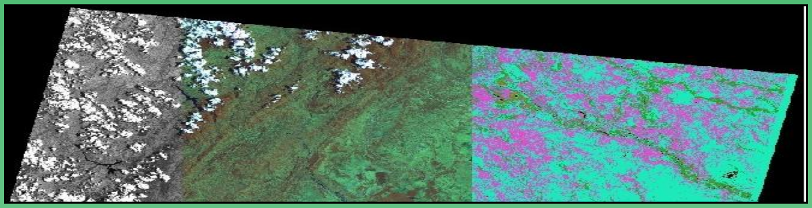
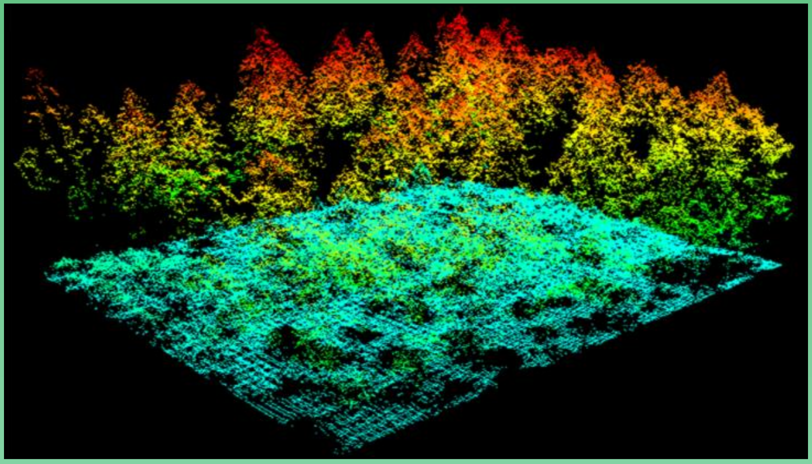
Ethiopian Environment and Forest Research Institute

TECHNICAL MANUAL ON THE USE OF SATELLITE IMAGES IN ECOLOGICAL STUDIES



QGIS INTERFACE



Prepared by

Nesibu Yahya
Solomon Mulat
Melaku Getachew

February 2019
Addis Ababa, Ethiopia

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Contents

Preface

Remote sensing is an important technology to support ecological studies. In Ethiopia, many ecological studies are undergoing in research and higher learning institutions at a regional and national scale. However, the techniques of remote sensing were underutilized in many ecological types of researches in Ethiopia. We are strongly believed that ecological studies will be improved one-step ahead in Ethiopia, if the techniques of remote sensing are applied. Therefore, we developed this technical manual to create a link between ecology and remote sensing. This manual aims to show the theoretical background and practical techniques on the use of satellite imagery in ecological studies.

The manual will have adequate roles for researchers and student in higher learning institutions to fill up their skill gap on the use of satellite image analysis in QGIS environment. In addition, it is also our hope that this manual will support researchers and practitioners to apply the concept and principle of image classification on ecological studies and management.

This manual is not intended, primarily, to introduce the basic concepts of remote sensing. Indeed, we started with a brief introduction and background theories of satellite image as a brainstorm. The manual is, mainly, focuses on the utilization of remote sensing data for ecological studies. Moreover, advanced procedures of image classification are included in the manual. Therefore, the manual is more understandable for those who have basic knowledge of remote sensing and the skill of using remote sensing software packages.

We hope it will help readers to improve their knowledge and skill on the technique of satellite image acquisition, processing and classification in QGIS software program.

How to use this manual

The first two chapters of this manual describe the theoretical background and ecological remote sensing. The first chapter covers a brief introduction to the science of remote sensing and GIS. The second chapter explains the basic theoretical lesson on the application of remote sensing in ecological studies. Besides the first two chapters, all the remaining chapters of the manual illustrate the systematic and practical exercise that shows image classification and processing using QGIS.

During the practical section, it is necessary to install QGIS software and Google Earth to exercise practically. Even if these software programs are free of charge, it is recommended to download from the official websites of the provider to avoid the risk of a computer virus. Practicing the exercises using sample remote sensing data is highly recommended. Thus, we suggest application of the acquired practical knowledge from the manual to solve the actual problems in your specific area of expertise.

1. Brief introduction to GIS and remote sensing

Understanding the principles and terminologies in remote-sensing data is relevant prior to satellite image manipulation. In this chapter, we introduce the basic terms of remote sensing and GIS. It starts from the simple definition and continues to describe basic principles and concepts of remote sensing and related spatial data. Finally, the chapter deals with software programs of remote sensing and the sources of remote sensing data, particularly satellite imageries.

1.1. Definition of GIS and remote sensing

The acronym GIS stands for Geographical Information System. There are plenty of definitions given for GIS and remote sensing. We will use the following well-known definitions of remote sensing and GIS for this manual. According to ESRI, geographic information system (GIS) is a computer-based tool for mapping and analyzing things that exist and events that happen on earth. GIS technology integrates common database operations such as query and statistical analysis with the unique visualization and geographic analysis benefits offered by maps.

Remote sensing is defined as “a science (and to some extent an art) of acquiring information about the Earth's surface without actually being in contact with it. This is done by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information.” (Jensen, 2007).

Our eyes, photo camera, remote control, x-ray machines, satellites are excellent examples of remote sensing device.

1.2. Principles of remote sensing

In remote sensing, there are different principles that should be understood before conducting satellite image processing and classification. These principles will be covered in the subsequent sections.

Radiation, reflection, absorption and transmission

In remote sensing, the incoming energy that arises from the sun and interacts with earth surface is called **radiation**. When the incoming radiation from the Sun reaches the feature of the Earth, some of the energy at specific wavelengths can be **reflected, absorbed and transmitted** through the surface material. **Absorption** is a situation when the incoming radiation (energy) is absorbed into the surface. **Transmission** happens when the incoming radiation passes through a target or surface. **Reflection** occurs when the incoming radiation "bounces" off the target and is redirected back.

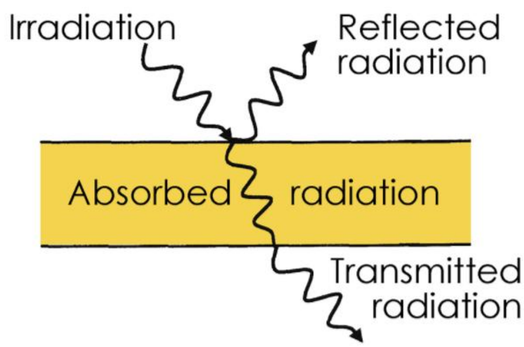


Figure 1: Different patterns of radiation

Raster and Vector

In GIS, the two primary types of spatial models are vector and raster. Certainly, understanding the difference between the two models is prerequisite in performing of any spatial analysis using GIS. Real-world features are represented by point, line and polygon in a vector model. Vector data is mostly used to represent features, which has a discrete boundary such as a parcel of lands, rivers and town. On the other hand, grids of a pixel in the raster model represent the features in the real world. In this case, each pixel value in a raster data (e.g. satellite image) has at least a red, green and blue value. Similarly, each pixel of the Digital Elevation Model (DEM) represents a specific elevation value. Rather, the raster data model has applied to model either a discrete or a continuous element of the real world. GIS software used different computer formats in the visualization of raster and vector data model on a computer system (Table 1).

Table 1: Possible list of computer formats for raster and vector models.

Raster format	Vector format
• **GeoTIFF** – TIFF variant enriched with GIS relevant metadata • **ADRG** – ARC Digitized Raster Graphics • **RPF** – Raster Product Format, military • **DRG** – Digital raster graphic • **ECRG** –Enhanced Compressed ARC Raster Graphics • **Esri grid** –ASCII raster formats used by ESRI • **IMG** – image file format used by ERDAS • **MrSID** – Multi-Resolution Seamless Image Database • **JPEG2000** – Open-source raster format	• **Shapefile** – Most popular vector data developed by Esri • **KML** – Keyhole Markup Language a XML based • **Spatialite** – is a spatial extension to SQLite, • **GML** – Geography Markup Language – Open GIS format used for exchanging GIS data • **GeoJSON** – a lightweight format based on JSON, used by many open source GIS packages • **GeoMedia** – Intergraph's Microsoft Access based format for spatial vector storage • **Simple Features** – specification for vector data

1.3. Characteristics of remote sensing

Pixel size

Raster image is the most important product of remote sensing. It stores information in the smallest unit of the image called pixels. Usually, pixels (sometimes referred to as a cell) have a rectangular shape and contain a unique color information that comes together to create the entire raster image. The sizes of these pixels determine the resolution of the image.

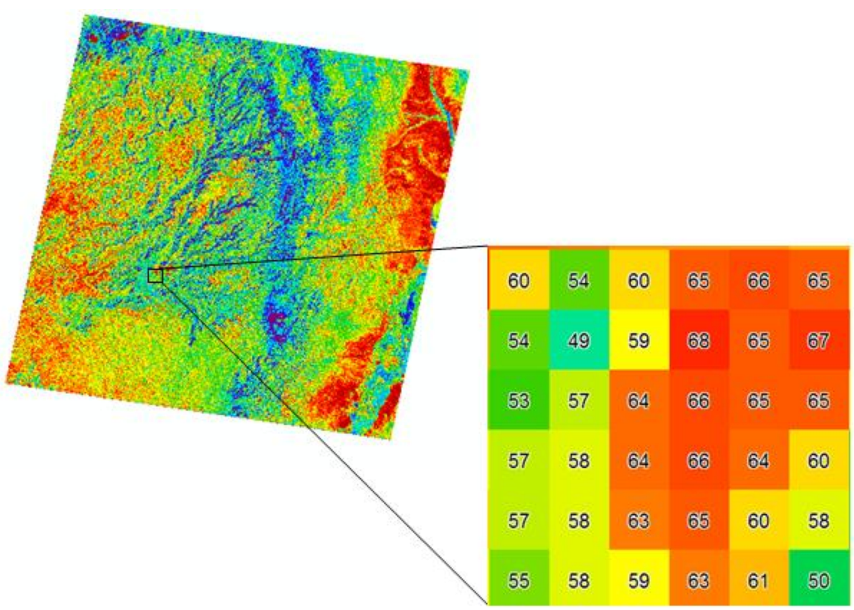


Figure 2: An example of raster image with pixel and digital numbers

Digital Number

In a digital image, each of the smallest units of the image (pixel) contain a numeric value assigned to each individual pixel. These numeric values are known as Digital number (Figure 2).

Band or Channel

In remote sensing, the electromagnetic spectrum is the continuous range of electromagnetic radiation from gamma rays to radio waves. The set of adjacent wavelength with a common characteristic in this electromagnetic spectrum are referred to as Band (Channels). For instance, the wavelength range from 0.45µm to 0.51µm (µm = micrometers) stands for a single band in visible light, which represent the blue band in the Landsat 8 image.

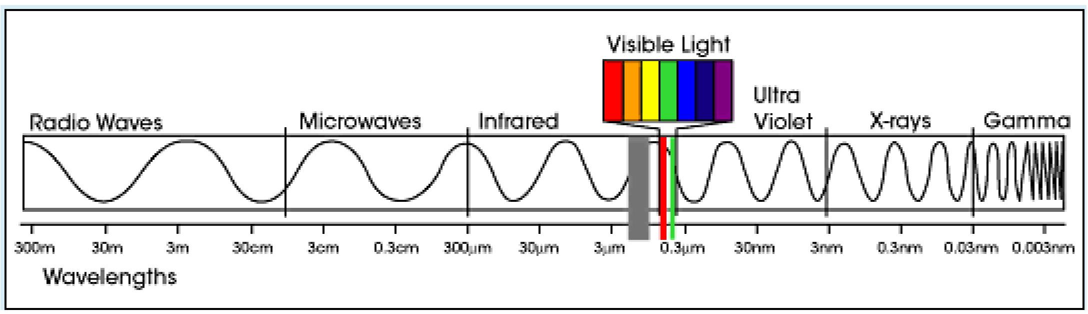


Figure 3: Electromagnetic spectrum and their range of wavelength.

Spatial, spectral and temporal resolutions

The spatial, spectral and temporal resolutions are the most important characteristics of satellite images.

Spatial resolution (ground resolution) is the ground surface area captured and creates one pixel in the satellite image. For instance, spatial resolution of Operational Land Imager (OLI) sensor in Landsat 8 image is 30 meter.

Spectral resolution is the number and width of spectral bands or range of wavelength in which the device can sense. The Landsat OLI sensor has eleven spectral bands while Landsat TM has only seven spectral bands.

Temporal resolution is a measure of frequency by which a sensor revisits the same part of the Earth's surface. The temporal resolution (recycle period) of Operational Land Imager (OLI) sensor in Landsat 8 image is 16 days. This means Landsat sensor recapture the image of specific part of the Earth's surface in every 16 days.

1.4. GIS and Remote sensing data and software program

Common satellites/sensors

At the global level, different satellites may have different missions. It can be launched with a mission to monitor and forecast environmental management such as weather condition (GOES, NOAA and AVHRR), land observation (Landsat, SPOT, Sentinel and IRS), Marin and ocean observations (Nimbus-7 satellite, MOS, SeaWiFS). There are also other sensors such as FLIR, RADAR and LiDAR for broader application of environmental monitoring and forecasting. Several specific characteristics of frequently used sensors (primarily satellite systems) in different ecological study and management are presented in Table 2.

Table 2: Characteristics of frequently used sensors/satellites

Sensor/ Satellite	Number of spectral bands	Spatial Resolution	Cycle period (temporal resolution)
GOES	5	1-41 km	Geostationary
NOAA /AVHRR	5	1.1 km	1 day repeat cycle
Landsat TM	7	30 m	16 day repeat cycle
Landsat OLI	11	30 m	16 day repeat cycle
MODIS	Multi-spectral	250-1000m	1day repeat cycle
IKONOS	4	4 m	5 day repeat cycle
Sentinel-2	13	10-60 m	15-30 day repeat cycle
SPOT 7	5	2.2-8.8 m	1-5 days repeat cycle

Open sources of geospatial data

Geospatial data are more deficient to conduct environmental studies. Some of these data are more expensive and difficult to afford by developing countries like Ethiopia. Particularly, purchasing high and medium resolution satellite images are not easy for researchers and practitioners. Therefore, the possible solution is searching freely available geospatial data from the internet. In order to reduce this gap, several institutions are providing different free GIS and remote sensing data at global and regional scales. We indicated limited sources of open geospatial data providers in table 3 for the purpose of this manual, but the reader can explore further to get more providers.

The free geospatial data are important to minimize cost. However, these data have a limitation on the level of spectral and spatial resolution. This limitation has significantly reduced the accuracy of any analysis results from free satellite images.

Table 3: Possible list of open sources of geo-spatial data

Organization/Provider	**Type of the data**	**URL**
DIVA-GIS	Country level raster and vector data	http://www.diva-gis.org/gdata
USGS	Raster data usually Landsat satellite images	https://earthexplorer.usgs.gov/
Worldclim-Global Climate Data	Climate raster data	http://www.worldclim.org/
ESRI	Country vector data	https://hub.arcgis.com/pages/open-data
UNEP	National, sub regional, regional and statistics or as geospatial data sets (maps)	http://geodata.grid.unep.ch/#
Global Land Cover Facility	Global scale land cover data	http://landcover.org/
ISRIC Soil Grid Information	Soil raster data	http://www.soilgrids.org

QGIS and remote sensing

QGIS is an open source GIS software facility for geospatial data manipulation, analysis and mapping. It is very powerful GIS software, which enables us to conduct spatial analysis. The software has many platforms for domain-specific analysis, and is highly applicable for environmental analysis such as ecological and hydrological modeling, mapping of ecosystem services and risk of forest fire. Compared with other GIS softwares, QGIS provides the following benefits.

- Free and open source
- Efficient and effective data handling and storage facility,
- Powerful graphics for presentation
- Very simple Graphical User Interface (GUI)
- Rapid response by developing and integrating demand driven Geo-processing tools

2. Introduction to ecological studies using remote sensing

In the previous chapter, we discussed the principles and terminologies related to remote sensing. This chapter presents the idea of ecological remote sensing, which integrates the science of remote sensing with ecology. The basis of the relationship between remote sensing and ecology will be described. The chapter begins with the simple definitions of ecology and remote sensing, and gives emphasis on the study of ecological remote sensing. Here, several categories of ecological remote sensing and techniques of its application are briefly illustrated.

2.1. Definitions of ecology and ecological remote sensing

The definition of ecology is "the scientific study of the interactions of organisms between each other and their environment" (Begon *et al*, 1990). Ecological studies are essential to understand, describe, predict and monitor the relationship of living organisms with their surrounding environment.

Several data collection approaches are implemented in generating ecological information. Ground survey and remote sensing data collection methods are the two main approaches to investigate the ecological interaction. Although the exact ground survey is required in getting of accurate results, it is more labor and time intensive compared to remote sensing approach in different ecological studies. Thus, a remote sensing technology has become an important mechanism to generate more ecological information with low cost and labor. Particularly, satellite remote sensing is constructive at generating consistent observation of ecological changes ranging from local to global scale.

Therefore, the term ecological remote sensing is used to represent the study of ecology, which involves remote sensing technology. There are different areas of the ecosystem that can be supported by remote sensing such as modeling of species distribution, species movement, ecosystem process, climate change, protected areas, ecosystem services, and land use change (Robert *et al*, 2015).

However, a divergence between ecology and remote sensing technology is becoming a major challenge. For this reason, remote sensing specialists focused on the basic science of remote sensing in the generation of advanced technologies, rather than implementing the technologies in ecological studies. Ecologists, then again, are doing their ecological researches and developments using very conventional way in the presence of advanced remote sensing approaches, which could assist ecological studies. Thus, remote sensing technologies are underutilized within many ecological communities. Turner *et al* (2015) listed data continuity, data affordability, and data accesses as the major factor to the under utility of remote sensing data such as satellite data within ecologist. In order to create opportunities for the advancement of both disciplines (remote sensing and ecology), promoting an interdisciplinary effort is needed among these communities (Pettorelli *et al*, 2014).

2.2. Areas of ecological remotes sensing

Ecological remote sensing is not only the study of land-cover classification as many ecologists judge, but also it is manifold. Turner *et al* (2003) categorize approaches of ecological remote sensing study into two broad categories. Both categories will be discussed below.

- **Direct approach** involves an observation of vegetation categories and even animal populations in the ecosystem from remotely sensed images such as the application of high spatial resolution and hyperspectral sensors.
- **Indirect approach** involves the derivation of several environmental parameters from remotely sensed images as proxies for the ecological process.

Then again, Kerr and Ostrovsky (2003) classify the areas of ecological remote sensing into the following three classifications.

- **Land cover classification:** this class of ecological remote sensing is useful in the identification of several vegetation types and derivation of habitats. It enables to model the distribution of individual species and/or sets of species using remote sensing techniques over a large area.
- **Integrated ecosystem measurement:** this class of ecological remote sensing dealt with measurement and estimation of several ecosystem functions at different spatial extent. Derivation of a biophysical parameter such as Leaf Area Index (LAI) and Net Primary Productivity (NPP) using Normalized Difference Vegetation Index (NDVI) is the best example of this ecological remote sensing class.

- **Change detection:** this class of ecological remote sensing is important to monitor ecological changes through time such as temporal change of climate and habitat loss. Such study needs acquisition of continues satellite image over time and a significant area.

This manual mainly deals with the first class of ecological remote sensing (Land cover classification). We prioritize land cover classification in this manual due to the considerable recent interest in this regard. Land cover data is used as the main source of other ecological remote sensing studies. Many ecological studies such as ecosystem service mapping, habitat mapping, and inventory and monitoring of forest and its carbon dynamics, are highly dependent on land cover classification data.

2.3. Spatial scale in ecological remote sensing

The spatial scales at which ecological phenomena are studied are the important characteristics to determine the quality of ecological data. The detail of spatial scale is an influential factor in the generation of ecological remote sensing data. For instance, if using data from multiple sensors (assuming that they have different spatial detail), the resulting ecological information will differ. In ecological studies, the imagery of fine resolution is crucial over coarse resolution imagery to generate accurate ecological information through detection of small objects (Alpin, 2005).

Currently, several satellite images are available to study ecological phenomenon at a different scale ranging from landscape level to species level. Wang *et al* (2010) attempted to list the following remote sensing instruments/images categories, which have different spatial scales and can be applied in several ecological remote sensing.

- **Coarse spatial resolution**

Coarse spatial resolution images have been implemented in several ecological investigations at a national or global scale. All images that have a spatial resolution more than 30m are included under the coarse resolution. **MODIS** and **NOAA /AVHRR** are the two important coarse space born images. At the landscape level, coarse resolution images are important to estimate deforestation and forest fragmentation in global ecological biomes. In addition, it is important to study the current and to model the future global climatic conditions.

