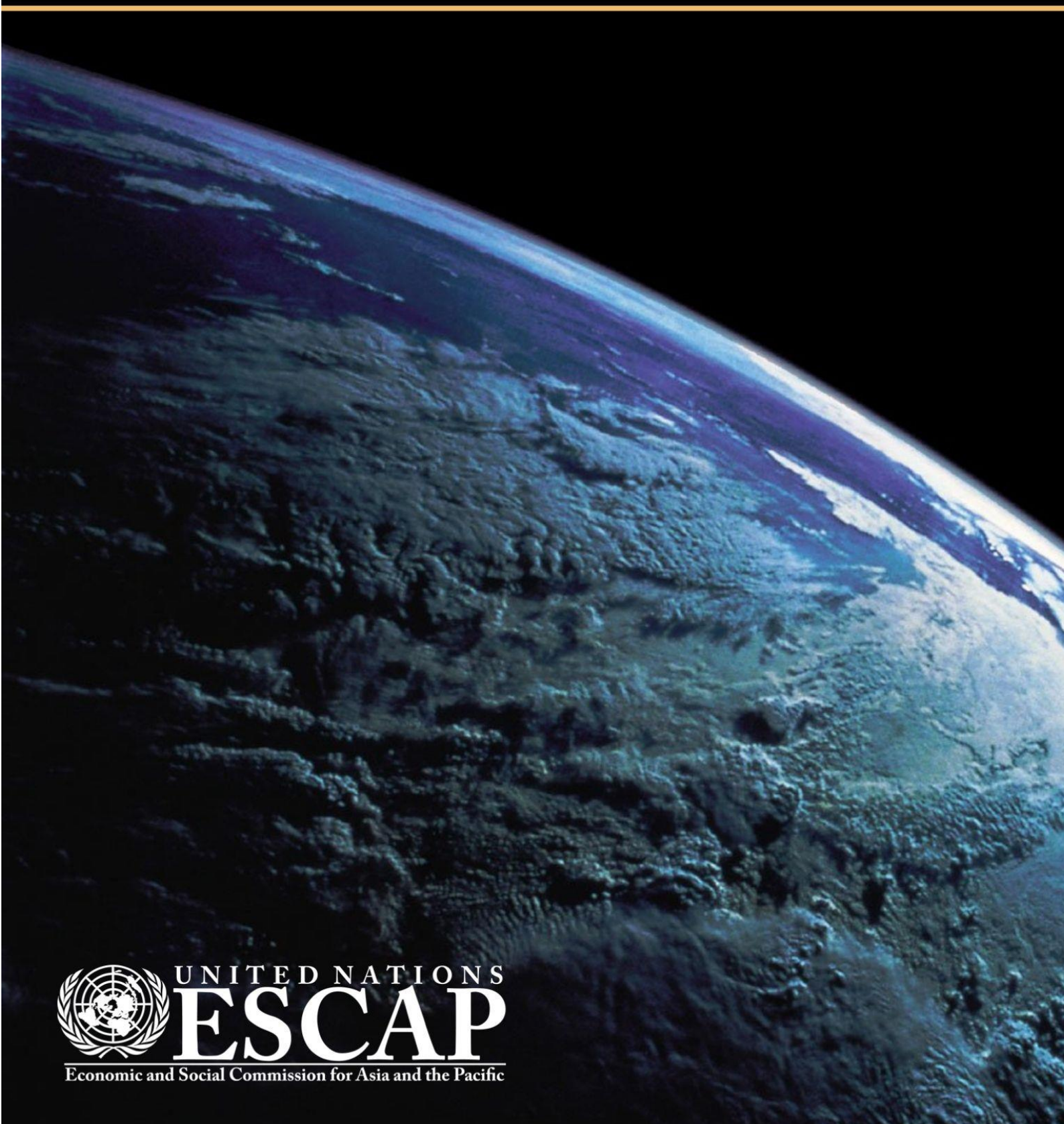
Producing land cover change maps and statistics

Step by step guide on the use of QGIS and RStudio



UNITED NATIONS
ESCAP
Economic and Social Commission for Asia and the Pacific

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Step by step guide on the use of QGIS and RStudio

ESCAP September 2020

Acknowledgments:

This guide was prepared by Aahlaad Musunuru and Ayodele Marshall, under the supervision of Rikke Munk Hansen.

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Contents

How to use this guide

This guide shows you step-by-step how to create land cover change maps and statistics.

The guide explains the use of open-source software, namely Quantum Geographic Information System (QGIS) to construct a map displaying land cover change over time, and RStudio to generate land cover change statistical tables. Maps and tables are generated in accordance with the land cover categories of the System of Environmental-Economic Accounting (SEEA).

The guide takes you through 4 steps:

Step 1: Download the data you want to work with from available open sources – **Data downloading**

Step 2: Strip and clean the data downloaded to filter the layers relevant to your chosen geographical area – **Data pre-processing**

Step 3: Produce the land cover change map – **Data processing**

Step 4: Present the land cover change statistics in matrix and table form – **Presenting the findings**

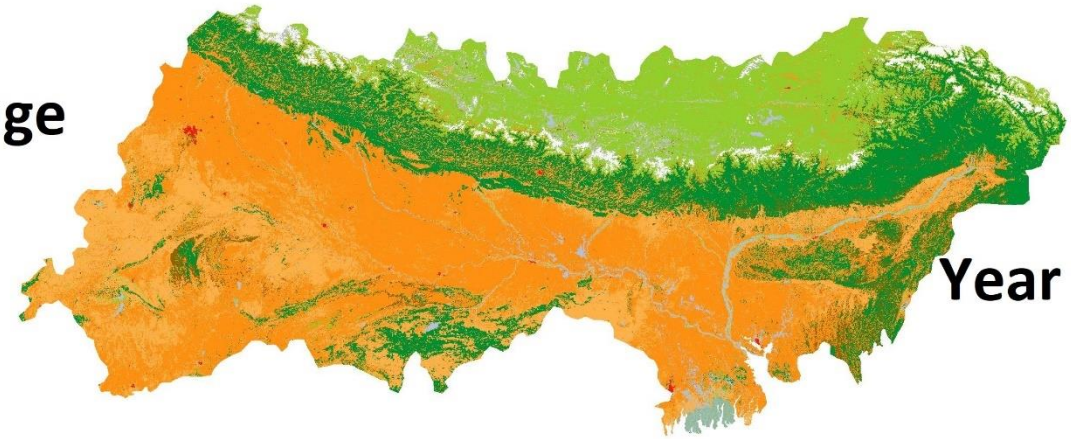
In total, these steps should take approximately 4 hours to complete from start to finish.

Before embarking on step 1, make sure you have QGIS and RStudio on your computer. First time users can refer to the **Appendix** for help to download and install QGIS and RStudio.

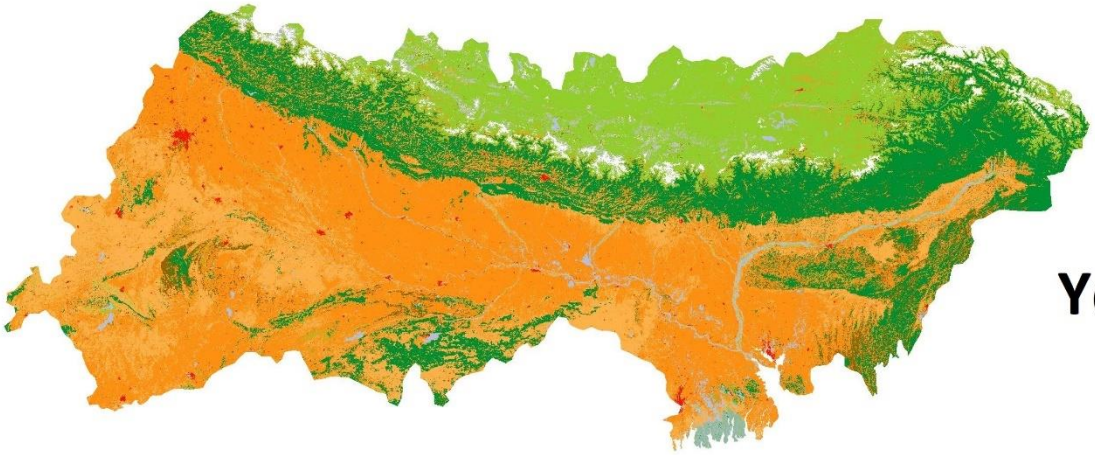
For illustrative purposes, the guide uses select open-source data for a specific geographical area, the Ganga Brahmaputra River Basin in India. The maps generated in this exercise are shown on the page below. You can generate your own maps and choose other data which suit your purpose and the geographical area of your interest; and the guide advises how to do so. The **Appendix** to this guide provides a list of open-source datasets that may be useful for your own purposes.

So, let's get started!

Land Cover Change



Year 1995



Year 2015

0 250 500 km

Land Cover

- Artificial surface
- Herbaceous crops
- Woody area
- Multiple or layered crops
- Grassland
- Tree covered areas
- Mangroves
- Shrub covered areas
- Shrubs and or herbaceous (flooded)
- Sparsely natural vegetated areas
- Terrestrial barren land
- Permanent snow and glaciers
- Inland water bodies
- Other

Step 1 – Data downloading

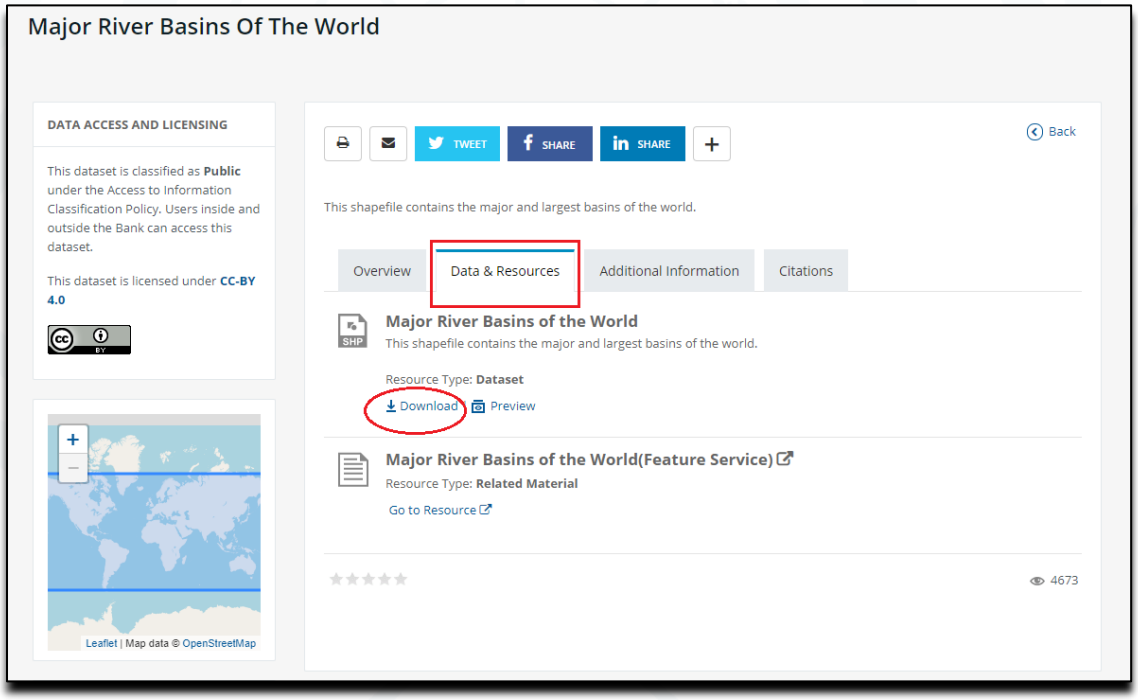
In this section, we will show how to download both raster datasets and vector datasets for use in developing the land cover change maps.

