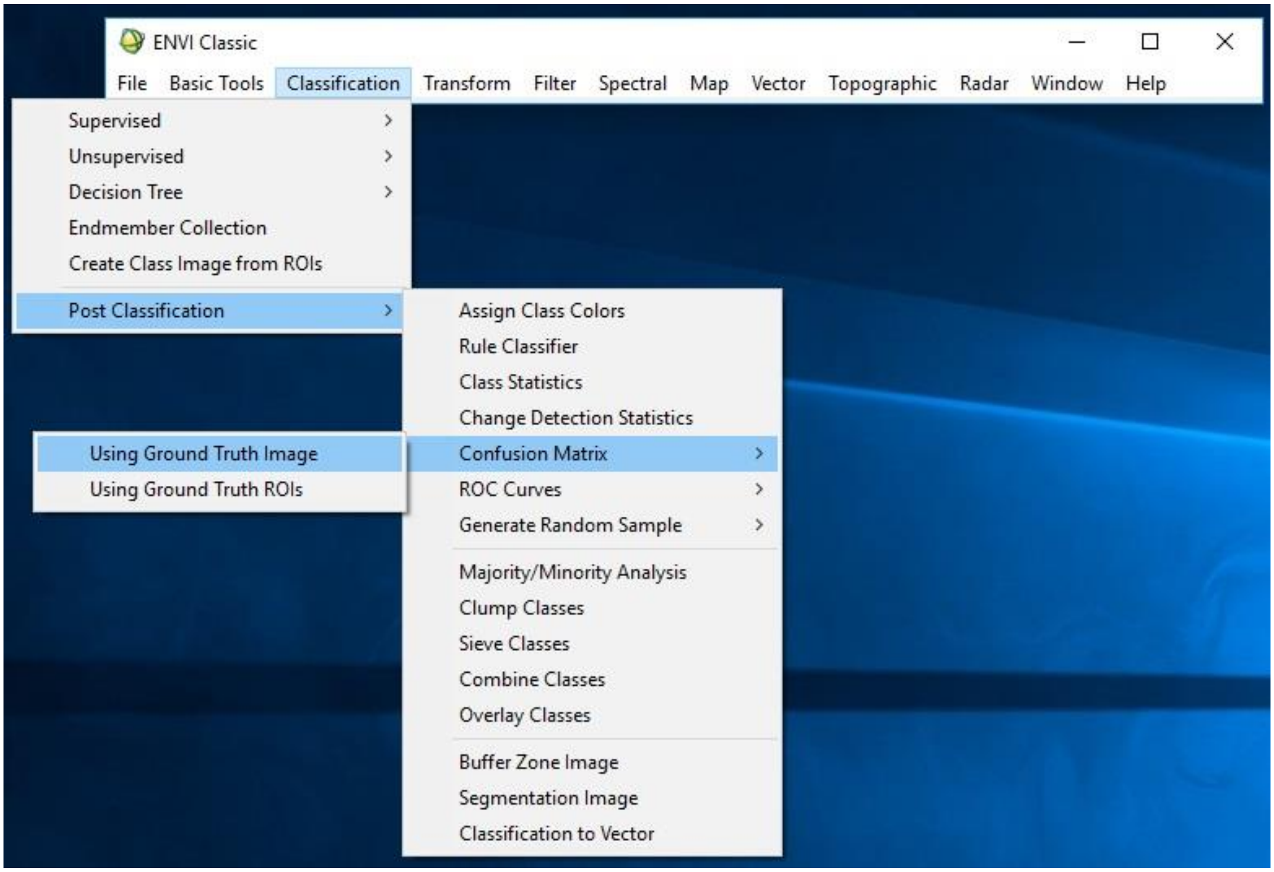


Figure 3. 33 Obtaining Confusion Matrix from ENVI.

- If more than one classification has been done, select the classification needed to calculate the confusion matrix, and then specify the match classes parameters.

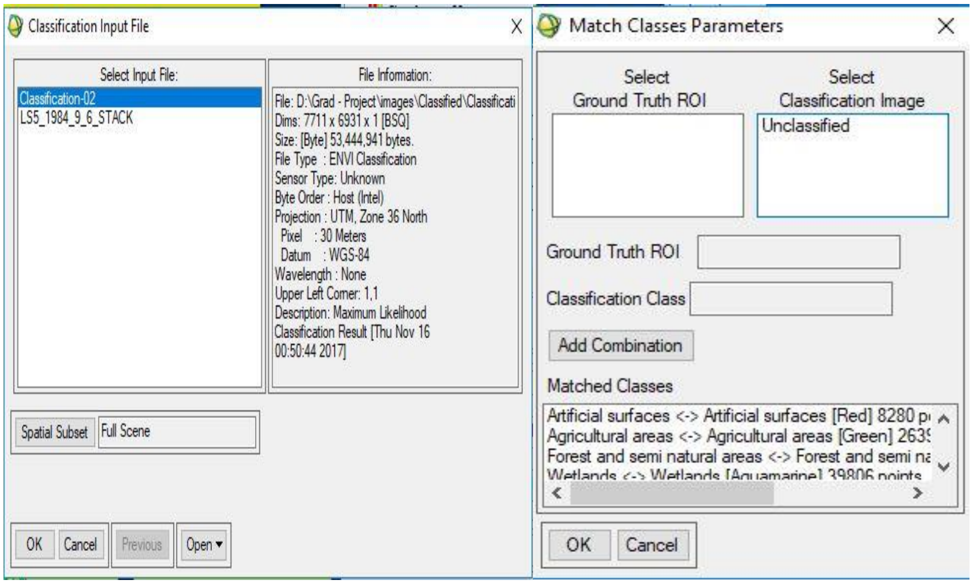
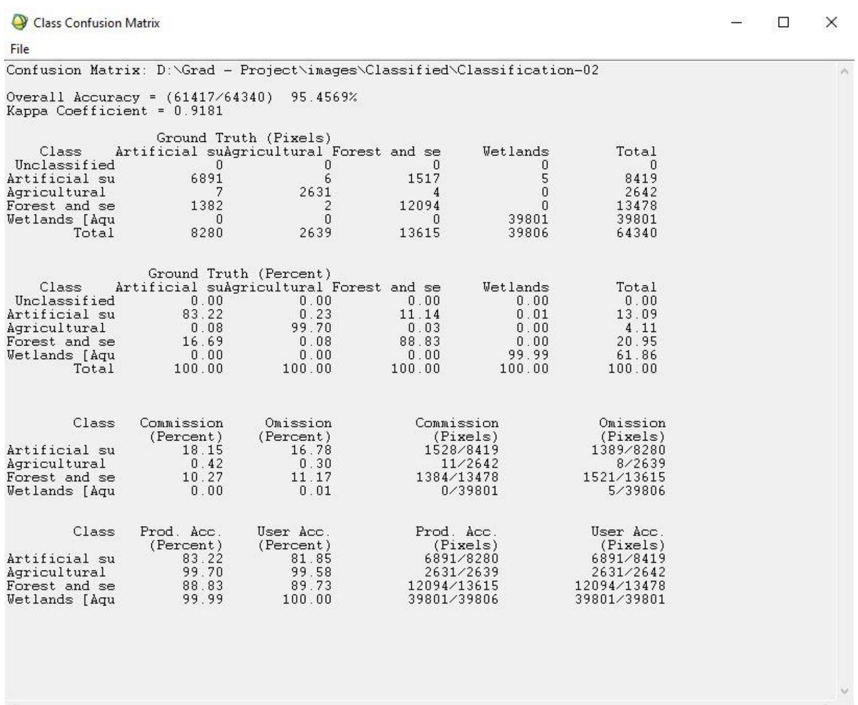


Figure 3. 34 Classification and match classes parameters selection.

- The ENVI software provides the confusion matrix as a report as shown in the figure below, and this report could be saved as a text file.



Confusion Matrix: D:\Grad - Project\images\Classified\Classification-02

Overall Accuracy = (61417/64340) 95.4569%
Kappa Coefficient = 0.9181

Ground Truth (Pixels)

Class	Artificial su	Agricultural	Forest and se	Wetlands	Total
Unclassified	0	0	0	0	0
Artificial su	6891	6	1517	5	8419
Agricultural	7	2631	4	0	2642
Forest and se	1382	2	12094	0	13478
Wetlands [Aqu	0	0	0	39801	39801
Total	8280	2639	13615	39806	64340

Ground Truth (Percent)

Class	Artificial su	Agricultural	Forest and se	Wetlands	Total
Unclassified	0.00	0.00	0.00	0.00	0.00
Artificial su	83.22	0.23	11.14	0.01	13.09
Agricultural	0.08	99.70	0.03	0.00	4.11
Forest and se	16.69	0.08	88.83	0.00	20.95
Wetlands [Aqu	0.00	0.00	0.00	99.99	61.86
Total	100.00	100.00	100.00	100.00	100.00

Class	Commission (Percent)	Omission (Percent)	Commission (Pixels)	Omission (Pixels)
Artificial su	18.15	16.78	1528/8419	1389/8280
Agricultural	0.42	0.30	11/2642	8/2639
Forest and se	10.27	11.17	1384/13478	1521/13615
Wetlands [Aqu	0.00	0.01	0/39801	5/39806

Class	Prod. Acc. (Percent)	User Acc. (Percent)	Prod. Acc. (Pixels)	User Acc. (Pixels)
Artificial su	83.22	81.85	6891/8280	6891/8419
Agricultural	99.70	99.58	2631/2639	2631/2642
Forest and se	88.83	89.73	12094/13615	12094/13478
Wetlands [Aqu	99.99	100.00	39801/39806	39801/39801

Figure 3. 35 Confusion matrix.

CHAPTER FOUR

RESULTS & CALCULATIONS

4.1 Image Classification

4.2 Data Analysis

4.3 Results

4.4 Change Detection

4.5 Accuracy Assessment

4.6 Conclusion

4.1 Image Classification

After applying the process described in the previous chapter (Methodology) on the images obtained of the West Bank, a raster data were produced for the land cover classification of the study area according to CORINE classes. And after converting the data into manageable vector data, the results were as following.

The classes used for classification were:

- Artificial surfaces: for the urban and built-up areas.
- Agricultural areas: for the vegetation cover.
- Forest and semi natural areas: for the open spaces.
- Water bodies: for the sea and water courses.

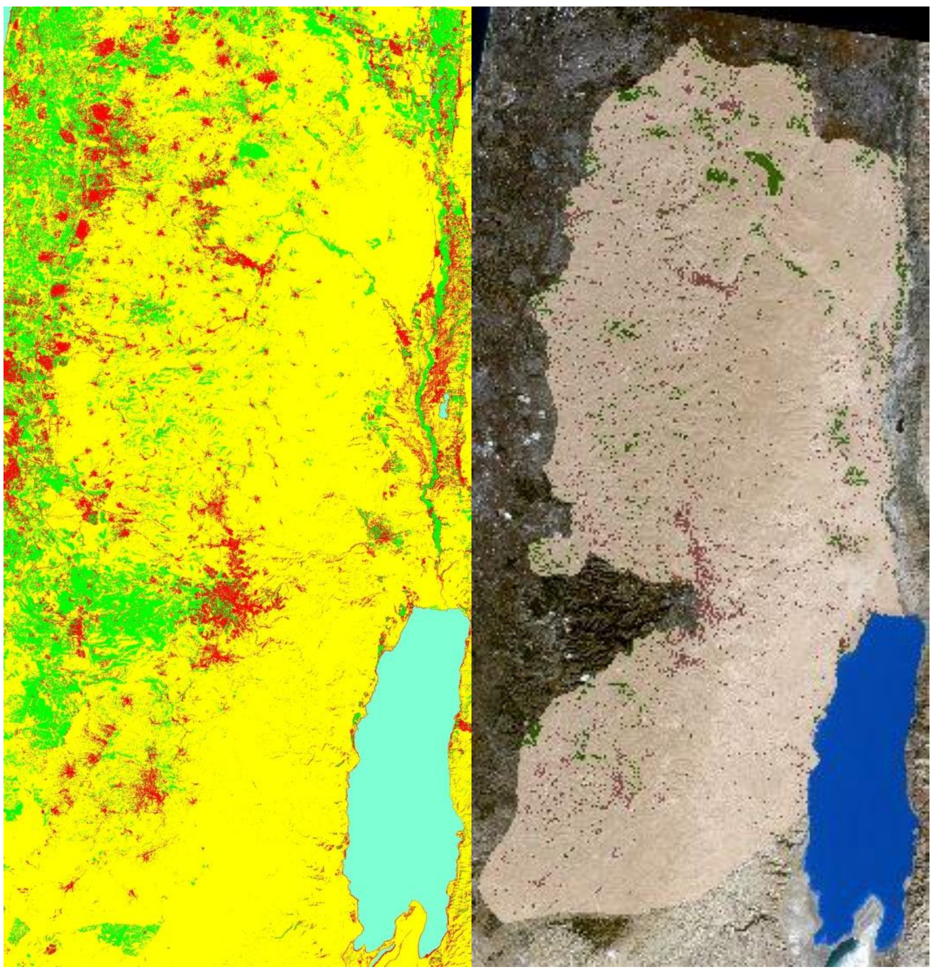


Figure 4. 1 Output of image classification.

4.2 Data Analysis

After clipping the study area of the classified image, and then analyzing this image and making the statistical calculations on it, the results were as following.

4.2.1 Landsat Satellite

4.2.1.1 1984 Image:

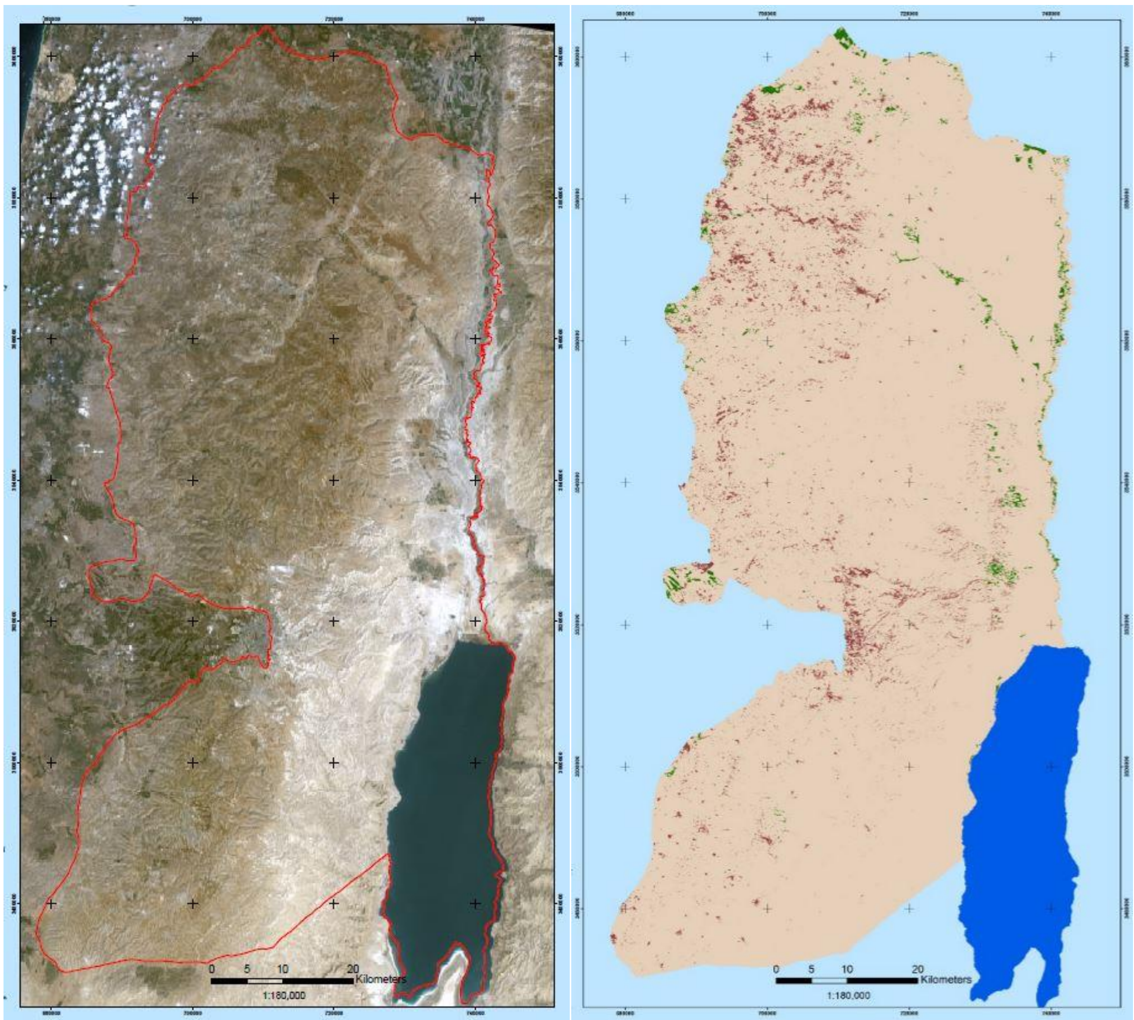


Figure 4. 2 Study area 1984 classified image.