- **Medium spatial resolution**

This category of spatial resolution involves a medium resolution detail to study ecological phenomena. This category of remote sensing instrument produced an image, which has a spatial resolution ranging from 10m to 30m. **Landsat, SPOT HRV** and **Sentinel** images are the most popular instrument in this category, which are used in an ecological application. In most cases, satellite images from this category used to study ecology at the landscape (i.e. at larger) scale. For instance, land cover change at landscape scale is the most popular ecological study using these instruments. It is applicable, however, to study species-specific ecological studies to some extent. Thus, it can produce accurate results in the identification of different species.

- **High-spatial resolution**

Since the level of accuracy from coarse and medium resolution images are getting insufficient for most species-specific ecological investigation, the new generation of high spatial resolution has emerged. The high spatial resolution contains very fine resolution pixels, which can identify very small objects and organisms on the Earth. The satellite images under this category have resolution ranges from 0.5m - 10m. Instruments such as **SPOT-5**, **IKONOS**, **QuickBird**, **OrbView-3** can produce high spatial resolution image in the commercial domain. The special benefit of this category in the ecological study is the identification and characterization of small objects and species in the ecological system. As a result, it provides accurate data, which enable to describe detail ecological phenomena.

- **LiDAR**

Light Detection and Ranging (**LiDAR**) is an active remote sensing technology that uses a laser technology to illuminate a target object and a photodiode to register the backscatter radiation. It enables to provide a high spatial resolution image of horizontal and vertical information (Lim *et al*, 2003). **LiDAR** is an important laser technology to enhance the accuracy of different ecological researches. For instance, **LiDAR** technology is applied in bathymetry, forestry and biodiversity science and conservation. In particular, it provides better spatial information in forestry science to produce information on forest structure, species distribution and above ground biomass.

In general, all the above categories of spatial resolutions are applied in ecological studies. In this manual, however, we will focus on the medium resolution images. Although **LiDAR** has high spatial resolution, it has a limitation of high cost, which is difficult to afford by developing countries like Ethiopia. Therefore, the medium resolution is important to optimize the tradeoff between the level of accuracy and the amount of cost.

2.4. Techniques in ecological remote sensing

There are several techniques of remote sensing in the investigation of the ecological process. In practice, these techniques can be incorporated to achieve a single objective. For instance, in order to produce a single land cover map of the specific area, we can combine the techniques image classification and vegetation index. Wang *et al* (2010) selected the five remote sensing techniques in the ecological study as discussed below.

- **Image Classification**

Image classification is a remote sensing technique that consists of the process of assigning different types of land uses (e.g. forestland, grassland, farmland and settlement) into each raster pixel. It is an important technique to extract land-cover and biophysical information directly from remotely sensed data (Jensen *et al*, 2009).

- **Vegetation Index**

Vegetation index is an important remote sensing technique in ecological studies. It is dimensionless radiometric relative abundance and activity of green vegetation, including leaf area index (LAI), percentage green cover, chlorophyll content, and green biomass. It is important in enhancing sensitivity to biophysical parameters, normalizing or modeling external effects, normalizing internal effects, and assisting validation effort and quality control (Jensen *et al*, 2007). Vegetation index is used as supplement approach in image classification and change detection.

- **Inversion Algorithms**

In remote sensing, various models are developed to characterize Earth environments by explaining statistical relationships between sensor properties and ecological process. Inversion algorithms are the core of the inverse model, which mostly follow the physical laws and establish cause-and-effect relationships between sensor property as an input and biophysical property as an output. For example, G.vieilledent *et al* (2016) developed a map of forest carbon in Madagascar (R^2 = 70% and RMSE = 40 Mg ha^{-1}) using a combination of spatial bioclimatic envelopes and ground-based forest inventory. Therefore, this algorithm is an important technique in many ecological investigations such as ecosystem service, species distribution model and habitat mapping.

- **Data Fusion**

Since different satellites images vary in their spatial and temporal resolution, it is important to fuse them together to produce a single image with better spatial and temporal resolution. The technique of data fusion is defined as "the combination of two or more different images to form a new image by using a certain algorithm" (Pohl and Genderen, 1998). This technique has been applied widely in plenty of ecological studies as mapping forest disturbance through fusing Landsat and MODIS images (Hilker *et al*, 2009).

- **Integration of Remote Sensing and GIS**

Notably, remote sensing and GIS are excellent tools in studying several ecological processes in an easy way. Although these disciplines are separate, they are frequently combined in practice. Through combining remote sensing data with GIS data (vector data), several ecological studies can be conducted. In watershed management, for example, integration of the two disciplines is applied in developing sustainable development plan at the watershed scale (Chowdary *et al*, 2009). Further ecological research and development can be supported through remote sensing and GIS technology.

However, not all the aforementioned techniques of ecological remote sensing are discussed in this manual. We attempt to discuss in the manual only the technique of image classification and vegetation index in QGIS software program.

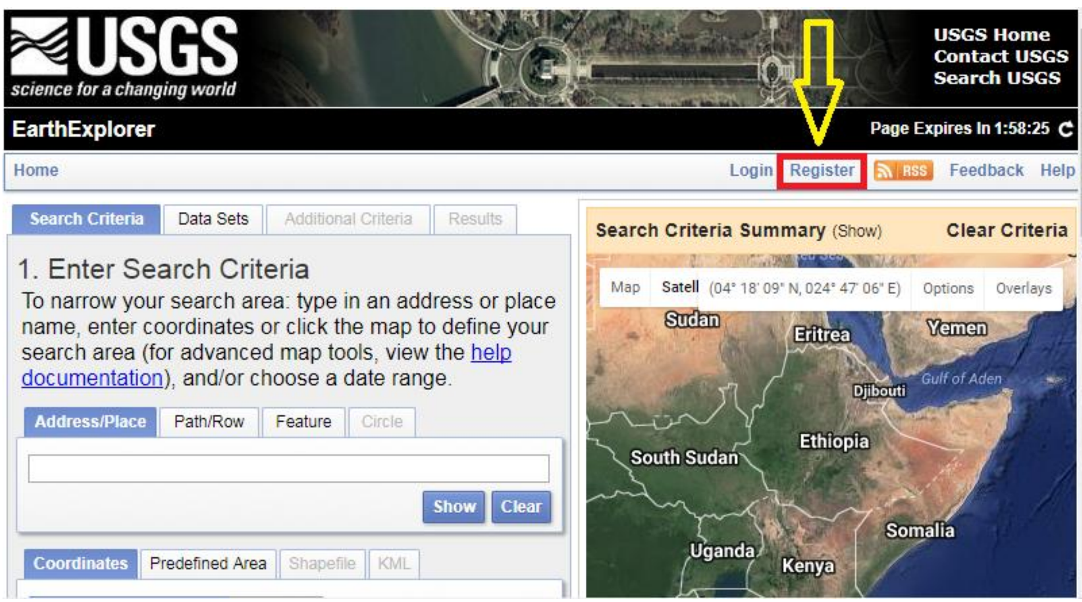
3. Satellite image acquisition and pre-processing

In the previous chapters, we have been looking a brief introduction to remote sensing and concepts of ecological remote sensing at theoretical bases. Now, we will start the practical section that will focus on image acquisition and other image preprocessing activities.

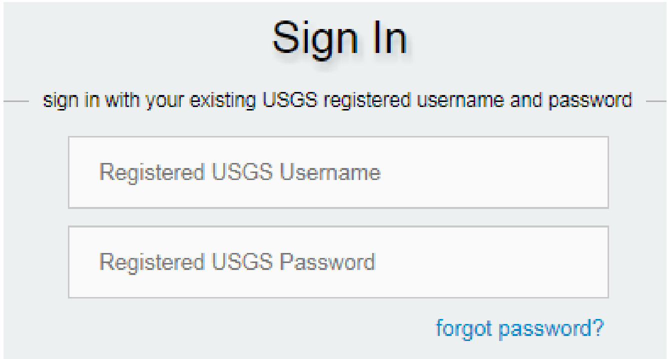
3.1. Satellite image acquisition

The first step of image preprocessing is obtaining of a satellite image from data providers. For the purpose of this manual, we will demonstrate downloading procedure of the free Landsat image as an example from the USGS database (https://earthexplorer.usgs.gov/). Please follow the following procedure to procure satellite image from the website.

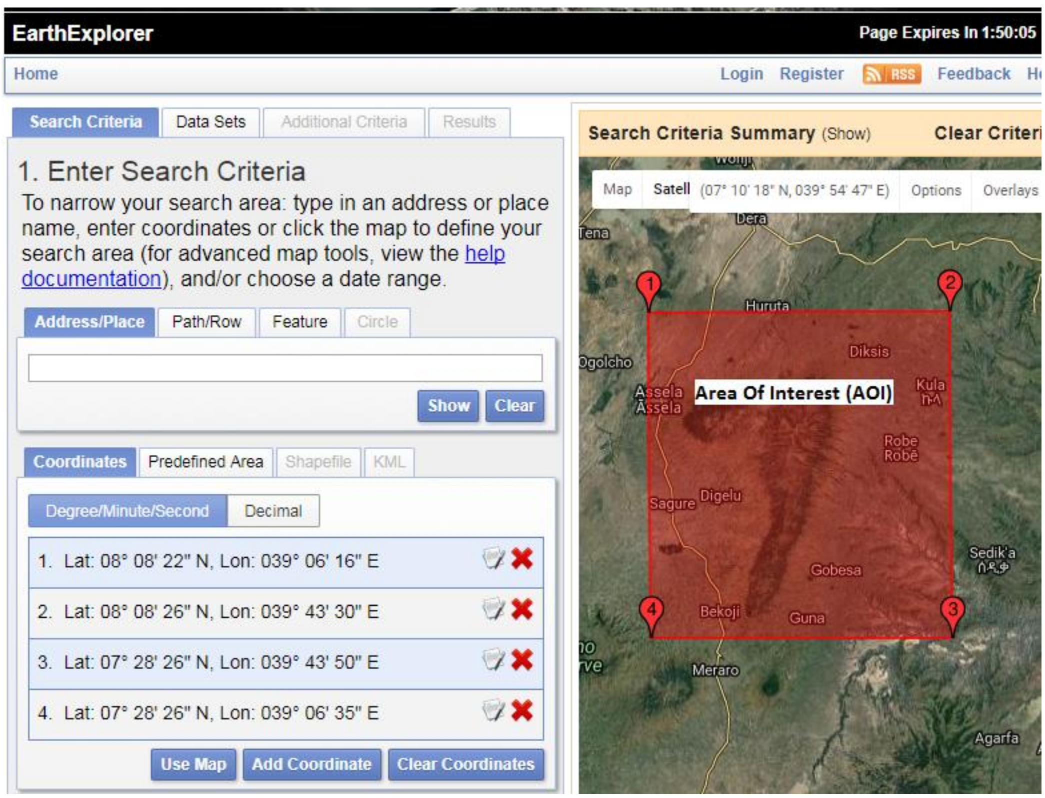
1. First, create your own user account on the “EarthExplorer” website (http://earthexplorer.usgs.gov/) by click on “Register”, and then fill out the required forms.



2. Once you registered, click on “Login” and then sign in using your own username and password.

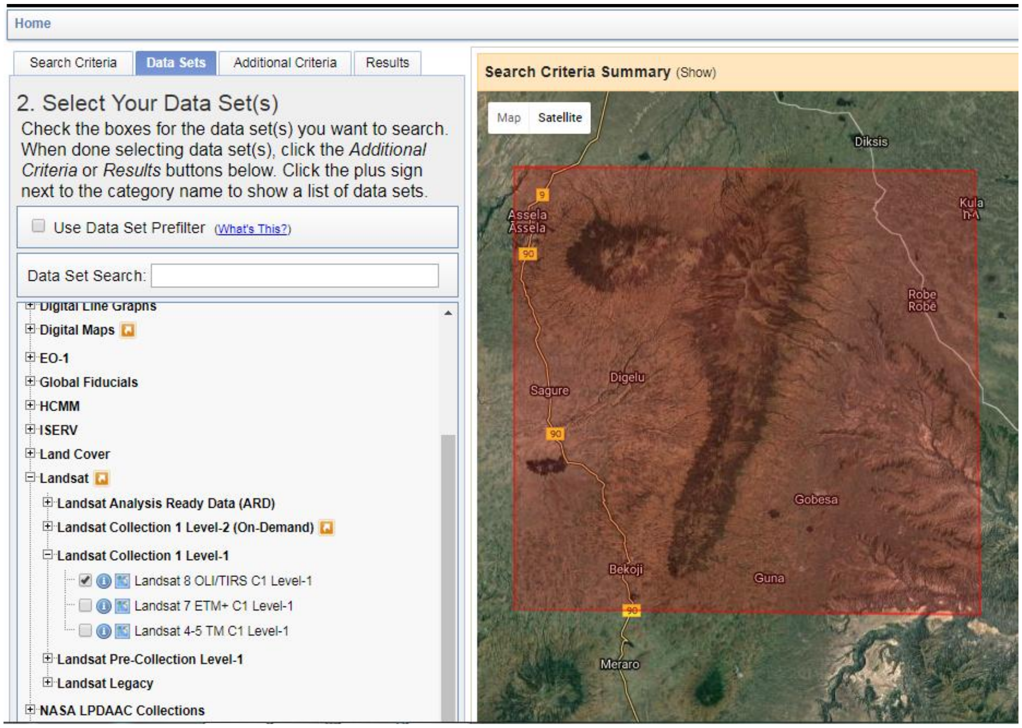


3. Delineate your Area of Interest (AOI) by clicking on the map window (right side of the interface).



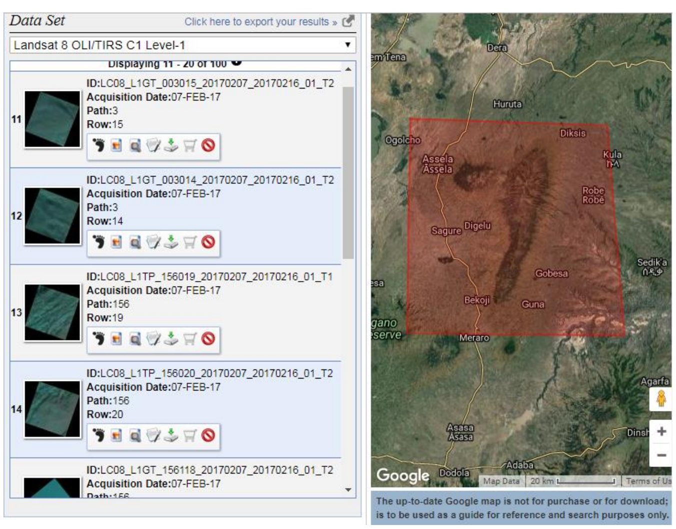
4. Then, set your additional searching criteria for the image before the downloading process is started. For instance, choose the appropriate image capturing season (e.g. dry season or wet season) and the quality of images (e.g. free from a cloud). In most cases, these parameters depend on the objectives of your study.

5. Then, click on "Data sets" button to choose the type of sensor. Here, there is a different possible list of satellites in the data set. For now, extract the "Landsat" option and choose "Landsat collection 1 Level-1". Then, check the option "Landsat8 OLI/TIRS C1 Level-1".

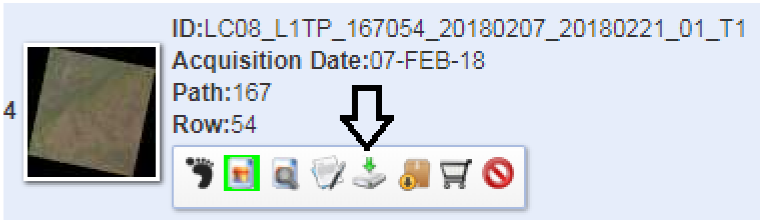


6. Click on "Results" tab to find the result of your search.

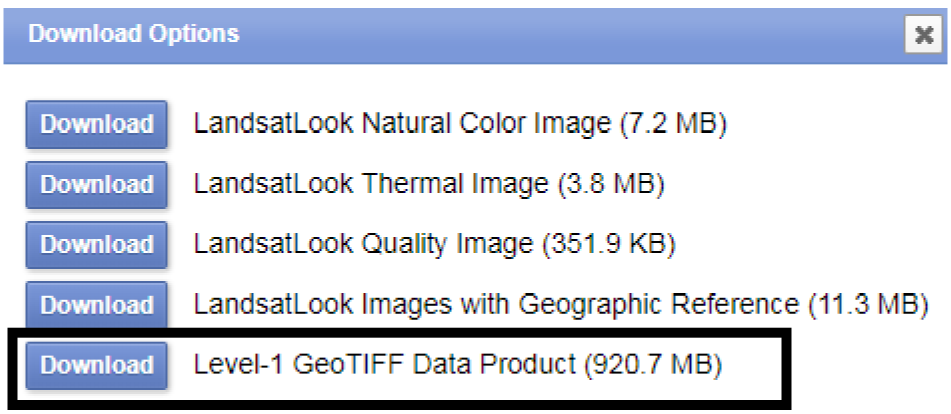
7. Now, there are lists of possible search results on the left side of the interface. Here, each satellite images has its own ID, date of acquisition, number of path and row.



8. Download the selected image by click on the download button under the selected image.



9. Then, select the "Level-1 GeoTIFF Data Product" from the list of downloading options dialog box.



After downloading is completed, we will find a zipped file containing several bands of the image. Then, unzip the downloaded "tar.gz" file. The file name of the downloaded files is very long, and it contains information about the downloaded image (Figure 4). Now, the data is ready for processing.

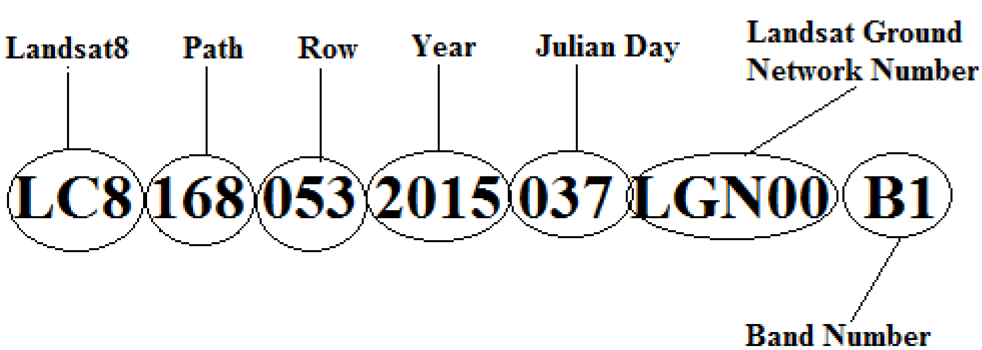


Figure 4: The information contained in the file name of the downloaded satellite image

3.2. Satellite image pre-processing

After the image is procured, various raster image processing will be conducted to make imageries ready for interpretation and classification. This process is called image preprocessing. It is needed to enhance the quality and visibility of a raster image. The most important preprocessing activities with their practical procedure will be discussed in this subchapter.

Geo-referencing

Sometimes, raw satellite images may not well align into the known coordinate system. Therefore, it needs to be geo-referenced. Geo-referencing is one of the image preprocessing activities, by which aligning of any geographic data (satellite image, scanned paper map, aerial photographs, etc) to a known coordinate system is carried out. There is a possibility to carry out this process in QGIS software.

1. First, click on start button and open QGIS desktop (Refer to the QGIS installation manual for successful installation of QGIS).
2. Add the geographically referenced (e.g. vector map) and unreferenced (e.g. scanned image) images into the opened QGIS desktop. Let us say the scanned paper map shown on the left side of Figure 5 is not geo-referenced while the image found on the right side is geo-referenced. Then, you will conduct geo-referencing by aligning the unreferenced image into a referenced image.