1.1 Downloading vector data

We start with downloading the Major River Basins of the World from World Bank, which provides shape file[1] boundaries for all major river basins in the world. Please note that the **Appendix** outlines examples of the most frequently used vector data and we encourage you to investigate these examples.

To download the shape files used in this exercise:

1. Click this link (https://datacatalog.worldbank.org/dataset/major-river-basins-world)
2. Click on the tab "Data & Resources" and click on the "Download" link
3. Save the downloaded data in a folder named "Downloaded Data" in a convenient location on your system



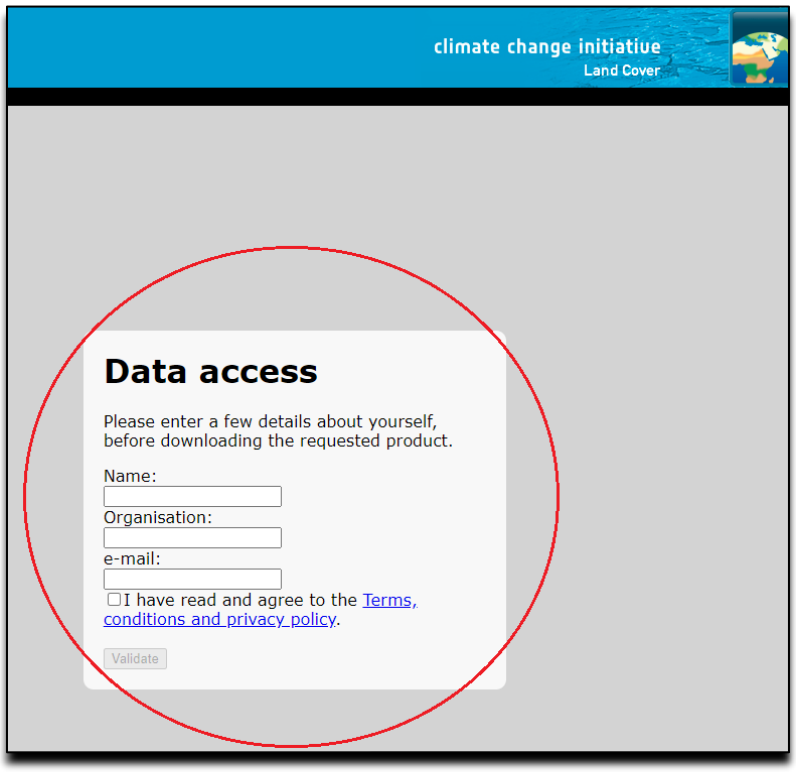
[1] The **shapefile** format is a geospatial vector data format for geographic information system (GIS) software. It is developed and regulated by Esri as a mostly open specification for data interoperability among Esri and other GIS software products. The shapefile format can spatially describe vector features: points, lines, and polygons, representing, for example, water wells, rivers, and lakes. Each item usually has attributes that describe it, such as *name* or *temperature*.

1.2 Downloading ESA Global land cover datasets

Now we are going to Download Global land cover data from the European Space Agency (ESA) with 300-meter resolution, for years 1995 and 2015. Please note that the **Appendix** outlines examples of the most frequently used earth observation data and we encourage you to investigate these examples.

To download the land cover data used in this exercise:

1. Click on the link (http://maps.elie.ucl.ac.be/CCI/viewer/download.php)
2. When the landing page of "The Land Cover CCI Climate Research Data Package (CRDP)" emerges, you will be prompted to complete the section circled below to register and download the Global land cover data. Provide **Name**, **Organisation** and a **Valid e-mail** as these are required fields.
3. After filling the required fields, read the "Terms, conditions and privacy policy" and check "I have read and agree…"
4. Click "Validate"



After clicking "Validate", a new page will appear from which you download the relevant data

5. Go to Land Cover Maps-v2.0.7 Section
6. Click the link "by_year: 24 tif files, 1 band"

Land Cover Maps - v2.0.7

Download product user guide Download quick user guide

24 consistent global land cover maps at 300 m spatial resolution, on an annual basis from 1992 to 2015.

The annual LC maps v2.0.7 for years 2000, 2005 and 2010 replace completely the "v1.6.1 epoch-based" dataset as the annual LC maps v2.0.7 have been improved both in the representation of the areas stable over time and in the characterization of change.

Each pixel value corresponds to the label of a land cover class defined based on the UN Land Cover Classification System (LCCS). LCCS classifiers support the further conversion into Plant Functional Types distribution required by the Earth System Models. The typology counts 22 classes.

The 24 LC maps series is delivered along with 4 quality flags which document the products:

- *qualityflag1* pixel has been processed or not,
- *qualityflag2* pixel status as defined by the pre-processing,
- *qualityflag3* number of valid observations available to derive the classification,
- *qualityflag4* number of land cover changes detected over the 24 years.

These 4 quality flags document the full time series and are not year specific.

These maps are derived from a unique baseline LC map which is generated thanks to a classification chain applied on the entire MERIS FR and RR archive from 2003 to 2012.

Independently from this baseline, LC changes are detected at 1 km based on a time series of annual global classifications generated from AVHRR HRPT (1992 - 1999), SPOT-Vegetation (1999 - 2012) and PROBA-V (2013 - 2015). Systematic analysis of the temporal trajectory of each pixel allowed depicting the major changes for a simplified land cover typology matching the IPCC classes. These classes are: cropland, forest, grassland, wetlands, settlements and other lands; the latter class being further split into shrubland, sparse vegetation, bare area and water.

LC map 2015
1 tif file, zip compression - 258Mo
1 netcdf file, zip compression - 2.33Go

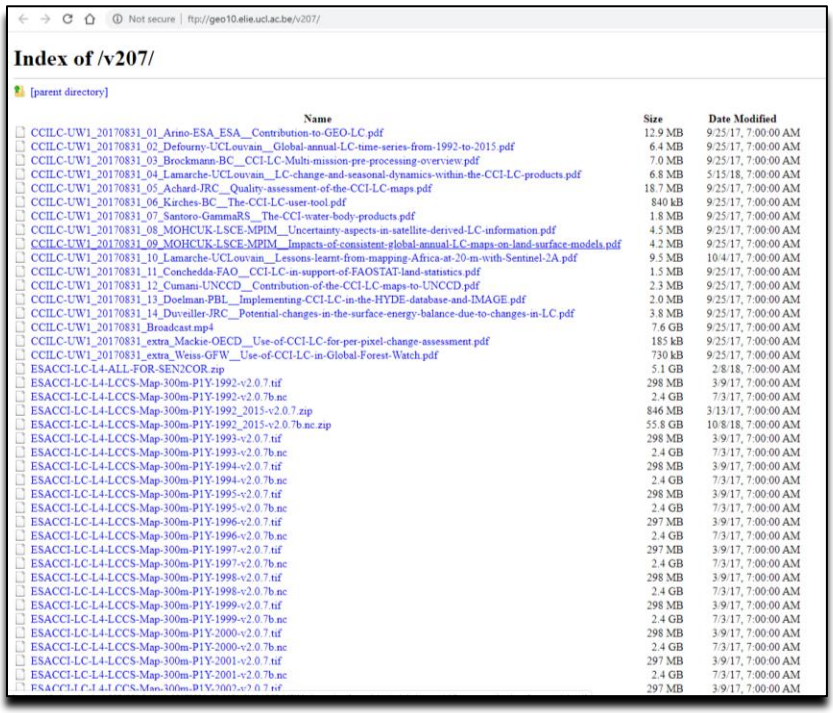
LC maps full 1992-2015 serie
1 tif file, 24 bands, zip compression - 846Mo
1 netcdf file, 24 bands, zip compression - 55.8Go
by year: 24 tif files, 1 band - approx. 300Mo/tif

ESACCI-LC for Sen2Cor data package
54 tif files, zip compression - 5.1Go
Rem: includes LC maps, water bodies v4 and snow products

Quality flags
1 tif file, 4 bands, zip compression - 2.13Go
Rem: already included in the 24-bands netcdf file

Legend
Legend (csv)
Symbology for ENVI (.dsr)
Symbology for ArcGis (.lyr)
Symbology for QGis (.qml)

7. After clicking the link, this window will appear:



Not secure | ftp://geo10.elie.ucl.ac.be/v207/

Index of /v207/

[parent directory]

Name	Size	Date Modified
CCILC-UW1_20170831_01_Arino-ESA_ESA__Contribution-to-GEO-LC.pdf	12.9 MB	9/25/17, 7:00:00 AM
CCILC-UW1_20170831_02_Defourny-UCLouvain__Global-annual-LC-time-series-from-1992-to-2015.pdf	6.4 MB	9/25/17, 7:00:00 AM
CCILC-UW1_20170831_03_Brockmann-BC__CCI-LC-Multi-mission-pre-processing-overview.pdf	7.0 MB	9/25/17, 7:00:00 AM
CCILC-UW1_20170831_04_Lamarche-UCLouvain__LC-change-and-seasonal-dynamics-within-the-CCI-LC-products.pdf	6.8 MB	5/15/18, 7:00:00 AM
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ESACCI-LC-L4-LCCS-Map-300m-P1Y-1992-v2.0.7.tif	298 MB	3/9/17, 7:00:00 AM
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ESACCI-LC-L4-LCCS-Map-300m-P1Y-1996-v2.0.7.tif	297 MB	3/9/17, 7:00:00 AM
ESACCI-LC-L4-LCCS-Map-300m-P1Y-1996-v2.0.7b.nc	2.4 GB	7/3/17, 7:00:00 AM
ESACCI-LC-L4-LCCS-Map-300m-P1Y-1997-v2.0.7.tif	297 MB	3/9/17, 7:00:00 AM
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ESACCI-LC-L4-LCCS-Map-300m-P1Y-1998-v2.0.7b.nc	2.4 GB	7/3/17, 7:00:00 AM
ESACCI-LC-L4-LCCS-Map-300m-P1Y-1999-v2.0.7.tif	298 MB	3/9/17, 7:00:00 AM
ESACCI-LC-L4-LCCS-Map-300m-P1Y-1999-v2.0.7b.nc	2.4 GB	7/3/17, 7:00:00 AM
ESACCI-LC-L4-LCCS-Map-300m-P1Y-2000-v2.0.7.tif	298 MB	3/9/17, 7:00:00 AM
ESACCI-LC-L4-LCCS-Map-300m-P1Y-2000-v2.0.7b.nc	2.4 GB	7/3/17, 7:00:00 AM
ESACCI-LC-L4-LCCS-Map-300m-P1Y-2001-v2.0.7.tif	297 MB	3/9/17, 7:00:00 AM
ESACCI-LC-L4-LCCS-Map-300m-P1Y-2001-v2.0.7b.nc	2.4 GB	7/3/17, 7:00:00 AM
ESACCI-LC-L4-LCCS-Map-300m-P1Y-2002-v2.0.7.tif	297 MB	3/9/17, 7:00:00 AM

8. In the window, look for the ".tif"[2] files with the general title of "ESACCI-LC-L4-LCCS-Map-300m-P1Y" and the years of your choosing. For the exercise done in this guide, we looked for years 1995 and 2015 as we are comparing the land cover changes along the Ganga Bhramaputra River Basin for that 20-year period.
   These are: ESACCI-LC-L4-LCCS-Map-300m-P1Y-1995-v2.0.7.tif
   ESACCI-LC-L4-LCCS-Map-300m-P1Y-2015-v2.0.7.tif
9. Download these files and save them in a convenient folder of your choosing. For this exercise, we saved the files in a folder named "Downloaded Data".

You have completed Step 1 – Data downloading! Well done so far!

[2] Tagged Image File Format, abbreviated TIFF or TIF, is a computer file format for storing raster graphics images.

Step 2 – Data pre-processing

After we have downloaded the data, the next action is Data pre-processing done using QGIS. QGIS is a geographic information system that supports viewing, editing and analysis of geospatial data.

More information on how to download and install and use QGIS is provided in the **Appendix** to this guide.