Classification name : West Bank & DeadSea 1984

Input image stack	:	LT05_1984_Classified-05
Number of features B	:	5 (B1+B2+B3+B4+B7)
Minimum area of each class	:	5x 30 150
Training parcels	:	roi-04.roi
Mask	:	

	Class errors							
	Commission Ci	Omission Oi	Commission Ci			Omission Oi		
Class	%	%	C.j-Cii	/	C.j	Ci.-Cii	/	Ci.
C1	30.03%	8.94%	1504	/	5009	344	/	3849
C2	0.19%	1.67%	8	/	4300	73	/	4365
C3	10.52%	30.80%	392	/	3728	1485	/	4821
C4	0.00%	0.01%	0	/	38314	2	/	38316

Cij	Reference or ground truth classes i (pixels)				
Class j (classified)	C1	C2	C3	C4	C.j
C1	3505	24	1480	0	5009
C2	3	4292	5	0	4300
C3	341	49	3336	2	3728
C4	0	0	0	38314	38314
Ci.	3849	4365	4821	38316	51351

	Class accuracy							
	Producer accuracy Ai	User accuracy Ui	Producer accuracy Ai			User accuracy Ui		
Class	%	%	Cii	/	Ci.	Cii	/	C.j
C1	91.06%	69.97%	3505	/	3849	3505	/	5009
C2	98.33%	99.81%	4292	/	4365	4292	/	4300
C3	69.20%	89.48%	3336	/	4821	3336	/	3728
C4	99.99%	100.00%	38314	/	38316	38314	/	38314

Cij/n	Reference or ground truth classes i (percent)				
Class j (classified)	C1	C2	C3	C4	C.j/n
C1	91.06	0.55	30.70	0.00	9.75
C2	0.08	98.33	0.10	0.00	8.37
C3	8.86	1.12	69.20	0.01	7.26
C4	0.00	0.00	0.00	99.99	74.61
Total column	100.00	100.00	100.00	100.00	100.00
Ci./n	7.50%	8.50%	9.39%	74.62%	100%

General statistics					
Overall accuracy	=	49447	/	51351	= 96.29%
Mean accuracy	=				= 71.72%
Kappa coefficient	=	0.91214354			

Figure 4. 3 The 1984 classification confusion matrix.

Table6 Study area 1984 statistics.

Class Name	Area (km2)	Percentage %
Agricultural Areas	61.28	0.97%
Artificial Surfaces	153.24	2.44%
Forest and Semi natural areas	5424.70	86.21%
Water Bodies	653.01	10.38%

4.2.1.2 1998 Image:

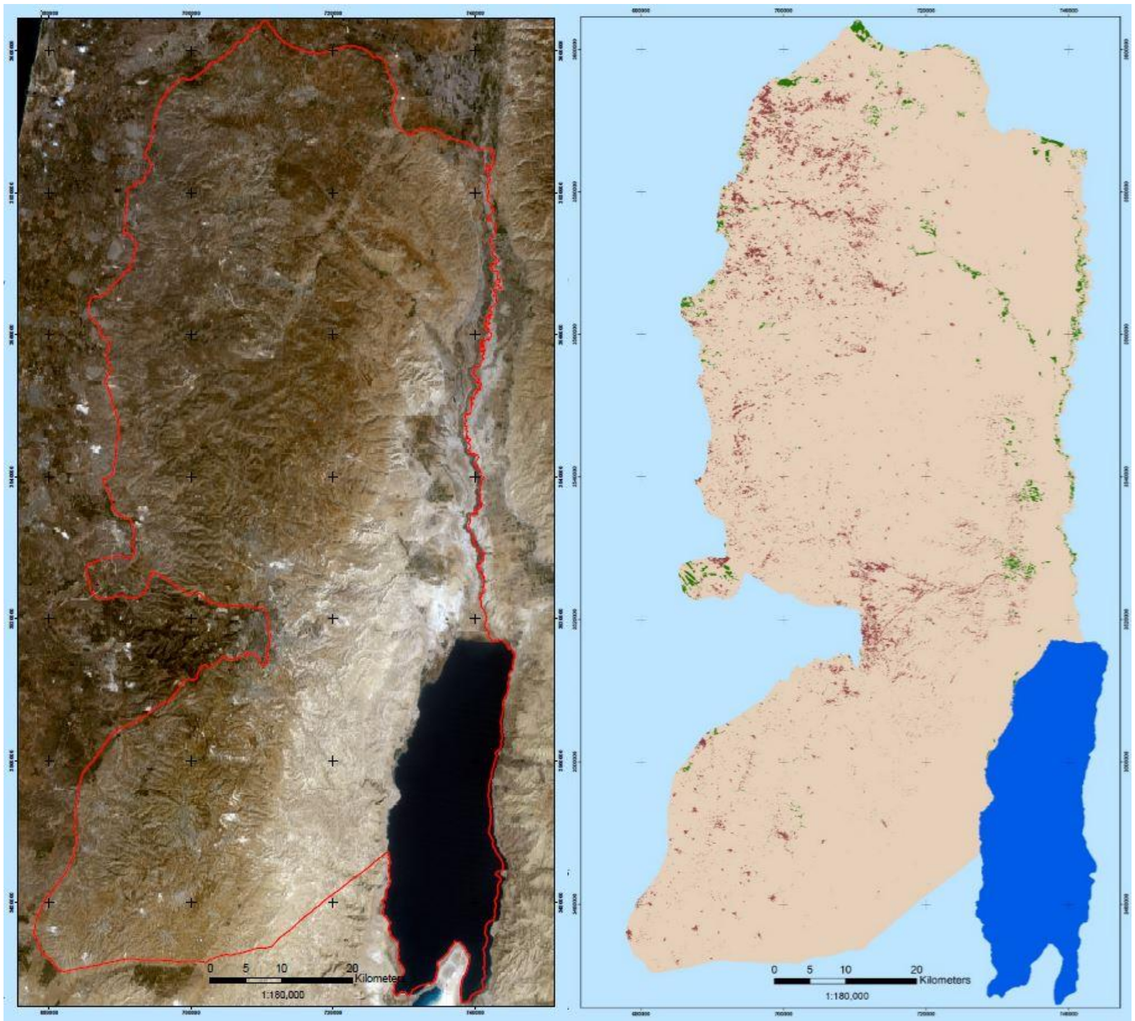


Figure 4. 4 Study area 1998 classified image.

Classification n a m e : West Bank & DeadSea 1998

Input image stack	:	LT05_1998_Classified-05
Number of features B	:	5 (B1+B2+B3+B4+B7)
Minimum area of each class	:	5x 30 150
Training parcels	:	roi-03.roi
Mask	:	

	Class errors								
	Commission Ci	Omission Oi	Commission Ci			Omission Oi			
Class	%	%	C.j-Cii	/	C.j	Ci.-Cii	/	Ci.	
C1	9.77%	5.72%	214	/	2191	120	/	2097	
C2	1.30%	8.23%	27	/	2078	184	/	2235	
C3	10.53%	12.38%	194	/	1843	233	/	1882	
C4	6.59%	0.51%	110	/	1668	8	/	1566	

Cij	Reference or ground truth classes i (pixels)				
Class j (classified)	C1	C2	C3	C4	C.j
C1	1977	0	214	0	2191
C2	3	2051	19	5	2078
C3	117	74	1649	3	1843
C4	0	110	0	1558	1668
Ci.	2097	2235	1882	1566	7780

	Class accuracy							
	Producer accuracy Ai	User accuracy Ui	Producer accuracy Ai			User accuracy Ui		
Class	%	%	Cii	/	Ci.	Cii	/	C.j
C1	94.28%	90.23%	1977	/	2097	1977	/	2191
C2	91.77%	98.70%	2051	/	2235	2051	/	2078
C3	87.62%	89.47%	1649	/	1882	1649	/	1843
C4	99.49%	93.41%	1558	/	1566	1558	/	1668

Cij/n	Reference or ground truth classes i (percent)				
Class j (classified)	C1	C2	C3	C4	C.j/n
C1	94.28	0.00	11.37	0.00	28.16
C2	0.14	91.77	1.01	0.32	26.71
C3	5.58	3.31	87.62	0.19	23.69
C4	0.00	4.92	0.00	99.49	21.44
Total column	100.00	100.00	100.00	100.00	100.00
Ci./n	26.95%	28.73%	24.19%	20.13%	100%

General statistics					
Overall accuracy	=	7235	/	7780	= 92.99%
Mean accuracy	=				= 74.63%
Kappa coefficient	=	0.90621101			

Figure 4. 5 The 1998 classification confusion matrix.

Table7 Study area 1998 statistics.

Class Name	Area (km2)	Percentage %
Agricultural Areas	178.58	2.84%
Artificial Surfaces	238.66	3.79%
Forest and Semi natural areas	5230.18	83.12%
Water Bodies	644.81	10.25%

4.2.1.3 2003 Image:

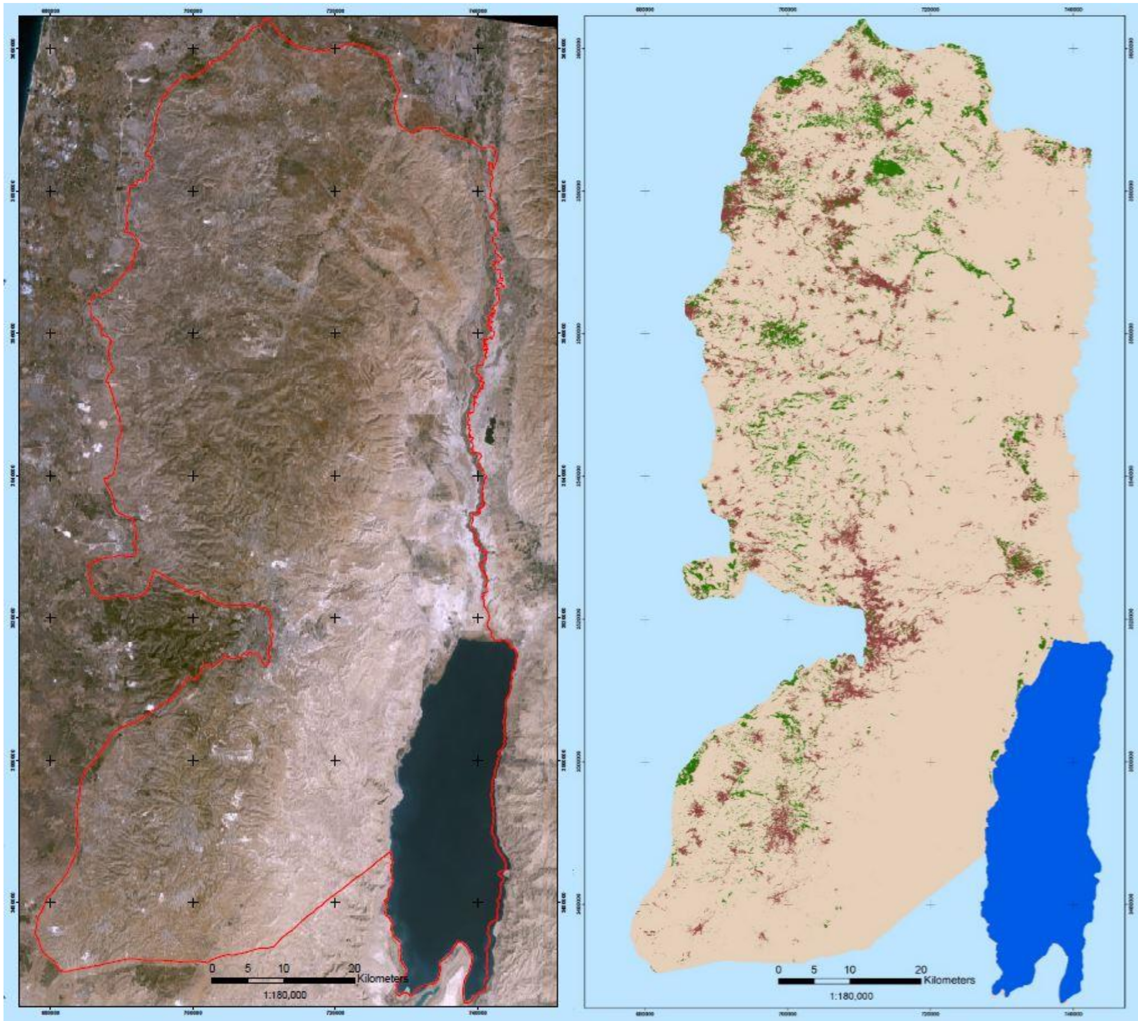


Figure 4. 6 Study area 2003 classified image.

Classification name : West Bank & DeadSea 2003

Input image stack	:	LT05_2003_Classified-05
Number of features B	:	5 (B1+B2+B3+B4+B5)
Minimum area of each class	:	5x 30 = 150
Training parcels	:	roi-03.roi
Mask	:	

	Class errors							
	Commission Ci	Omission Oi	Commission Ci			Omission Oi		
Class	%	%	C.j-Cii	/	C.j	Ci.-Cii	/	Ci.
C1	17.05%	6.78%	291	/	1707	103	/	1519
C2	3.47%	0.91%	55	/	1587	14	/	1546
C3	4.93%	12.02%	99	/	2010	261	/	2172
C4	0.00%	0.75%	0	/	8902	67	/	8969

Cij	Reference or ground truth classes i (pixels)				
Class j (classified)	C1	C2	C3	C4	C.j
C1	1416	6	226	59	1707
C2	12	1532	35	8	1587
C3	91	8	1911	0	2010
C4	0	0	0	8902	8902
Ci.	1519	1546	2172	8969	14206

	Class accuracy							
	Producer accuracy Ai	User accuracy Ui	Producer accuracy Ai			User accuracy Ui		
Class	%	%	Cii	/	Ci.	Cii	/	C.j
C1	93.22%	82.95%	1416	/	1519	1416	/	1707
C2	99.09%	96.53%	1532	/	1546	1532	/	1587
C3	87.98%	95.07%	1911	/	2172	1911	/	2010
C4	99.25%	100.00%	8902	/	8969	8902	/	8902

Cij/n	Reference or ground truth classes i (percent)				
Class j (classified)	C1	C2	C3	C4	C.j/n
C1	93.22	0.39	10.41	0.66	12.02
C2	0.79	99.09	1.61	0.09	11.17
C3	5.99	0.52	87.98	0.00	14.15
C4	0.00	0.00	0.00	99.25	62.66
Total column	100.00	100.00	100.00	100.00	100.00
Ci./n	10.69%	10.88%	15.29%	63.14%	100%

General statistics						
Overall accuracy	=	13761	/	14206	=	97%
Mean accuracy	=				=	76%
Kappa coefficient	=	0.94383546				

Figure 4. 7 The 2003 classification confusion matrix.

Table 8 Study area 2003 statistics.

Class Name	Area (km2)	Percentage %
Agricultural Areas	281.61	4.48%
Artificial Surfaces	325.78	5.18%
Forest and Semi natural areas	5070.99	80.59%
Water Bodies	613.84	9.76%

4.2.1.4 2013 Image:

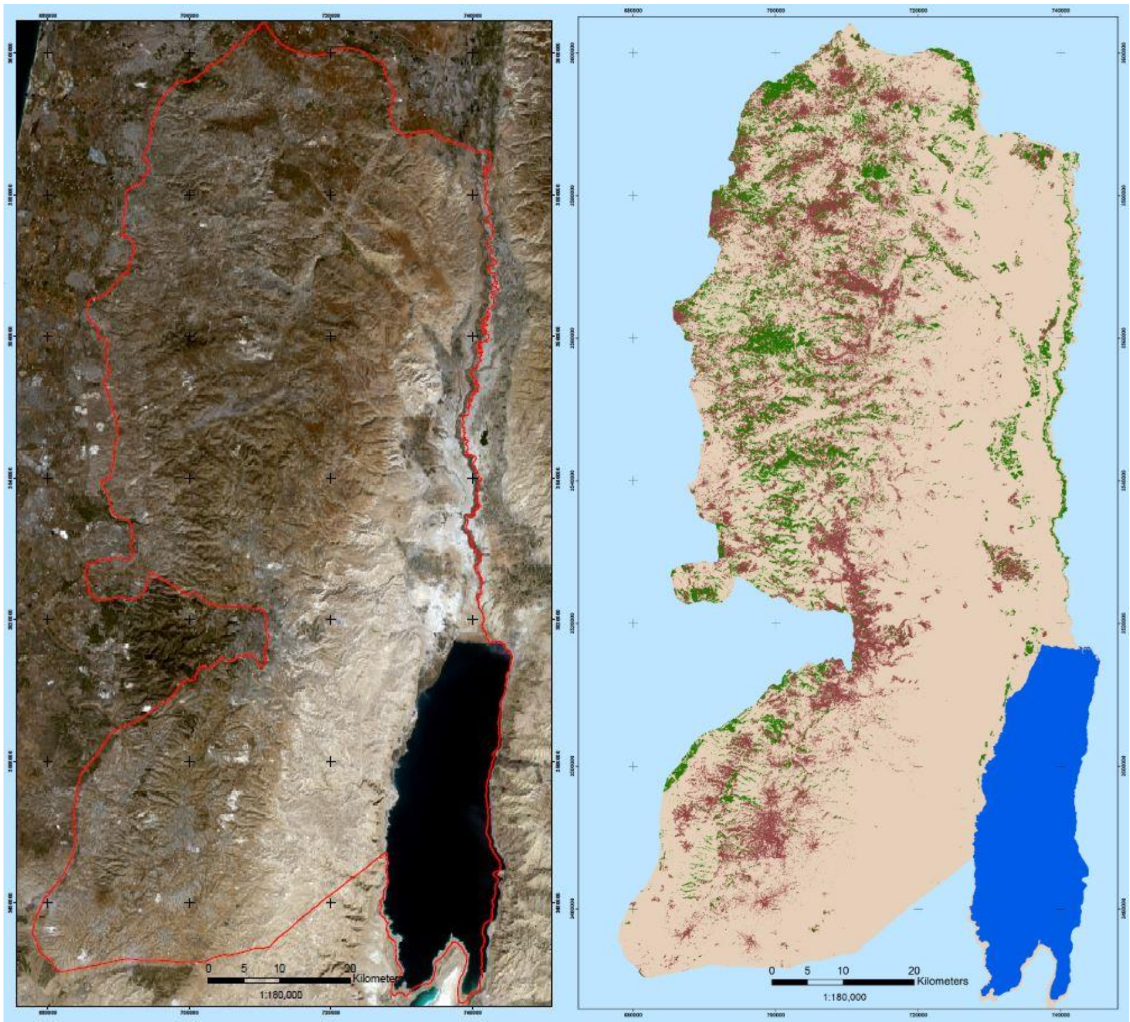


Figure 4. 8 Study area 2013 classified image.