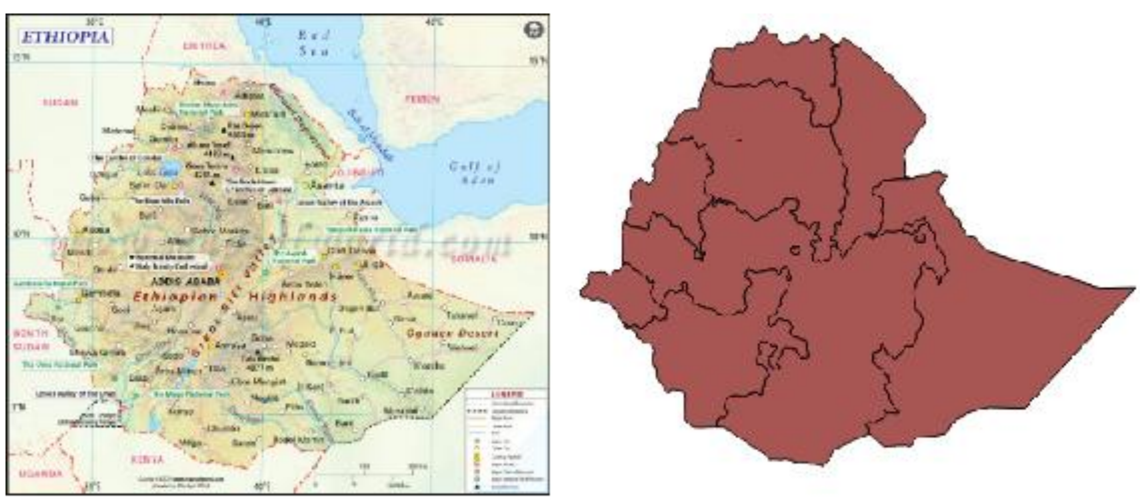
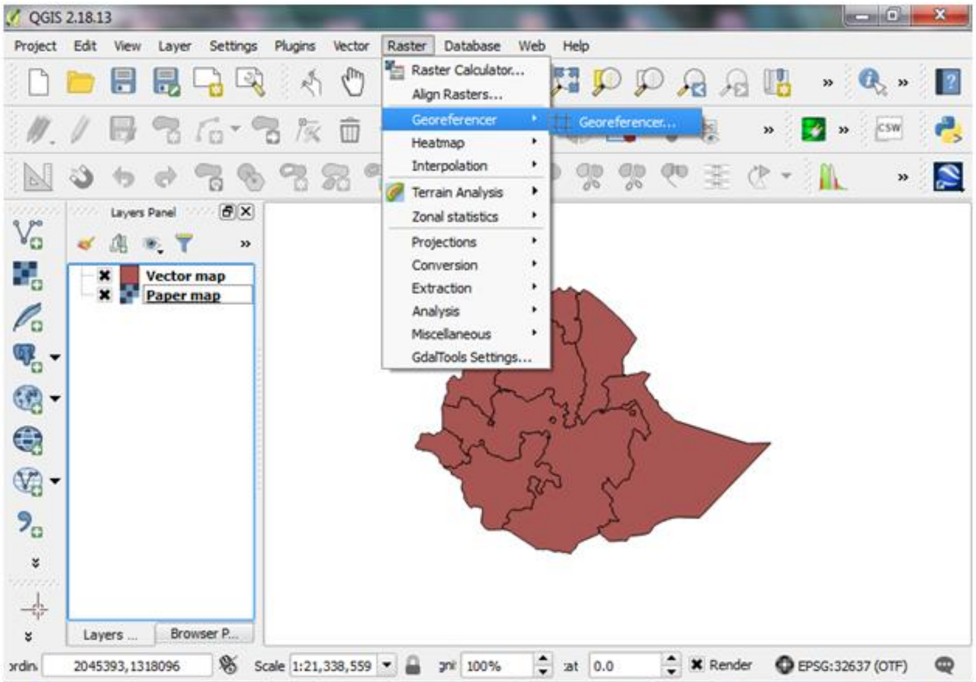
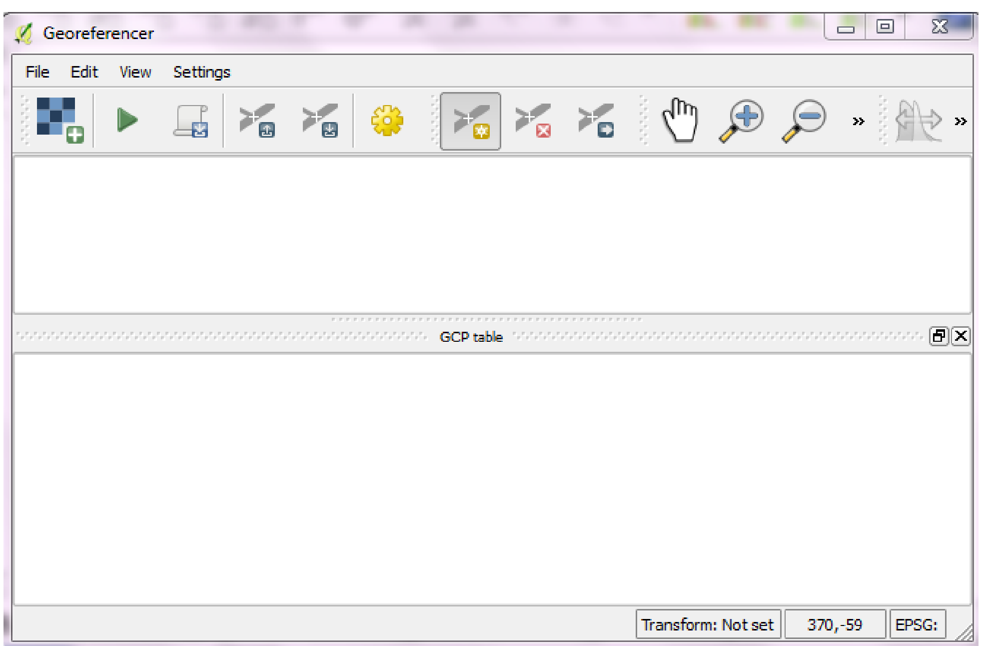


Figure 5: unreferenced scanned image (left) and referenced digital image (right)

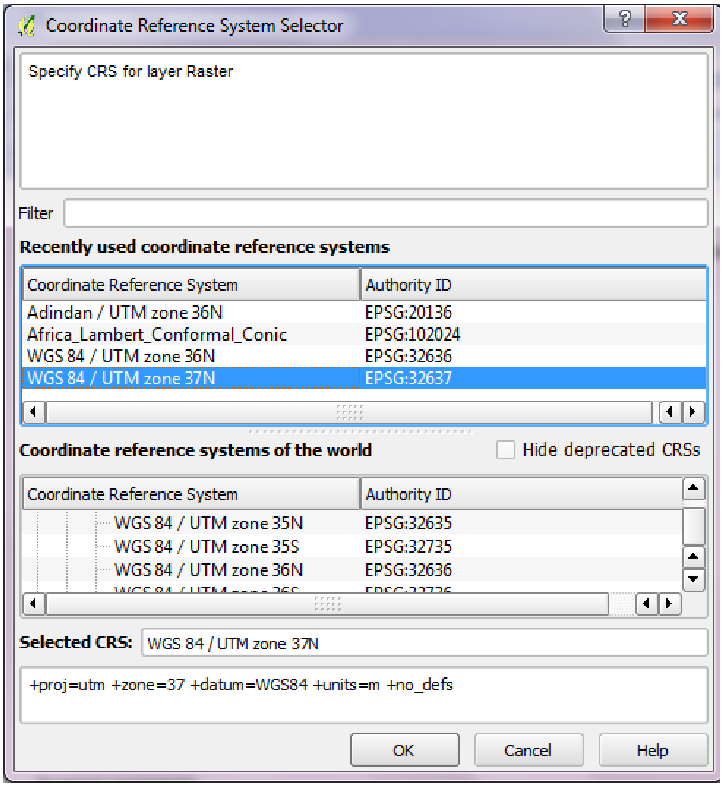
3. Then, click on “Raster” from the menu bar of QGIS desktop. Click on the “Geo-referencer” from the list and choose “Geo-referencer” again.



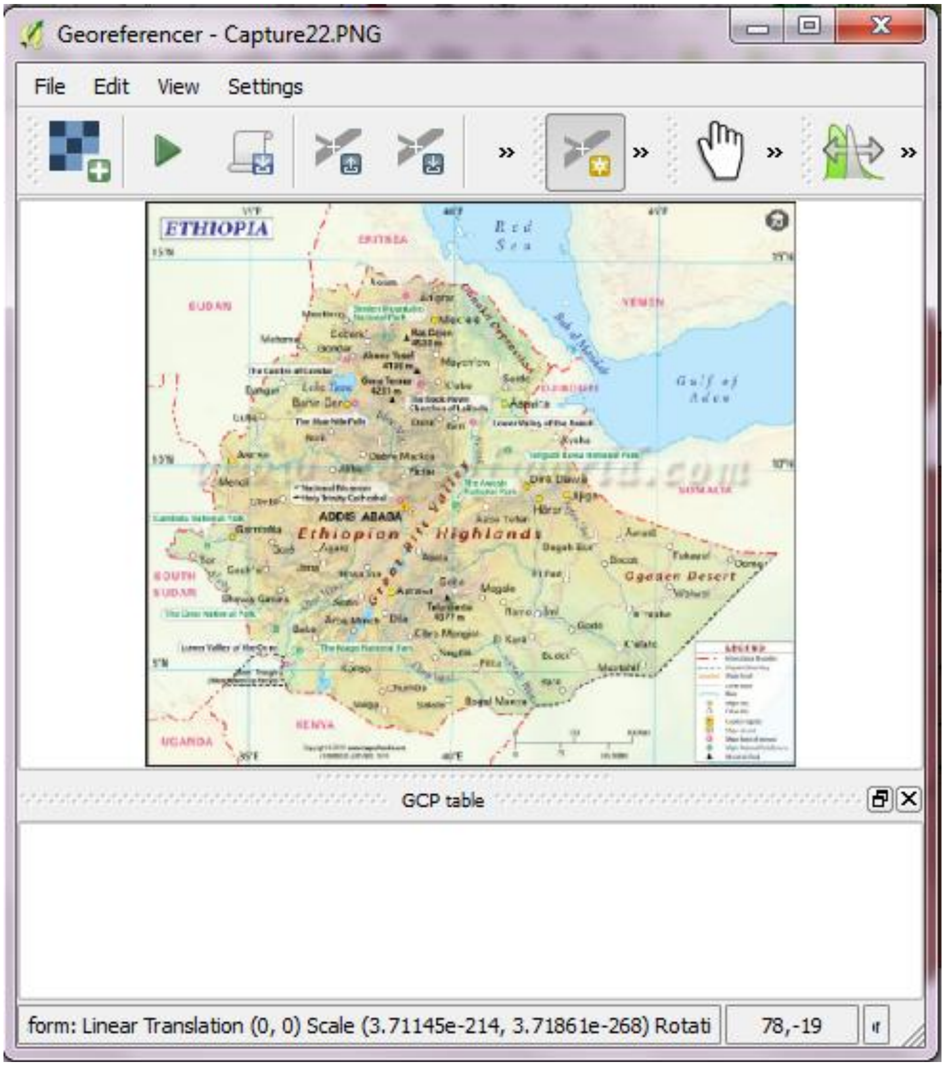
4. Now, the “Georeferencer” window appears. This window has two parts. The top part is where the raster will be displayed and the bottom section where the table of ground control points will be displayed if you have.



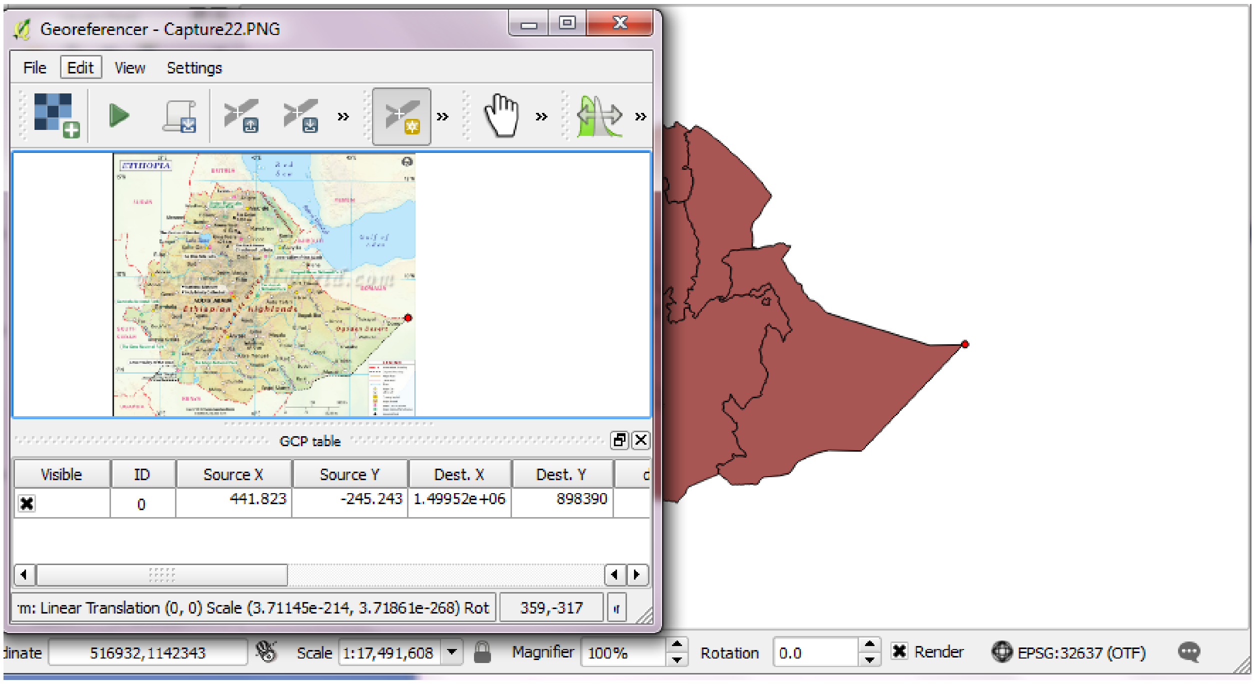
5. Add the raster (scanned map) into the above window by clicking on "Add raster" icon on the upper part of the window. Then, the Coordinate Reference System (CRS) window is opened. Set your coordinate system in this window and click "OK".



6. The scanned topographic map is displayed on the upper section of the Georeferencer window. Click on "Add point"  icon from the Georeferencer window to add a referenced point.



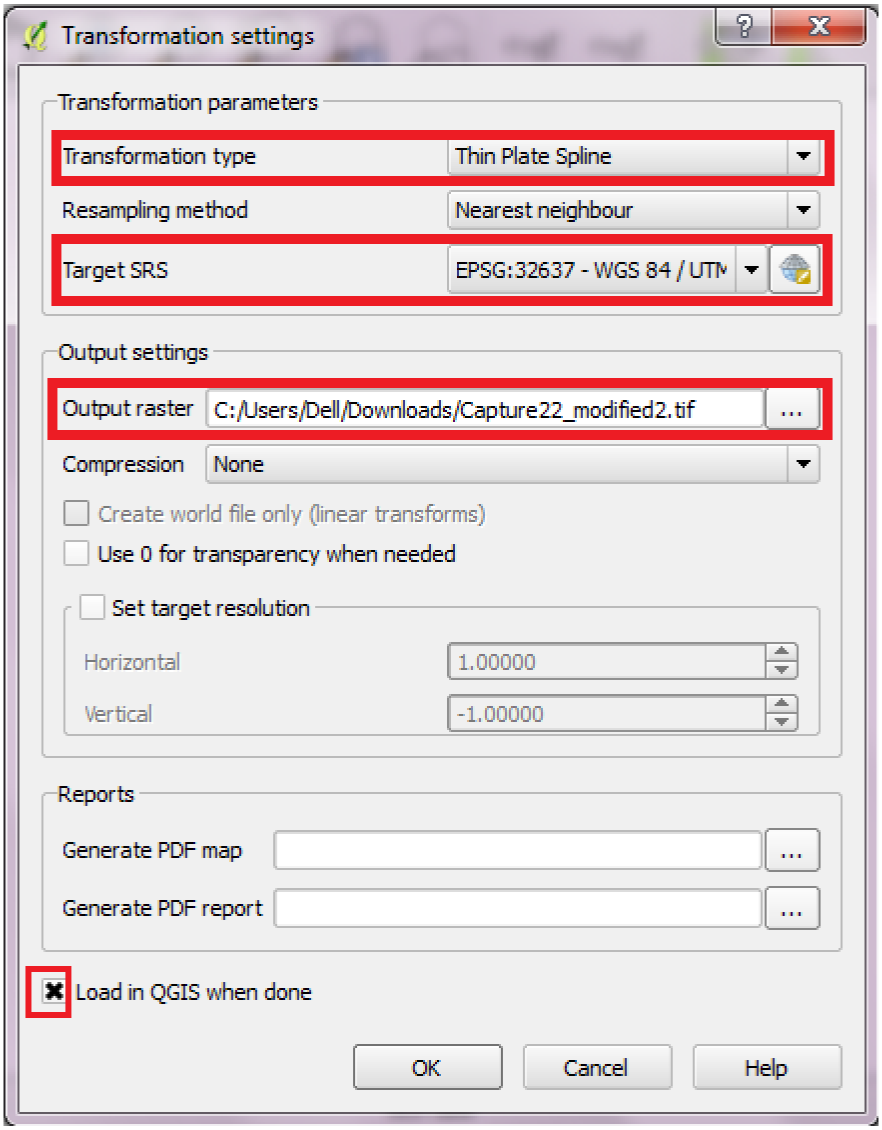
7. At this time, the topographic map is ready for Geo-referencing. Therefore, start clicking one corner from the topographic map, then "Enter map coordinate" dialog box will pop-up. At this time, you have options either writing X, Y (North/East) coordinate of that specific point or clicking from the map. For now, let us choose the second option and click on "From map canvas" button. Then, click the same point of the referenced map as a topographic map. Now, you can see the empty X, Y boxes are filled with values. These values are known as X, Y coordinates of the topographic map. Now, click on "OK". The bottom section of the window comprises a table, which contains the X, Y coordinates and other statistical parameters regarding the referencing.



8. Now, we geo-referenced the topographic map only for a single point. Similarly, back to the "Georeferencer window" and start geo-referencing to create more reference points. At least four Ground Control Points (GCPs) covering the entire image are needed. The more points you have, the more your geo-referencing is accurate and aligned to the target coordinate.
9. Once you finished, and have enough GCPs, Click on "Settings" from the "Georeferencer window" and choose the "Transformation settings".
10. From the "Transformation setting" dialog box, set the transformation type.

Here, please note that the **Thin Plate Spline** (TPS) algorithm is a more modern and widely used technique of geo-referencing. This is important and applied when very low-quality maps are being processed. Other types of transformations also have their own uniqueness.

11. Once you set the transformation type, insert your target SRS and output directory. Finally, check the box "load in QGIS when done". Then, click "Ok".



12. Click on the file button from "Geo-referencer" window. Then, click on the "start georeferencing". Wait until the progress is completed. This will start the process of aligning the two images using more GCPs.
13. Now, geo-processing is completed. Therefore, we need to verify the alignment of the two images. Just for comparison, load Google Earth as background base map and compare them.

Conversion of Digital Number (DN) to radiance and then to reflectance

Most of the satellite images including Landsat have pixels of a grid, which is coded by a numeric value called Digital Number (DN). If you want to analyze multi-scene Landsat image for change detection, it is important converting of DN to radiance then to reflectance. However, if the classification is only for a one-time shoot, the image can be classified using DN without converting to radiance. Conversion of DN involves two important steps; 1) Converting the digital number (DN) values in each pixel to radiance, 2) Converting the derived radiance to reflectance.