The steps in this section can be described as trimming the data downloaded and extracting the data relevant to mapping land cover change.

2.1 Loading vector data into QGIS

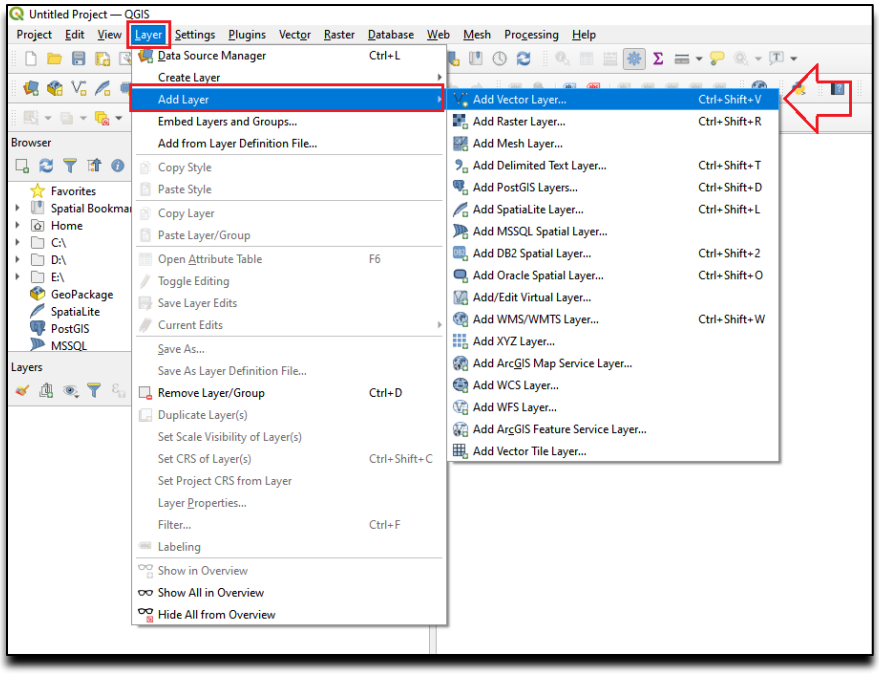
For this exercise, we created a new folder and named it "Data Pre-Processing". We encourage that the user does the same or choose a folder name and location that is convenient.

Open QGIS Desktop with GRASS, and do the following:

1. Click on "Layer"
2. Go to "Add Layer"
3. Select "Add Vector Layer"[3]

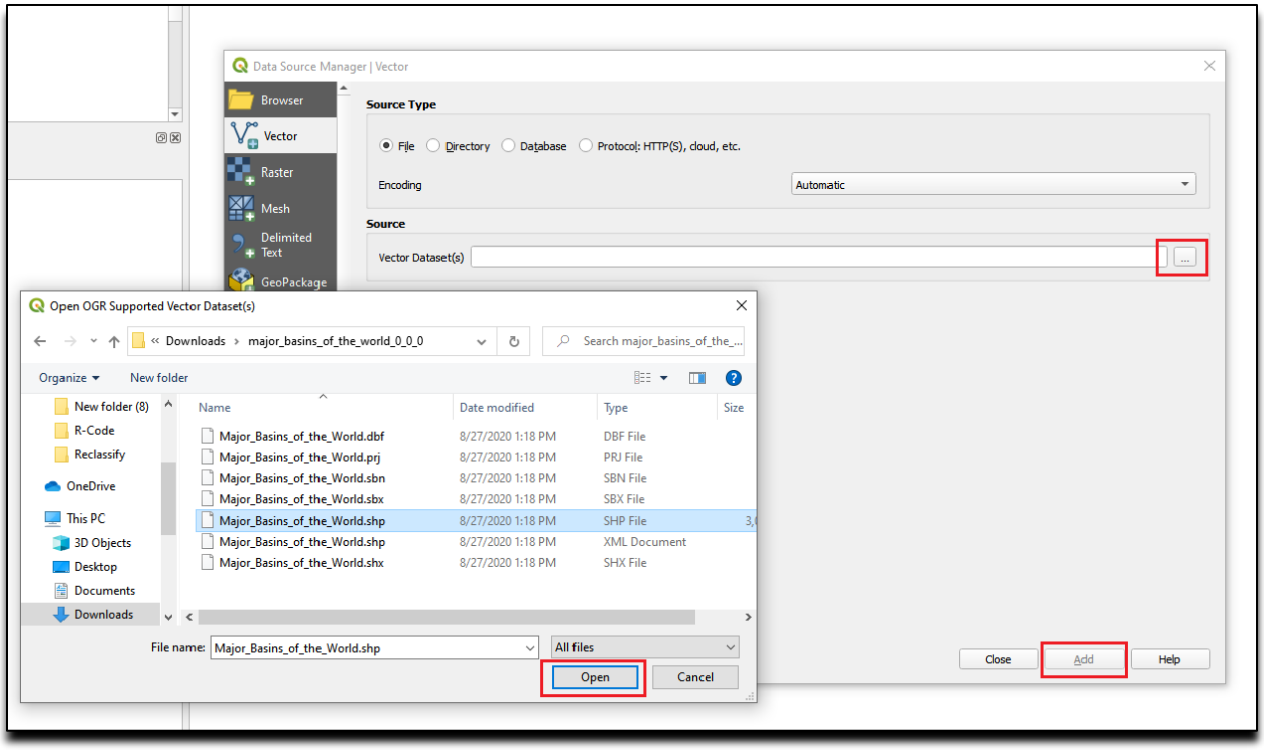
These steps are indicated in the picture shown below:

[3] **Vector layers** are, along with raster **layers**, one of the two basic types of data structures that store data. **Vector layers** use the three basic GIS features – lines, points, and polygons – to represent real-world features in digital format.



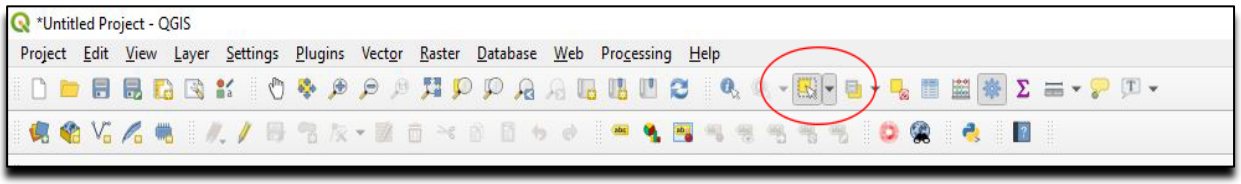
4. Next, Click the Browse button  and select the file "Major Basins of the World" in .shp file format
5. Click "Open"
6. Click "Add" and close the window

These steps are shown in the picture below:

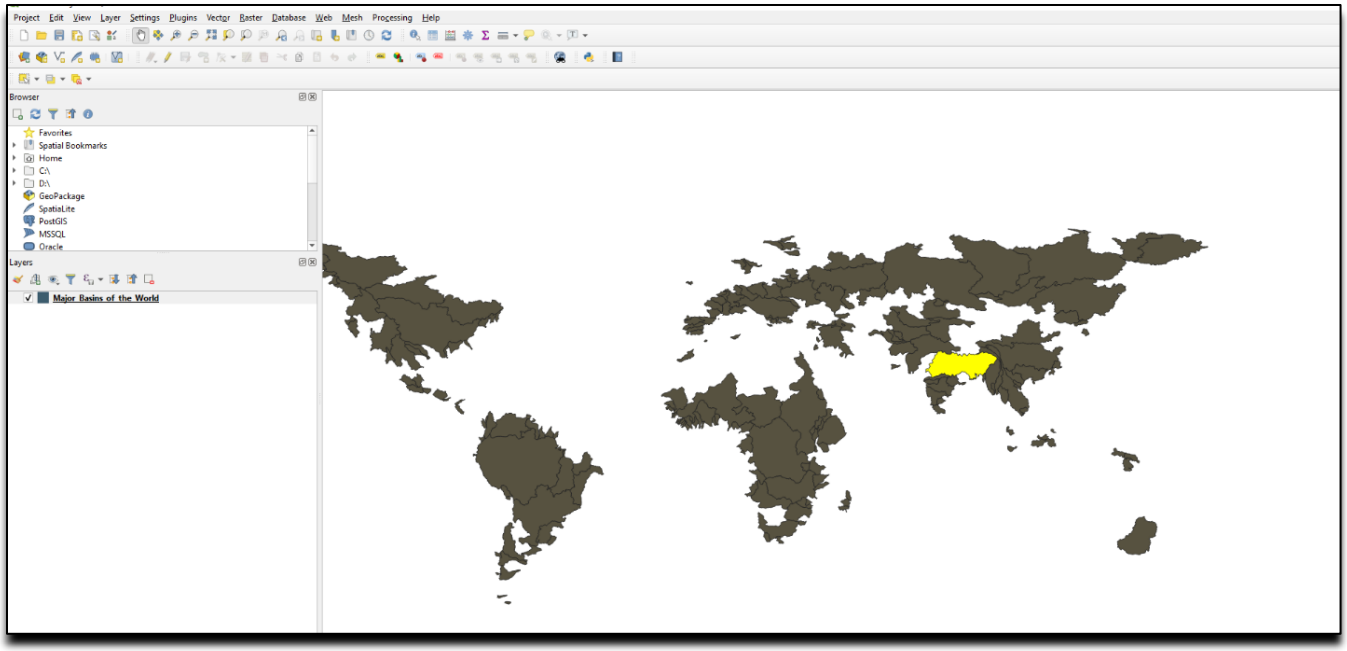


2.2 Extracting shape file for chosen area (Ganga Bhramaputra River Basin)

1. On the toolbar, click the button "Select", as outlined in the picture below:

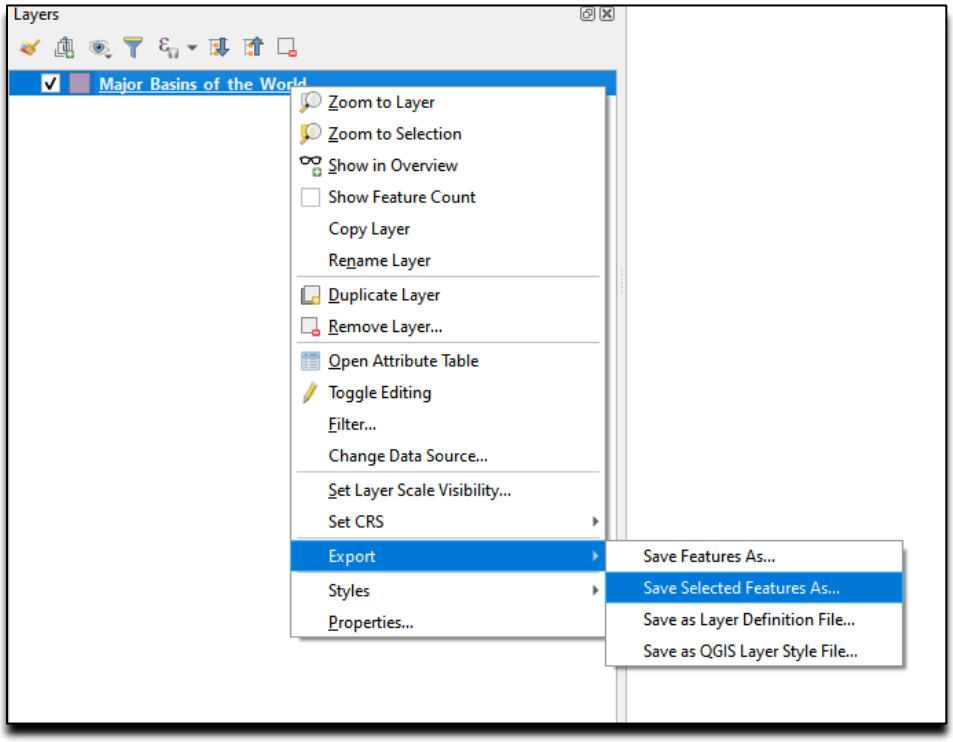


2. In the map that appears on the Map Panel of the QGIS Interface, click on your chosen region to highlight it. In this exercise, we clicked to highlight the Ganga Bhramaputra River Basin in Shape File Form (.shp) and an image like the one below appears:

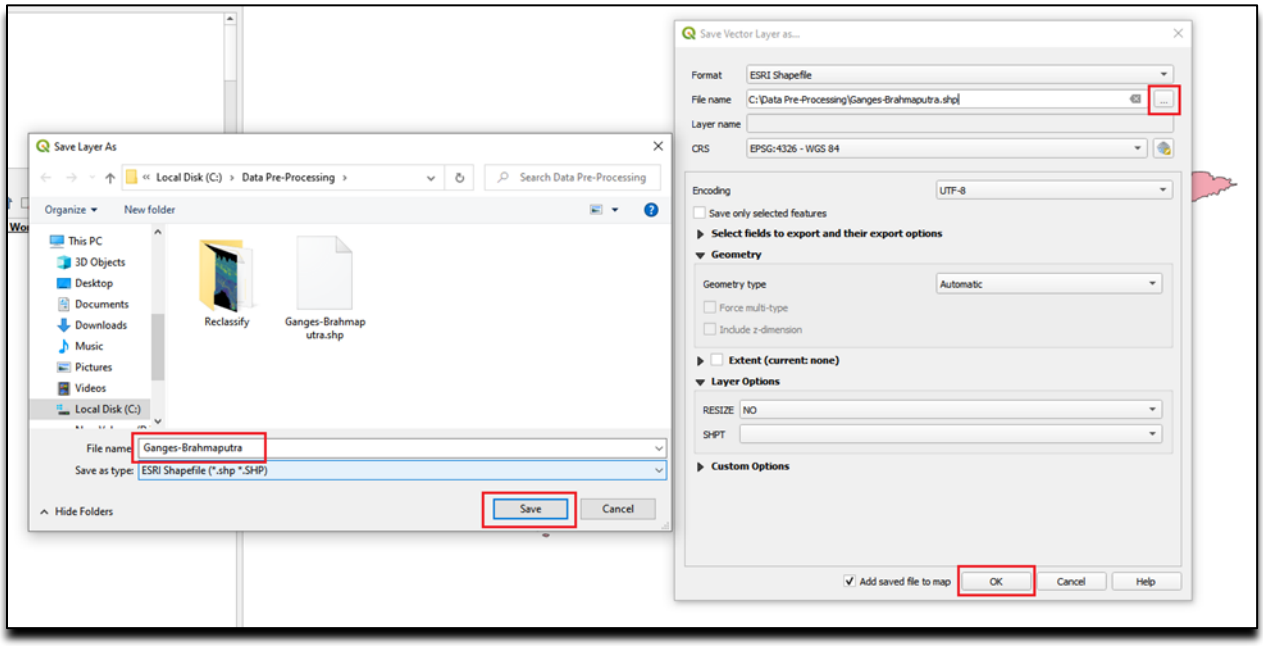


3. In the left bottom panel (called the layer panel) of the QGIS interface, right click on the file "Major River Basins in the World"
4. Select "Export"
5. Select "Save Selected Feature As"

These steps are highlighted in the picture below:



6. Next, select "Browse" and open the folder "Data Pre-Processing" (or the folder that you chose)
7. Name the File with a name of your choosing. For this exercise, we name it Ganges-Brahmaputra.shp
   As noted in the picture below, please ensure that the "Format" is "ESRI Shapefile". For some users, the default is .csv.
8. Click "Save"
9. Click "Ok"



10. In the Layer Panel, right click on "Major River Basins of the World"
11. Click "Remove Layer"

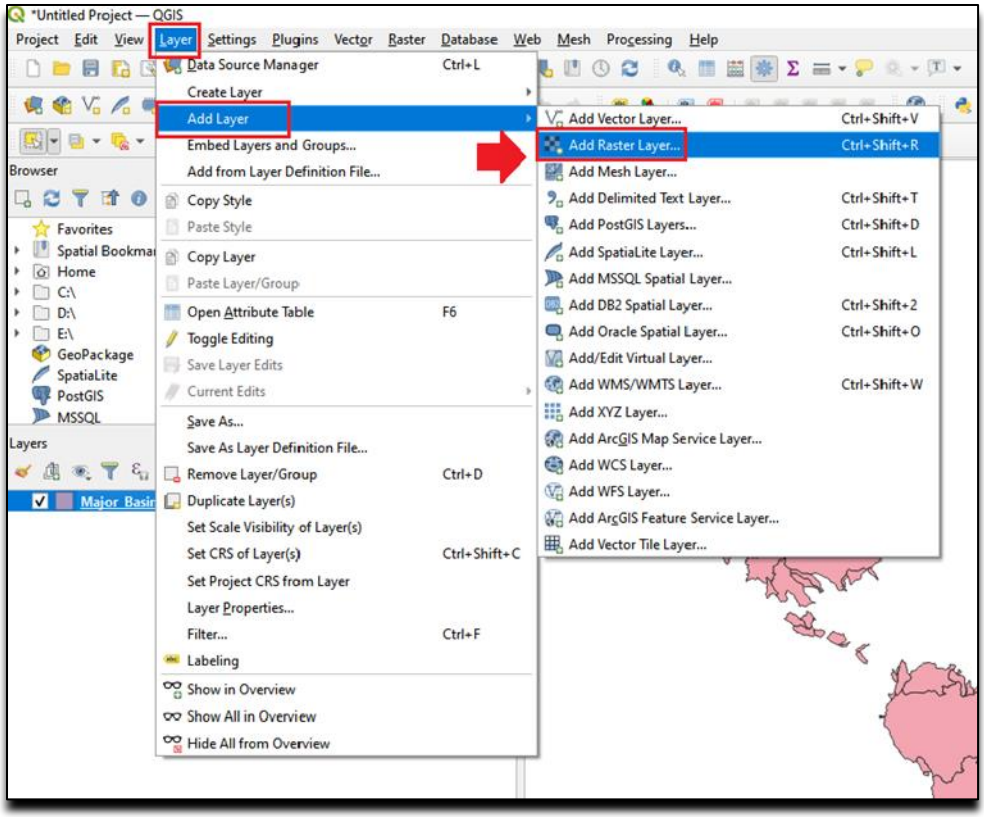
This step has extracted the relevant Ganges-Brahmaputra from the river basin data and has removed data that is not relevant.

2.3 Adding ESA land cover data to QGIS

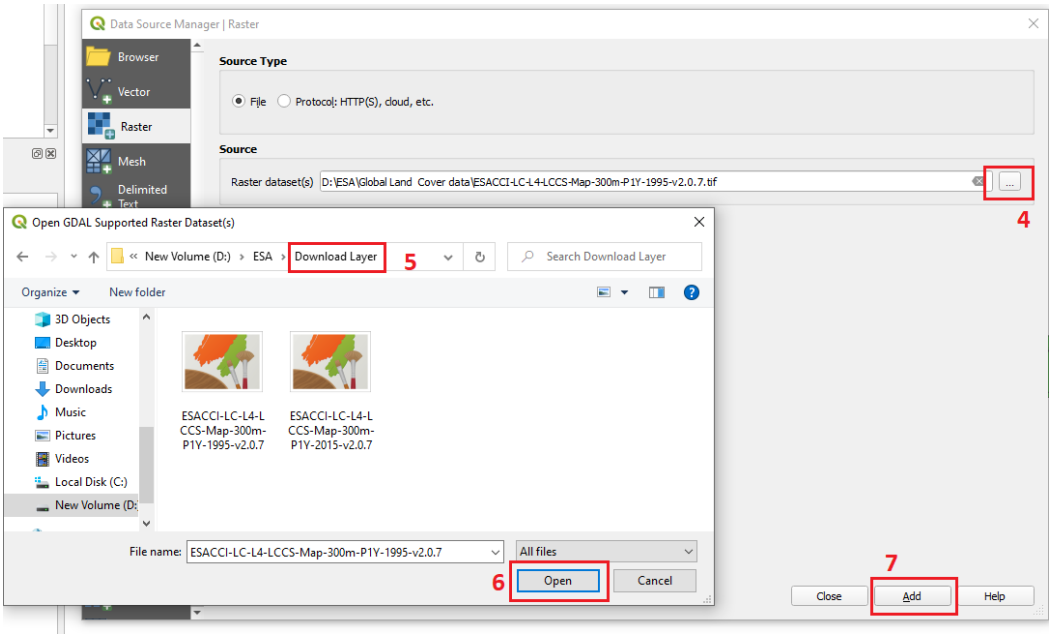
The next steps add the ESA Global land cover datasets to QGIS:

1. On the QGIS toolbar, click on "Layer"
2. Click on "Add Layer"
3. Select "Add Raster Layer"[4]

[4] A **raster** consists of a matrix of cells (or pixels) organized into rows and columns (or a grid) where each cell contains a value representing information. **Rasters** are digital aerial photographs, imagery from satellites, digital pictures, or even scanned maps.



4. A new window will appear; click on  as illustrated in the picture below
5. Select "Download Layer"
6. Open "ESACCI-LC-L4-LCCS-Map-300m-P1Y-1995-v2.0.7.tif"
7. Click "Add"

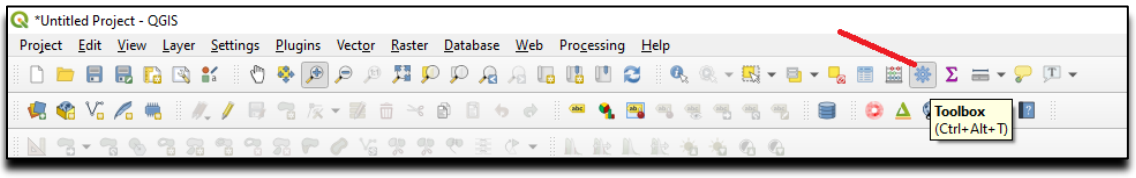


8. Again, click on  as illustrated in the picture above
9. Select "Download Layer"
10. Open "ESACCI-LC-L4-LCCS-Map-300m-P1Y-2015-v2.0.7.tif"
11. Click "Add

2.4 Clipping ESA Global land cover datasets

The next steps add the ESA Global land cover datasets to QGIS, and layers each respective file with the extracted Ganges-Brahmaputra.shp file