Classification name : West Bank & DeadSea 2013

Input image stack	:	LT08_2013_Classified	
Number of features B	:	5 (B1+B2+B3+B4+B5)	
Minimum area of each class	:	5x 30 =	150
Training parcels	:	roi-03.roi	
Mask	:		

	Class errors								
	Commission Ci	Omission Oi	Commission Ci			Omission Oi			
Class	%	%	C.j-Cii	/	C.j	Ci.-Cii	/	Ci.	
C1	3.50%	1.97%	36	/	1030	20	/	1014	
C2	24.37%	5.63%	454	/	1863	84	/	1493	
C3	0.00%	1.56%	0	/	8583	136	/	8719	
C4	4.49%	16.65%	77	/	1714	327	/	1964	

Cij	Reference or ground truth classes i (pixels)				
Class j (classified)	C1	C2	C3	C4	C.j
C1	994	9	5	22	1030
C2	19	1409	130	305	1863
C3	0	0	8583	0	8583
C4	1	75	1	1637	1714
Ci.	1014	1493	8719	1964	13190

	Class accuracy							
	Producer accuracy Ai	User accuracy Ui	Producer accuracy Ai			User accuracy Ui		
Class	%	%	Cii	/	Ci.	Cii	/	C.j
C1	98.03%	96.50%	994	/	1014	994	/	1030
C2	94.37%	75.63%	1409	/	1493	1409	/	1863
C3	98.44%	100.00%	8583	/	8719	8583	/	8583
C4	83.35%	95.51%	1637	/	1964	1637	/	1714

Cij/n	Reference or ground truth classes i (percent)				
Class j (classified)	C1	C2	C3	C4	C.j/n
C1	98.03	0.60	0.06	1.12	7.81
C2	1.87	94.37	1.49	15.53	14.12
C3	0.00	0.00	98.44	0.00	65.07
C4	0.10	5.02	0.01	83.35	12.99
Total column	100.00	100.00	100.00	100.00	100.00
Ci./n	7.69%	11.32%	66.10%	14.89%	100%

General statistics						
Overall accuracy	=	12623	/	13190	=	96%
Mean accuracy	=				=	75%
Kappa coefficient	=	0.91866415				

Figure 4. 9 The 2013 classification confusion matrix.

Table 9 Study area 2013 statistics.

Class Name	Area (km2)	Percentage %
Agricultural Areas	533.93	8.49%
Artificial Surfaces	483.11	7.68%
Forest and Semi natural areas	4682.76	74.42%
Water Bodies	592.43	9.42%

4.2.1.5 2016 Image:

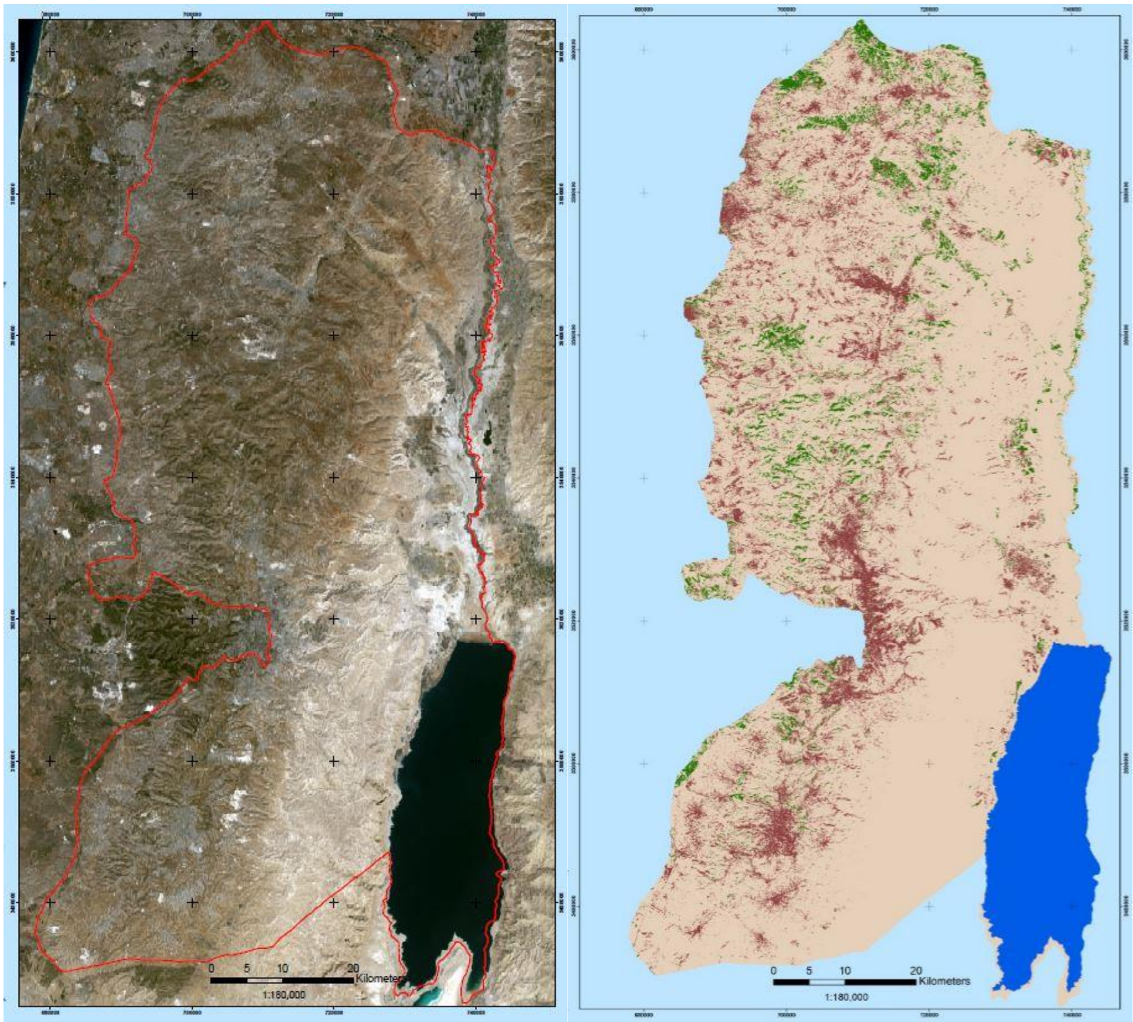


Figure 4. 10 Study area 2016 classification.

Classification name : West Bank & DeadSea 2016

Input image stack	:	LT08_2016_Classified
Number of features B	:	5 (B1+B2+B3+B4+B5)
Minimum area of each class	:	5x 30 = 150
Training parcels	:	roi-03.roi
Mask	:	

	Class errors							
	Commission Ci	Omission Oi	Commission Ci			Omission Oi		
Class	%	%	C.j-Cii	/	C.j	Ci.-Cii	/	Ci.
C1	12.07%	1.03%	53	/	439	4	/	390
C2	3.70%	11.66%	109	/	2942	374	/	3207
C3	0.00%	0.14%	0	/	7750	11	/	7761
C4	19.44%	7.09%	332	/	1708	105	/	1481

Cij	Reference or ground truth classes i (pixels)				
Class j (classified)	C1	C2	C3	C4	C.j
C1	386	47	6	0	439
C2	4	2833	0	105	2942
C3	0	0	7750	0	7750
C4	0	327	5	1376	1708
Ci.	390	3207	7761	1481	12839

	Class accuracy							
	Producer accuracy Ai	User accuracy Ui	Producer accuracy Ai			User accuracy Ui		
Class	%	%	Cii	/	Ci.	Cii	/	C.j
C1	98.97%	87.93%	386	/	390	386	/	439
C2	88.34%	96.30%	2833	/	3207	2833	/	2942
C3	99.86%	100.00%	7750	/	7761	7750	/	7750
C4	92.91%	80.56%	1376	/	1481	1376	/	1708

Cij/n	Reference or ground truth classes i (percent)				
Class j (classified)	C1	C2	C3	C4	C.j/n
C1	98.97	1.47	0.08	0.00	3.42
C2	1.03	88.34	0.00	7.09	22.91
C3	0.00	0.00	99.86	0.00	60.36
C4	0.00	10.20	0.06	92.91	13.30
Total column	100.00	100.00	100.00	100.00	100.00
Ci./n	3.04%	24.98%	60.45%	11.54%	100%

General statistics						
Overall accuracy	=	12345	/	12839	=	96%
Mean accuracy	=				=	76%
Kappa coefficient	=	0.9314746				

Figure 4. 11 The 2016 classification confusion matrix.

Table 10 Study area 2016 statistics.

Class Name	Area (km2)	Percentage %
Agricultural Areas	270.73	4.30%
Artificial Surfaces	574.85	9.14%
Forest and Semi natural areas	4866.63	77.34%
Water Bodies	580.02	9.22%

4.2.1.6 2017 Image:

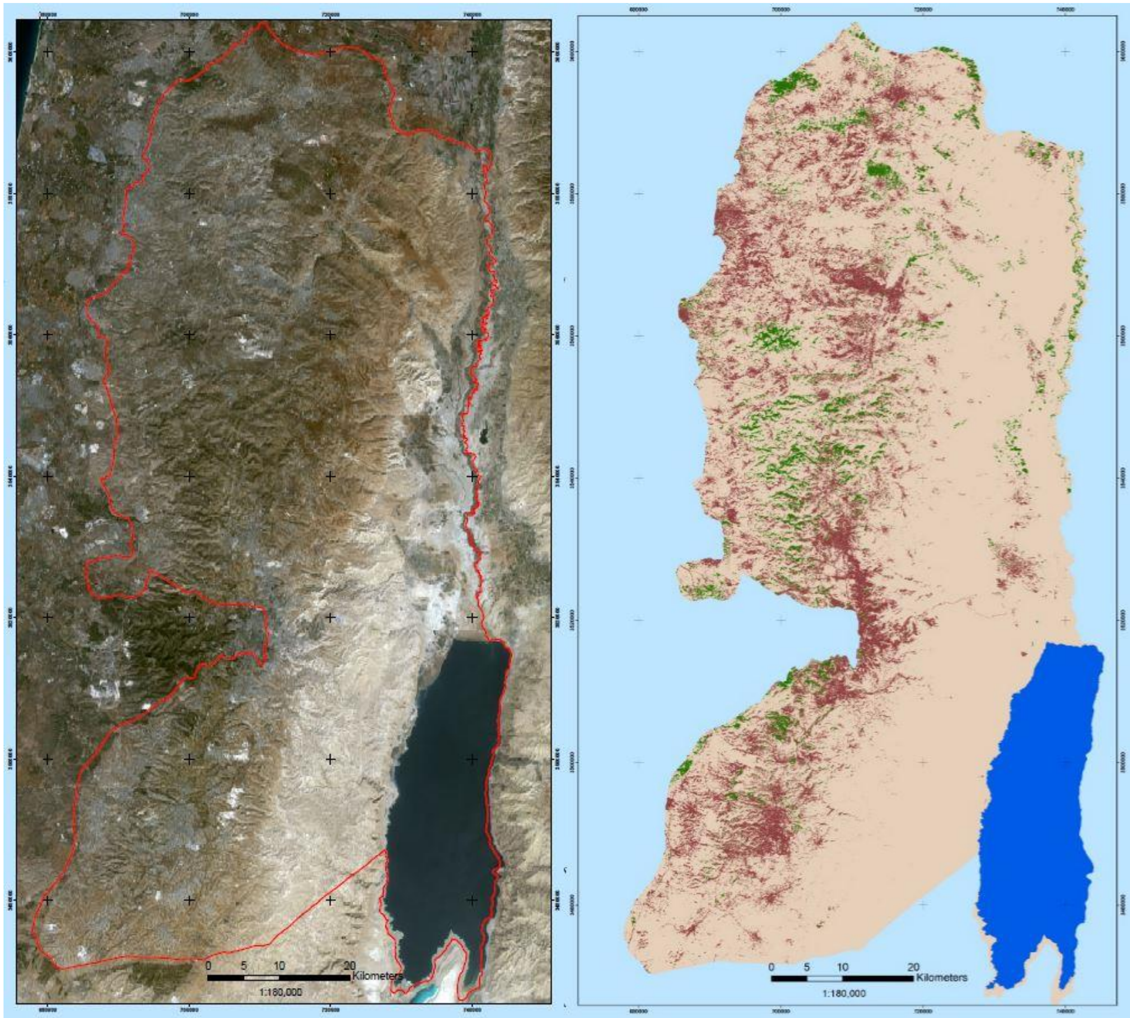


Figure 4. 12 Study area 2017 Classification.

Classification name : West Bank & DeadSea 2017

Input image stack	:	LT08_2017_Classified
Number of features B	:	5 (B1+B2+B3+B4+B5)
Minimum area of each class	:	5x 30 = 150
Training parcels	:	roi-03.roi
Mask	:	

	Class errors							
	Commission Ci	Omission Oi	Commission Ci			Omission Oi		
Class	%	%	C.j-Cii	/	C.j	Ci.-Cii	/	Ci.
C1	16.94%	5.94%	284	/	1677	88	/	1481
C2	8.16%	1.32%	40	/	490	6	/	456
C3	3.67%	11.28%	93	/	2531	310	/	2748
C4	0.00%	0.17%	0	/	7748	13	/	7761

Cij	Reference or ground truth classes i (pixels)				
Class j (classified)	C1	C2	C3	C4	C.j
C1	1393	1	277	6	1677
C2	0	450	33	7	490
C3	88	5	2438	0	2531
C4	0	0	0	7748	7748
Ci.	1481	456	2748	7761	12446

	Class accuracy							
	Producer accuracy Ai	User accuracy Ui	Producer accuracy Ai			User accuracy Ui		
Class	%	%	Cii	/	Ci.	Cii	/	C.j
C1	94.06%	83.06%	1393	/	1481	1393	/	1677
C2	98.68%	91.84%	450	/	456	450	/	490
C3	88.72%	96.33%	2438	/	2748	2438	/	2531
C4	99.83%	100.00%	7748	/	7761	7748	/	7748

Cij/n	Reference or ground truth classes i (percent)				
Class j (classified)	C1	C2	C3	C4	C.j/n
C1	94.06	0.22	10.08	0.08	13.47
C2	0.00	98.68	1.20	0.09	3.94
C3	5.94	1.10	88.72	0.00	20.34
C4	0.00	0.00	0.00	99.83	62.25
Total column	100.00	100.00	100.00	100.00	100.00
Ci./n	11.90%	3.66%	22.08%	62.36%	100%

General statistics						
Overall accuracy	=	12029	/	12446	=	97%
Mean accuracy	=				=	76%
Kappa coefficient	=	0.93901917				

Figure 4. 13 The 2017 classification confusion matrix.

Table 11 Study area 2017 statistics.