As described above, conversion of DN to radiance needed for many single-image analyses. This will be conducted for all bands of Landsat image including visible, shortwave and thermal infrared. We implement the following spectral radiance scaling method equation to convert the value of DN to radiance.

$$\mathbf{L_\lambda = ((LMAX_\lambda - LMIN_\lambda)/(QCALMAX-QCALMIN)) * (QCAL-QCALMIN) + LMIN_\lambda}$$

Where

L_λ	Spectral Radiance at the sensor's aperture in watts/(meter squared * ster * µm)
QCAL	the quantized calibrated pixel value in DN
$LMIN_\lambda$	the spectral radiance that is scaled to QCALMIN in watts/(meter squared * ster * µm)
$LMAX_\lambda$	the spectral radiance that is scaled to QCALMAX in watts/(meter squared * ster * µm)
QCALMIN	the minimum quantized calibrated pixel value (corresponding to $LMIN_\lambda$) in DN = 1 for LPGS products = 1 for NLAPS products processed after 4/4/2004 = 0 for NLAPS products processed before 4/5/2004
QCALMAX	the maximum quantized calibrated pixel value (corresponding to $LMAX_\lambda$) in DN = 255

The second step is calculating reflectance from the derived radiance. Reflectance is a normalized, unitless measure of the ratio of the amount of light energy reaching the earth's surface to the amount of light bouncing off the surface and returning to the top of the atmosphere.

$$\mathbf{RF= \pi * L_\lambda * D^2/ESUN_\lambda * \cos \theta_S}$$

Where

RF=unit less planetary reflectance

$L_{\lambda=}$ Spectral Radiance at the sensor's aperture in watts/(meter squared * ster * µm)

D= Earth-Sun distance in astronomical unit

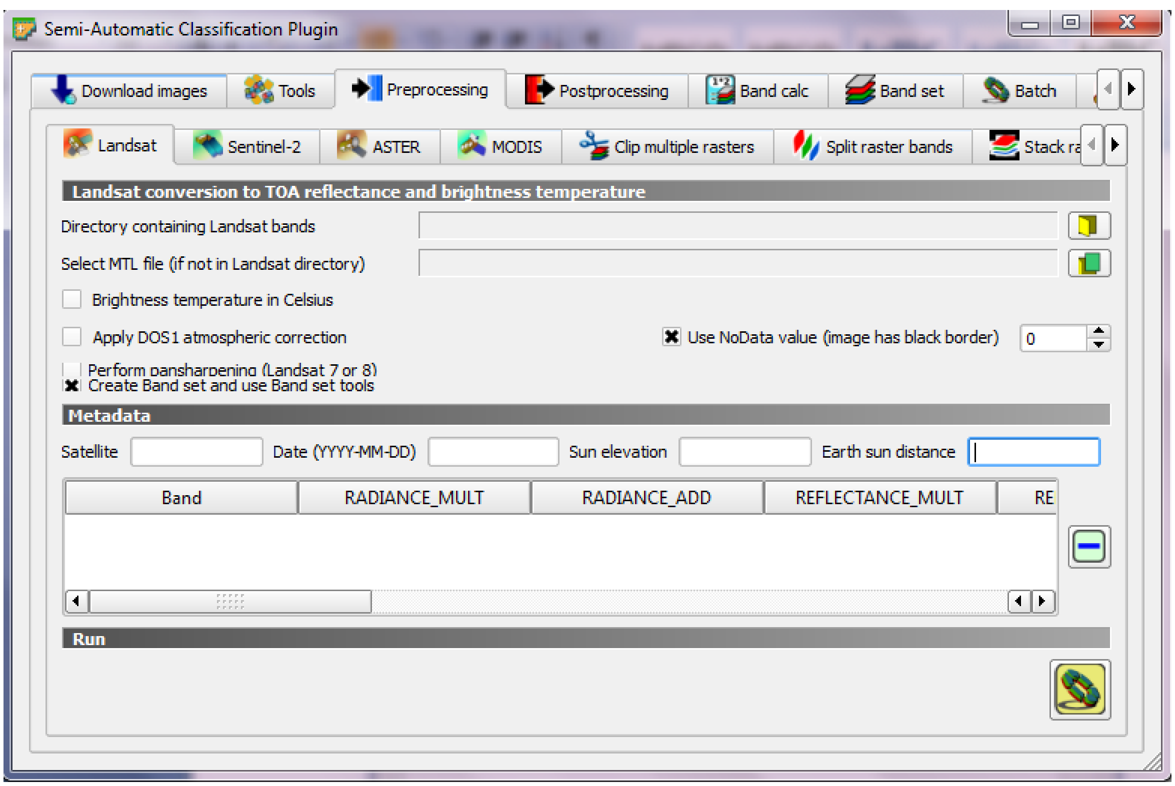
$ESUN_\lambda$ = mean solar exoatmospheric irradiances

θ_s = solar zenith angle

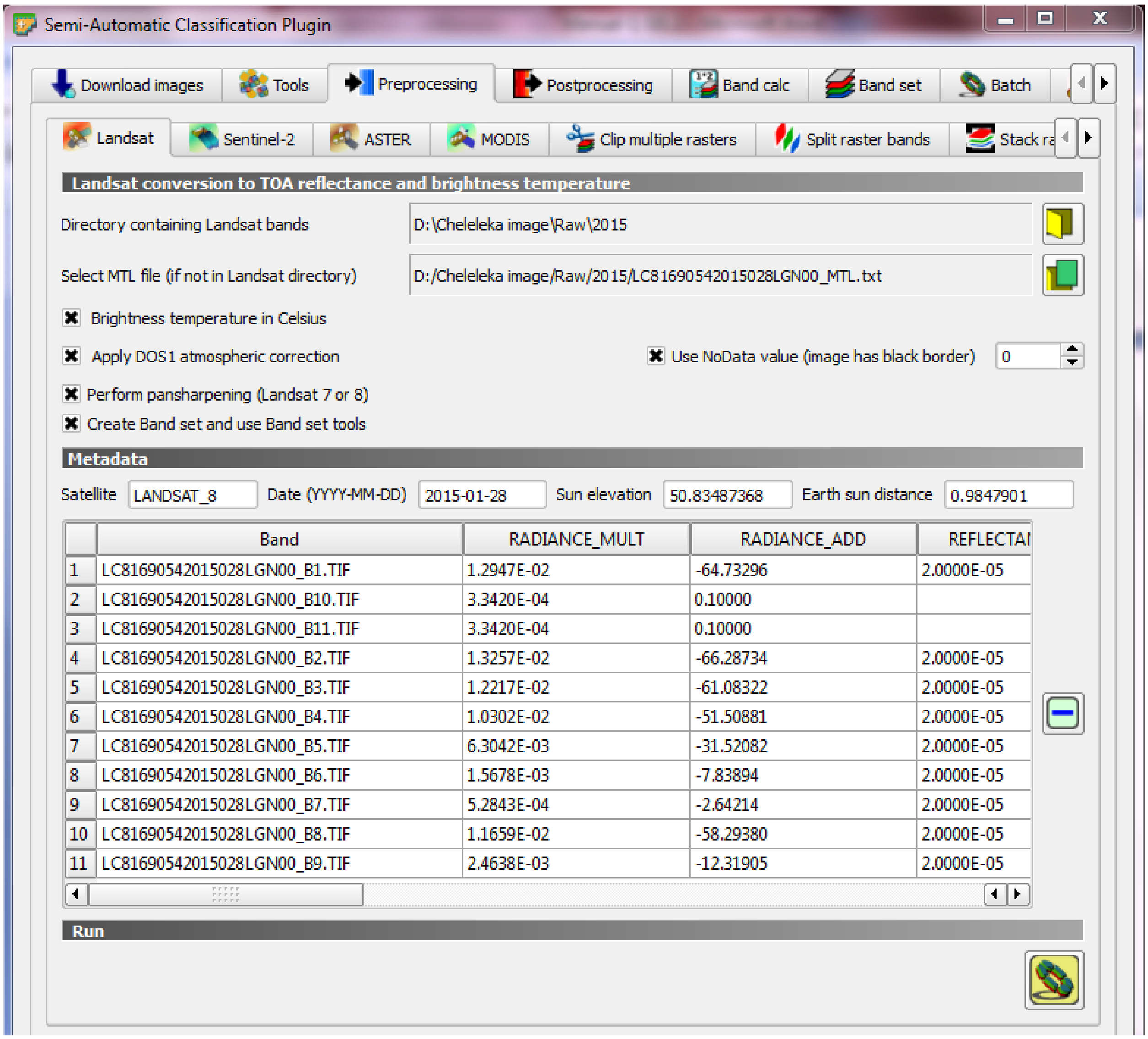
All the above parameters are available on MTL file of the image, which is downloaded with Landsat scene by default. Do not be anxious about such complex calculation, since QGIS provide tools to perform this task automatically.

QGIS has possibilities to compute such complex calculation automatically. The best option is to install two new plug-ins called SCP-plug-in and Semi-Automated classifications plug-in. These are the most comprehensive plug-ins for image classification processing. Therefore, the plugs can convert directly from DN to reflectance following the instructions below.

1. Start QGIS desktop.
2. Install the two important plug-ins (SCP-plug-in and Semi-Automated classification plug-in) from the internet.
3. After installing the plug-in, SCP option will be displayed on the status bar of QGIS
4. Click on SCP and you can see the different tools related to raster data processing for image classification.
5. Click on the "preprocessing" option, and click on the "Landsat". Now, you can see the window of Semi-Automated classification plug-in.



6. Click on “select directory” to select the directory of containing Landsat bands button
7. Add MTL file of the Landsat scene by clicking on the second option. When you add MTL file, the lower section of the window, automatically, display the information of each band of Landsat.



8. Check the necessary checkboxes then click on the” run“ button. The output directory request will pop-up when you click on run. Choose the appropriate output directory. The progress might take several minutes to execute until the execution progress bar is done.

Creating mosaic image

Sometimes, your study area may fall on to the boundary of two independent scenes of the satellite. In such cases, you need to merge two adjacent scenes of the satellite image. In raster processing, creating of one single raster image by merging multiple adjacent scenes is known as a mosaic image. There are different possibilities to perform such process on QGIS. The following instruction contains the important procedures to conduct this process on QGIS.

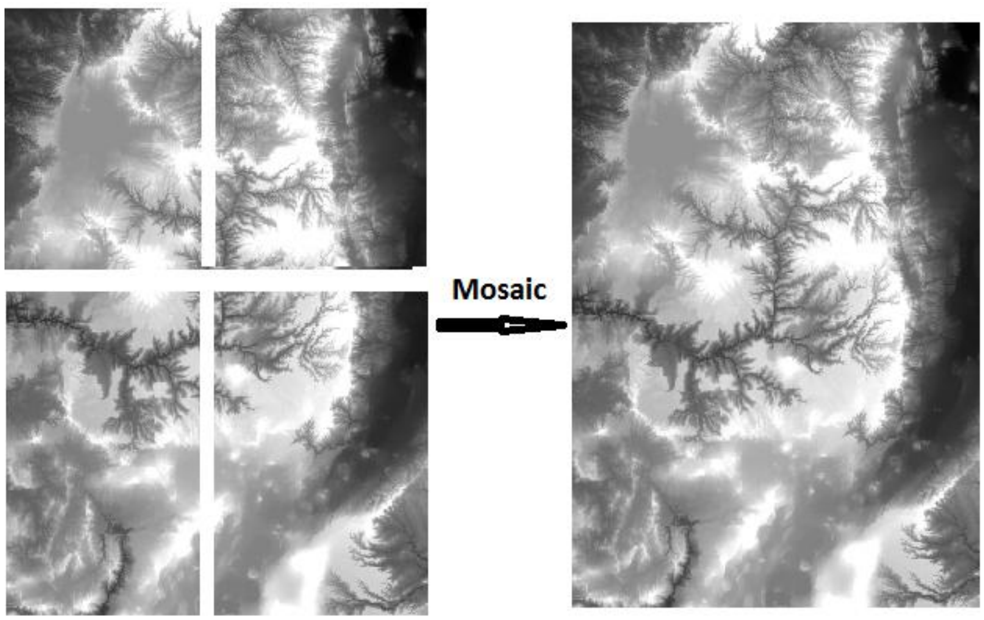
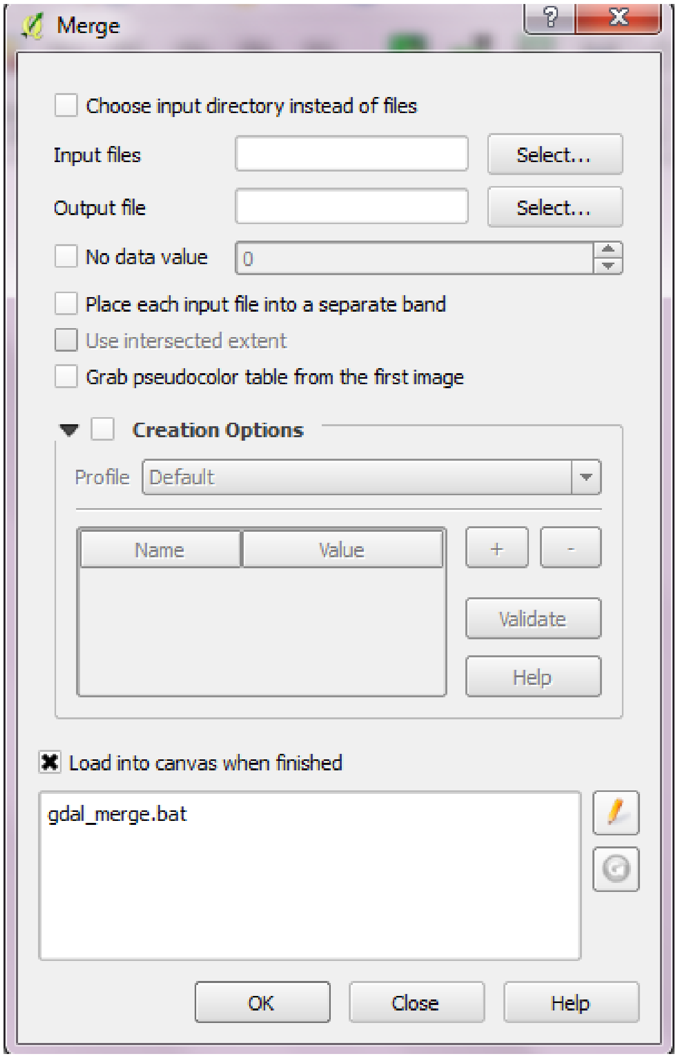
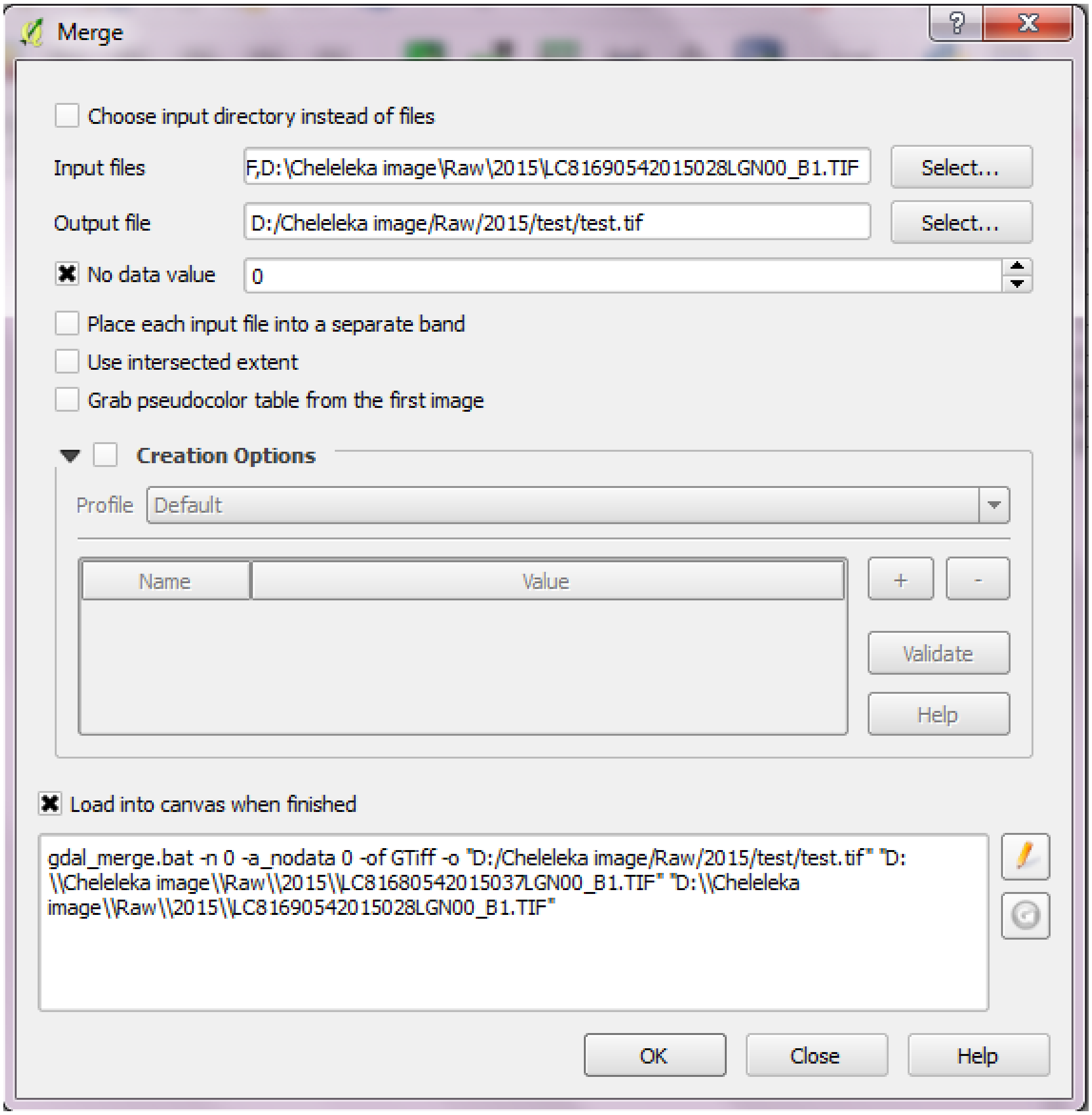


Figure 6: Graphical illustration of mosaic image

1. Open QGIS desktop.
2. Click on "Raster", and go to the "misilanoues" then click on "Merge". The "Merge" window is opened.



3. Search raster files and add on the input files box.
4. Select the output directory, where to save your final output (mosaic image).
5. Check the necessary checkboxes depending on your interest, then click on "OK".



6. The final output will be displayed only if you check the option “Load into canvas when finished”.

Creating band composite

As discussed earlier, every band of the image has its own role in classification to distinguish different features on the Earth. Therefore, it is important to identify and select bands that are necessary for the analysis. Then, the selected bands of the image should be stacked to create a single composite image containing different bands. In short, the term composite is a process of creating a single raster dataset from multiple individual bands. QGIS software provides different tools to carry out band combination or layer stack.

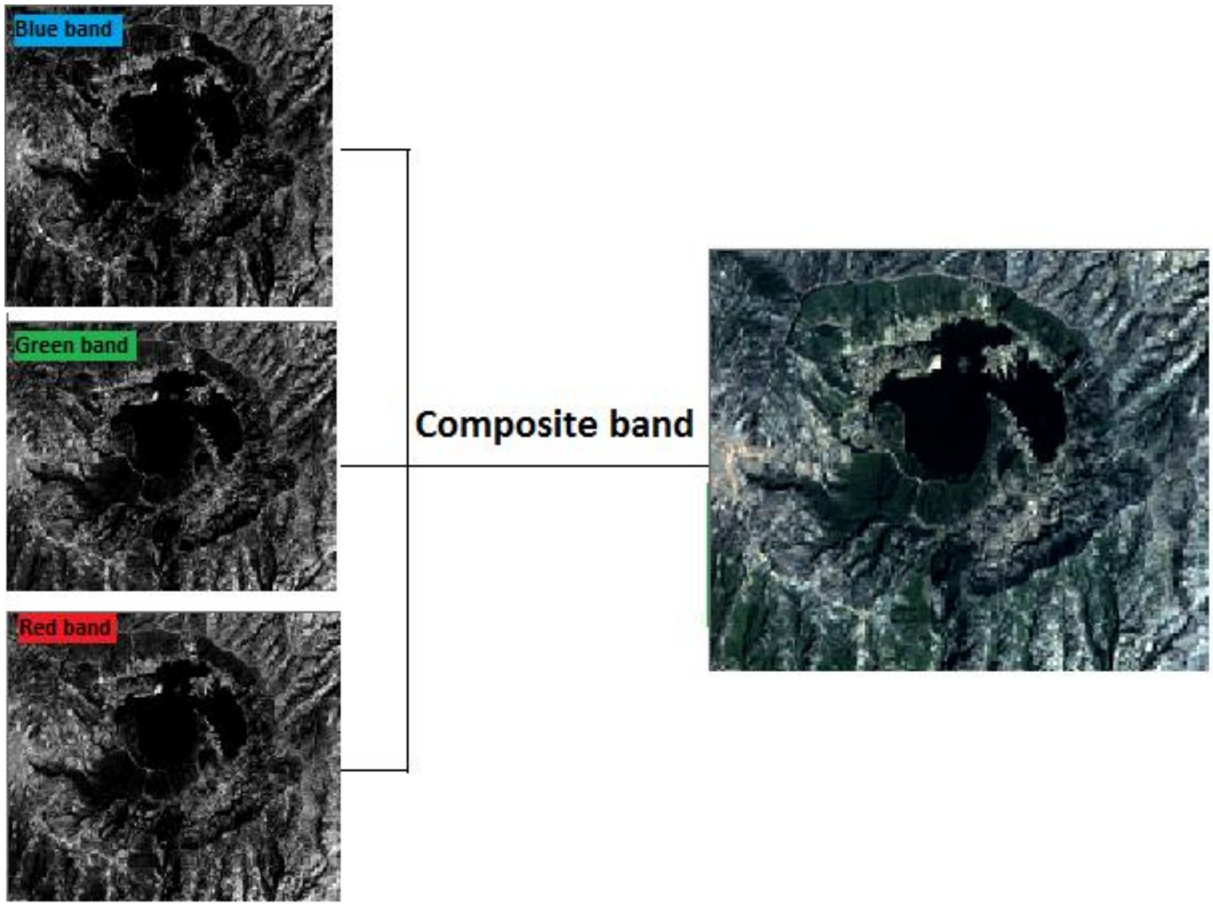
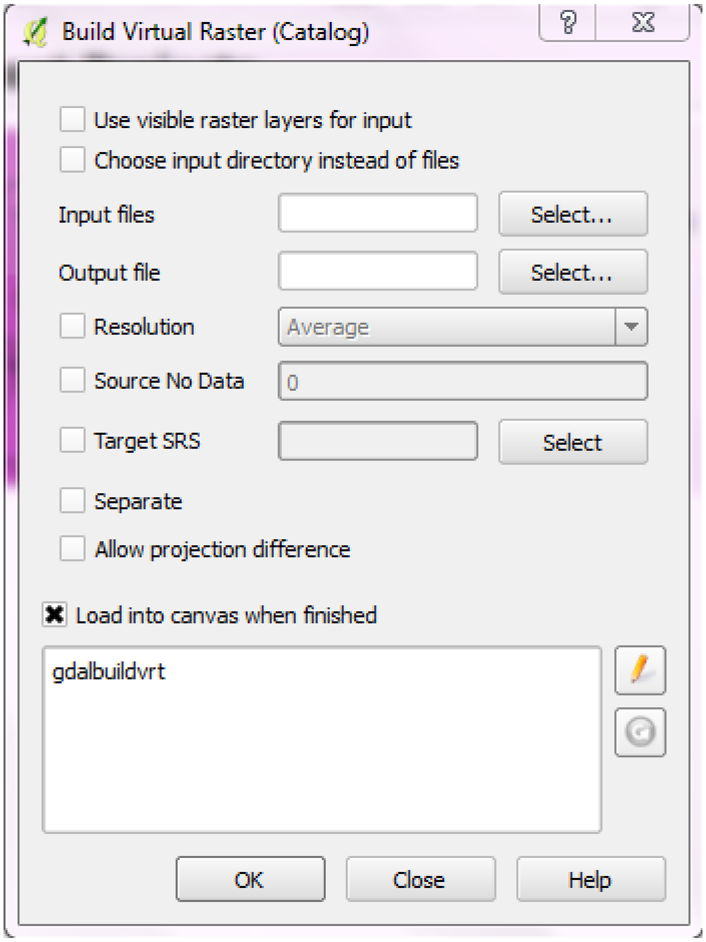