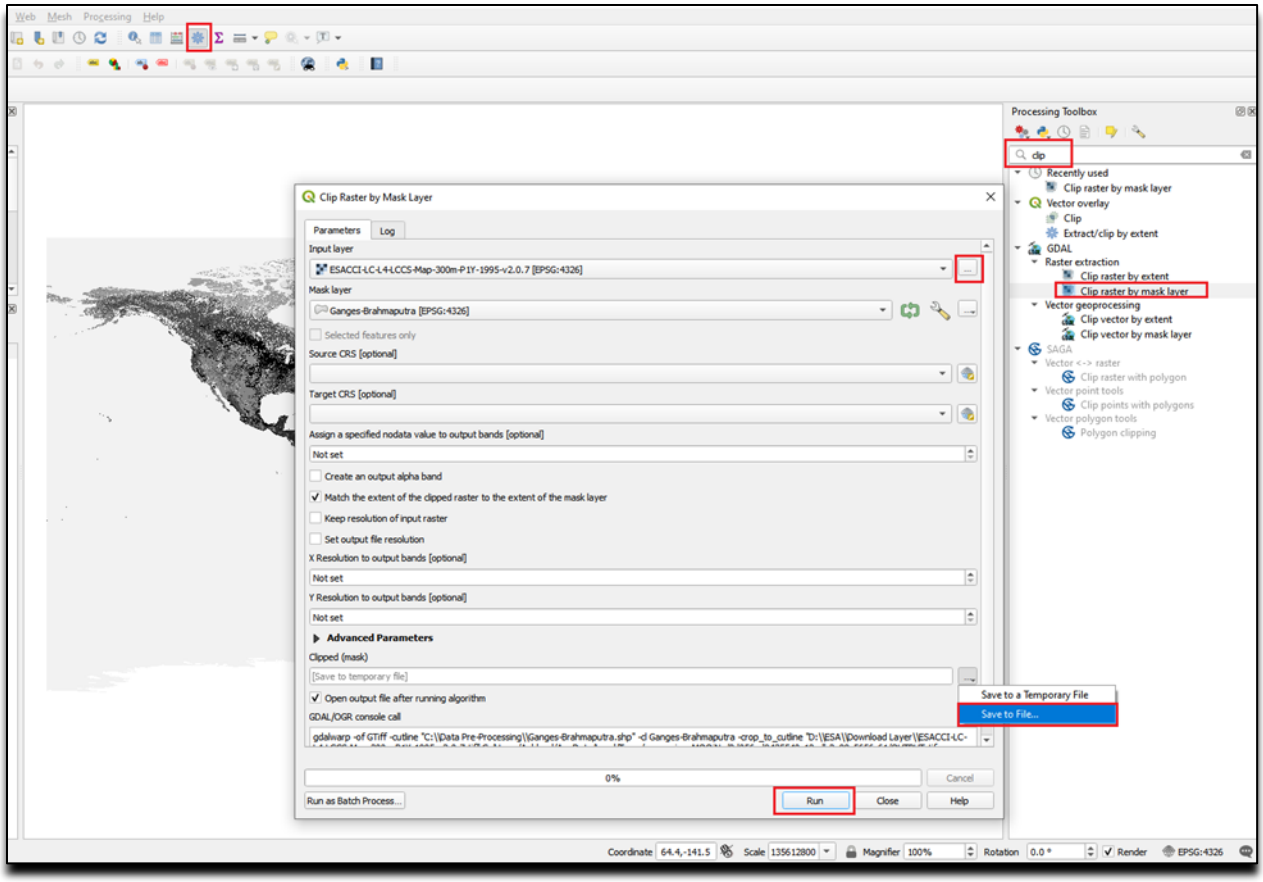
1. For first-time QGIS downloads, click the button highlighted in the  picture below, as the Processing Toolbox may not appear automatically



2. When the Processing Toolbox appears, search for "Clip"
3. Select "Clip Raster by Mask Layer"
4. In the window that appears, complete the Parameters as follows:
    a. Input Layer = "ESACCI-LC-L4-LCCS-Map-300m-P1Y-1995-v2.07.tif" by clicking the drop-down button
    b. Mask Layer = "Ganges-Brahmaputra.shp"
    c. Assign a specified no data value to output bands [optional] = "Not set"
    d. Select "Match the extent of the clipped raster to the extent of the mask layer"
    e. Under "Advanced Parameters" Heading, by Clipped (mask), click Browse button
    f. Select "Save To File" and name it "Year 1995 Land Cover"

g. Click "Run"
h. Click "Close" after the Program runs

These steps are outlined in the picture below:



The 1995 Ganges- Brahmaputra River Basin Mask Layer should now appear in the window.

5. In the Processing Toolbox, search for "Clip"
6. Select "Clip Raster by Mask Layer"
7. In the window that appears, complete the Parameters as follows:
    a. Input Layer = "ESACCI-LC-L4-LCCS-Map-300m-P1Y-2015-v2.07.tif" by clicking the drop-down button
    b. Mask Layer = "Ganges-Brahmaputra.shp"
    c. Assign a specified nodata value to output bands [optional] = Set as default
    d. Select "Match the extent of the clipped raster to the extent of the mask layer"
    e. Under "Advanced Parameters" Heading, by Clipped (mask), click Browse button
    f. Select "Save To File" and name it "Year 2015 Land Cover"
    g. Click "Run"
    h. Click "Close" after the Program runs

The 2015 Ganges- Brahmaputra River Basin Mask Layer should now appear in the window.

8. In Layer Panel, right click on "ESACCI-LC-L4-LCCS-Map-300m-P1Y-1995-v2.07.tif"

9. Click “Remove Layers”
10. In Layer Panel, right click on “ESACCI-LC-L4-LCCS-Map-300m-P1Y-2015-v2.07.tif”
11. Click “Remove Layers”

You have completed Step 2 – Data pre-processing! Let’s keep going!

Step 3 – Data processing and visualization

In this section, we will show how to present the findings of the land cover change analysis via the following broad sections:

1. Equating the ESA land cover classifications data to SEEA[5] land cover classifications
2. Visualize the land cover change using maps developed in QGIS
3. Develop land change transition matrix and percentage of land cover change using R

3.1 Converting ESA to SEEA land cover classifications

For the purposes of our land cover change mapping, the 31 ESA Classifications are equated to the **SEEA Classifications**. The resulting conversion is used to illustrate the land cover change along the Ganga Brahmaputra River Basin in this guide.

According to the ESA, land cover classification is distinguished into 31 classifications as shown in the figure below and discrete numbers are assigned to each category, with values ranging from 0 (“No Data”) to 220 (“Permanent Snow and Ice”).

Value	Label	Color
0	No Data	
10	Cropland, rainfed	
11	Herbaceous cover	
12	Tree or shrub cover	
20	Cropland, irrigated or post-flooding	
30	Mosaic cropland (>50%) / natural vegetation (tree, shrub, herbaceous cover) (<50%)	
40	Mosaic natural vegetation (tree, shrub, herbaceous cover) (>50%) / cropland (<50%)	
50	Tree cover, broadleaved, evergreen, closed to open (>15%)	
60	Tree cover, broadleaved, deciduous, closed to open (>15%)	
61	Tree cover, broadleaved, deciduous, closed (>40%)	
62	Tree cover, broadleaved, deciduous, open (15-40%)	
70	Tree cover, needleleaved, evergreen, closed to open (>15%)	
71	Tree cover, needleleaved, evergreen, closed (>40%)	
72	Tree cover, needleleaved, evergreen, open (15-40%)	
80	Tree cover, needleleaved, deciduous, closed to open (>15%)	
81	Tree cover, needleleaved, deciduous, closed (>40%)	
82	Tree cover, needleleaved, deciduous, open (15-40%)	
90	Tree cover, mixed leaf type (broadleaved and needleleaved)	
100	Mosaic tree and shrub (>50%) / herbaceous cover (<50%)	
110	Mosaic herbaceous cover (>50%) / tree and shrub (<50%)	
120	Shrubland	
121	Evergreen shrubland	
122	Deciduous shrubland	
130	Grassland	
140	Lichens and mosses	
150	Sparse vegetation (tree, shrub, herbaceous cover) (<15%)	
151	Sparse tree (<15%)	
152	Sparse shrub (<15%)	
153	Sparse herbaceous cover (<15%)	
160	Tree cover, flooded, fresh or brakish water	
170	Tree cover, flooded, saline water	
180	Shrub or herbaceous cover, flooded, fresh/saline/brakish water	
190	Urban areas	
200	Bare areas	
201	Consolidated bare areas	
202	Unconsolidated bare areas	
210	Water bodies	
220	Permanent snow and ice	

[5] System of environmental-economic accounting

There are individual colors assigned to each of the 31 Classifications.

The steps in this section show how to convert the ESA land cover classifications to the System of Economic and Environmental Accounting (SEEA) land cover classifications.

The reclassification is done for the Year 1995 Land Cover and the Year 2015 Land Cover files.

1. Open "Notepad" (for Windows)
2. Copy Text as follows
   0 = 0
   10 11 = 2
   12 = 3
   20 30 40 = 4
   50 thru 90 = 6
   100 thru 110 = 4
   120 thru 122 = 8
   130 = 5
   140 = 9
   150 thru 153 = 10
   160 170 = 7
   180 = 9
   190 = 1
   200 201 202 = 11
   210 = 13
   220 = 12

3. Save as "SEEA Classes" and Close
4. In the Processing toolbox, search for "reclass" in the Search bar
5. Select "r.reclass" and a new window appears
6. In the window that appears, complete the Parameters as follows:
   a. Input Raster Layer = "Year 1995 Land Cover" by clicking the drop-down button
   b. For file containing reclass rules = click the Browse button and look for the Notepad entitled "SEEA Classes", as previously saved
   c. Under the "Advanced Parameters" heading, by Reclassified, click the Browse button
   d. Select "Save To File" and name it "Year 1995 SEEA Reclass" in a new folder entitled "Reclassify"
   e. Click "Run"
   f. Click "Close" after the Program runs

Now, for the reclassification for the Year 2015 Land Cover Layer:

7. In the Processing toolbox, search for "reclass" in the Search bar
8. Select "r.reclass" and a new window appears
9. In the window that appears, complete the Parameters as follows:
   a. Input Raster Layer = "Year 2015 Land Cover" by clicking the drop-down button

b. For file containing reclass rules = click the Browse button and look for the Notepad entitled "SEEA Classes", as previously saved
c. Under the "Advanced Parameters" heading, by Reclassified, click the Browse button
d. Select "Save To File" and name it "Year 2015 SEEA Reclass" in a new folder entitled "Reclassify"
e. Click "Run"
f. Click "Close" after the Program runs

These steps remove the layers that have now become irrelevant and keep only the "Year 1995 SEEA Reclass" and "Year 2015 SEEA Reclass" Layers:

10. In the Layers Panel, right click on all other layers (except the "Year 1995 SEEA Reclass" and "Year 2015 SEEA Reclass" layers)
11. Click "Remove Layers"

SEEA Land Cover Colors and Labels

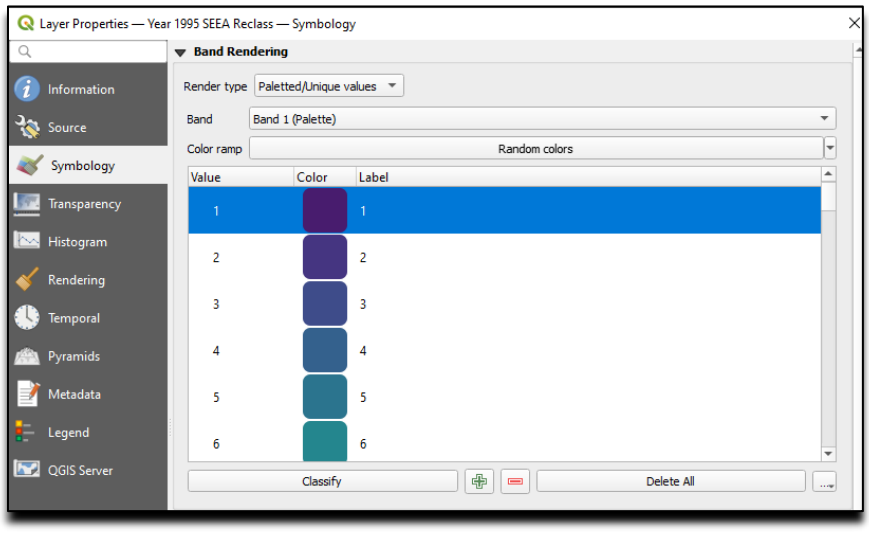
Continuing with the reclassification of the Land Cover Classifications, this section of steps charts the classifications to the SEEA Land Cover Classifications by defining the labels and colors for each of the 14 SEEA Land Cover Classifications according to the SEEA 2012 – Central Framework[6]:

Value	Color	HTML Code for Color	Land Cover Type
1		#ff1400	Artificial surface
2		#ffb24a	Herbaceous crops
3		#629448	Woody area
4		#ff9011	Multiple or Layered crop
5		#93cf2c	Grassland
6		#018f33	Tree cover areas
7		#94ba96	Mangrove
8		#966400	Shrub cover areas
9		#00dc82	Shrubs and or herbaceous areas
10		#ffebaf	Sparsely natural vegetated areas
11		#bfbfbf	Terrestrial barren land
12		#ffffff	Permanent snow and glacier
13		#b3c3e4	In land water Bodies

[6] The System of Environmental-Economic Accounting (SEEA) is a framework that integrates economic and environmental data to provide a more comprehensive and multipurpose view of the interrelationships between the economy and the environment and the stocks and changes in stocks of environmental assets, as they bring benefits to humanity. It contains the internationally agreed standard concepts, definitions, classifications, accounting rules and tables for producing internationally comparable statistics and accounts. The SEEA framework follows a similar accounting structure as the System of National Accounts (SNA). The framework uses concepts, definitions and classifications consistent with the SNA in order to facilitate the integration of environmental and economic statistics.