Class Name	Area (km2)	Percentage %
Agricultural Areas	231.40	3.68%
Artificial Surfaces	582.09	9.25%
Forest and Semi natural areas	4899.54	77.87%
Water Bodies	579.20	9.21%

4.2.2 Sentinel Satellite

4.2.2.1 2016 Image :

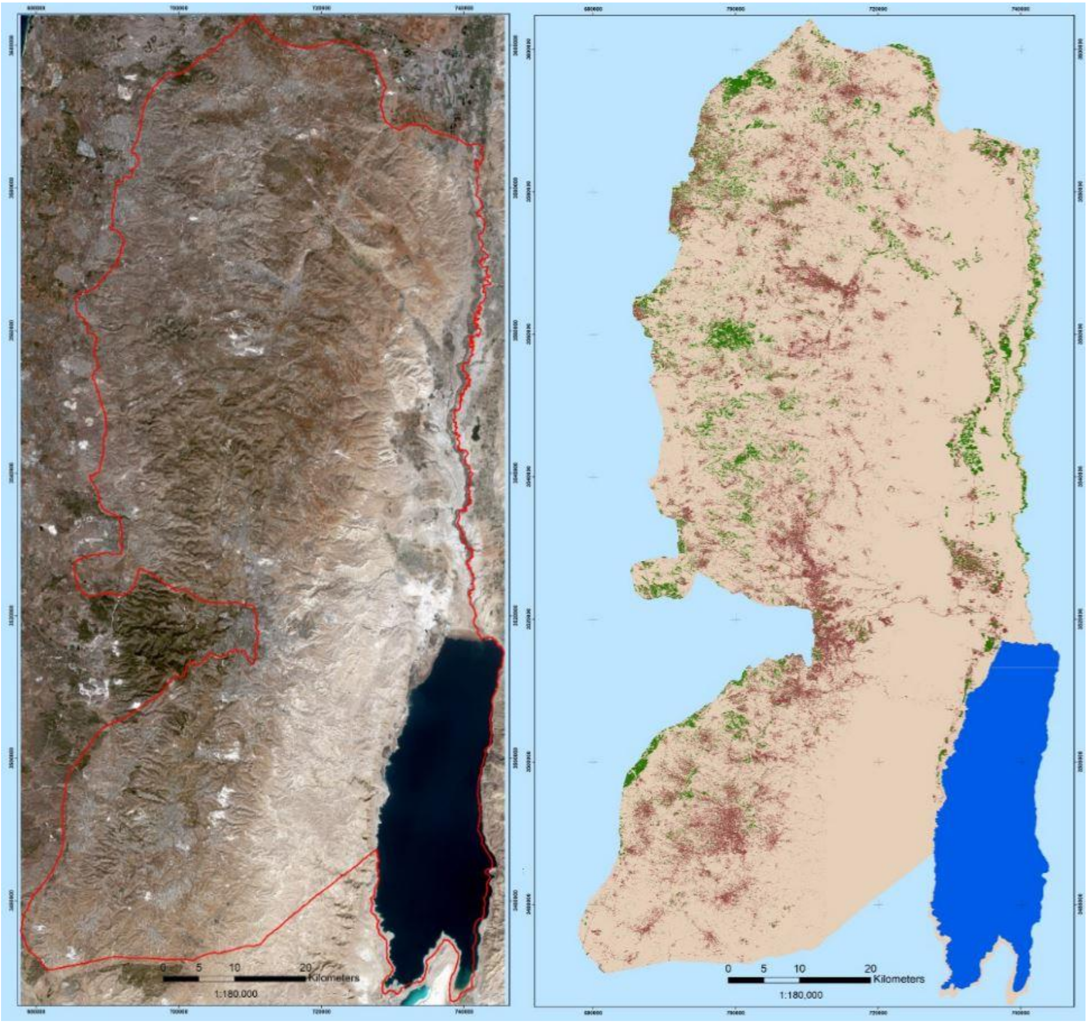


Figure 4. 14 Study area 2016 classification.

Classification name : West Bank & DeadSea 2016

Input image stack	:	S2A_2016_Classified
Number of features B	:	4 (B2+B3+B4+B8)
Minimum area of each class	:	4x 30 = 120
Training parcels	:	roi-04.roi
Mask	:	

	Class errors							
	Commission Ci	Omission Oi	Commission Ci			Omission Oi		
Class	%	%	C.j-Cii	/	C.j	Ci.-Cii	/	Ci.
C1	52.25%	13.27%	279	/	534	39	/	294
C2	0.00%	0.00%	0	/	510	0	/	510
C3	13.51%	14.05%	107	/	792	112	/	797
C4	0.00%	2.38%	0	/	9637	235	/	9872

Cij	Reference or ground truth classes i (pixels)				
Class j (classified)	C1	C2	C3	C4	C.j
C1	255	0	112	167	534
C2	0	510	0	0	510
C3	39	0	685	68	792
C4	0	0	0	9637	9637
Ci.	294	510	797	9872	11473

	Class accuracy							
	Producer accuracy Ai	User accuracy Ui	Producer accuracy Ai			User accuracy Ui		
Class	%	%	Cii	/	Ci.	Cii	/	C.j
C1	86.73%	47.75%	255	/	294	255	/	534
C2	100.00%	100.00%	510	/	510	510	/	510
C3	85.95%	86.49%	685	/	797	685	/	792
C4	97.62%	100.00%	9637	/	9872	9637	/	9637

Cij/n	Reference or ground truth classes i (percent)				
Class j (classified)	C1	C2	C3	C4	C.j/n
C1	86.73	0.00	14.05	1.69	4.65
C2	0.00	100.00	0.00	0.00	4.45
C3	13.27	0.00	85.95	0.69	6.90
C4	0.00	0.00	0.00	97.62	84.00
Total column	100.00	100.00	100.00	100.00	100.00
Ci./n	2.56%	4.45%	6.95%	86.05%	100%

General statistics						
Overall accuracy	=	11087	/	11473	=	97%
Mean accuracy	=				=	74%
Kappa coefficient	=	0.87505756				

Figure 4. 15 The 2016 classification confusion matrix.

Table 12 Study area 2016 statistics using Sentinel.

Class Name	Area (km2)	Percentage %
Agricultural Areas	307.55	4.89%
Artificial Surfaces	526.14	8.36%
Forest and Semi natural areas	4873.71	77.46%
Water Bodies	584.83	9.29%

4.2.2.2 2017 Image:

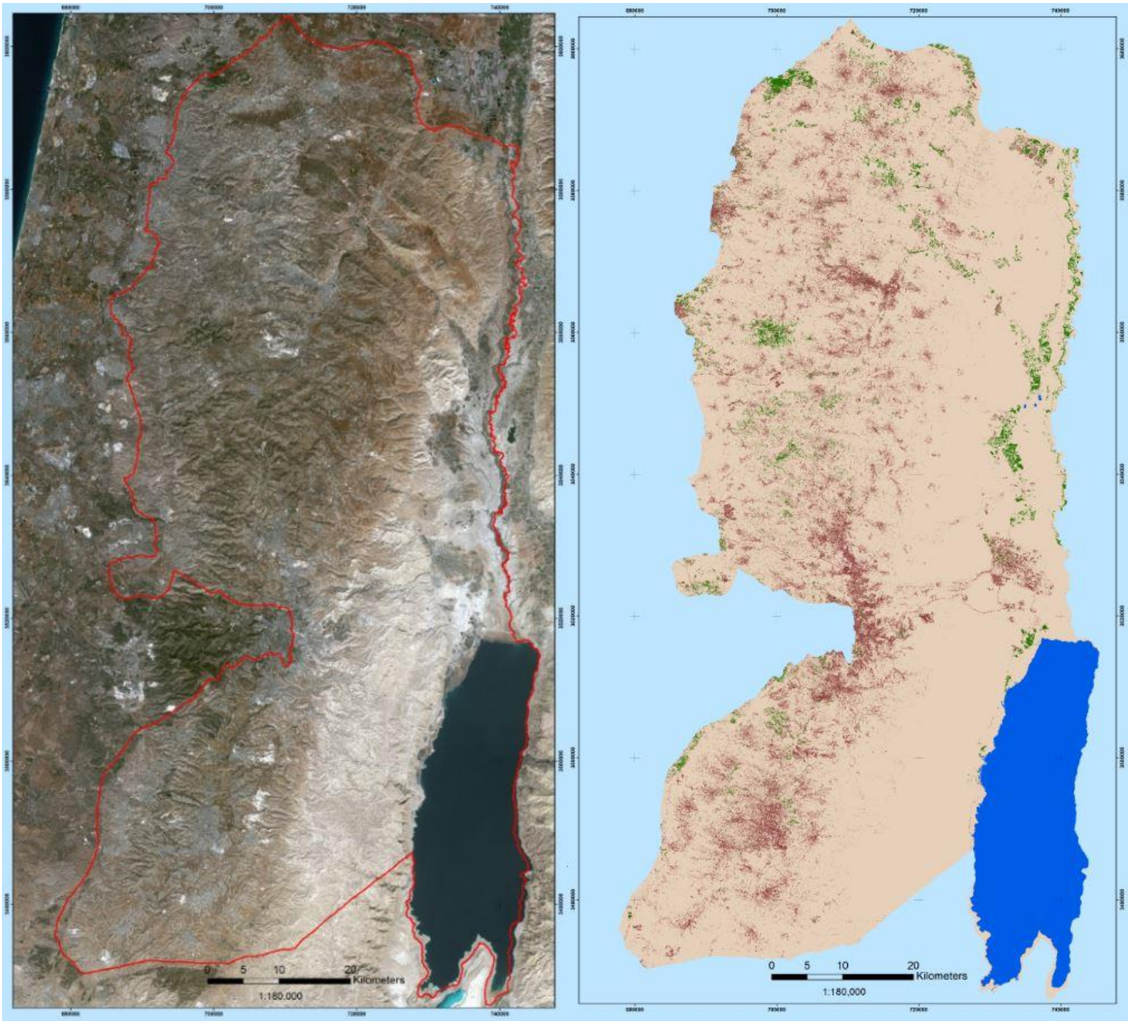


Figure 4. 16 Study area 2017 classification.

Classification name : West Bank & DeadSea 2017

Input image stack	:	S2A_2017_Classified
Number of features B	:	4 (B2+B3+B4+B8)
Minimum area of each class	:	4x 30 = 120
Training parcels	:	roi-04.roi
Mask	:	

	Class errors							
	Commission Ci	Omission Oi	Commission Ci			Omission Oi		
Class	%	%	C.j-Cii	/	C.j	Ci.-Cii	/	Ci.
C1	63.10%	15.20%	248	/	393	26	/	171
C2	0.00%	3.00%	0	/	194	6	/	200
C3	0.87%	7.35%	26	/	3000	236	/	3210
C4	0.00%	0.61%	0	/	979	6	/	985

Cij	Reference or ground truth classes i (pixels)				
Class j (classified)	C1	C2	C3	C4	C.j
C1	145	6	236	6	393
C2	0	194	0	0	194
C3	26	0	2974	0	3000
C4	0	0	0	979	979
Ci.	171	200	3210	985	4566

	Class accuracy							
	Producer accuracy Ai	User accuracy Ui	Producer accuracy Ai			User accuracy Ui		
Class	%	%	Cii	/	Ci.	Cii	/	C.j
C1	84.80%	36.90%	145	/	171	145	/	393
C2	97.00%	100.00%	194	/	200	194	/	194
C3	92.65%	99.13%	2974	/	3210	2974	/	3000
C4	99.39%	100.00%	979	/	985	979	/	979

Cij/n	Reference or ground truth classes i (percent)				
Class j (classified)	C1	C2	C3	C4	C.j/n
C1	84.80	3.00	7.35	0.61	8.61
C2	0.00	97.00	0.00	0.00	4.25
C3	15.20	0.00	92.65	0.00	65.70
C4	0.00	0.00	0.00	99.39	21.44
Total column	100.00	100.00	100.00	100.00	100.00
Ci./n	3.75%	4.38%	70.30%	21.57%	100%

General statistics					
Overall accuracy	=	4292 /	4566	=	94%
Mean accuracy	=			=	75%
Kappa coefficient	=	0.87671666			

Figure 4. 17 The 2017 classification confusion matrix.

Table 13 Study area 2017 statistics using Sentinel.

Class Name	Area (km2)	Percentage %
Agricultural Areas	242.22	3.85%
Artificial Surfaces	533.19	8.47%
Forest and Semi natural areas	4932.45	78.39%
Water Bodies	584.37	9.29%

4.3 Results

Based on the previous classification, calculation and analysis, the results were as the following:

For 1984 Image:

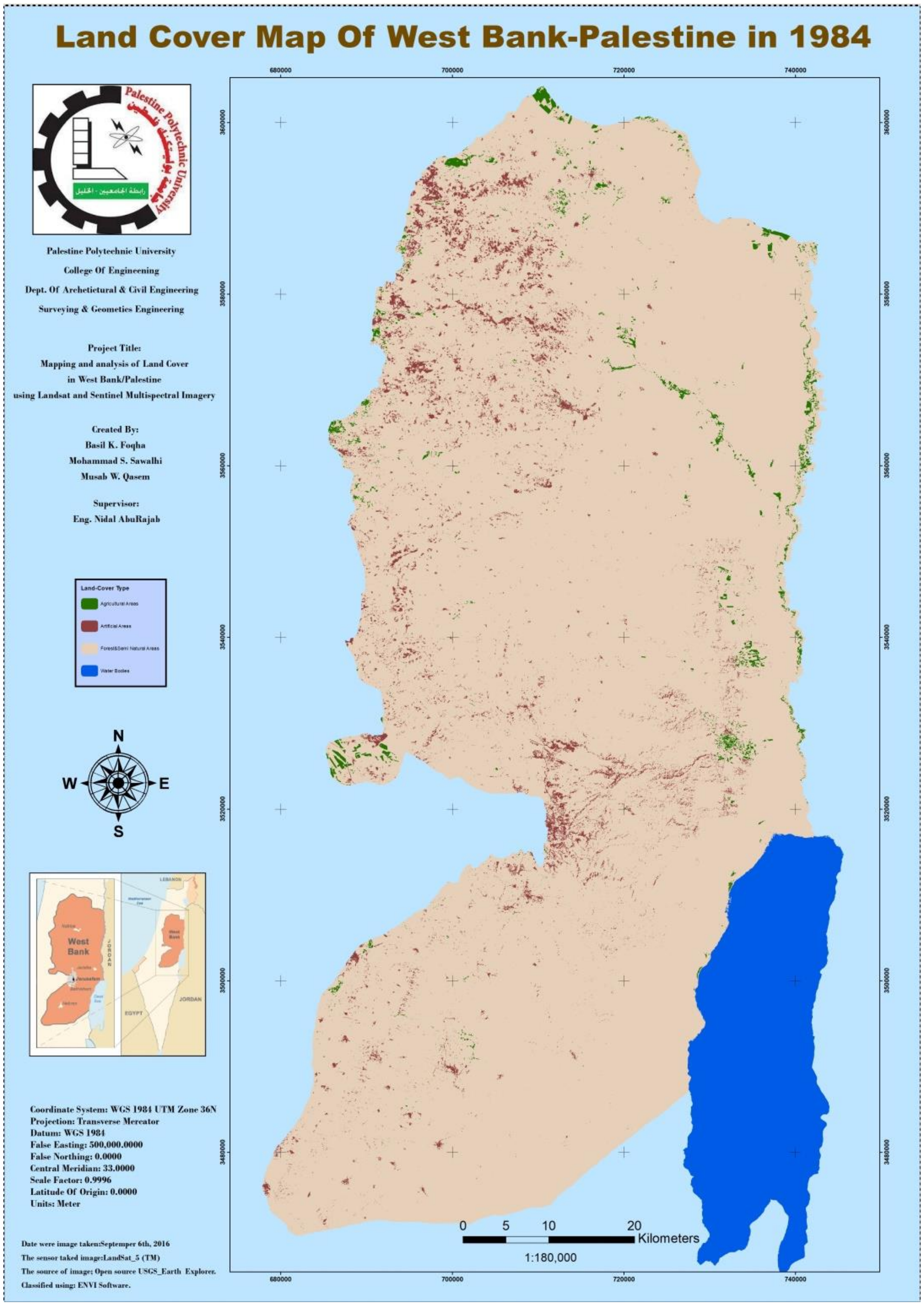


Figure 4. 18 Land Cover Map of West Bank-Palestine in 1984.

And the areas of the classes were:

Table14 Area and percentage of classification results of 1984 image.