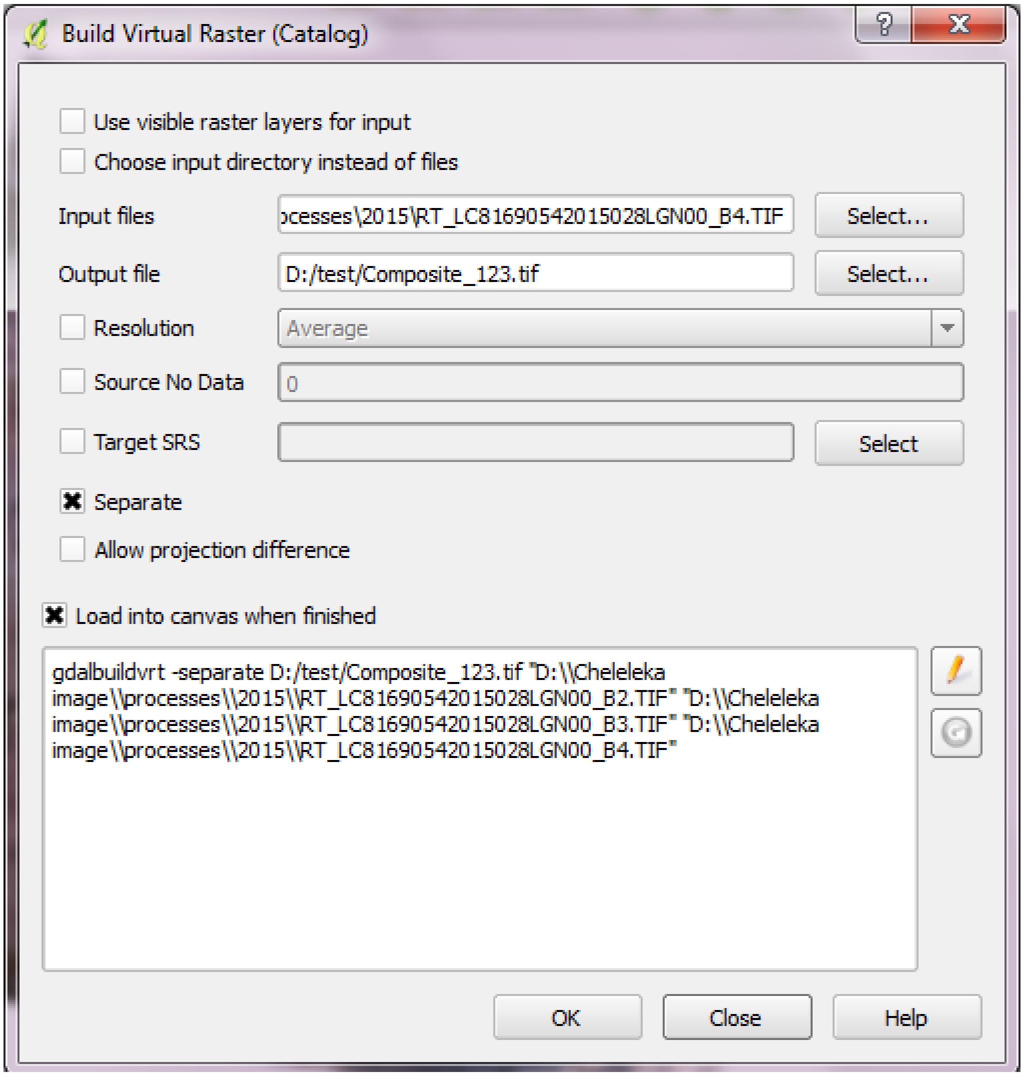
Figure 7: Graphical illustration of composite image

In order to carry out the process of image composite in QGIS, follow the following instruction below.

1. Open QGIS desktop.
2. Click on "Raster" from the menu bar and select "Miscellaneous " and choose "Build Virtual Raster" option.
3. Then, the "Build Virtual Raster" window will appear.



4. Select and add the list of selected bands for composite in the “Input files” box.
5. Select an appropriate directory as your final output in the “Output file” box.
6. Check the “Separate” checkbox.
7. If you have other requirements, you can set by checking the possible checkboxes from the “Build Virtual Raster catalog”. Finally, click on “OK”.



Clipping the image

Most often, after the above image preprocessing activities were completed, you may need to trim the image by the frame of your study area. The process of trimming unnecessary part of the image and shape it by the frame of the study area is referred to as clipping.

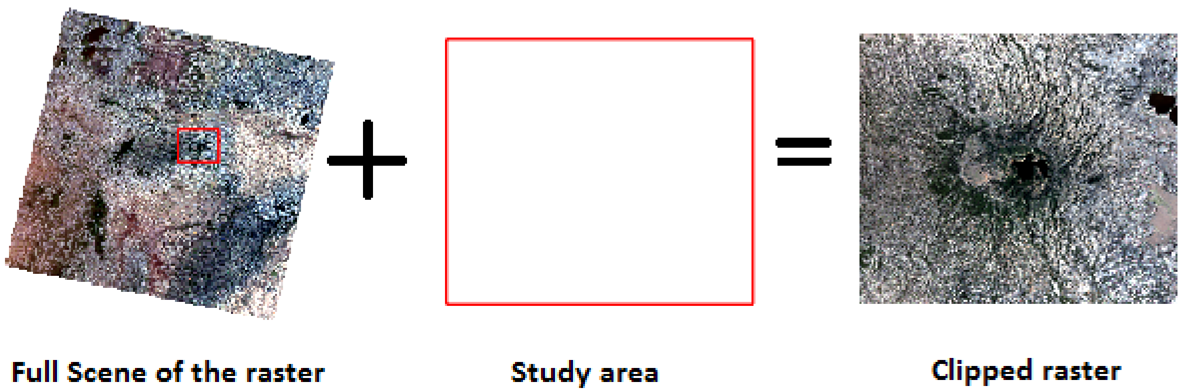
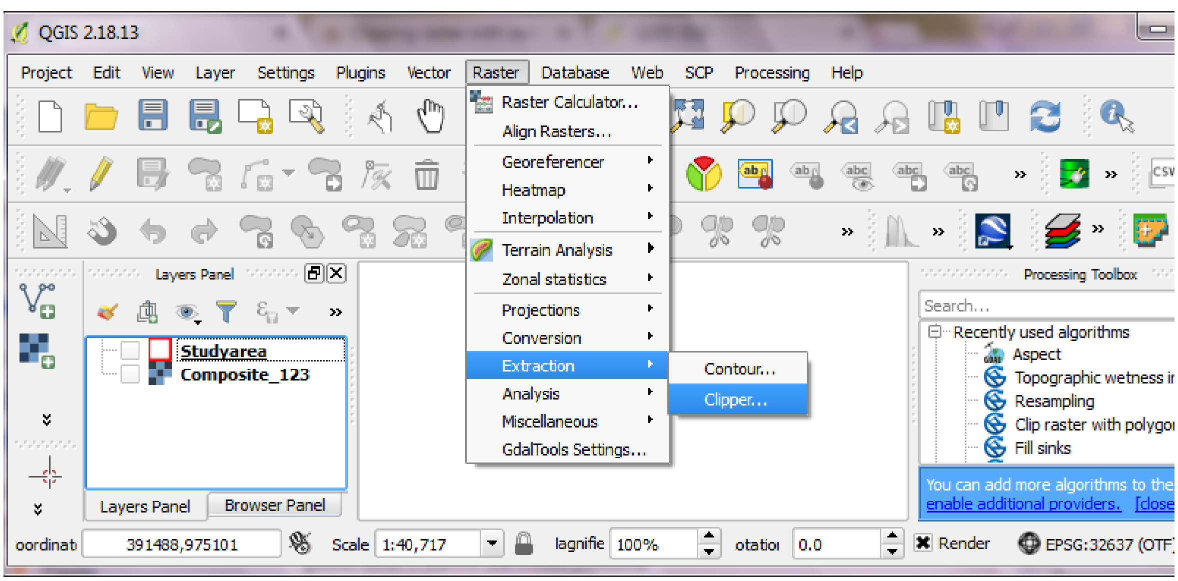


Figure 8: Graphical illustration of image clipping

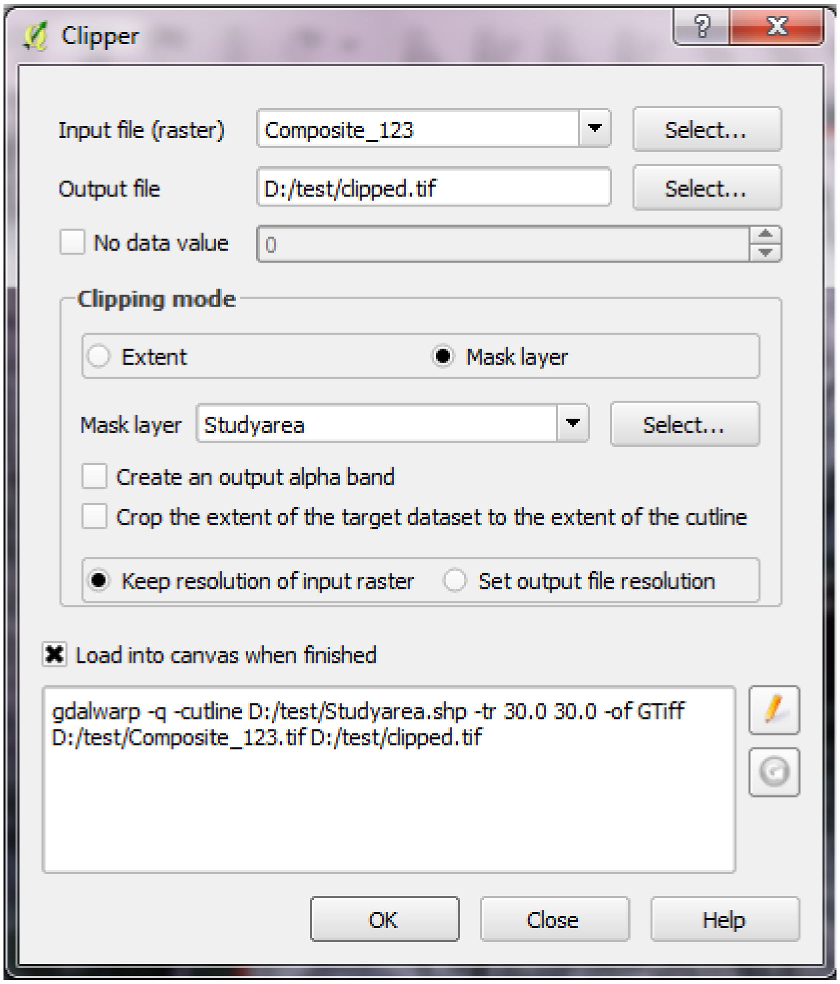
There is an automation method in QGIS to perform clipping of raster image in a simple way by following the procedure below.

1. Open QGIS desktop
2. Click on "Raster" from the menu bar, and then click on "Extraction". Choose the "Clipper" option from the list.



3. Now, the "Clipper" catalog appears. Then, continue to complete the necessary boxes in this catalog box.
4. Add the raster file that needs to be clipped in the "Input file (raster)" box. Write down the directory of the final output in the second box.

5. Then, under "Clipping mode" check "Mask layer" option. Add the shapefile of your study area in the "Mask layer" box.
6. Keep the rest option as default, and click on "OK".



4. Image interpretation and classification

In the previous chapter, we have dealt with the practical techniques of image acquisition and pre-processing. Hence, the image has become ready for interpretation and classification. In this chapter, we will address the process of image interpretation and classification in theory and practice. Moreover, we will see the steps to assess the accuracy of a classified image at the end of this chapter.

4.1. Image interpretation

Image interpretation is the processes of detection, identification, description and assessment of significant object and pattern of the image. It is an important process to detect different features on earth. There are two types of image interpretation. They are visual and digital image interpretation. We will make out the brief desciption and importance of visual and digital image interpretations in the subsequence topics.

Visual image interpretation

Visual interpretation is the process of identification and recognition of spatial and landscape patterns using visual perception and understanding of the image. Of course, most people in the world are highly experienced on the visual perception of their surrounding environment. This natural experience is important to apply to the interpretation of satellite imagery for better classification.

Accordingly, several elements of images exist that we can use to identify and recognize objects of the earth surface. The basic elements of visual interpretation are **shape, size, pattern, tone, texture, shadows, location, association** and **resolution** of either satellite image or aerial photograph. By using these elements, the user can identify the target or object from the image. Finally, recognized targets (e.g river, rock, forest, farmland… etc) in remotely sensed images based on the above visual elements allows the user to go for further interpretation and analysis.

As an example, please take a look the above Landsat image and you can identify the following objects from the image using different elements of visual interpretation.

- A road is identified from the image using the element shape.
- Settlement (buildings) are easily identified by its contrasting tone and shape.
- Forest can be identified at the top center of the image due to its dark tone and its location

Many of the objects can be identified using the above elements of visual interpretation. However, it needs practical experience and continues exercise in order to be effective in visual interpretation. Thus, supporting visual interpretation with band combination technique is important to identify many features and to reduce the extent of confusion.

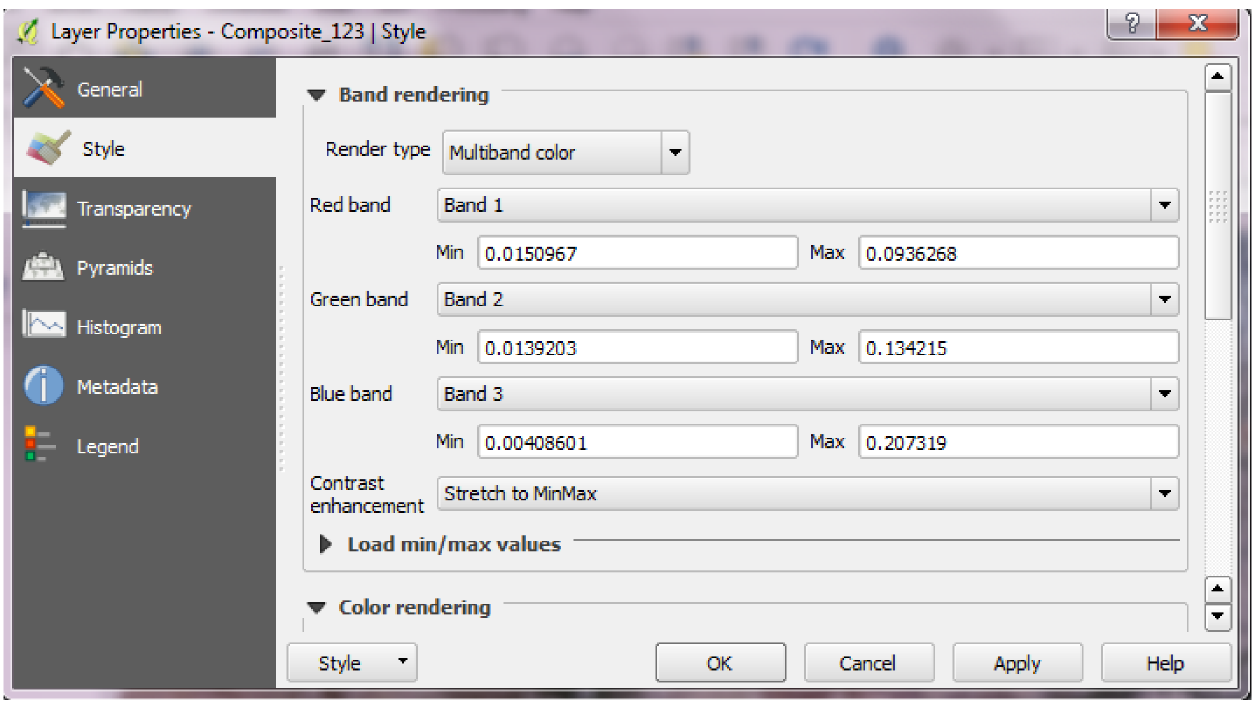
Band Combination

After multiple bands are combined together, understanding and practicing of band combination are important to support the process of visual interpretation and analysis. Band combination is an important process in image visualization and interpretation. Multiple combinations of different bands enable you to identify several features on the surface of the Earth. This allows distinguishing different types of land uses visually through the use of band combination.

However, care should be made when combining bands of images from different satellites. For instance, band combinations of the image from Landsat 8 is different from Landsat 7 or Landsat 5. Since Landsat 8 contain additional bands than Landsat 7 or 5, the band combinations used to create RGB (Red-Green-Blue) composites differ from Landsat 7 and Landsat 5.

In this part, we will discuss the capability of QGIS in the visualizing and symbolizing of satellite images under several band combinations using the following steps.

1. Open QGIS desktop.
2. Add composite raster image (Landsat image) into QGIS canvas
3. Right click on the layer of the loaded raster image. Then, click on "Properties". Now, the "Layer Properties" dialog box comes into view.



4. On this dialog box, you can change and combine different bands for red, green and blue bands. Then, click on "OK".

For further study, We suggest you reaing the detailed characteristics of the satellite or sensor. For the best combination of Landsat images, it's recommended to refer an official website of Landsat 8 (https://blogs.esri.com/esri/arcgis/2013/07/24/band-combinations-for-landsat-8/) and for Landsat 7 or 5 (http://web.pdx.edu/~emch/ip1/bandcombinations.html).

4.2. Image classification and accuracy assessment

Image classification

Image classification is a process of assigning different types of land uses (e.g. forestland, grassland, farmland and settlement) into each raster pixels. It plays an important role in the field of environmental management and research. Most of the land cover change researches and land use planning are depended on image classification techniques. This is important and applied in many other ecological and landscape studies.

So far, many classification techniques were designed in the science of remote sensing. In pixel-based classification, supervised and unsupervised classification are the two most widely used methods in many ecological studies. There is a difference between these two techniques. Unsupervised classification starts with a grouping of pixels into “clusters” based on their properties (Figure 9). For the grouping of this cluster, the analysts must use one of the different image-clustering algorithms such as K-means and ISODATA. In supervised classification, however, the analyst should create representative sample plots (training plots) for each land-cover classes (Figure 9). Then, the software determines the classes of the entire image depending on the training plots using one of the several algorisms. Maximum likelihood and minimum-distance are the most widely used algorithms in supervised classification techniques. Recently, random forest algorism is also becoming more familiar with different image classification studies.