The Steps to change the colors and labels are as follows:

1. In Layer Panel, right click on “Year 1995 SEEA Reclass”
2. Click “Properties”
3. Click “Symbology”
4. Under “Render Type”, look for “Paletted/Unique Values” in the dropdown box
5. Click “Classify” and the following window will appear

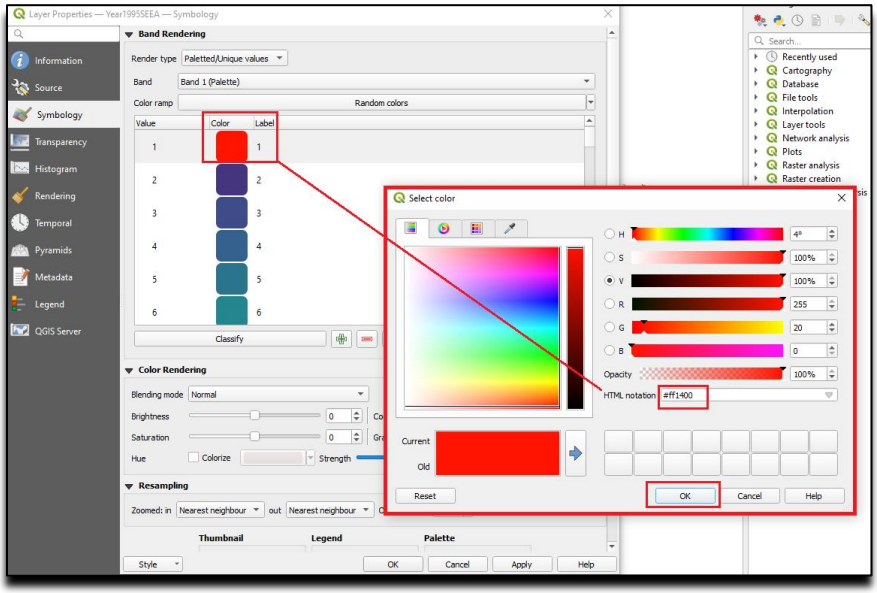


r

6. Under "Color" Tab, double-click on each of the 13 colours numbered from 1-13 to change the Colors using the HTML notation according to the SEEA Classification as below:

Value	Color	HTML Code for Color
1		#ff1400
2		#ffb24a
3		#629448
4		#ff9011
5		#93cf2c
6		#018f33
7		#94ba96
8		#966400
9		#00dc82
10		#ffebaf
11		#bfbfbf
12		#ffffff
13		#b3c3e4

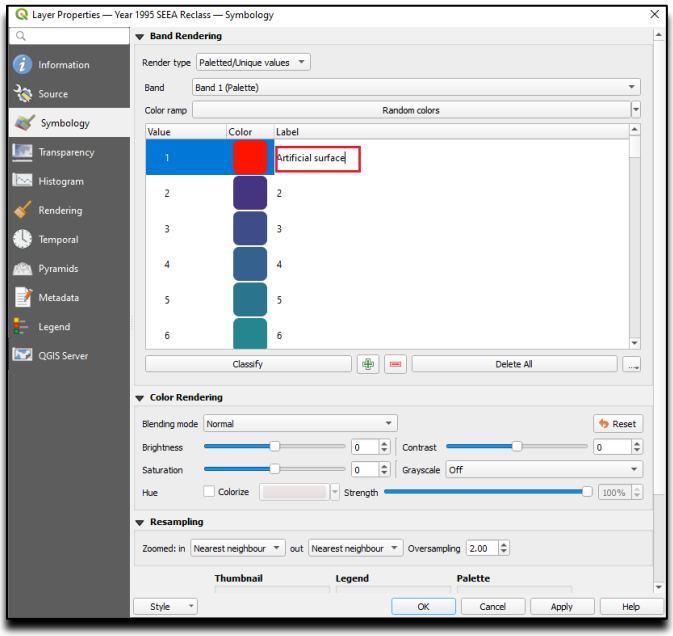
This step is outlined in the picture below:



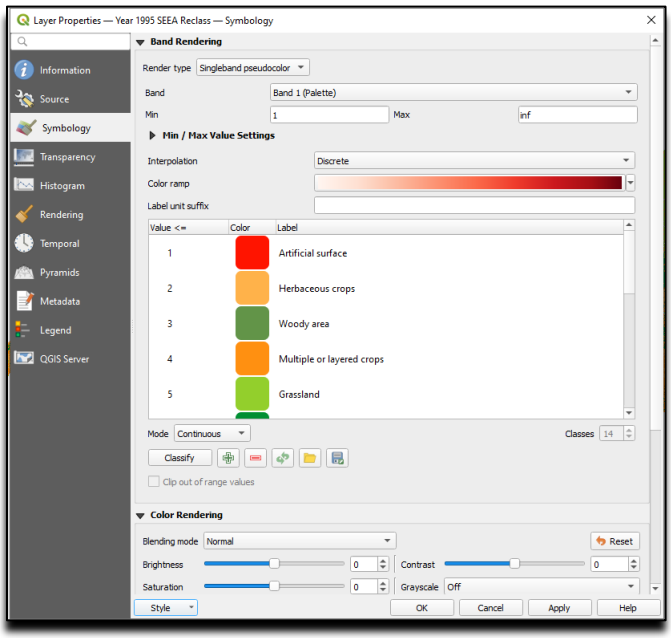
7. Under "Label" Tab, double-click on each of the 13 values numbered from 1-13 to change the Labels according the SEEA Classification as follows:

Value	Land Cover Type
1	Artificial surface
2	Herbaceous crop
3	Woody area
4	Multiple or Layered crop
5	Grassland
6	Tree cover areas
7	Mangrove
8	Shrub cover areas
9	Shrubs and or herbaceous areas
10	Sparsely natural vegetated areas
11	Terrestrial barren land
12	Permanent snow and glacier
13	In land water Bodies

This step is outlined in the picture below:



On completion, the Symbology window will look as follows:



8. Now click “Style” at the bottom of the page
9. Click “Save Style” at the bottom of the page

10. Save the *.qml[7] file with a name of your choosing

The following steps show how to apply the SEEA colors applied to the layers generated:

For the 1995 Layer:

11. In Layer Panel, right click on "Year 1995 SEEA Reclass"
12. Click "Properties"
13. Click "Symbology"
14. Click "Style"
15. Click "Load Style" and open the *.qml file saved in the step above
16. Click "Apply"

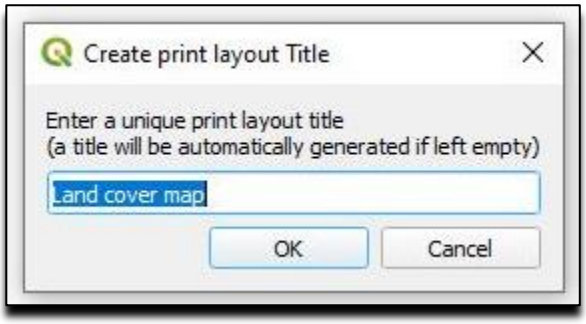
For the 2015 Layer:

17. In Layer Panel, right click on "Year 2015 SEEA Reclass"
18. Click "Properties"
19. Click "Symbology"
20. Click "Style"
21. Click "Load Style" and open the *.qml file saved in the step above
22. Click "Apply"

3.2 Mapping land cover change

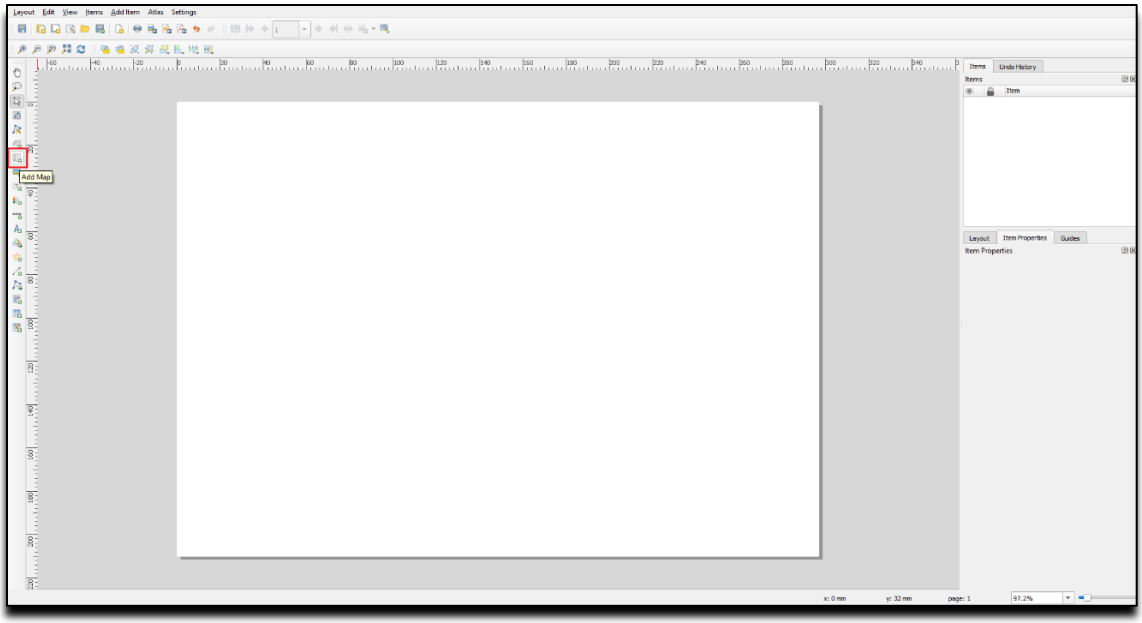
This set of steps produces the Land Cover Change Maps Layout for 1995 and 2015 showing the SEEA Land Cover Classifications:

1. In the Toolbar at the top of the page, Click on "Project"
2. Click on "New Print Layout" and the following window will appear