Class Name	Area (km2)	Percentage %
Agricultural Areas	61.28	0.97%
Artificial Surfaces	153.24	2.44%
Forest and Semi natural areas	5424.70	86.21%
Water Bodies	653.01	10.38%

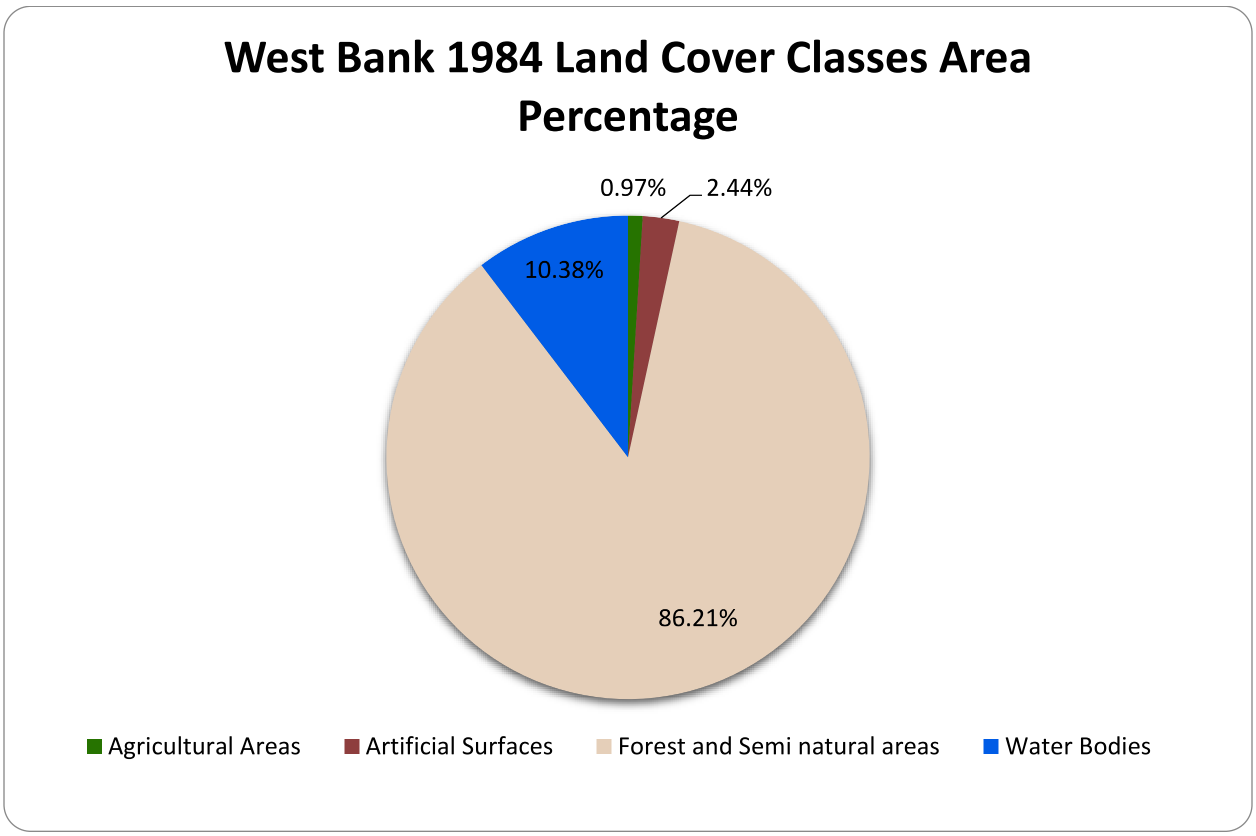


Figure 4. 19 West Bank 1984 Land Cover Area Percentage.

For 1998 image:

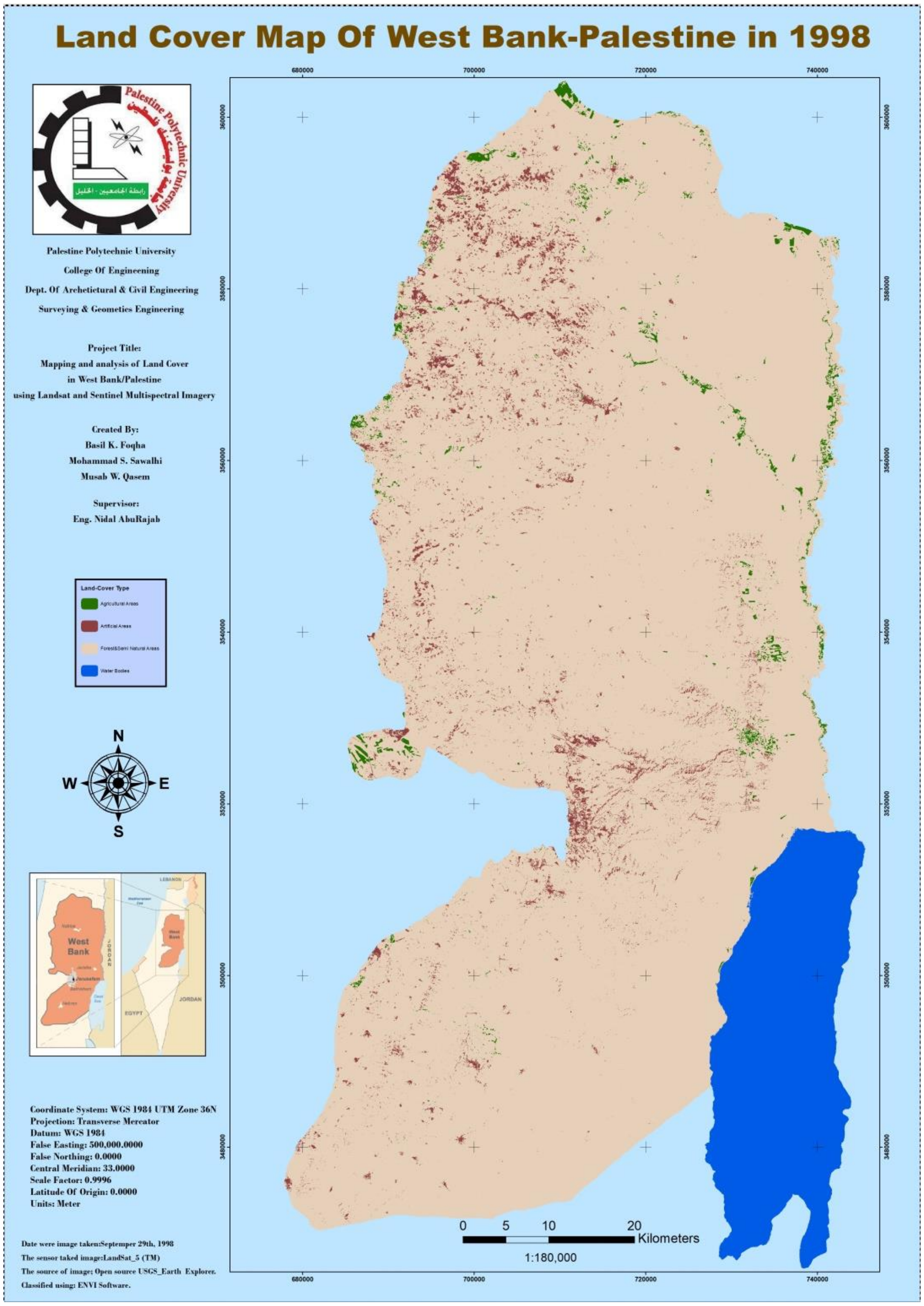


Figure 4. 20 Land Cover Map of West Bank-Palestine in 1998.

And the areas of the classes were:

Table15 Area and percentage of classification results of 1984 image.

Class Name	Area (km2)	Percentage %
Agricultural Areas	178.58	2.84%
Artificial Surfaces	238.66	3.79%
Forest and Semi natural areas	5230.18	83.12%
Water Bodies	644.81	10.25%

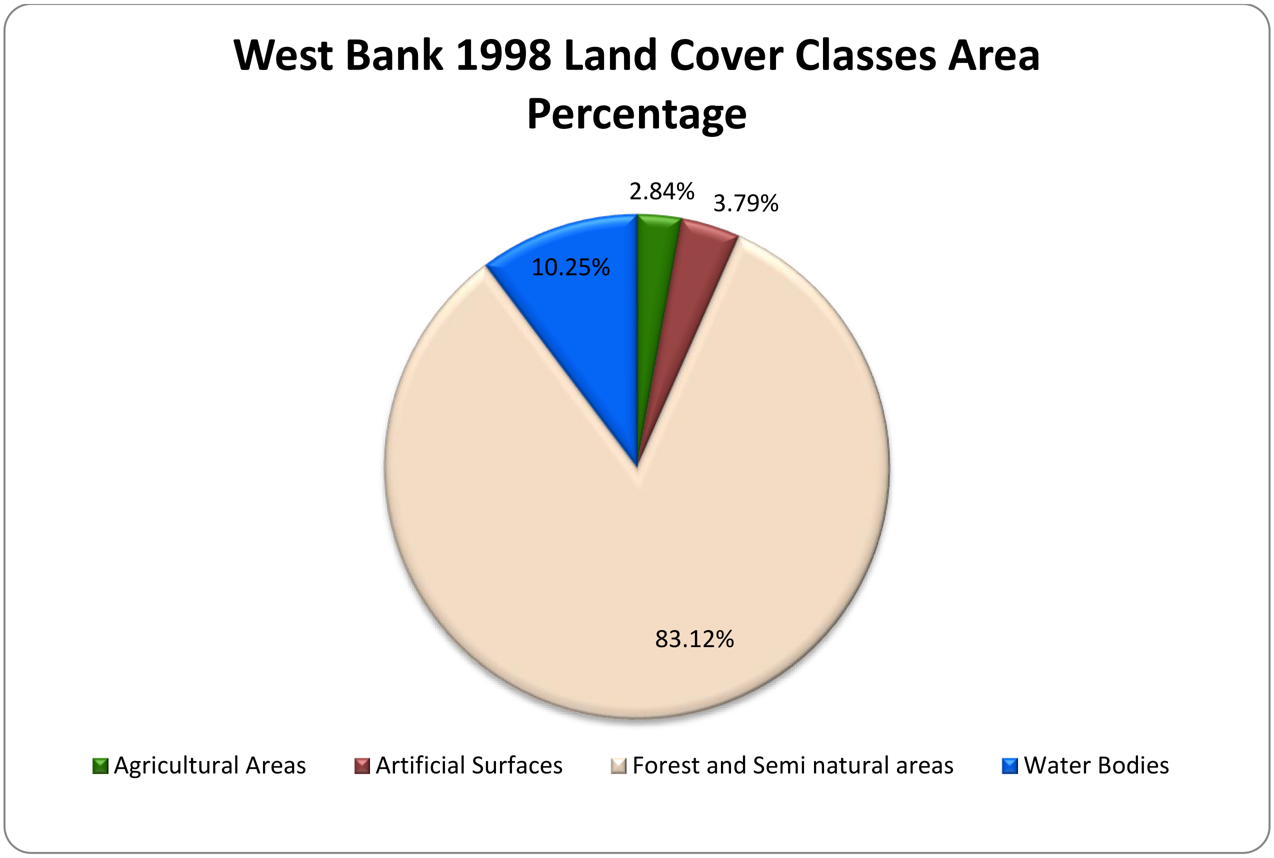


Figure 4. 21 West Bank 1998 Land Cover Classes Area Percentage.

For 2003 Image:

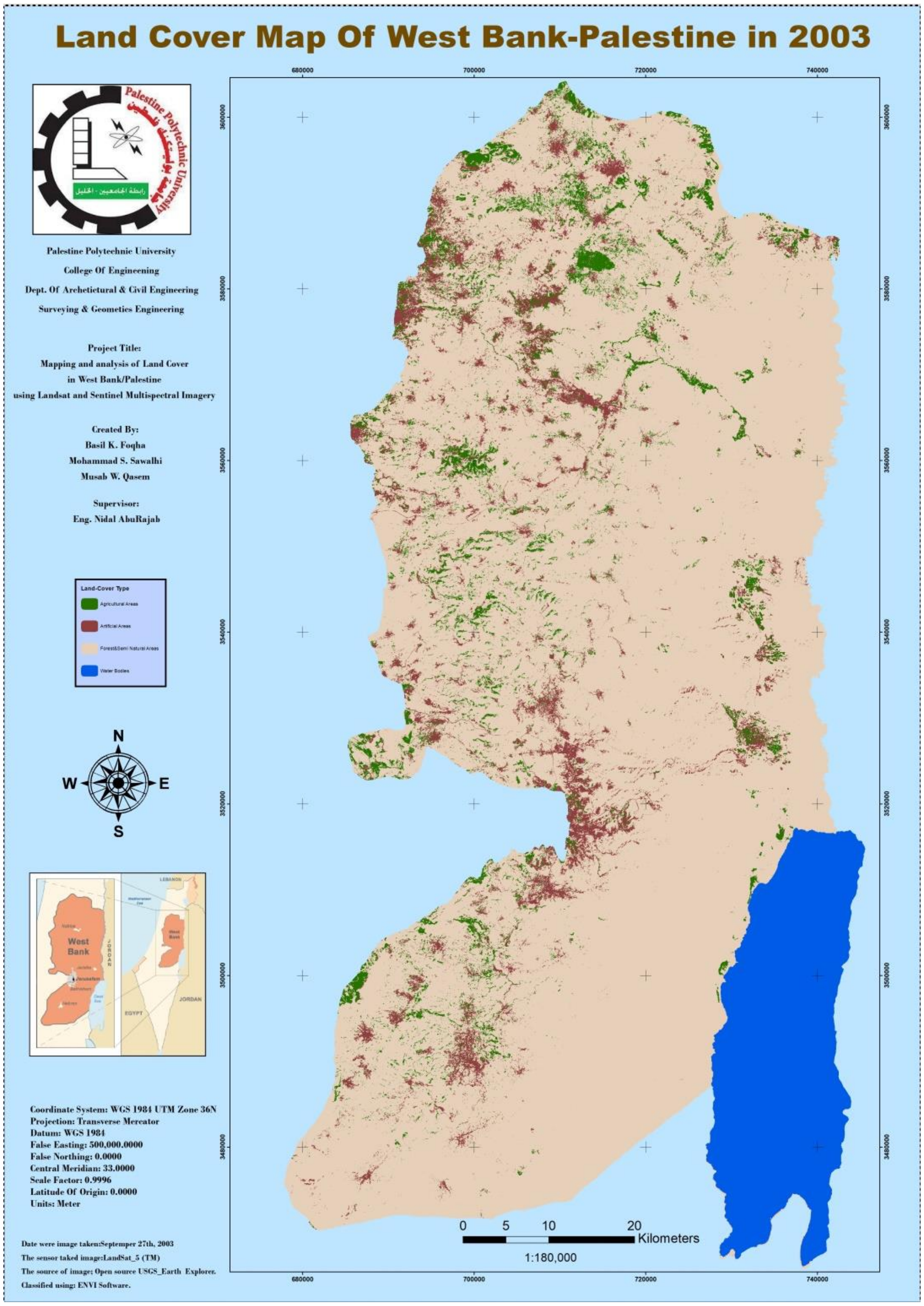


Figure 4. 22 Land Cover Map of West Bank-Palestine in 2003

And the areas of the classes were:

Table 16 Area and percentage of classification results of 2003 image.

Class Name	Area (km2)	Percentage %
Agricultural Areas	281.611	4.48%
Artificial Surfaces	325.781	5.18%
Forest and Semi natural areas	5070.995	80.59%
Water Bodies	613.838	9.76%

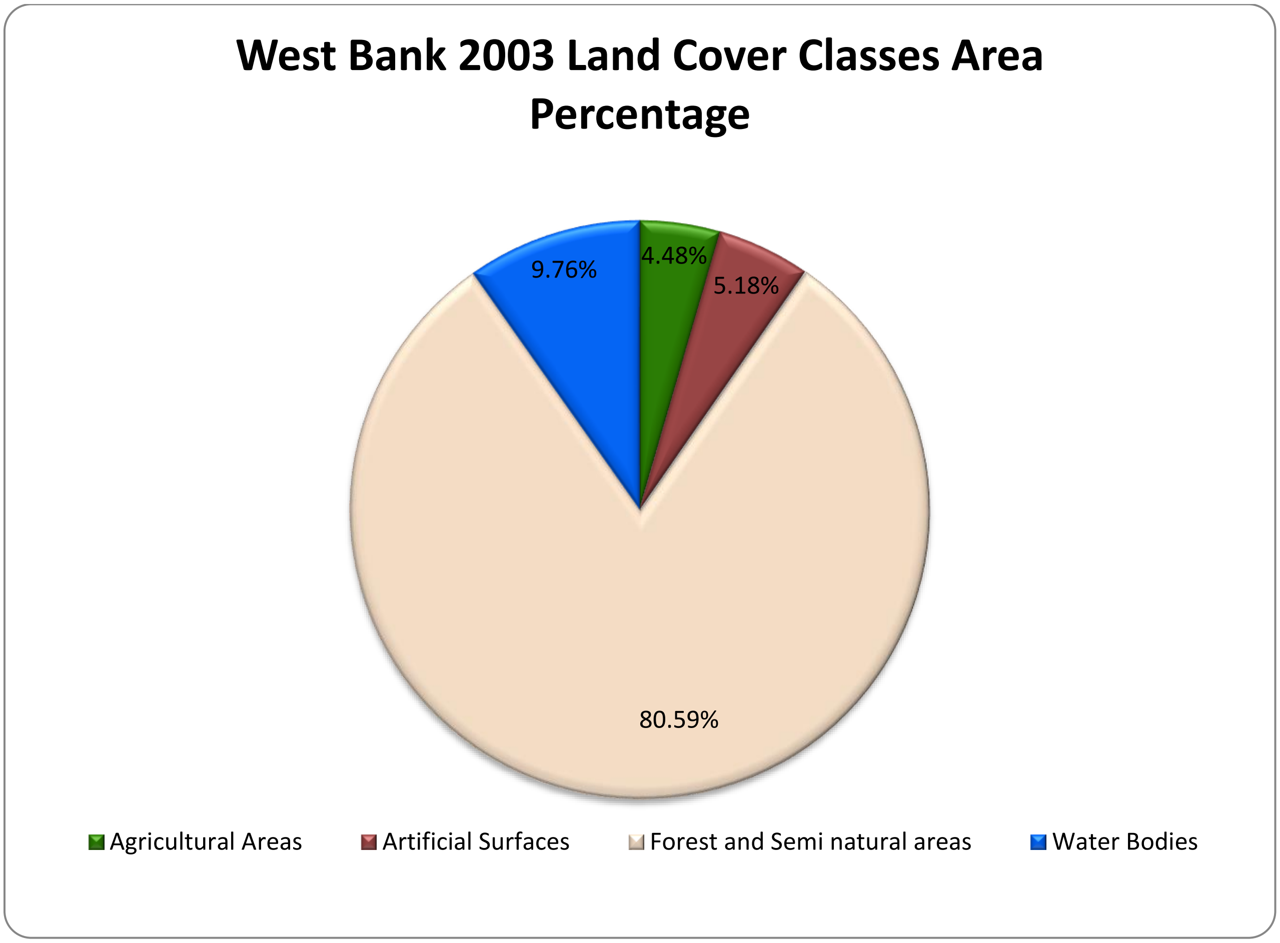


Figure 4. 23 West Bank 2003 Land Cover Classes Area Percentage.