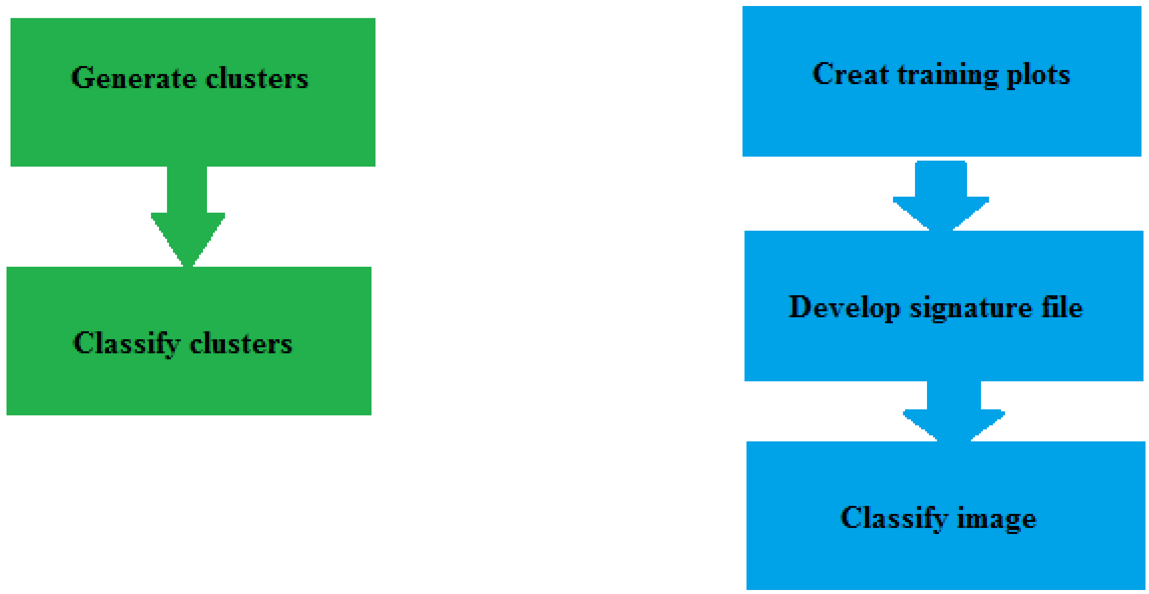
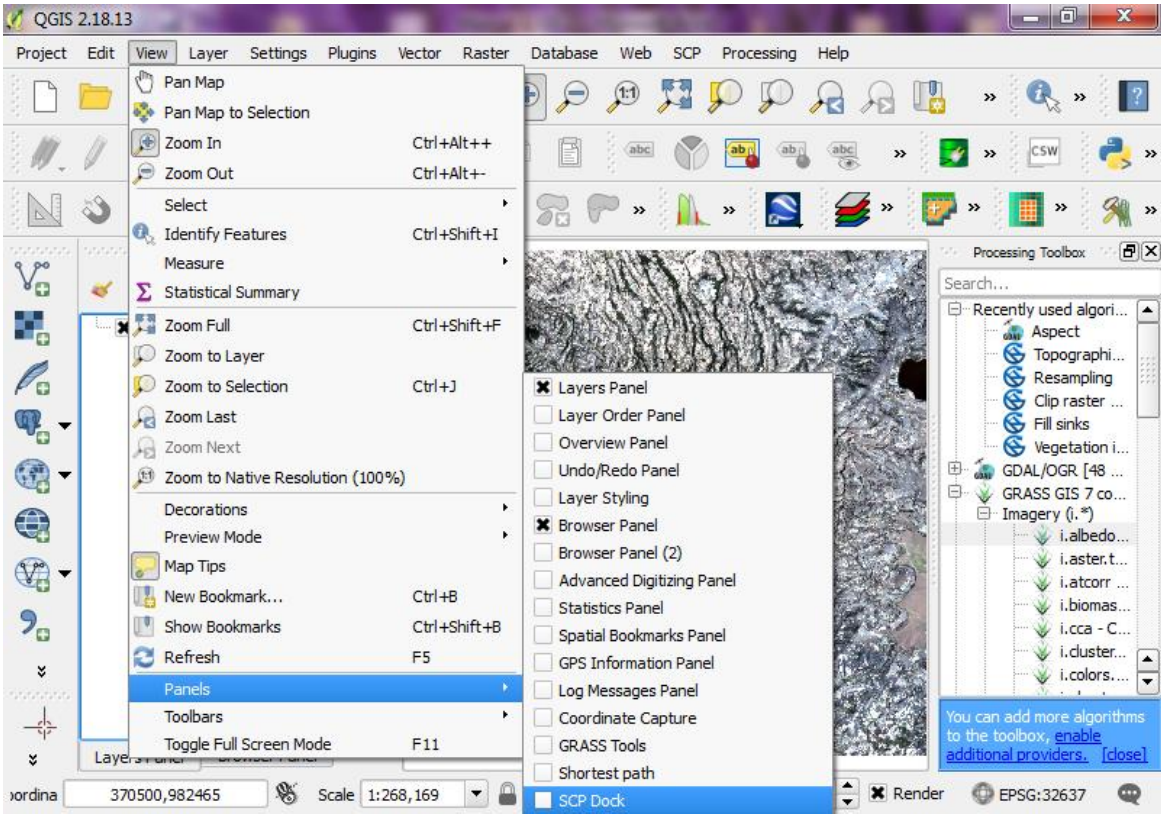


Figure 9: The major steps of unsupervised (Green) and supervised (Blue) classification techniques

In this manual, we will demonstrate the procedures that enable you to conduct supervised classification in QGIS environment. We focused on the practice of supervised technique since it is more acceptable and accurate than unsupervised classification. Follow the following procedure to conduct supervised classification on QGIS.

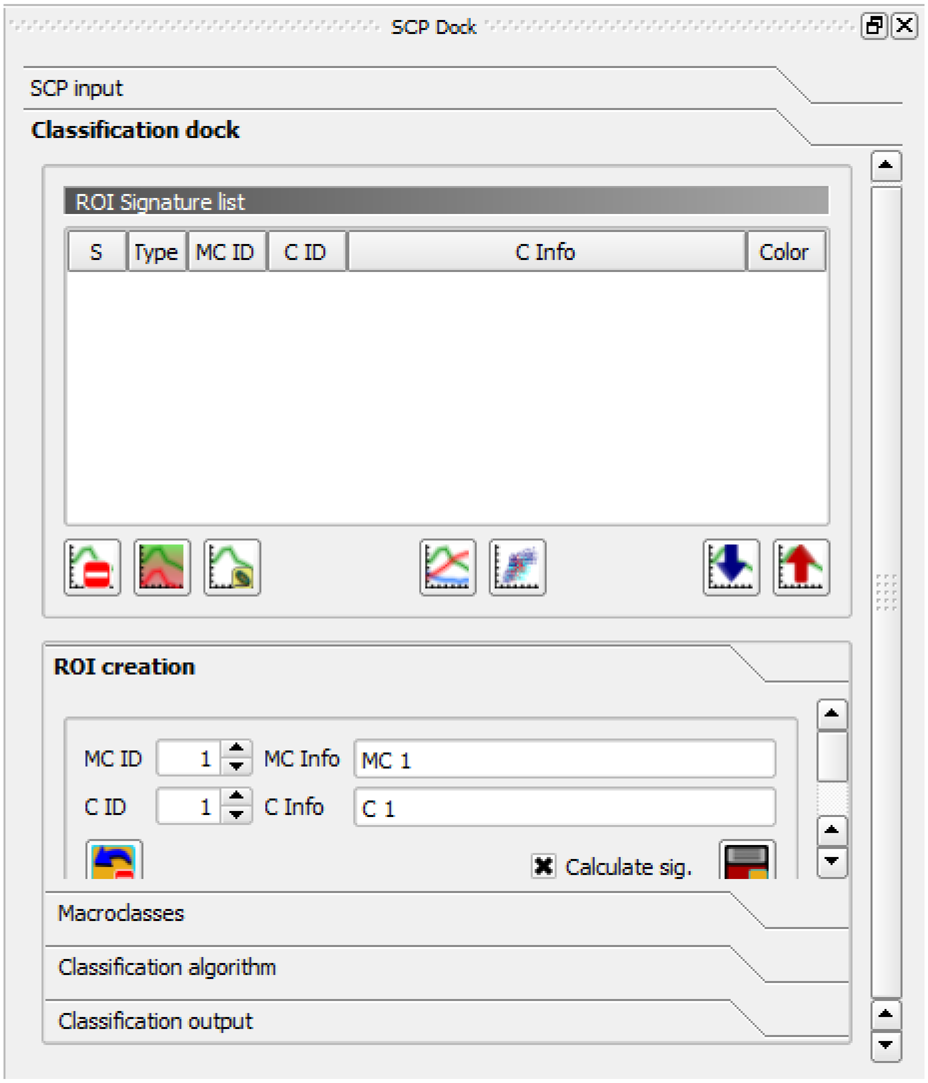
1. Open QGIS desktop.
2. Load the clipped and processed satellite image into QGIS desktop canvas.
3. Click on the “View” option from the menu bar of the QGIS window.
4. Click on the “Panel” option, and check the “SCP dock” checkbox from the lists. Then, the “SCP dock” window is opened on the left side of the “panel” list.

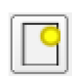


5. The “SCP dock” window of the Semi-Automatic classification plug-in (SCP) has two sections (these are SCP input and Classification dock).

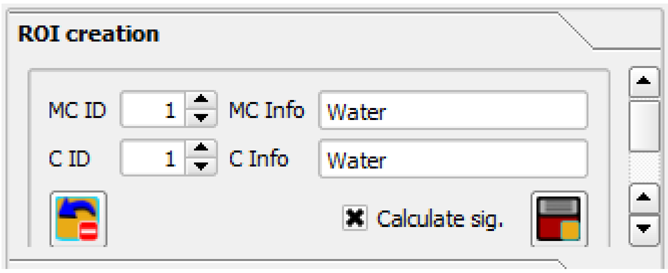
Several sub-sections have existed under the major sections that include steps of supervised image classification. The SCP input section contains an input image and training input options. The classification dock section consists of four sub-sections namely ROI creation, Macro classes, Classification algorithm and Classification output.

6. Click on the “SCP input” button, and add the loaded raster image as an input image.

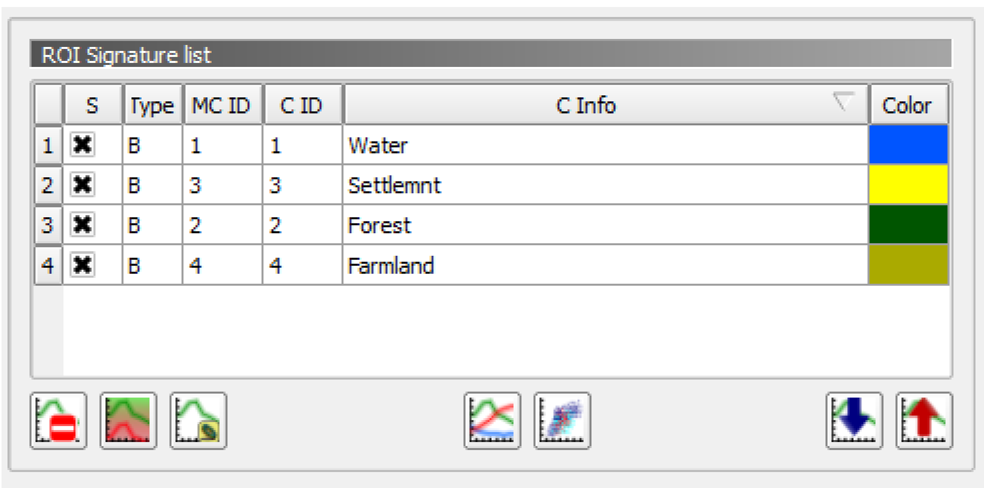


7. The next step is creating an empty region of interest (training plots) for the raster image. To start this, click on the "create a new training input" button  under the "SCP input" section. Save the newly created training plots in an appropriate location. Now, the newly created layer or Shapefile is automatically loaded into a layer panel.
8. Now, you can start developing of training plots or ROI (Region of Interest) for different land use types. As an example, start creating of ROI by digitizing using left click on the water feature of the image and finalize by right click.
9. When you finish digitization of ROI, click on the "ROI creation" sub-section under the "Classification dock". Give a unique numeric code for Major Class ID (MC ID) and Class ID

(C ID). Write the name of land use type in MC Info and C Info. Then, click on the save button , and it displayed on the ROI signature list as a single raw. Try to create as many training plots as possible, because the precision of classification is depended on the number and the quality of training plots.



10. Similarly, follow the same procedure to build training plots for other land use types.



11. Once developments of training plots are completed, click on the “Classification algorism” tab under the “Classification dock”.

12. Click on the active pointer of classification preview button from the toolbar of QGIS window. This will help to check the quality of classification before producing the final output. Always, it is necessary to perform a preview of classification as every time a new ROI (training plots) is added to the ROI Signature list.

13. Assuming that the results of classification previews were good, you can conduct the actual classification output. Click on the “Classification output” tab under the “Classification dock”.

Then, click on the “run” button and give the name and location directory of the output files. Finally, click on “Save”.

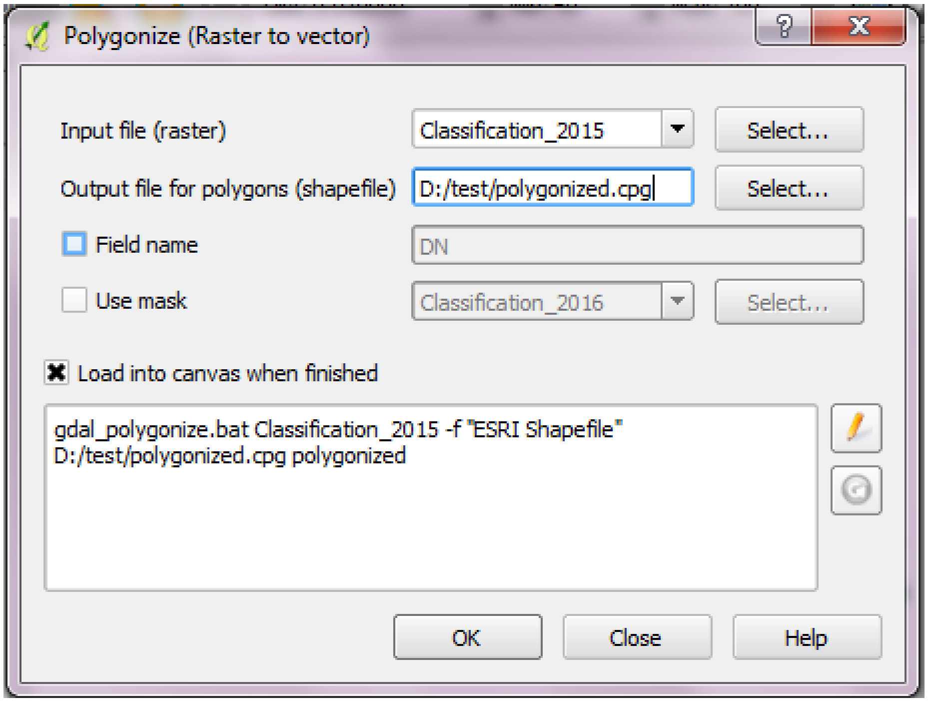
Accuracy assessment

Following the previous sections, we can produce a land-use classification map. Now, it is a time to exercise how to determine the quality of our classification using accuracy assessment. Accuracy assessment is a process of validating the quality of the classified image with the reality on the ground. In QGIS, it is possible to quantify the accuracy of your classified image. Accuracy assessment has three main steps.

- Generating random validation plots
- Organizing ground truth data (Reference data)
- Creating and interpretation of confusion matrix

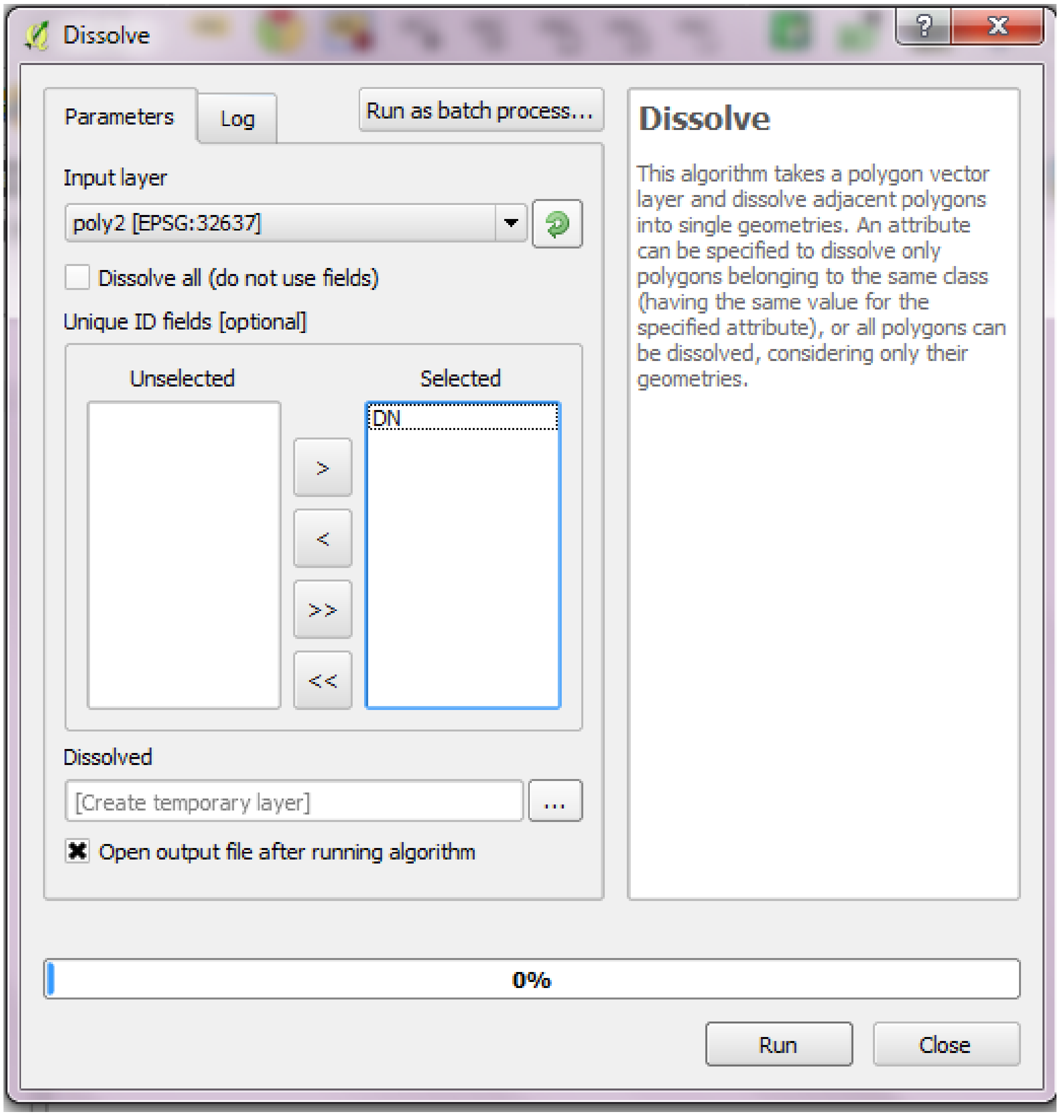
In order to generate a random sample plot for validation in QGIS, follow the following instruction

1. Open QGIS desktop
2. Load the classified image into QGIS window.
3. Then, convert the classified raster image to a vector model. To do this, click on the “Raster” option from the menu bar and select “Conversion”. Click on the option “Polygonized (Raster to Vector)”. In the “Polygonize” window, insert the classified image as an input raster files. Then, write-down the output location, and click on “OK”.



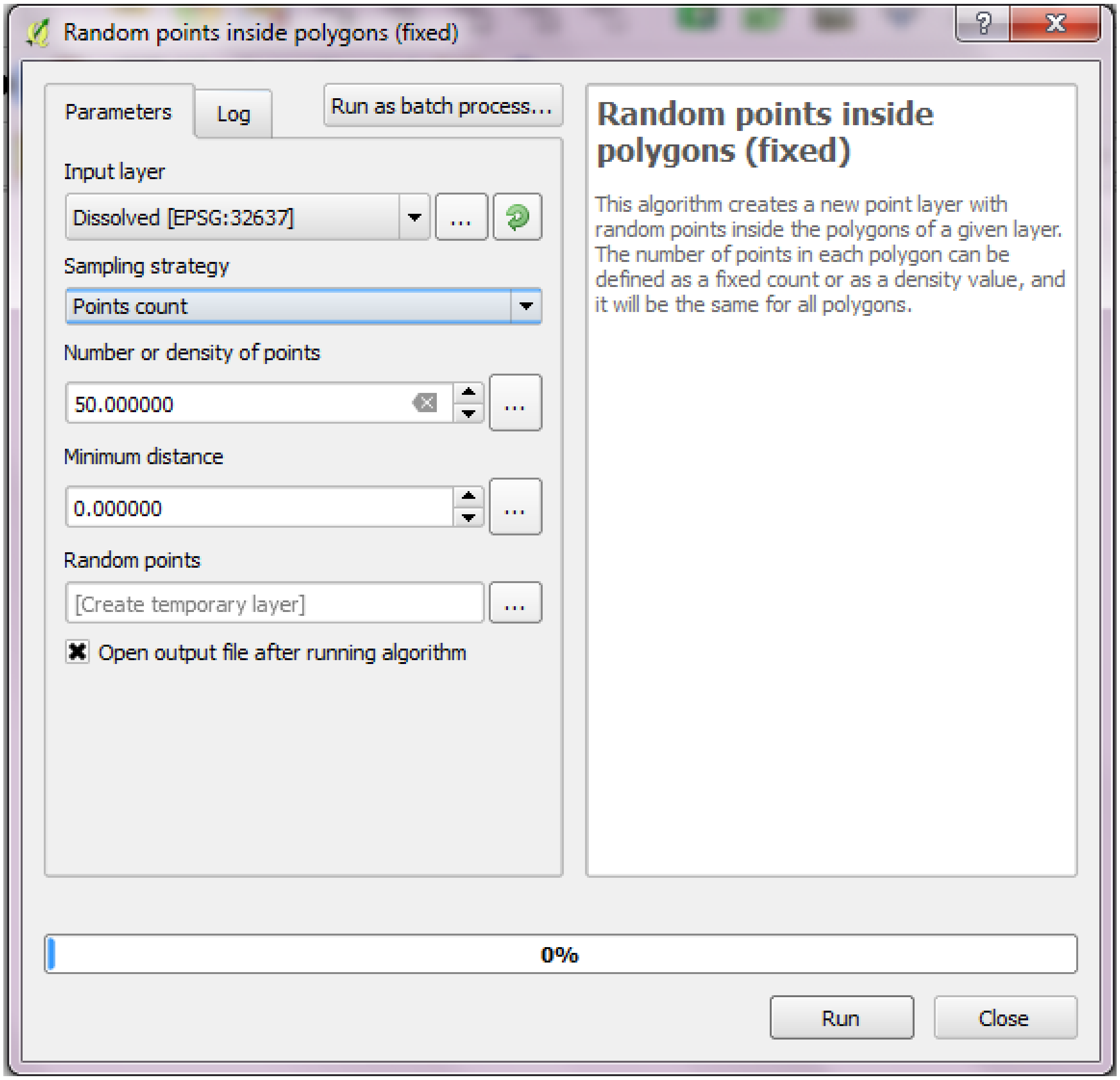
Now, the classified raster image is converted to vector. The next step is dissolving the same value of the pixel in the vector into a single cluster. To check this, right click on the converted vector layer and look at the attribute table of the vector. You can see repeated values of records in a single field (column). Therefore, the same values of this field should be grouped into a single value by the geo-processer called "Dissolve".