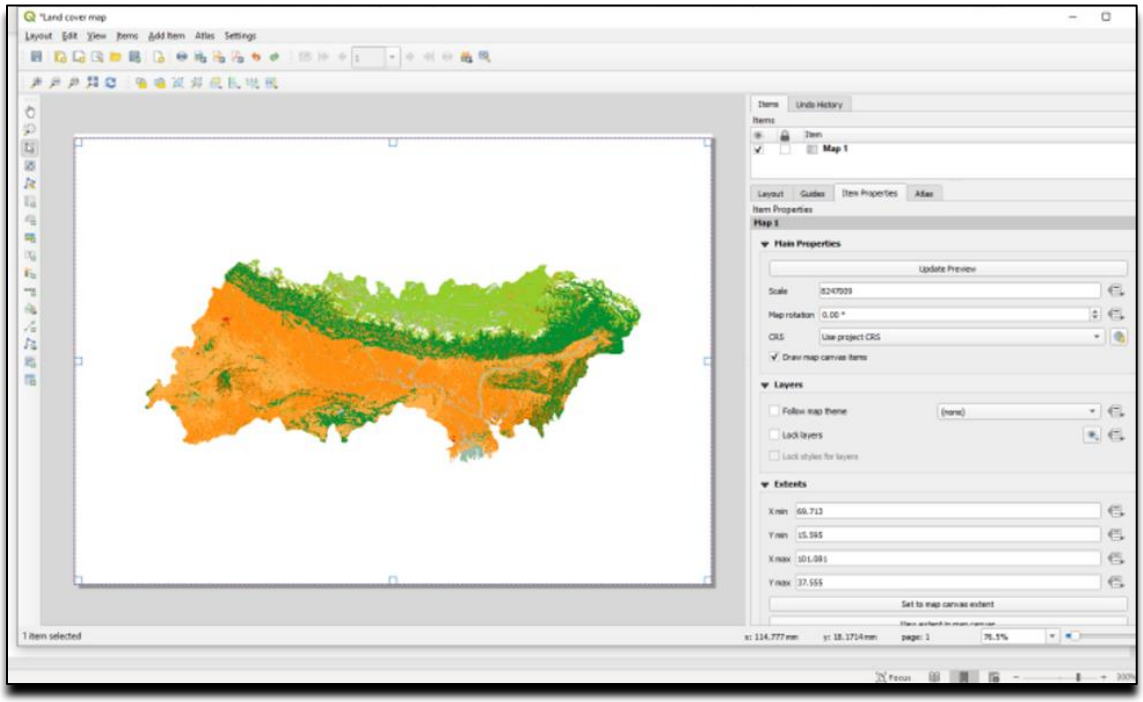


3. Define print Layout Title as "Land cover map" and click "OK"
4. On the new window that appears, on the toolbar to the left, click on "Adds a new Map to the layout"  as highlighted in the picture below:

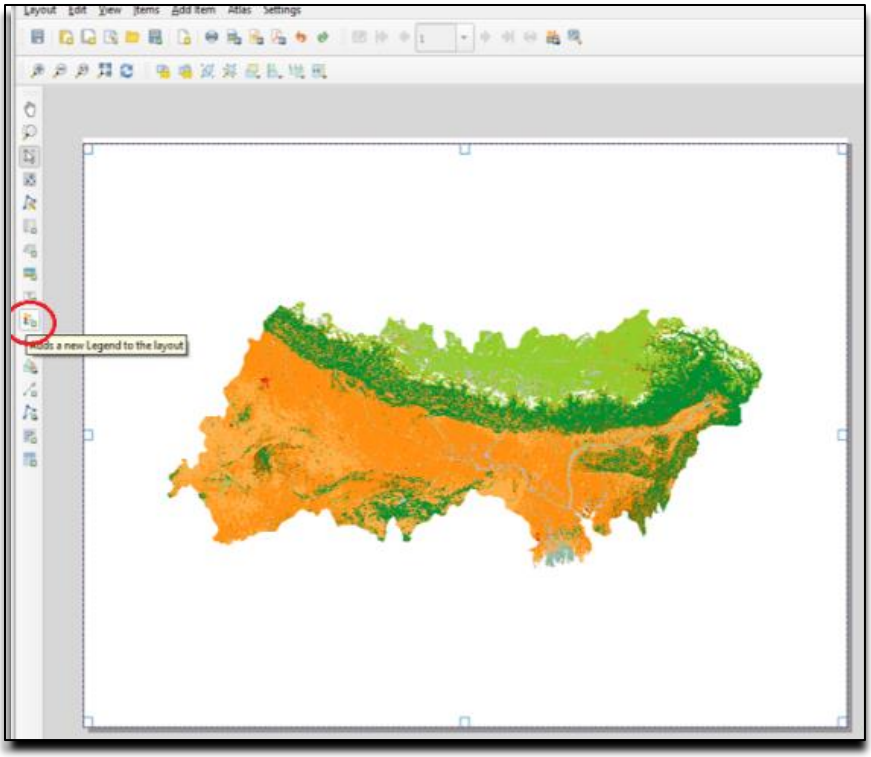
[7] QML (Qt Modeling Language) is a user interface markup language. It is a declarative language for designing user interface–centric applications.



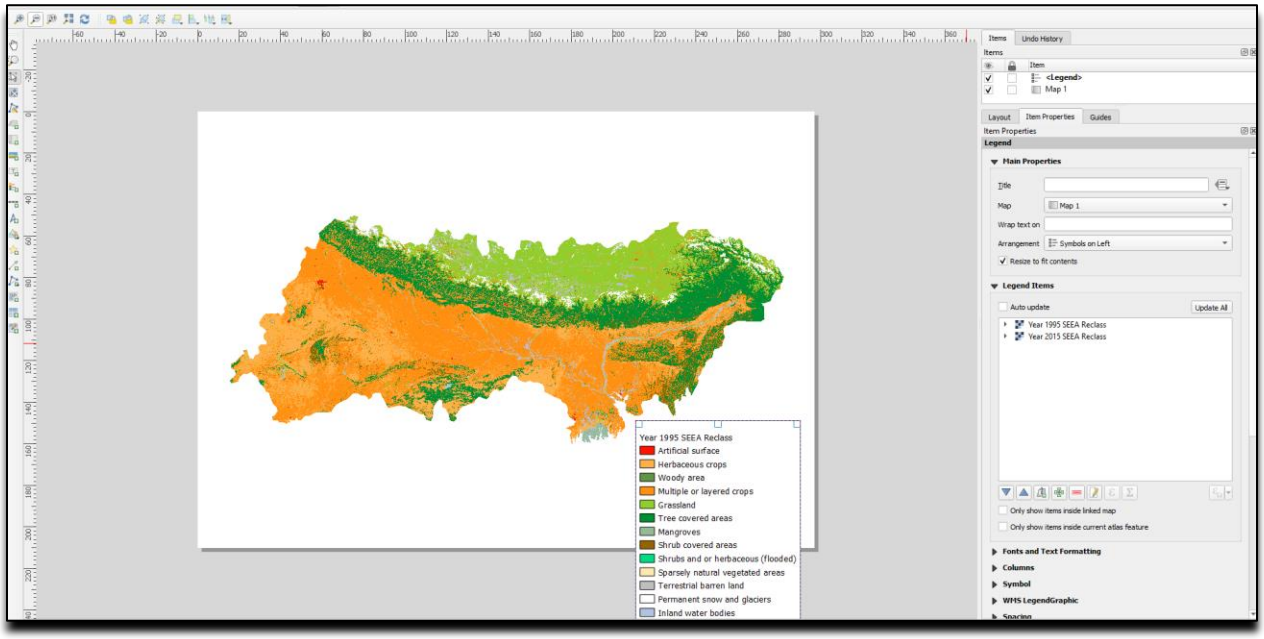
5. For the map to appear on the white screen, click on the white screen and draw a rectangle with the cursor. This image below reflects the selection as was made in this exercise, and yours may appear differently:



6. On the toolbar at the left, click on Adds a new Legend to the layout"  as highlighted in the picture below:

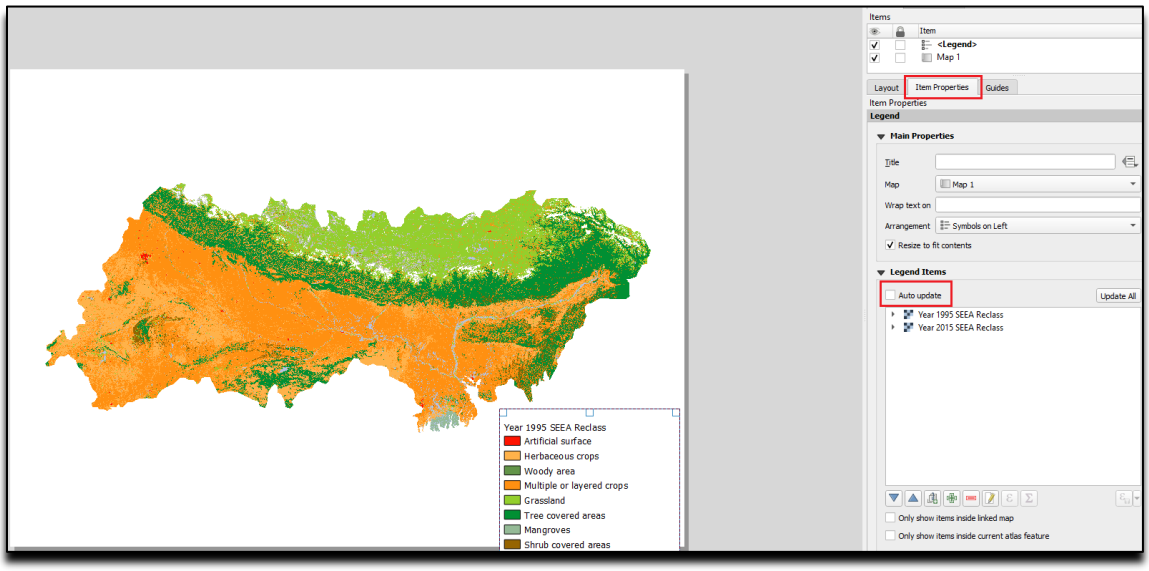


7. For the legend to appear on the map, click on the map and draw a rectangle with the cursor, and the following image will appear.

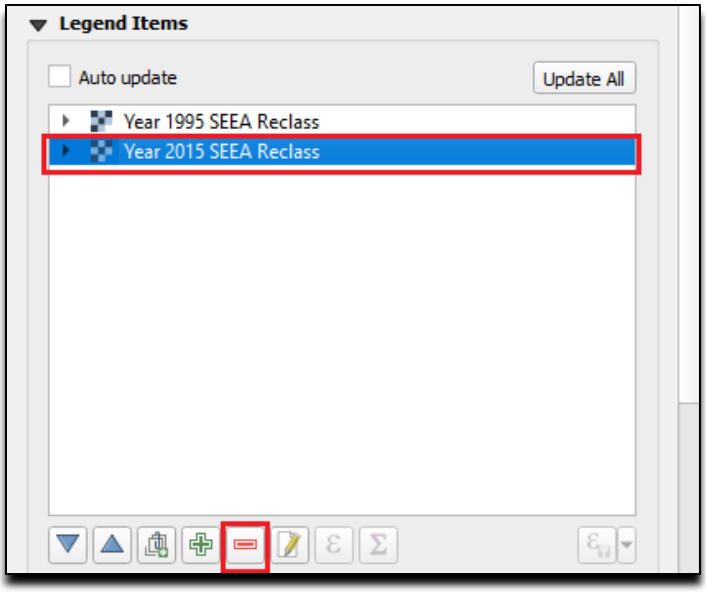


Multiple legends will appear on the screen, because of the numerous layers listed under "Legend Items". Following the next steps will remove the extra layers, which will then remove the extra legends:

8. On the Taskbar to the right of the picture below, click on the tab "Item Properties" and click off "Auto update" as highlighted the picture below:

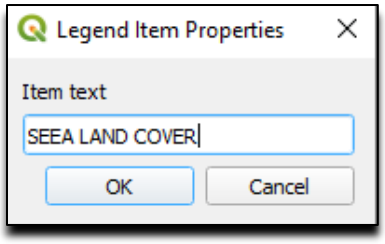


9. Highlight all the layers except for the first layer and click the minus button as shown in the picture below:

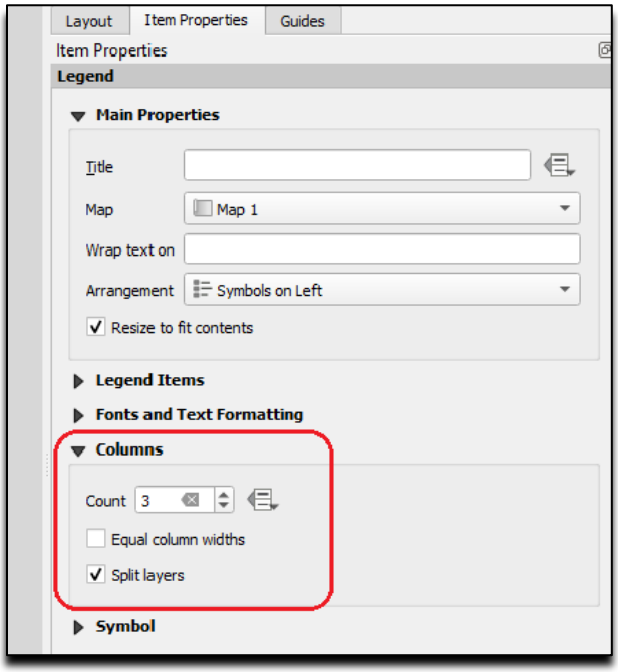


This should result in one legend remaining, which now requires formatting to fit on the screen.