For 2013 Image:

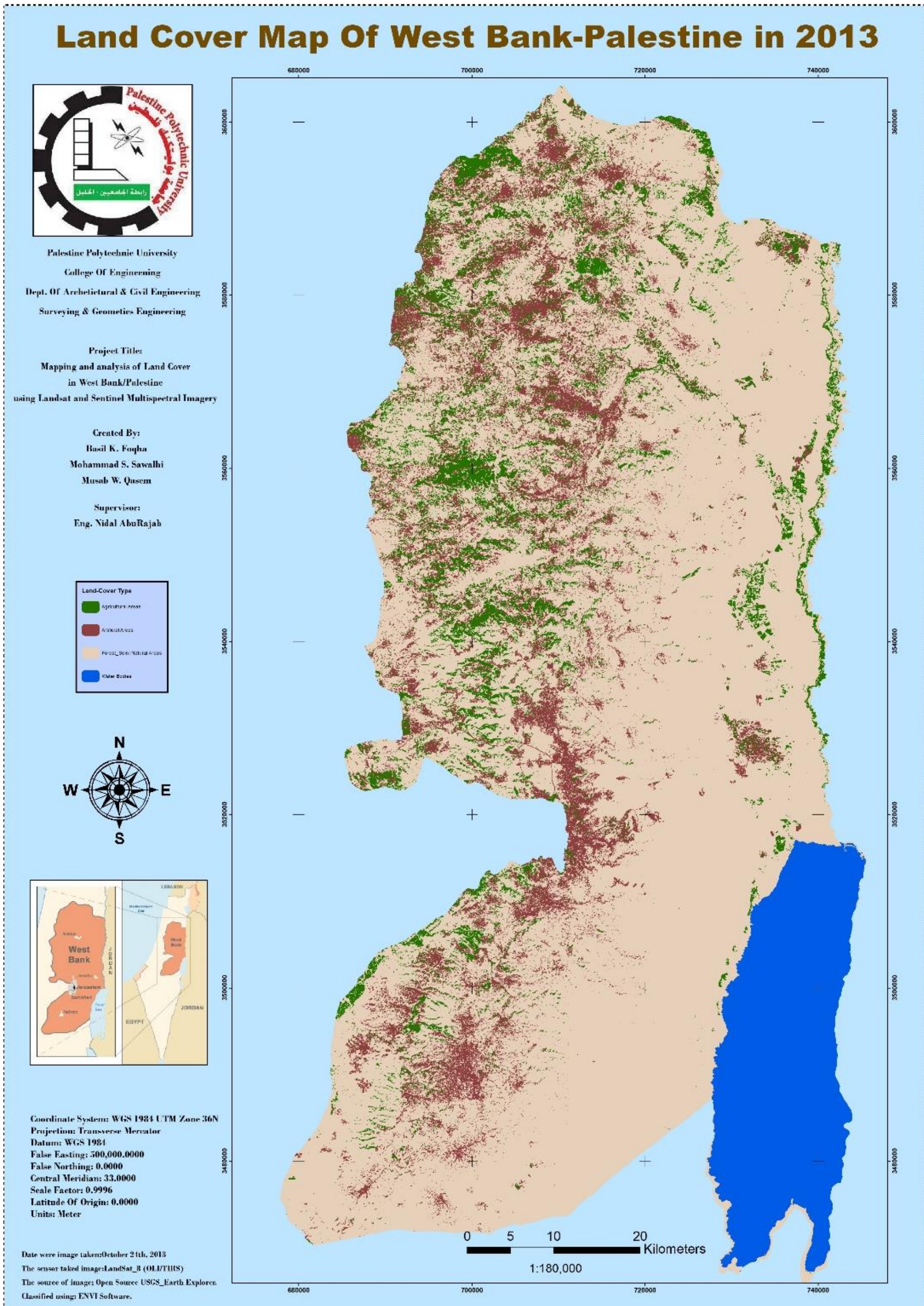


Figure 4. 24 Land Cover Map of West Bank-Palestine in 2013.

And the areas of the classes were:

Table 17 Area and percentage of classification results of 2013 image.

Class Name	Area (km2)	Percentage %
Agricultural Areas	533.93	8.49%
Artificial Surfaces	483.11	7.68%
Forest and Semi natural areas	4682.76	74.42%
Water Bodies	592.43	9.42%

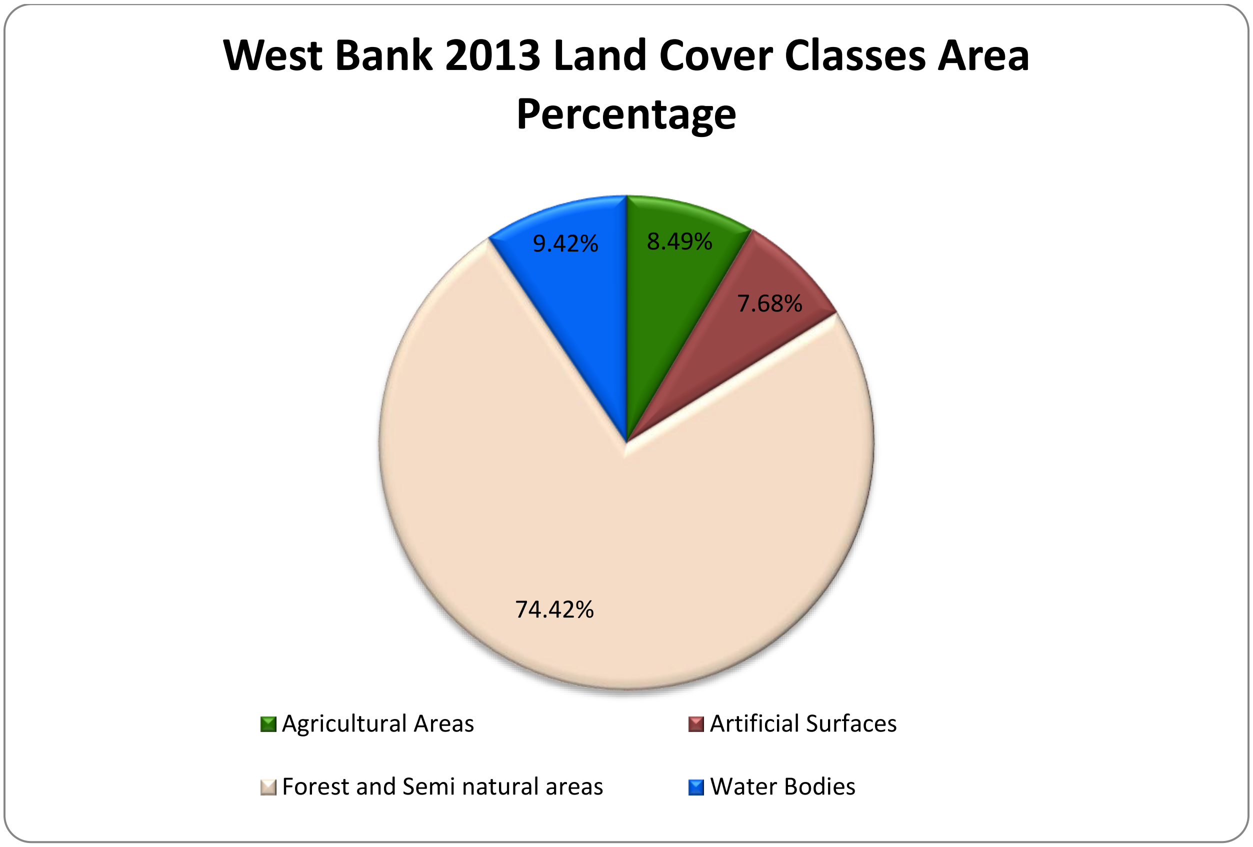


Figure 4. 25 West Bank 2013 Land Cover Classes Area Percentage.

For 2016 Image:

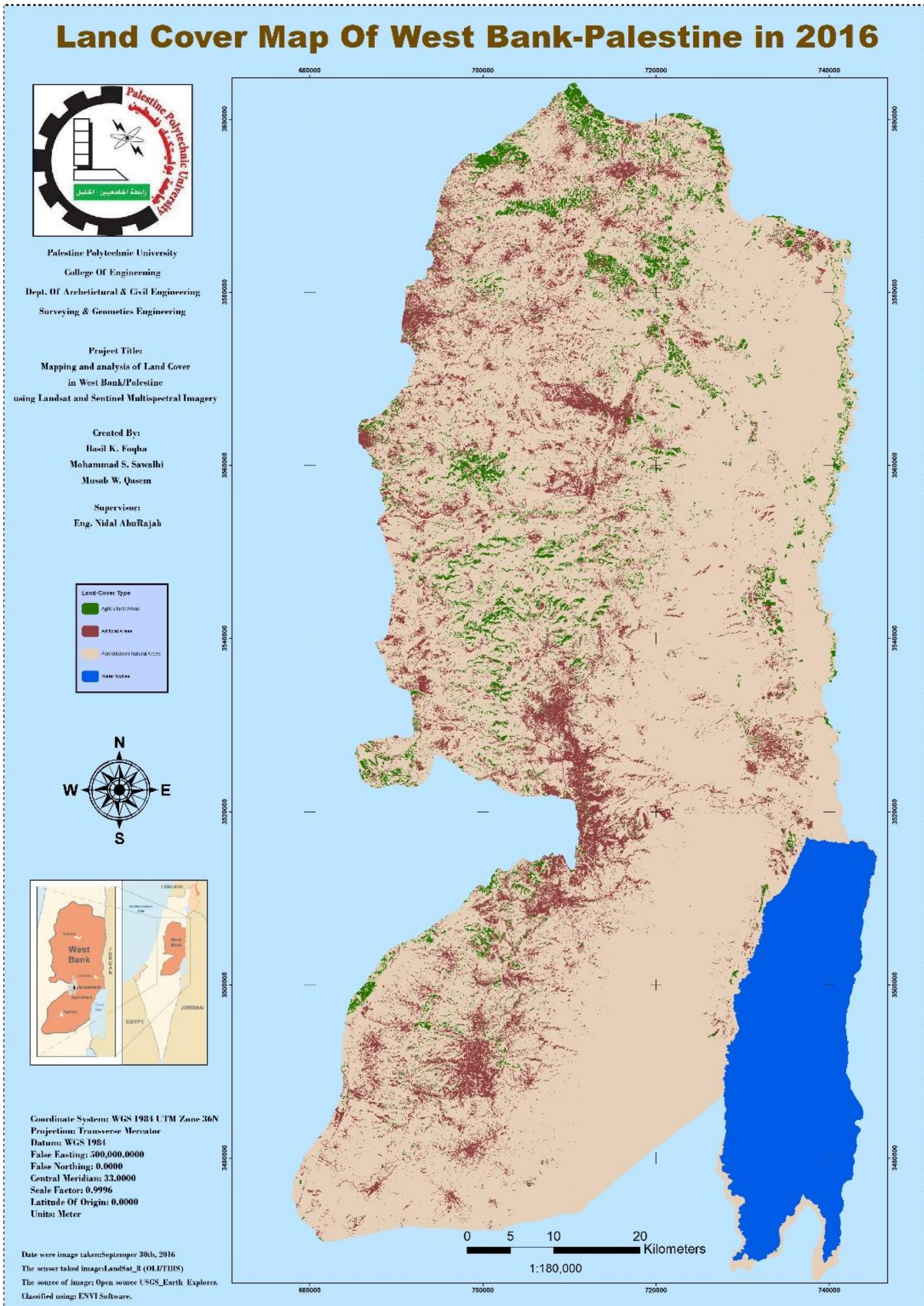


Figure 4. 26 Land Cover Map of West Bank-Palestine in 2016.

And the areas of the classes were:

Table 18 Area and percentage of classification results of 2016 image.

Class Name	Area (km2)	Percentage %
Agricultural Areas	270.73	4.30%
Artificial Surfaces	574.85	9.14%
Forest and Semi natural areas	4866.63	77.34%
Water Bodies	580.02	922%

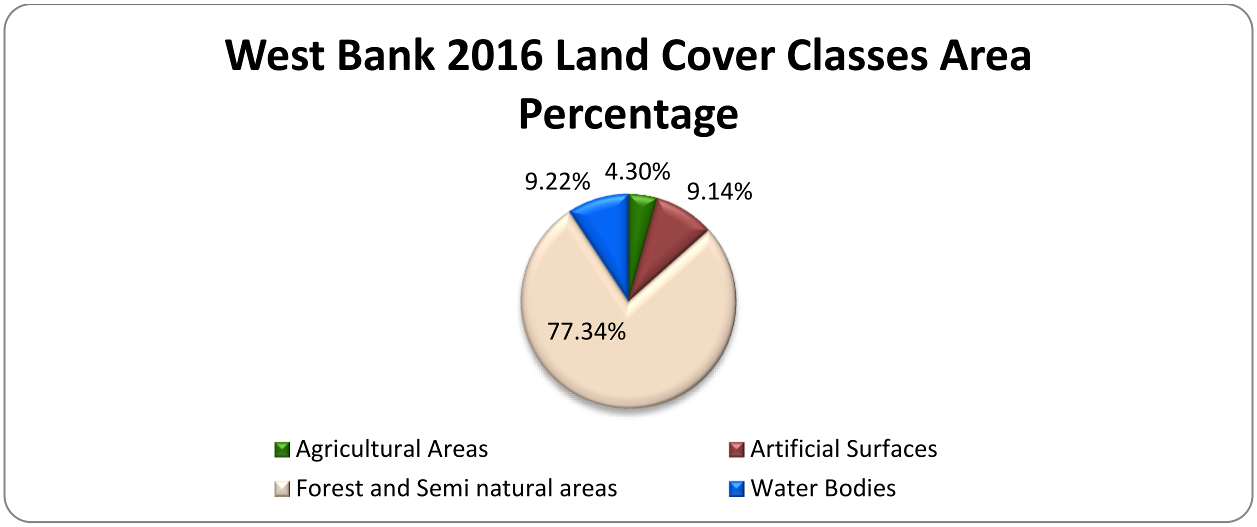


Figure 4. 27 West Bank 2016 Land Cover Classes Area Percentage.