4. In order to dissolve, click on the "Vector" option from the menu bar and select the "Geo-processing" tool. Click on "Dissolve" tool.
5. When the dissolve window appeared, insert the converted vector as an input layer. Uncheck the box called "Dissolve all". Under a unique ID field move the "DN" from unselected box to the selected box. Click on the "Run" button.



Now, the dissolved vector is ready to generate random points in each of its land-use types. Later, the generated random points will use as a representative plot for accuracy assessment.

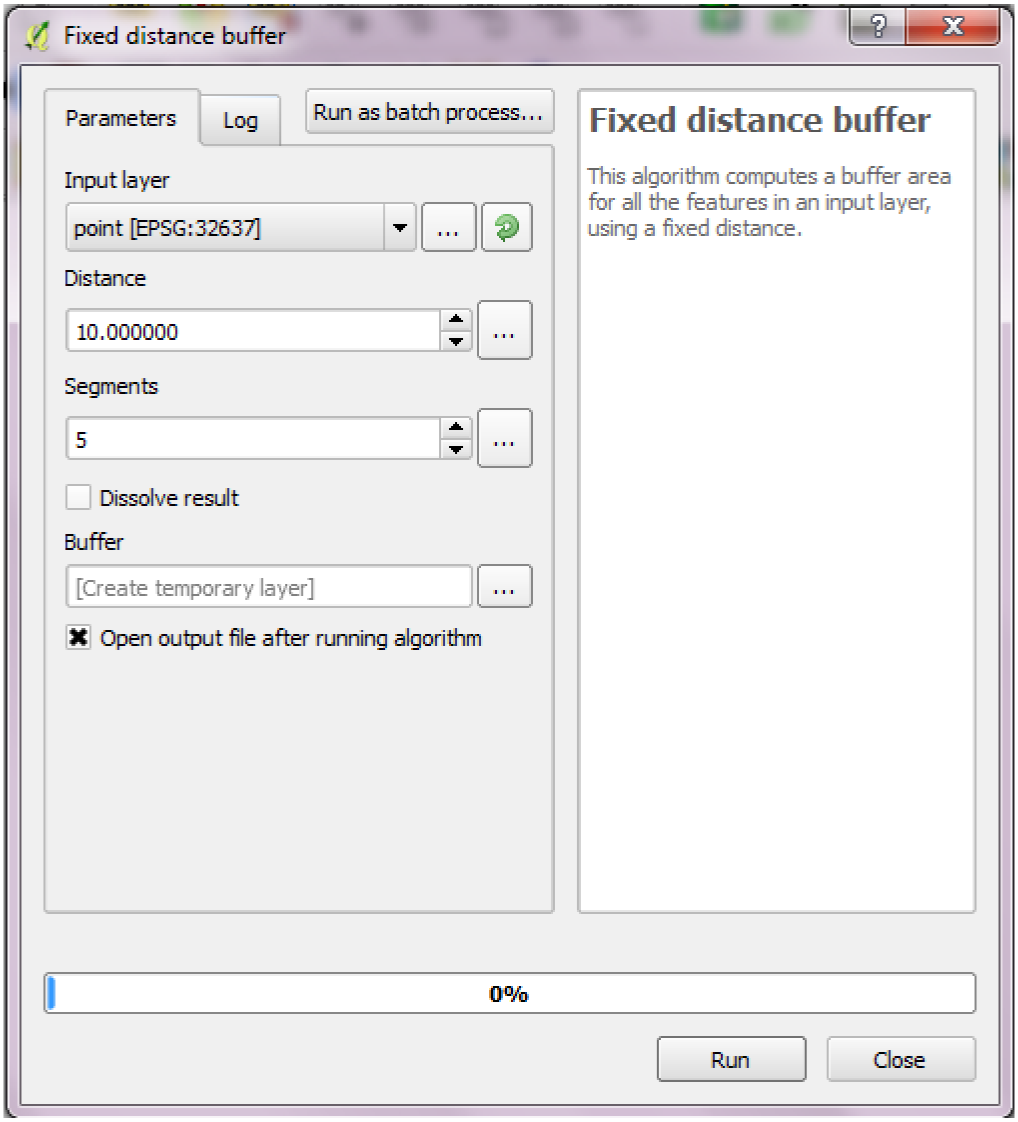
6. To generate random points, click on the “Vector” from the menu bar, and then click on the “Research tool”. Choose the option “Random point inside polygon (fixed)”. Insert the dissolved polygon as an input layer. Decide the number of sample plot in each land-use class, and write it under the “Number or density of points” box. Finally, click on “Run” button.



At this time, equal numbers of random plots are generated in each of the land-use classes that are needed for accuracy assessment. The next step is converting the generated random points to circular plots by using the geo-processing tool called "buffer". This is applied to create a circular plot.

7. To change point plots to circular plots, Click on the "Vector" option. Then, choose the "Geo-processing" tool. Then again, select the "Fixed distance buffer" option. Here, select the created random points as an input layer. Write down the radius under the "Distance" box. Click on the "Run" button. After the execution is completed, the circular polygon will be created around the random point plots. These polygons are representative plots to study the

accuracy of the classified image. Therefore, save these polygons in a proper location so that you can use it for the next step.



The next step of accuracy assessment is preparing ground truth data (reference data). To achieve this task, follow the procedure below in QGIS. This part is a continuation of the previous steps (generating random validation plots).

1. Open QGIS desktop.
2. Add the circular plots that were generated from the above steps (i.e. representative circular plots produced over the classified image).

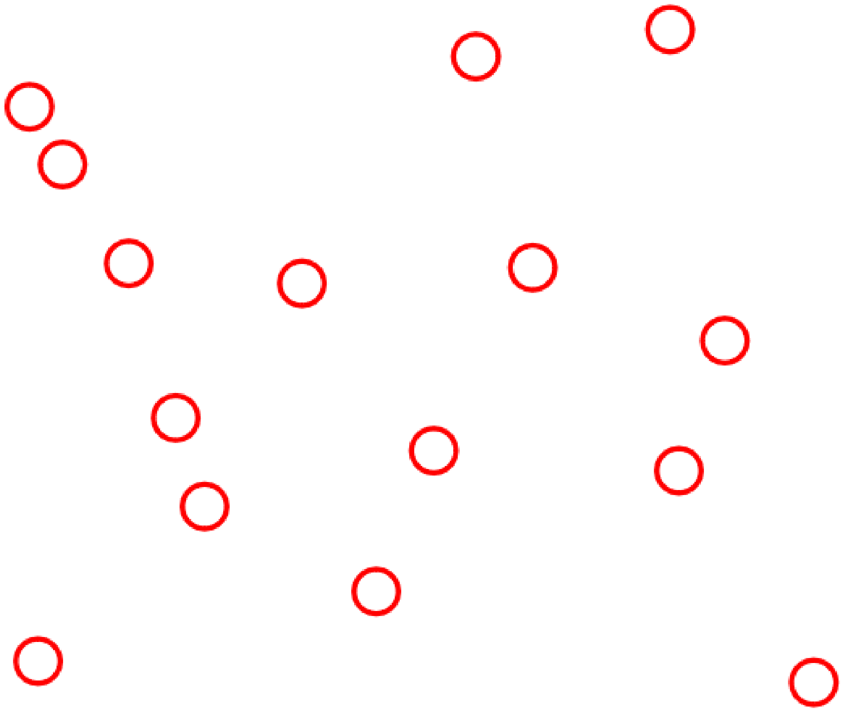
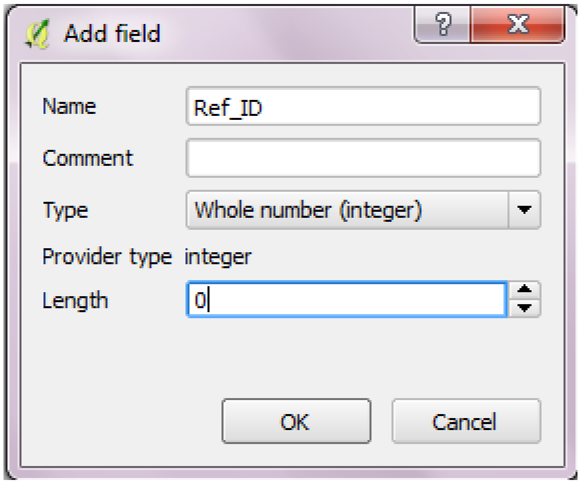


Figure 10: Representative circular plots to study accuracy assessment

3. Create a new field (column) for the representative polygon layer. The new column is used to record reference class ID. To create these, right click on the buffer polygon layer, and then choose the “Toggle editing”. Again, right click on the layer of buffer polygon, select “Open attribute table”.

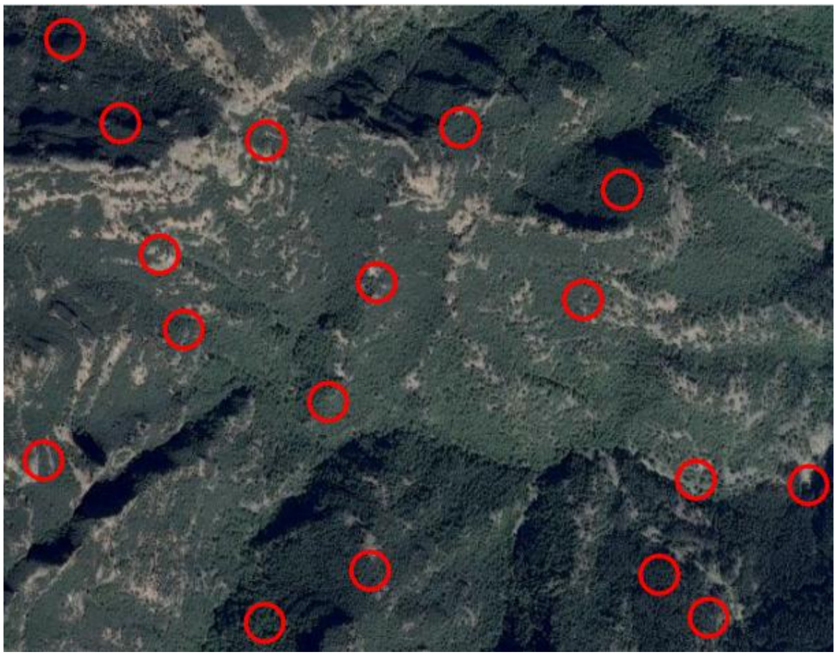
4. When the attribute table opens, click on the “New field”  button from the upper part of the table. Now, write the name of the newly created column on “Name” box and click on “OK”. At this time, the newly created column is added to the table.



5. Load images of Google Map as a base map (background map) on the opened canvas to record reference of land-use types. Click on the "Web" option from the menu bar, select the "OpenLayer plugin". Select the "Google satellite" from the option "Google maps". Now, the Google map image is loaded as a base map so that it enables you to fill up the land class ID of each circular plot.

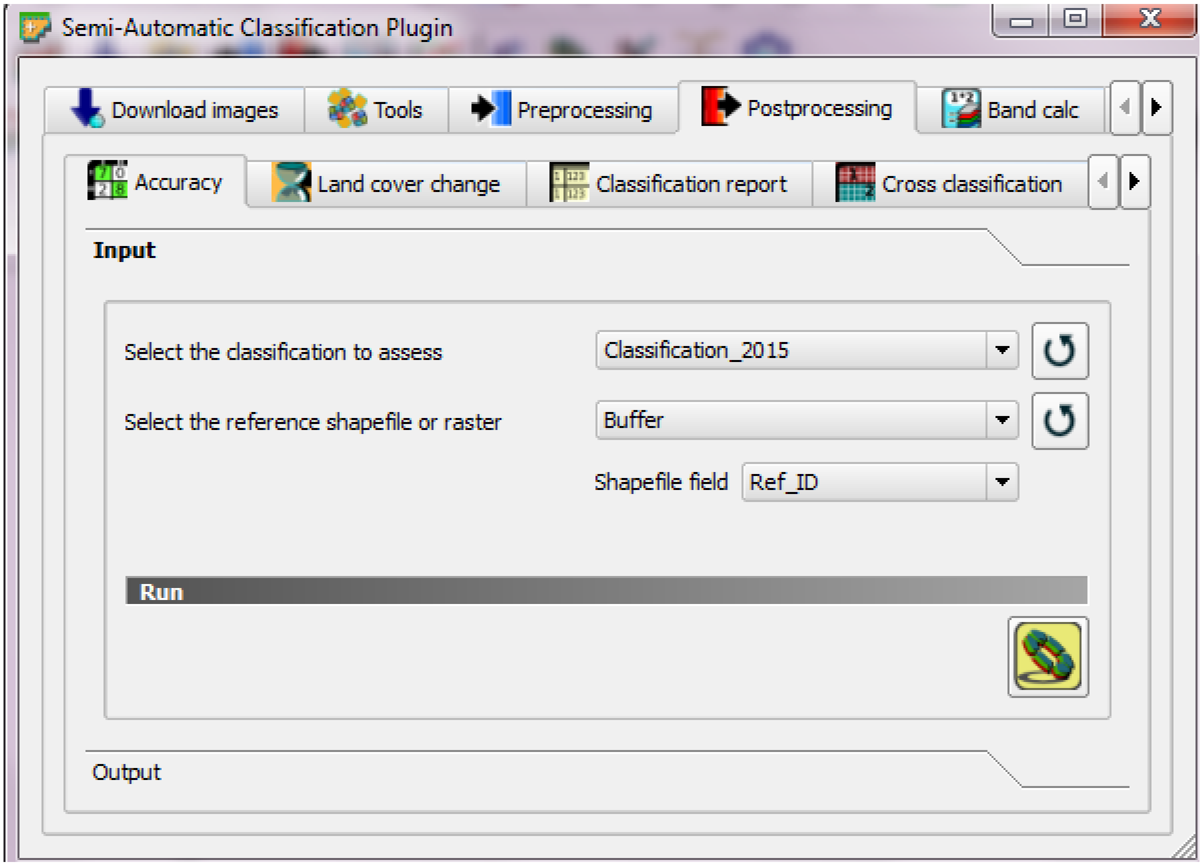
Please note that this plug-in requires the availability of high-speed internet service. In addition, the code given for reference should be corresponding with the classified image. For instance, if you code the number one (1) for farmland during classification, you should use the same code (number 1) for farmland during referencing.

6. After recording of the reference data in the circular plots, save the recorded value. Click on the "save edit" button  on the upper part of the attribute table. This file is important for the next step.



After reference plots are completed, the final step of accuracy assessment is to compare the level of agreement between reference and classified data. The level of agreement can be evaluated using confusion matrix. To conduct the final step of accuracy assessment, follow the following procedures.

1. Start QGIS desktop
2. Load the classified image and reference vector circular plots from the previous steps.
3. Click on the “SCP” from the menu bar. Choose the “postprocessing”, and click on the option “Accuracy” from the list.
4. In Semi-Automatic classification plug-in, add the classified image and reference data in the first and second boxes, respectively. Under the “Shapefile field”, select the newly created column in step 4 of the previous procedure. Click on the “Run” button.



5. Choose the file name and directory for the result. Finally, you can find a table of confusion matrix at the lower part of the window.

> ERROR MATRIX
> Reference

V_Classification	11.0	12.0	13.0	14.0	15.0	Total
11.0	49	0	0	0	1	50
12.0	5	41	1	0	3	50
13.0	3	0	45	1	1	50
14.0	0	0	0	0	0	0
15.0	3	1	1	0	45	50
Total	60	42	47	1	50	200

Overall accuracy [%] = 90.0
Class 11.0 producer accuracy [%] = 81.6666666667 user accuracy [%] = 98.0 Kappa hat = 0.971428571429
Class 12.0 producer accuracy [%] = 97.619047619 user accuracy [%] = 82.0 Kappa hat = 0.772151898734
Class 13.0 producer accuracy [%] = 95.7446808511 user accuracy [%] = 90.0 Kappa hat = 0.869281045752
Class 14.0 producer accuracy [%] = 0.0 user accuracy [%] = nan Kappa hat = nan
Class 15.0 producer accuracy [%] = 90.0 user accuracy [%] = 90.0 Kappa hat = 0.866666666667
Kappa hat classification = 0.866888519135

5. Calculating spectral indices and terrain analysis

Spectral indices and terrain analysis represent promising developments in image classification and have been used widely in the remote-sensing. In spite of their application for land use and cover classification, they still have underutilized their relevance in many ecological studies. This chapter discusses their performance in various fields of ecology.

5.1. Calculating spectral indices

Spectral indices are a mixture of reflectance at two or more wavelengths that indicate relative abundance of a feature on the Earth's surface. These indices play an important role to identify popular features on the satellite image (i.e. forest, water bodies bare land…etc). Several spectral indices are applied in ecological studies such as studies of forest and aquatic/wetlands ecosystems, vegetation ecology and ecosystem services.

Particularly, many indices are helpful in land-cover classification to identify features of the Earth. The NDVI, for instance, has a significant role in the identification of vegetation feature from the satellite image. During image classification, understanding the significance of the indices is very important to support the processes of classification (Table 4).

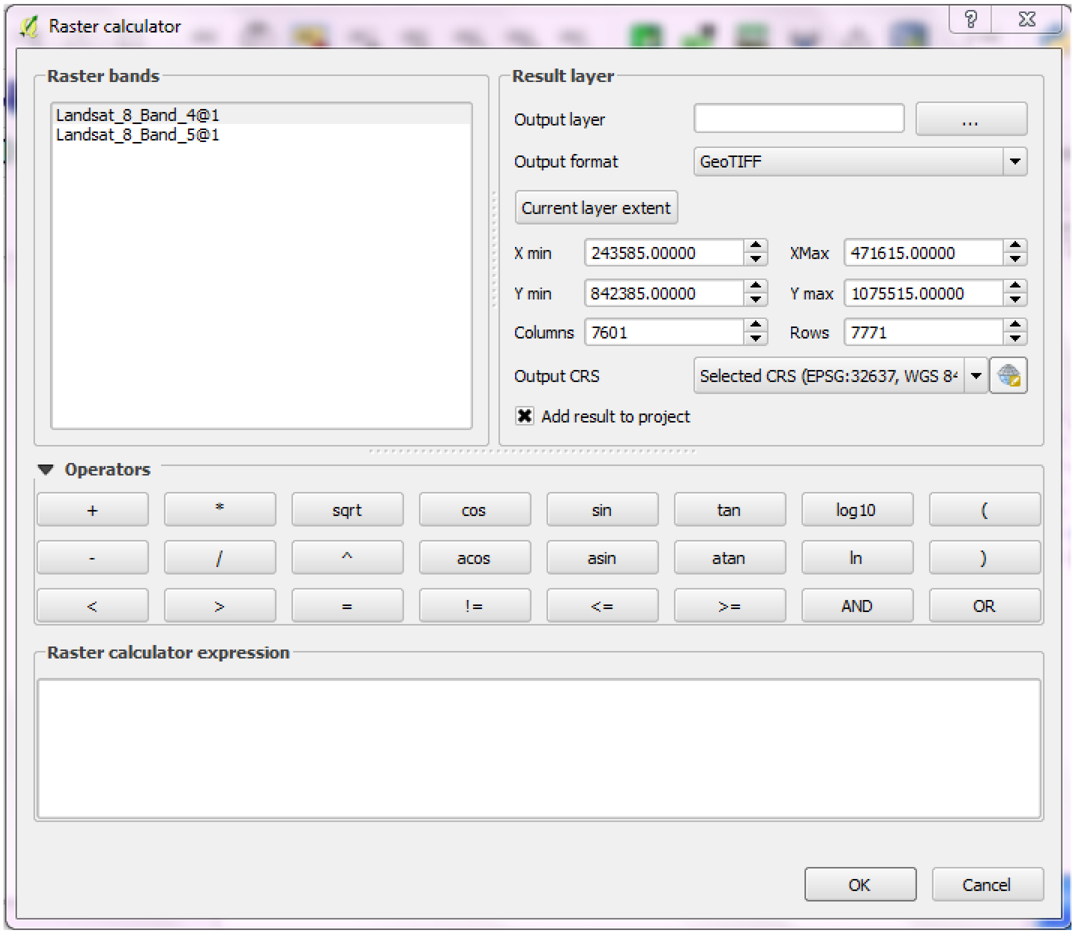
In QGIS, there is a possibility to calculate the indices using the raster calculator tool. We use the selected bands (e.g. the near-infrared and red bands for NDVI) of a raster as an input, and calculate the indices using their respective equations. Notably, all the input bands of a raster for index calculation should be processed using image pre-processing techniques (Chapter 3).