For 2017 Image:

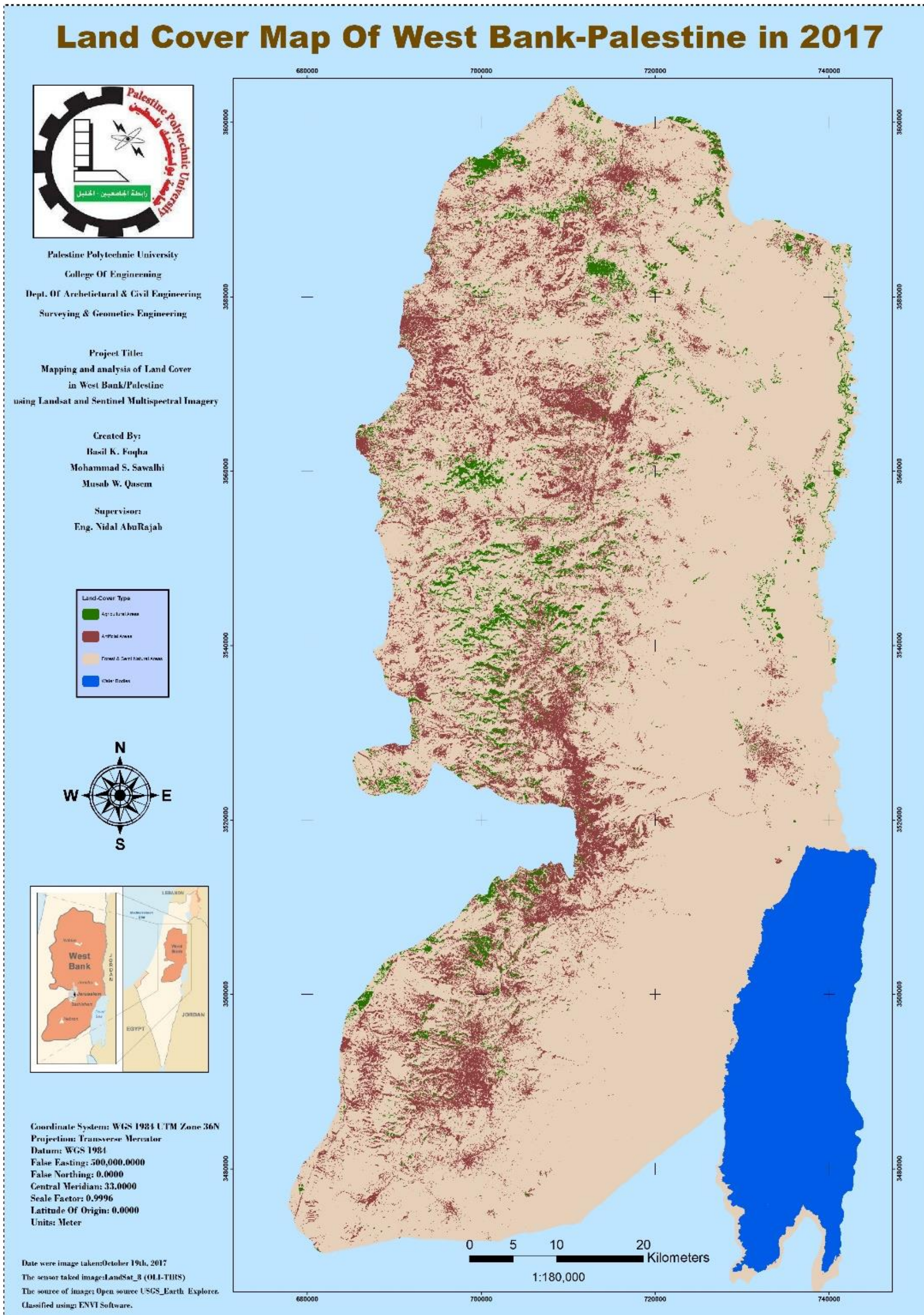


Figure 4. 28 Land Cover Map of West Bank-Palestine in 2017.

And the areas of the classes were:

Table 19 Area and percentage of classification results of 2017 image.

Class Name	Area (km2)	Percentage %
Agricultural Areas	231.40	3.68%
Artificial Surfaces	582.09	9.25%
Forest and Semi natural areas	4899.54	77.87%
Water Bodies	579.20	9.21%

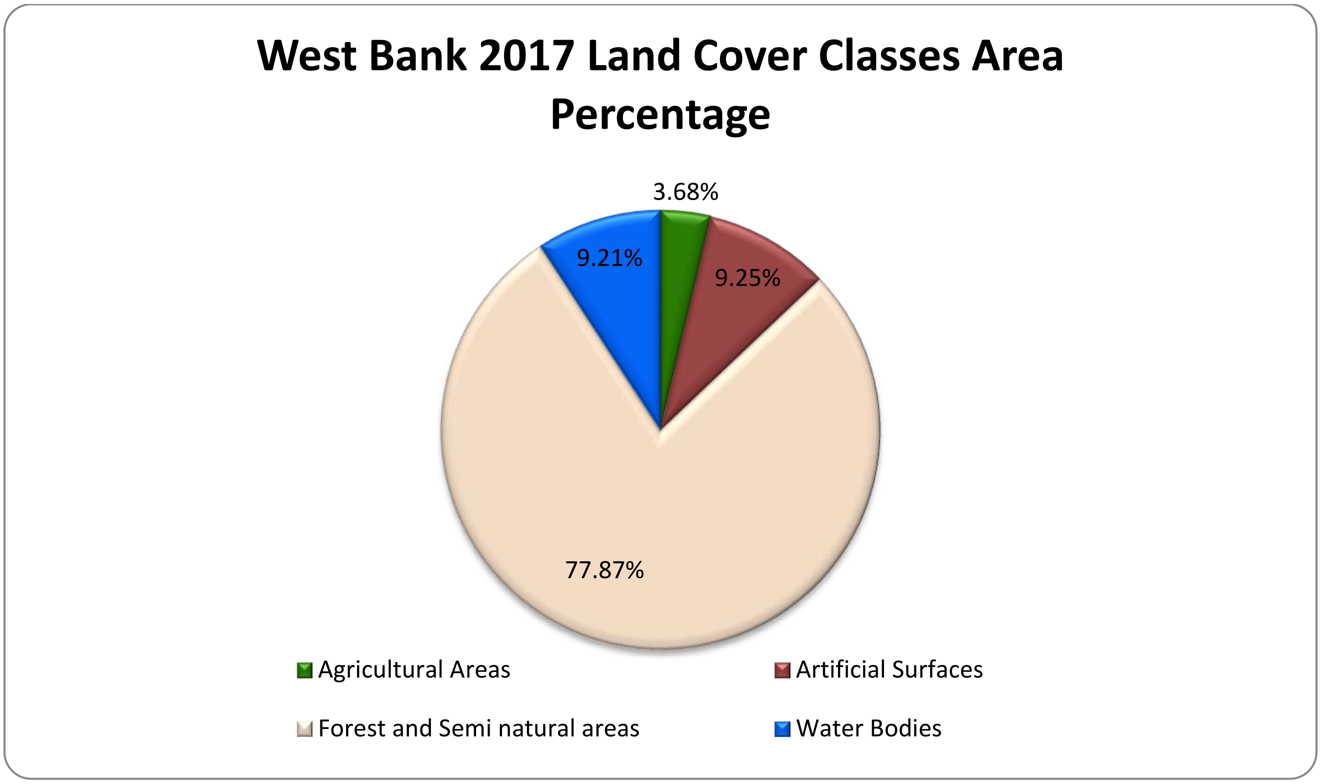


Figure 4. 29 West Bank 2017 Land Cover Classes Area Percentage.

For Sentinel 2016:

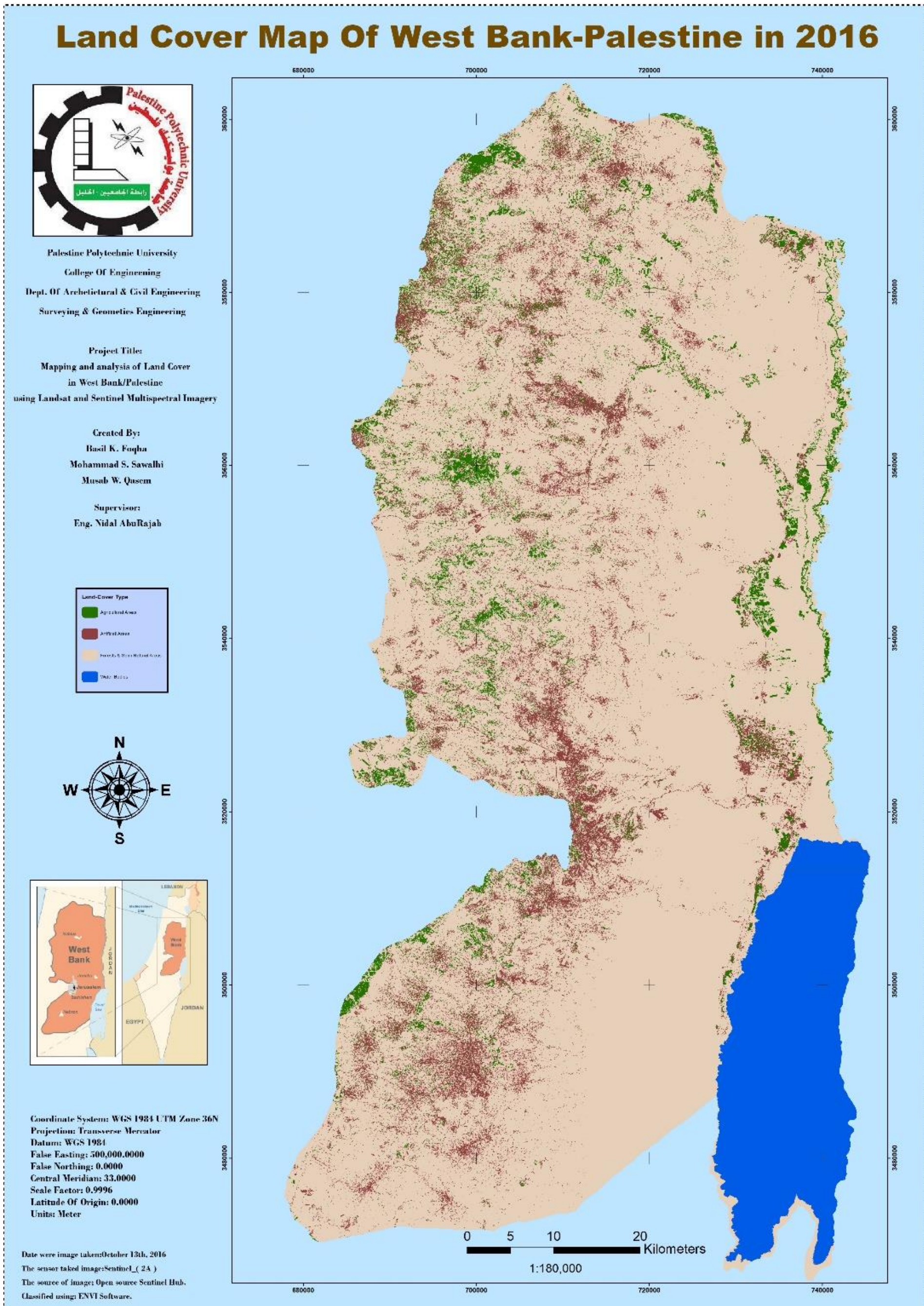


Figure 4. 30 Land Cover Map of West Bank-Palestine in 2016.

And the areas of classes were:

Table 20 Area and percentage of classification results of Sentinel 2016 image.

Class Name	Area (km2)	Percentage %
Agricultural Areas	307.55	4.89%
Artificial Surfaces	526.14	8.36%
Forest and Semi natural areas	4873.71	77.46%
Water Bodies	584.83	9.29%

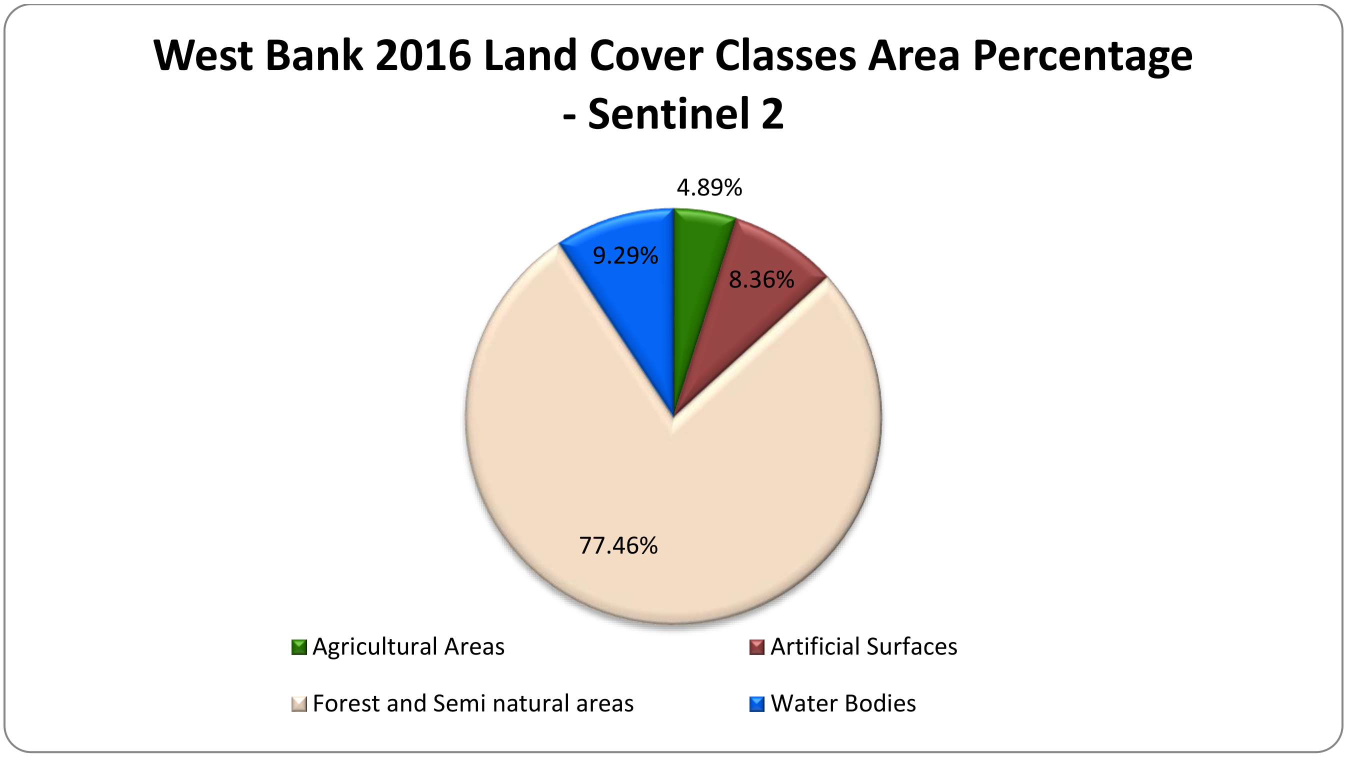


Figure 4. 31 West Bank Land Cover Classes Area Percentage - Sentinel 2.

For 2017 Sentinel:

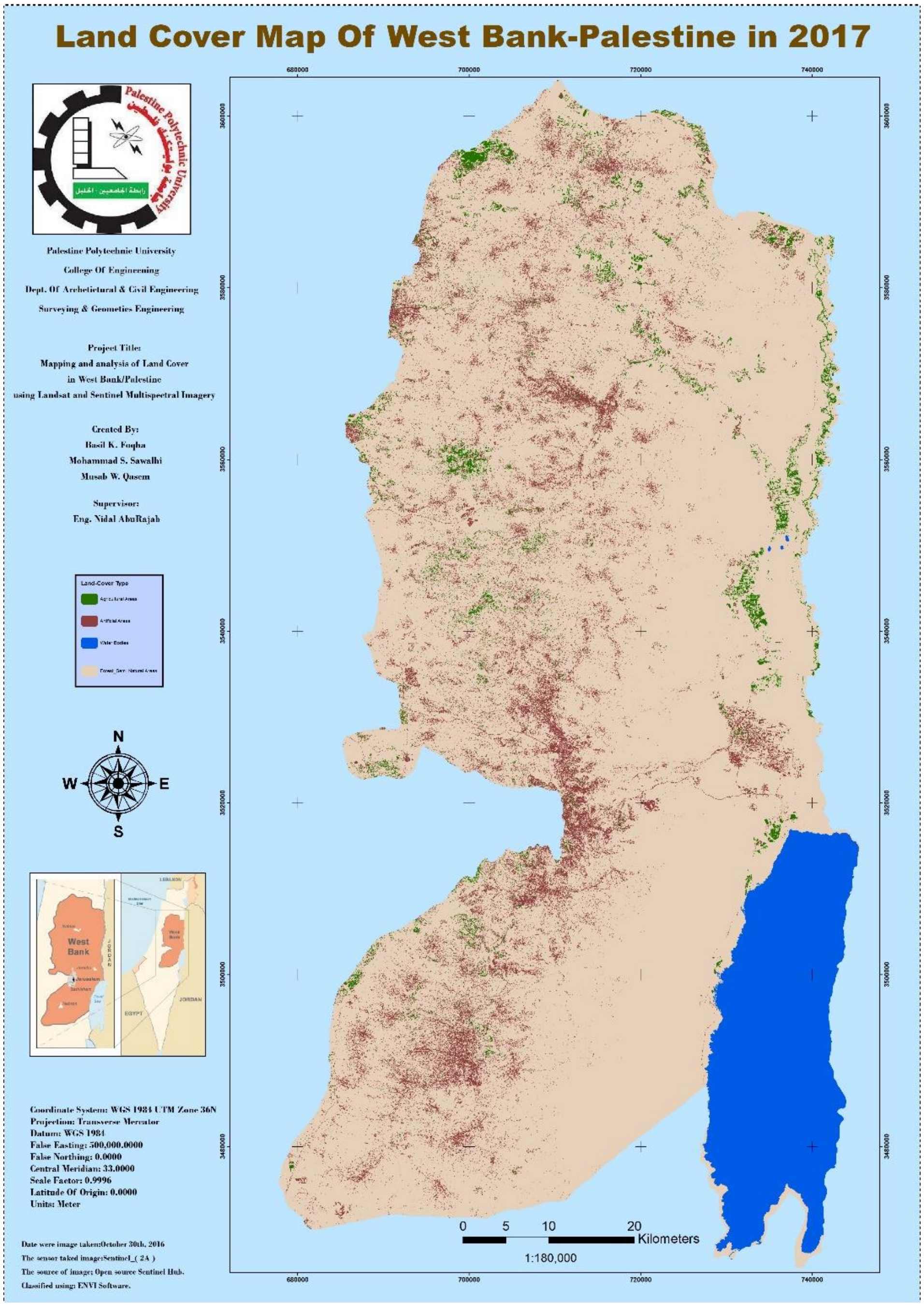


Figure 4. 32 Land Cover Map of West Bank - Palestine in 2017.

And the areas of the classes were:

Table 21 Area and percentage of classification results of Sentinel 2017 image.

Class Name	Area (km2)	Percentage %
Agricultural Areas	242.22	3.85%
Artificial Surfaces	533.19	8.47%
Forest and Semi natural areas	4932.45	78.39%
Water Bodies	584.37	9.29%

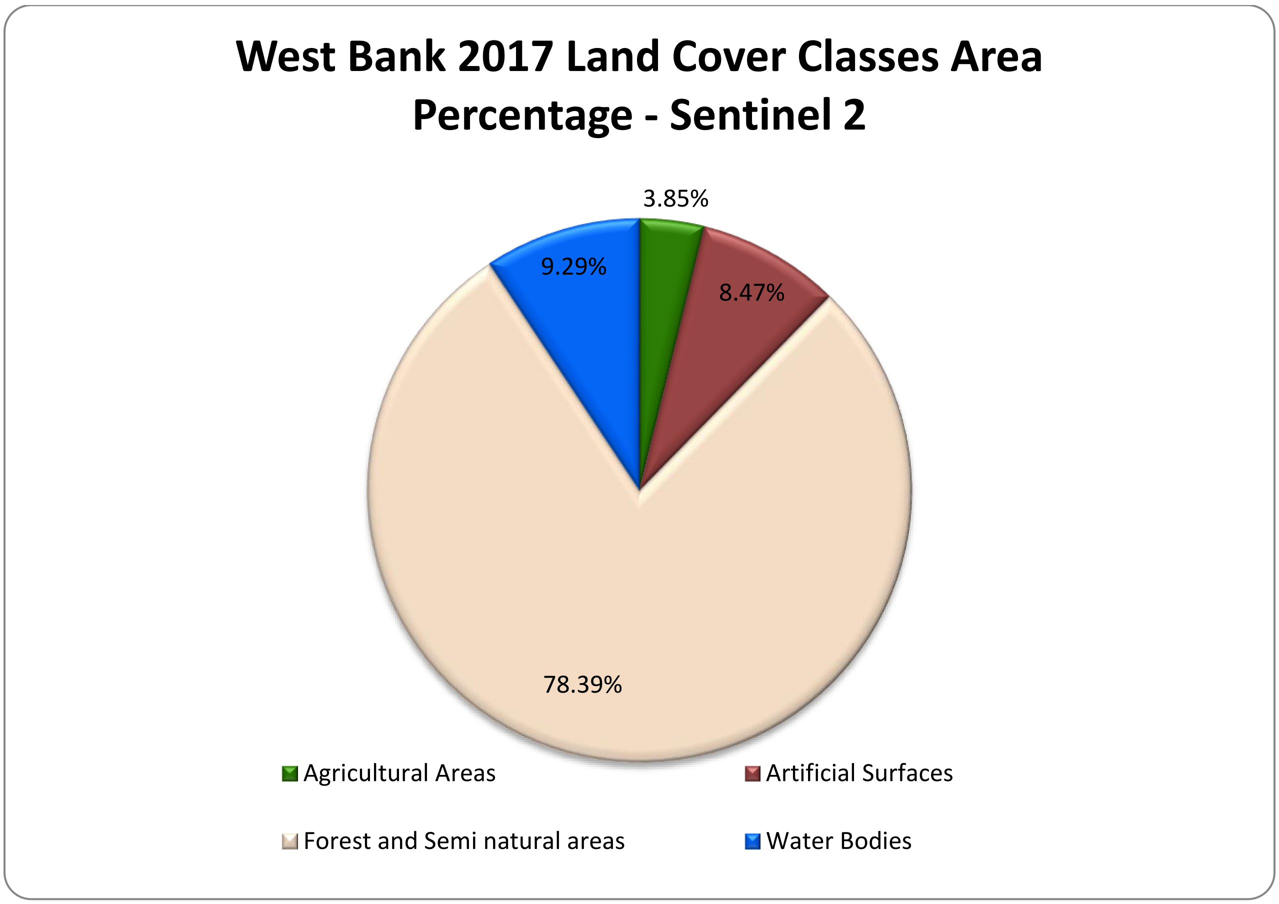


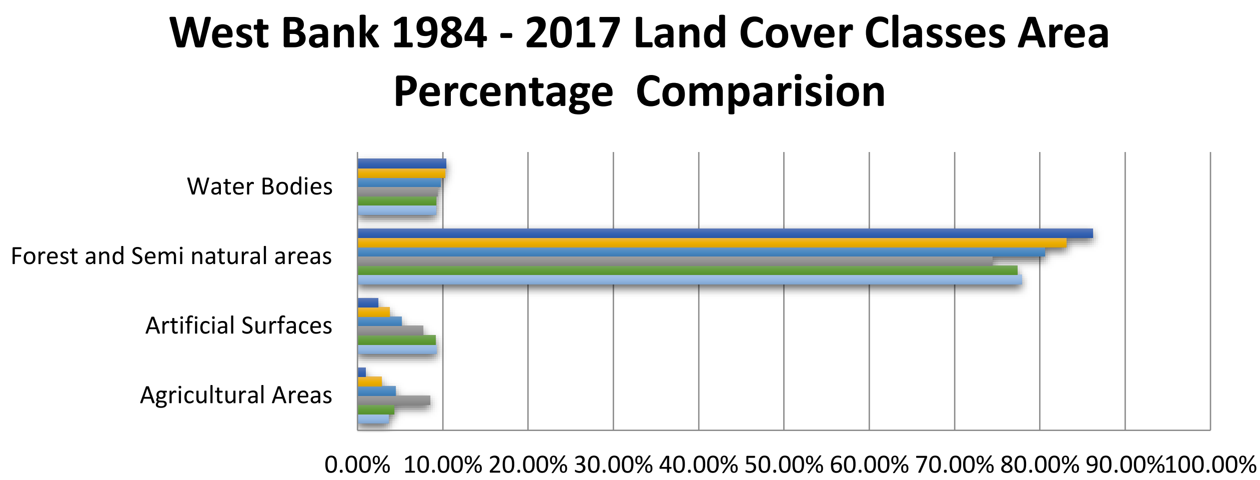
Figure 4. 33 West Bank 2017 Land Cover Classes Area Percentage - Sentinel 2.

4.4 Change Detection:

Looking at the statistical results and analysis, it is clear that the artificial areas increased through the time between 1984 and 2017, where the artificial area increased from 2.44% to 9.25%, which indicates that there was an urban growth in that period. In accordance to the PCBS (Palestinian Central Bureau of Statistics) the artificial areas in the West Bank in 2011 were approx. 297 km^2, and our statistics for 2013 shows that the artificial areas were 483 km^2 and that difference between the two statistics is a result of the 2 year gap, the fact that there are settlements not included in the PCBS statistics and also the fact that there are many illegal buildings in several areas like refugee camps which aren't included in PCBS statistics. And all of these factors are not such an obstacle for satellites.

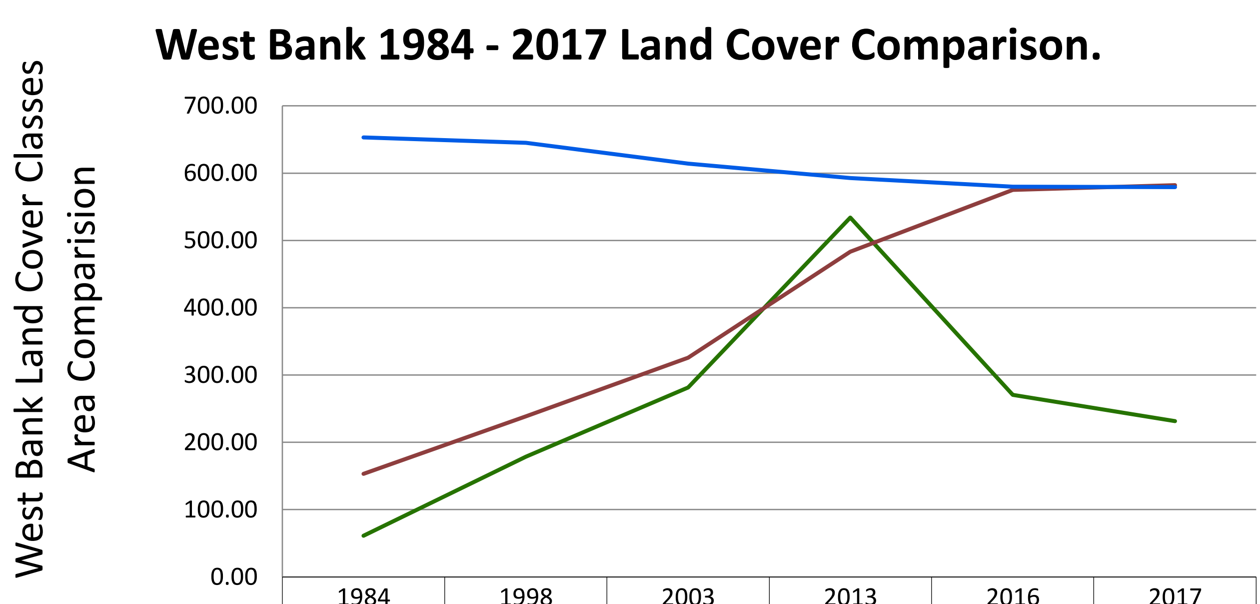
On the other hand, the Dead Sea and decreased within the same time period, where the Dead Sea area decreased from 10.38% to 9.21% and that's due to the Israeli occupations practices such as the salt extraction, and switching part of Jordan Rivers stream away from the Dead Sea.

As for the Forest and semi natural areas and the agricultural areas, the results were interchangeably increasing/decreasing. In general, forests and semi natural areas (open spaces) decreased from 86.21% to 77.87% and that's a result of the expansion of built up areas and somewhat the agricultural areas. The agricultural areas are slightly increasing from 0.97% to 3.68%, in 2013 the statistics indicates that there were rises and drops in agricultural areas, but that is only because of seasonal changes, but it is generally increasing.



	Agricultural Areas	Artificial Surfaces	Forest and Semi natural areas	Water Bodies
1984	0.97%	2.44%	86.21%	10.38%
1998	2.84%	3.79%	83.12%	10.25%
2003	4.48%	5.18%	80.59%	9.76%
2013	8.49%	7.68%	74.42%	9.42%
2016	4.30%	9.14%	77.34%	9.22%
2017	3.68%	9.25%	77.87%	9.21%

Figure 4. 35 West Bank 1984 - 2017 Land Cover Classes Area Percentage Comparison.



	1984	1998	2003	2013	2016	2017
Agricultural Areas	61.28	178.58	281.61	533.93	270.73	231.40
Artificial Surfaces	153.24	238.66	325.78	483.11	574.85	582.09
Water Bodies	653.01	644.81	613.84	592.43	580.02	579.20

Figure 4. 34 West Bank 1984 - 2017 Land Cover Comparison.

4.5 Accuracy Assessment:

The classification accuracy of remote sensing images presents the agreement between selected reference information and classified data. The determined classes are chosen from the original image. Confusion matrix is obtained by collecting data for each class randomly on the classification. The accuracy criterion can be calculated and evaluated with the help of this confusion matrix.

The confusion matrix was created for each classification and the overall, user's and producer's accuracy values of each class were analyzed to evaluate classification accuracy. The results were obtained, and it is clearly shown that the results are satisfying, with a range of overall accuracy of 92.99% - 98.59% and all kappa coefficient values above 0.90.

Table 22 Accuracy values for Images.

Sensor	Imagery	Overall Accuracy	Kappa Coefficient
Landsat 5	1984	96.29%	0.91210
Landsat 5	1998	92.99%	0.90621
Landsat 5	2003	96.87%	0.94383
Landsat 8	2013	95.70%	0.91866
Landsat 8	2016	96.00%	0.93148
Landsat 8	2017	96.65%	0.93902
Sentinel - 2	2016	98.59%	0.94457
Sentinel - 2	2017	97.90%	0.95566

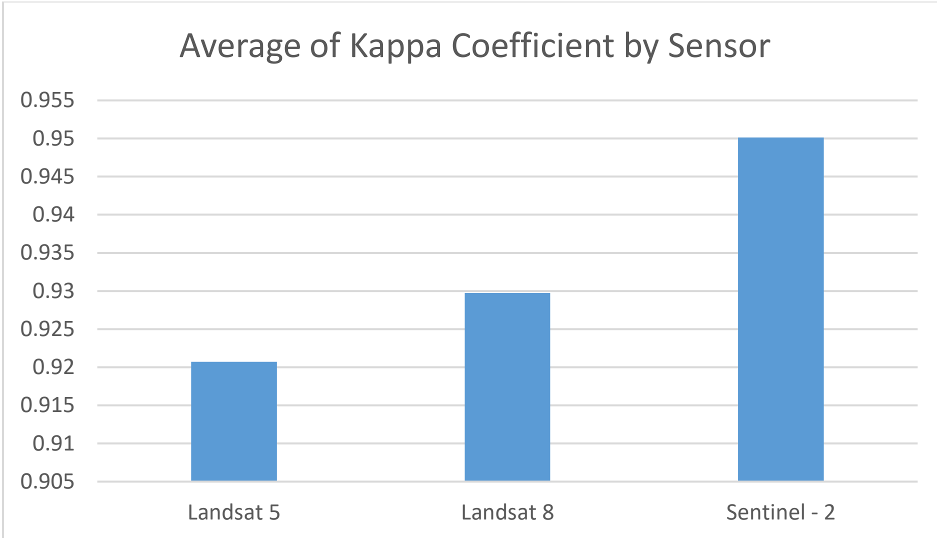


Figure 4. 36 Average of Kappa Coefficient by Sensor.

However, Sentinel-2 derived Land-Cover map presents better results than Landsat-8, and that's due to the spatial resolution difference between Sentinel-2 bands (10m) and Landsat-8 Bands (30m).

Table 23 2016 Class accuracy of Landsat-8 and Sentinel-2.

2016 Class Accuracy				
	Landsat-8 LULC		**Sentinel-2 LULC**	
	User's Accuracy	Producer's Accuracy	User's Accuracy	Producer's Accuracy
Agricultural Areas	88.34%	96.30%	98.46%	100.00%
Artificial Areas	98.97%	87.93%	86.73%	77.74%
Forest & Semi Natural Areas	99.86%	100.00%	92.32%	89.90%
Water Bodies	92.91%	80.56%	99.44%	99.92%
Overall Accuracy	96.00%		98.59%	
Kappa Coefficient	0.93148		0.95566	

Table 24 2017 Class accuracy of Landsat-8 and Sentinel-2.

2017 Class Accuracy				
	Landsat-8 LULC		Sentinel-2 LULC	
	User's Accuracy	Producer's Accuracy	User's Accuracy	Producer's Accuracy
Agricultural Areas	98.68%	91.84%	97.00%	100.00%
Artificial Areas	94.06%	83.06%	84.80%	68.72%
Forest & Semi Natural Areas	88.72%	96.33%	98.22%	99.13%
Water Bodies	99.83%	100.00%	99.39%	100.00%
Overall Accuracy	96.65%		97.90%	
Kappa Coefficient	0.93902		0.95566	

4.6 Conclusion:

Land-Cover Land-Use images are crucial for fast grown cities in order to understand the dynamics of urban growth. Satellite imagery is one of the main resources to monitor the changes on Earth, especially new generation Earth observation satellites such as Landsat-8 and Sentinel-2 can be obtained freely, and LULC images can be produced in a good temporal resolution. Temporal analyses of LULC help city planners and decision makers to improve the standards of the cities.

The recent launch of the Sentinel-2 sensor by the European Space Agency will increase open access to moderate-to high spatial resolution imagery for multiple applications. Compared to the spatial, spectral, and temporal resolution of satellites in the Landsat missions, the Sentinel-2 sensor presents better spatial resolution and additional bands in the red portion.

According to overall classification accuracies; it can be seen that, for both Maximum Likelihood Classification method, image classification accuracies of Sentinel-2 dataset is better than Landsat-8 dataset. But knowing that the accuracy assessment is pixel based; the confusion matrix and the kappa coefficient indicates that there is agreement between the classification and the image, but it doesn’t indicate that the statistics are certain. Therefore, the Sentinel-2 (10m) is more precise than Landsat-8 (30m) in spite of its high kappa coefficient value.

Finally, the growth of artificial areas in the West Bank is on account of agricultural and forest and semi natural areas, and it is mainly focused in the western areas of the West Bank. But in order to keep up with economical state there shouldn’t be on account of the agricultural areas, for the essential part that agriculture plays in the Palestinian economy.

The maps produced and statistics calculated of the land cover of the West Bank would be useful for planning a better future, and to forecast the obstacles -yet to come- through the analysis of these maps.

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