Table 4: Possible spectral indexes used for ecological studies in Landsat imagery (Landsat7: Blue=Band 1, Green = Band 2, Red=Band 3, NIR= Band 4, SWIR1 = Band 5, SWIR 2= Band 7; Landsat 8: Blue=Band 2, Green = Band 3, Red=Band 4, NIR= Band 5, SWIR1 = Band 6, SWIR 2= Band 7).

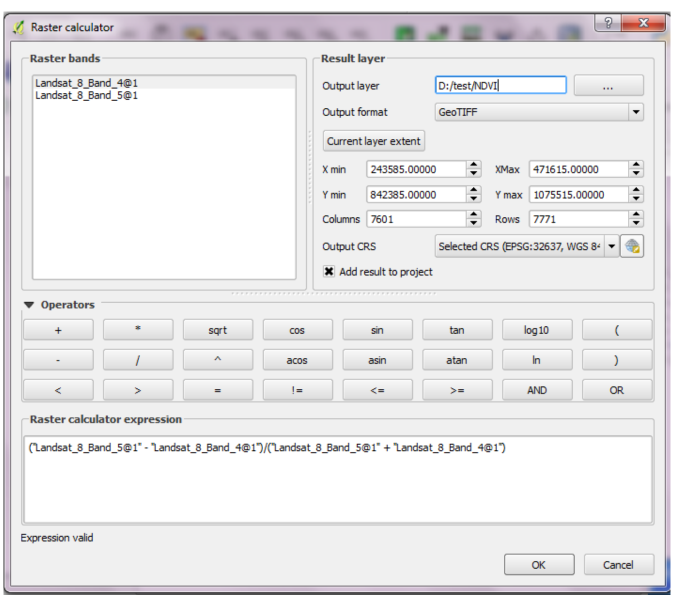
Index	Description	Equation	References
NDVI	Normalized Difference Vegetation Index	(NIR − Red)/(NIR + Red)	Rouse, 1974
EVI	Enhanced vegetation index	(NIR − Red)/(NIR + 6 (Red) − 7.5 (Blue) + 1)	Huete *et al*, 1997
SAVI	Soil adjusted vegetation index	((NIR − Red)/(NIR + Red + 0.5)) (1.5)	Huete, 1988
NDWI	Normalized Difference Water Index	(Green − NIR)/(Green + NIR)	Amare, 2016
NDMI	Normalized Difference Moisture Index	(NIR – SWIR1)/(NIR + SWIR1)	Amare, 2016
MNDWI	Modified Normalized Difference Water Index	(Green − SWIR1)/(Green + SWIR1)	Amare, 2016
WRI	Water Ratio Index	(Green + Red)/(NIR + SWIR1)	Amare, 2016
AWEI	Automated Water Extraction Index	4 ×(Green- SWIR1) − (0.25×NIR + 2.75 ×SWIR2)	Amare, 2016
MSAVI	Modified soil adjusted vegetation index (MSAVI)	(2 (NIR) + 1 − sqrt ((2 (NIR) + 1)2 − 8 (NIR − Red)))/2	Qi J *et al*, 1994
NDMI	Normalized difference moisture index (NDMI)	(NIR − SWIR1)/(NIR + SWIR1)	Gao BC, 1996
NBR	Normalized burn ratio (NBR)	(NIR − SWIR2)/(NIR + SWIR2)	Miller and Thode, 2007
NBR2	Normalized burn ratio-2 (NBR2)	(SWIR1 − SWIR2)/(SWIR1 + SWIR2)	Miller and Thode, 2007

As an example, let us see the steps in calculating NDVI on QGIS software, and you can follow the same procedure for the rest of indices using their specific equations (Table 4).

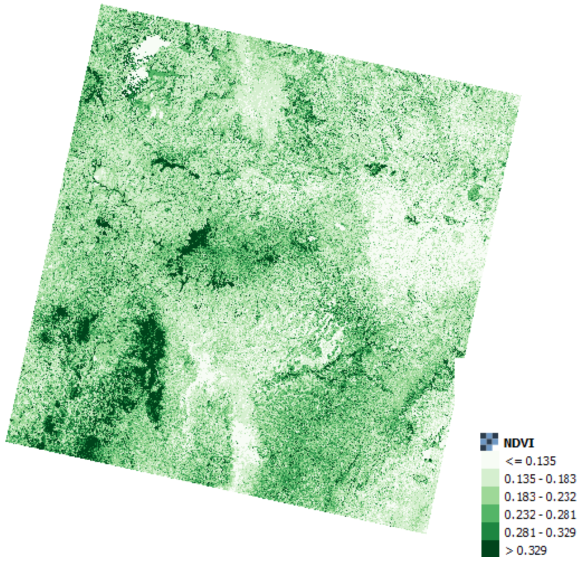
1. Open QGIS desktop software.
2. Add the processed Red (Band_3 for Landsat7/Band_4 for Landsat8) and Near-infrared (Band_4 for Landsat7/Band_5 for Landsat8) bands.
3. Click on the “Raster” from the menu bar and select the “raster calculator” option. Then, the raster calculator window is displayed.



4. Insert the formula of the NDVI in the box called "raster calculator expression". Put the output path in the uppermost right of the window.



5. Finally, click on “OK”.



5.2. Terrain analysis using DEM

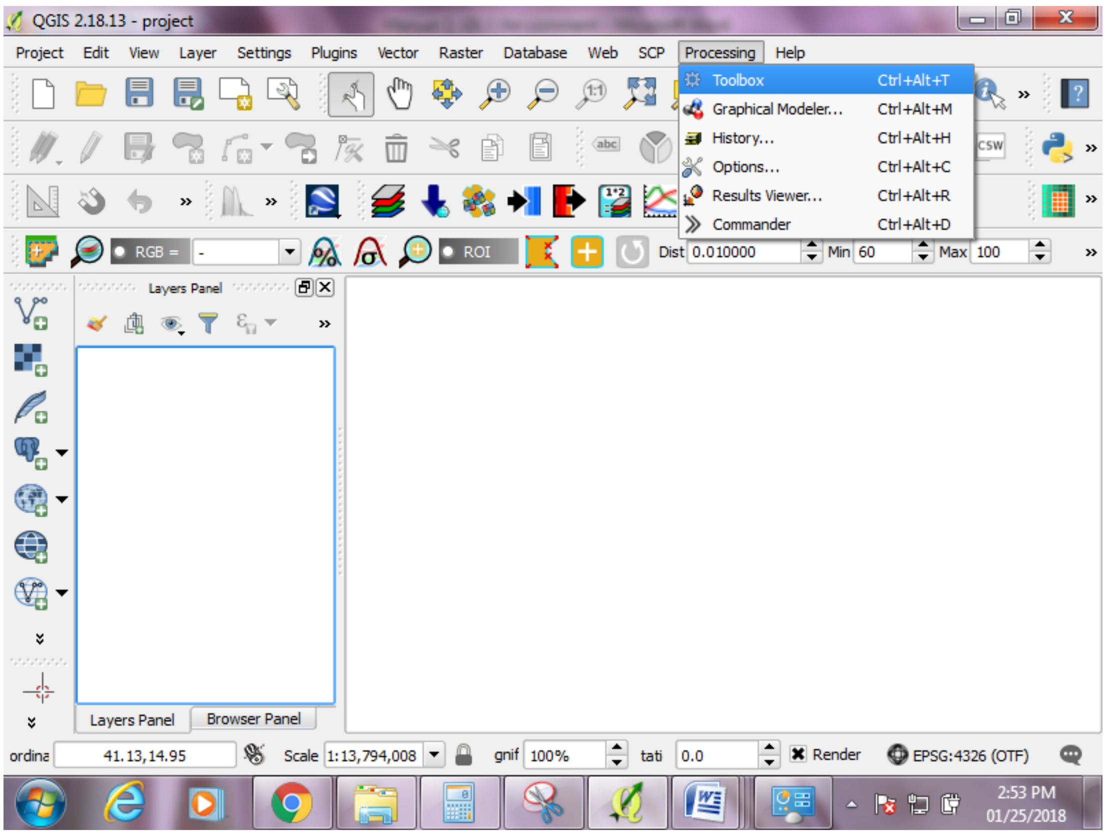
Terrain analysis is a method in remote sensing to calculate and visualize topographic parameters such as elevation, slope and aspect. It applies to various professional disciplines. Particularly, terrain analysis is essential in understanding the role of topographic variables in ecological processes, and it is applied in determining the relationship between the variables and changes of the ecosystem. In most of the land cover change studies; these parameters are important to model the future trends of the change at the landscape level. Deforestation risk analysis, carbon estimation of the forest, forest fire prediction and other ecological and hydrological modeling are depended on terrain analysis.

The major input raster file to conduct terrain analysis is a digital elevation model (DEM). The Space Shuttle Radar Topography Mission (SRTM) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) are the well-known free sources of DEM imageries at the global level. The USGS archive provides both types of DEM in free of charge (Satellite image acquisition 3.1).

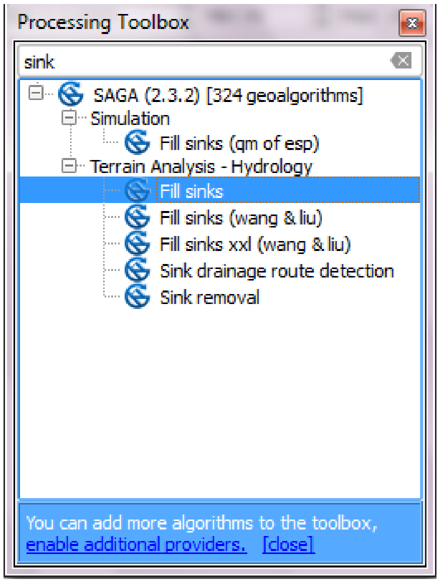
We suggest filling the sinks of the downloaded raw DEM before conducting terrain analysis. The sink fills process cleans out the DEM by removing unnecessary hole that happens in a single or multiple pixels.

Thus, follow the following procedure to fill the sink of the downloaded DEM image in QGIS software program.

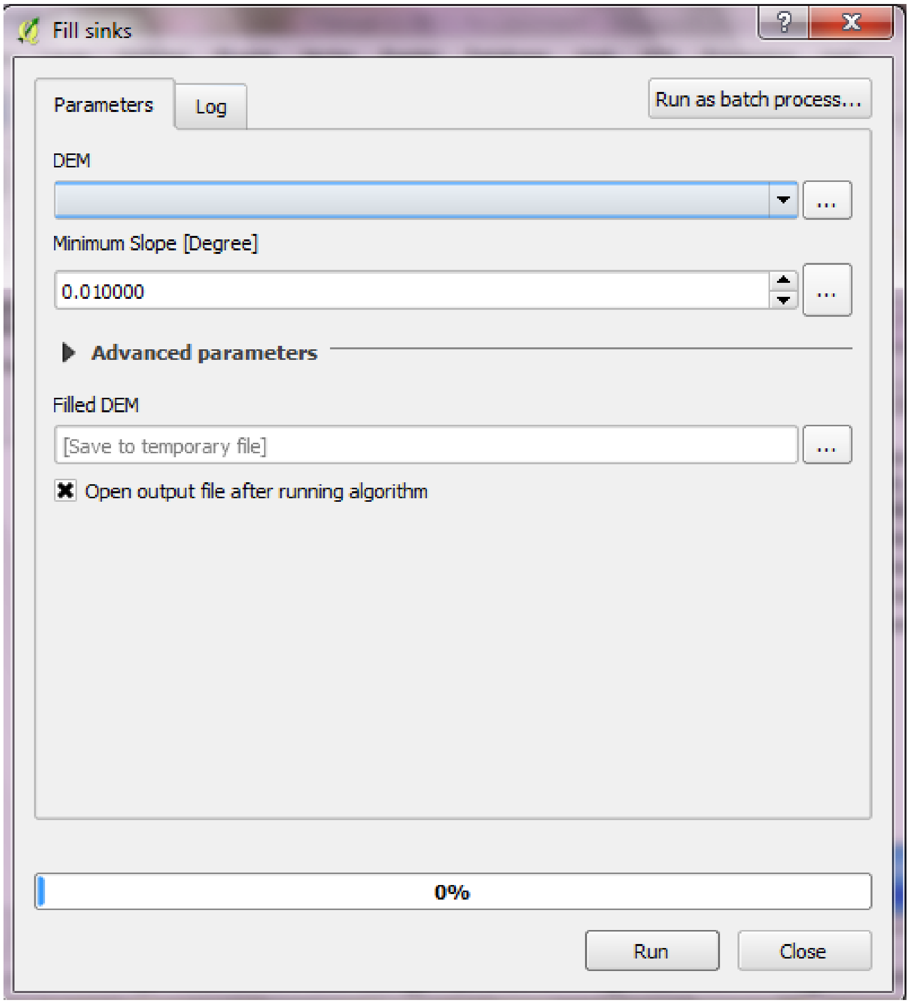
1. Open the QGIS desktop.
2. Load the raw DEM image into the QGIS canvas.
3. Click on the "processing" from the menu bar and choose toolbox.



4. Now, the processing toolbox appears at the right side of the map canvas.
5. Then, write "sink" in the toolbox and press the "Enter" button from the keyboard to search. Now, available tools are listed in the box.



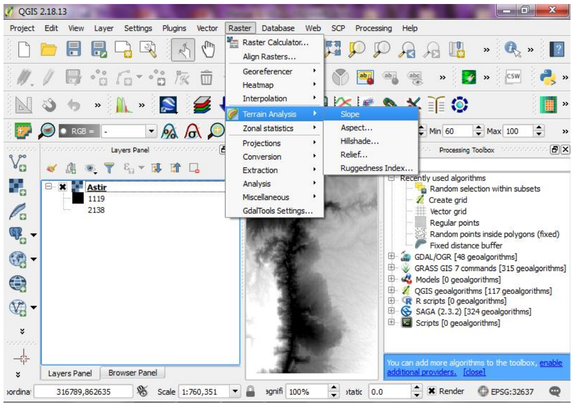
6. Now, click on the "Fill sinks" and the "Fill sinks" dialog box appears. Since QGIS does not have its own tool to carry out fill sink procedure, it utilizes the SAGA extension in QGIS.



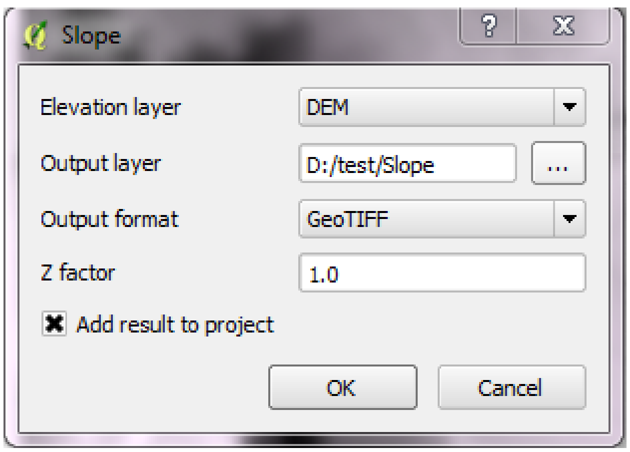
7. Insert the DEM layer in the DEM option. Finally, click on the "Run" button.

Now, The DEM image is ready for further terrain analysis. In QGIS, there is an opportunity to conduct terrain analysis. For this exercise, we will show you how the slope is calculated, and then you will exercise for the rest of topographic variables such as aspect.

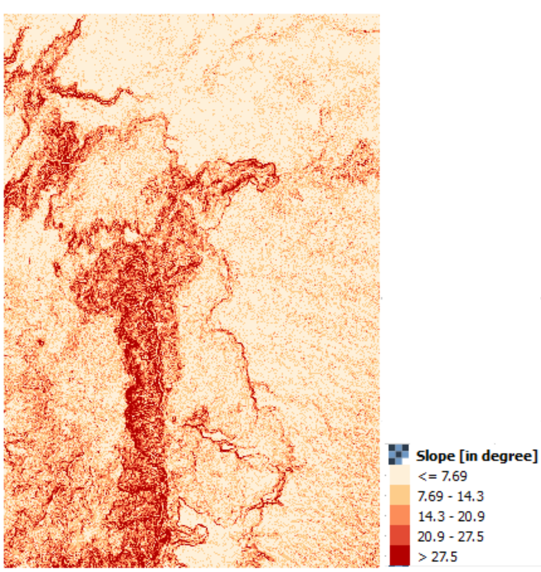
1. Open QGIS desktop.
2. Load DEM image into the QGIS canvas.
3. Click on the "Raster" then select the "Terrain analysis". From the list, select the option "slope".



4. Insert the processed DEM (Sink fill processed) in the box of the “Elevation layer”. Set the path of the final output on the “output layer”. Click on the “OK” button.



5. The result looks like the following



Additional options of terrain analysis (i.e. Aspect, Hill shade, Relief and Ruggedness index) are included in QGIS. Therefore, we recommend you to try it by yourself. The procedure is almost the same as slope. Their input raster is also the same (DEM).

6. Summary

Remote sensing provides a range of data and methods in ecological studies. Satellite images are one of the remote sensing data that can be used widely in ecology. The concept of ecological remote sensing integrates the science of remote sensing in the ecological application. Besides the existing of several categories of ecological remote sensing, we focused on land-cover classification that bases an inspection of satellite imagery. Land cover classification can be carried out with this simple training manual. There are a number of underutilized and free satellite imageries such as Landsat and Sentinel. As these satellite imageries are improved over time, we can expect to see products that have better resolution and accuracy. The detailed methodological approaches discussed, in this manual, are related to various image processing ranging from image acquisition to interpretation and classification. Finally, approaches to calculating spectral indices and terrain analysis were illustrated.

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Mr. Nesibu Yahya

Mr. Nesibu studied his BSc. on Dry land forestry from Mekelle University and his MSc is on Life Sciences specialized on Applied Agricultural and Forestry Sciences from Bern University of Applied Science, Switzerland. He has excellent skill on geo-spatial analysis and other ecological and statistical analysis on different software environment (ARCGIS, QGIS, SAGA, R and SPSS). Currently, he is working as research assistant under the directorate of ecosystem management in EEFRI.

Email: - sof.swt@gmail.com

Mr. Solomon Mulat

Mr. Solomon Mulat has received his BSc in Agroforestry from Hawassa University Wondo Genet College of Forestry and Natural Resource in 2011. He has also gained his MSc. in Geo-information Science and Earth Observation for Natural Resources Management from ITC, University of Twente the Netherlands in 2017. Since 2012, he has been working in the Ethiopian Environment and Forest Research Institute as Assistant researcher. He has skill and experience in geospatial and statistical data analysis using some application software and tools such as ArcGIS, ERDAS, ILWIS, QGIS, Collect Earth and R- Studio.

Email: - solibnm@gmail.com (solomon.mu19@yahoo.com)

Mr. Melaku Getachew

Mr. Melaku Getachew has studied his B.Sc at Dilla University in the field of NRM. Then after, he has got his MSc. from Bahir Dar University in the field of GIS and Remote sensing. He had been working as a Lecturer at Debre Markos University. He taught GIS, Remote sensing, and Surveying courses while he was there. Now, he is working in Ethiopian Environment and Forest Research Institute as a GIS researcher.

Email: - melegeta21@gmail.com

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