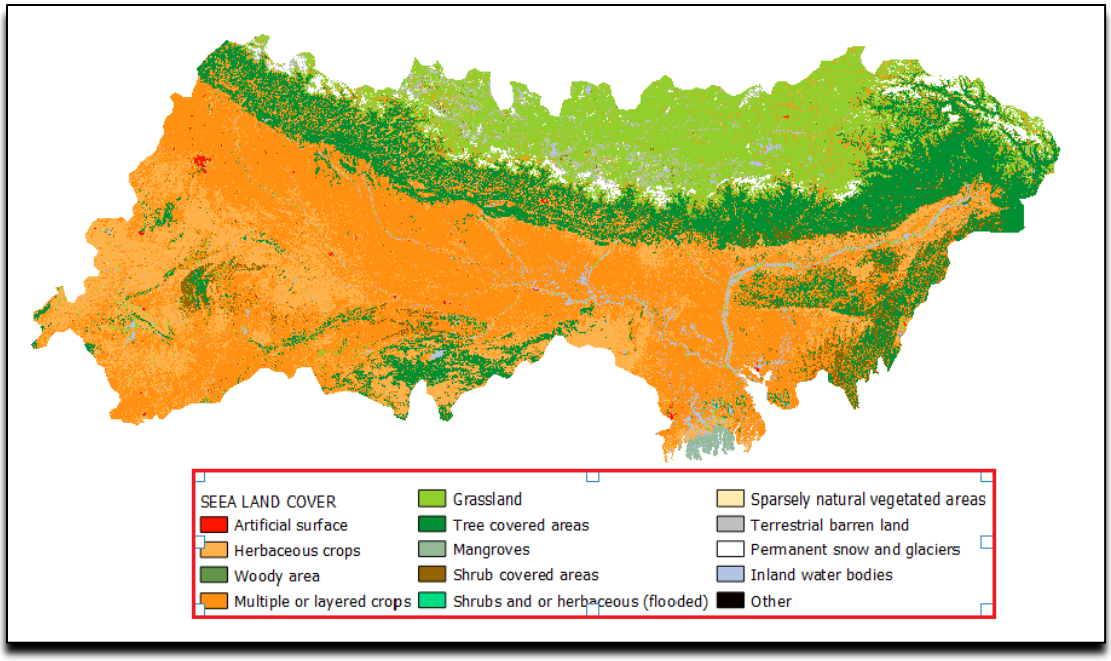
10. Continuing, double-click on the file "Year 1995 SEEA Reclass" and Rename as "SEEA LAND COVER" and Click "Ok" as shown in the image below:



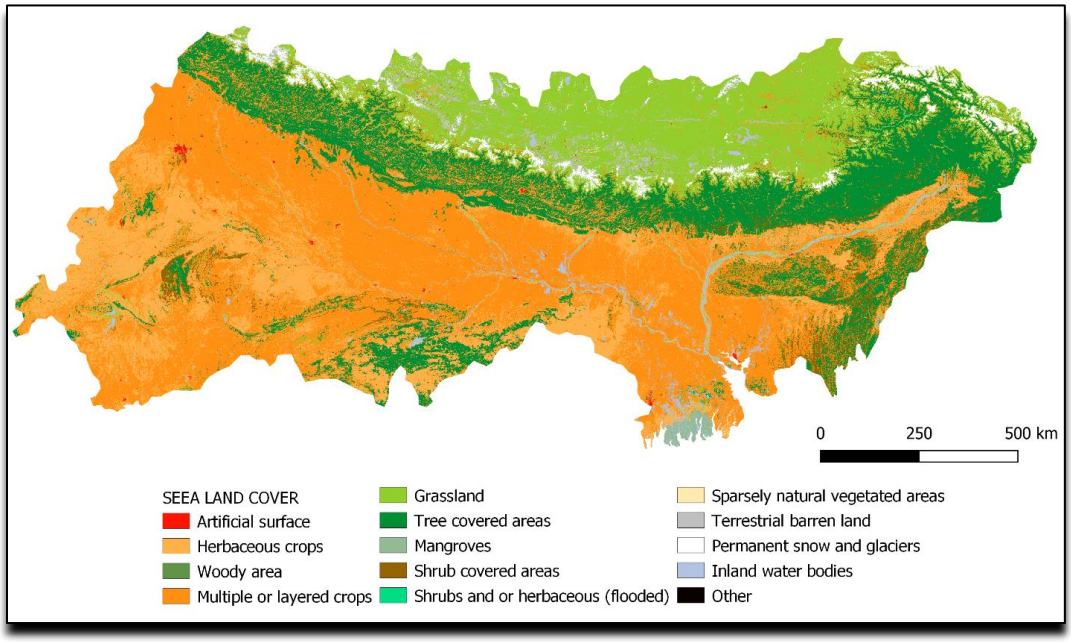
11. Scroll down to "Columns" and Change the Count to 3 and select the Split layers as shown in the picture below:



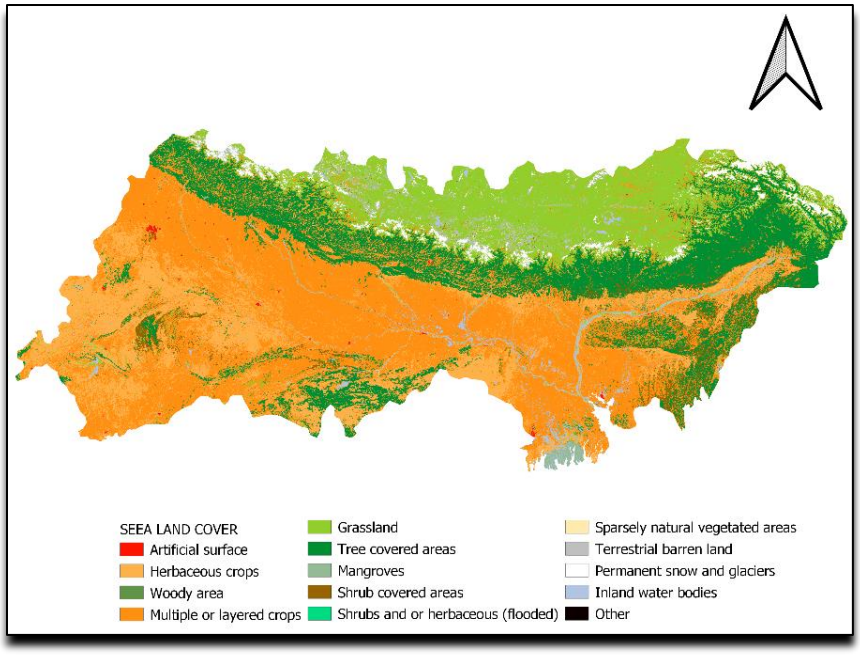
The legend will appear on the map, and can be shifted to the position of your choosing by clicking on the legend in the picture as below:



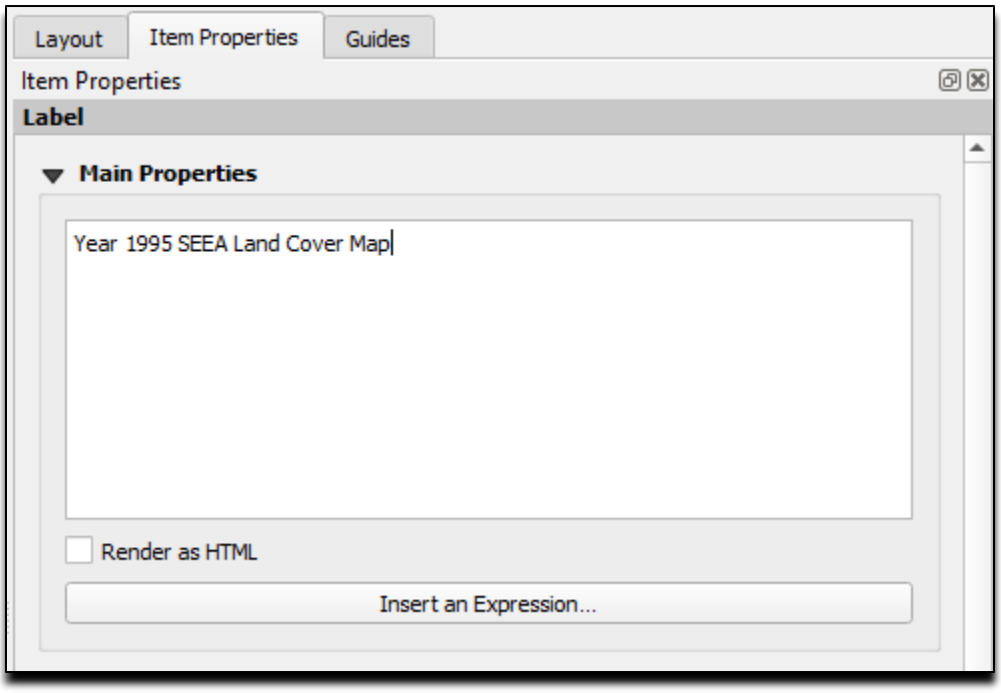
12. On the toolbar at the left of the interface, click "Adds a new Scale Bar to the layout" 
13. For the scale to appear on the map, click on the map and draw a rectangle with the cursor, and the following image will appear:



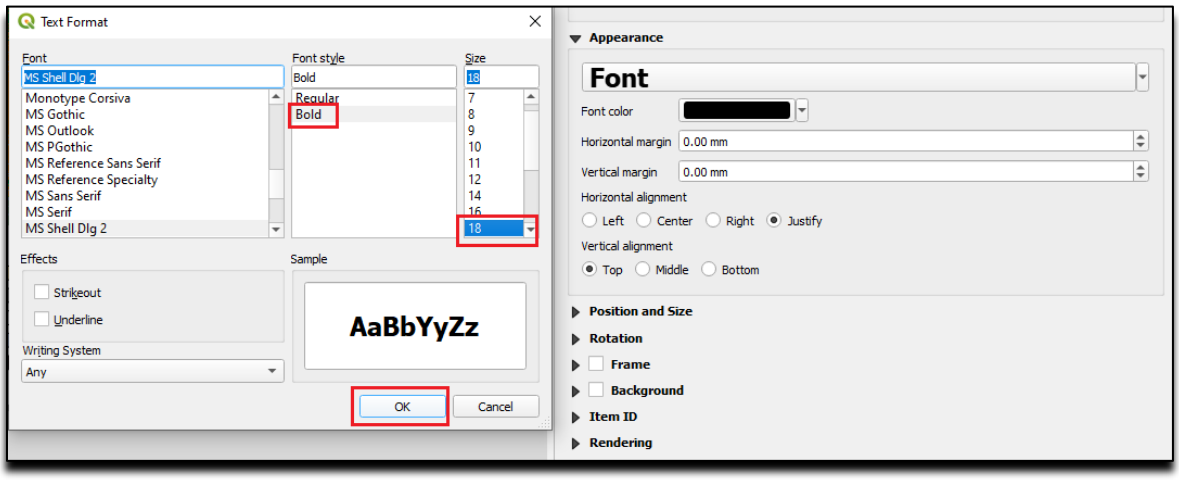
14. On the toolbar at the left of the interface, click "Adds a new North Arrow to the layout" 
15. Click on the top right-hand corner of the map and draw a rectangle with the cursor, and the north arrow will show on the map similarly to the picture below:



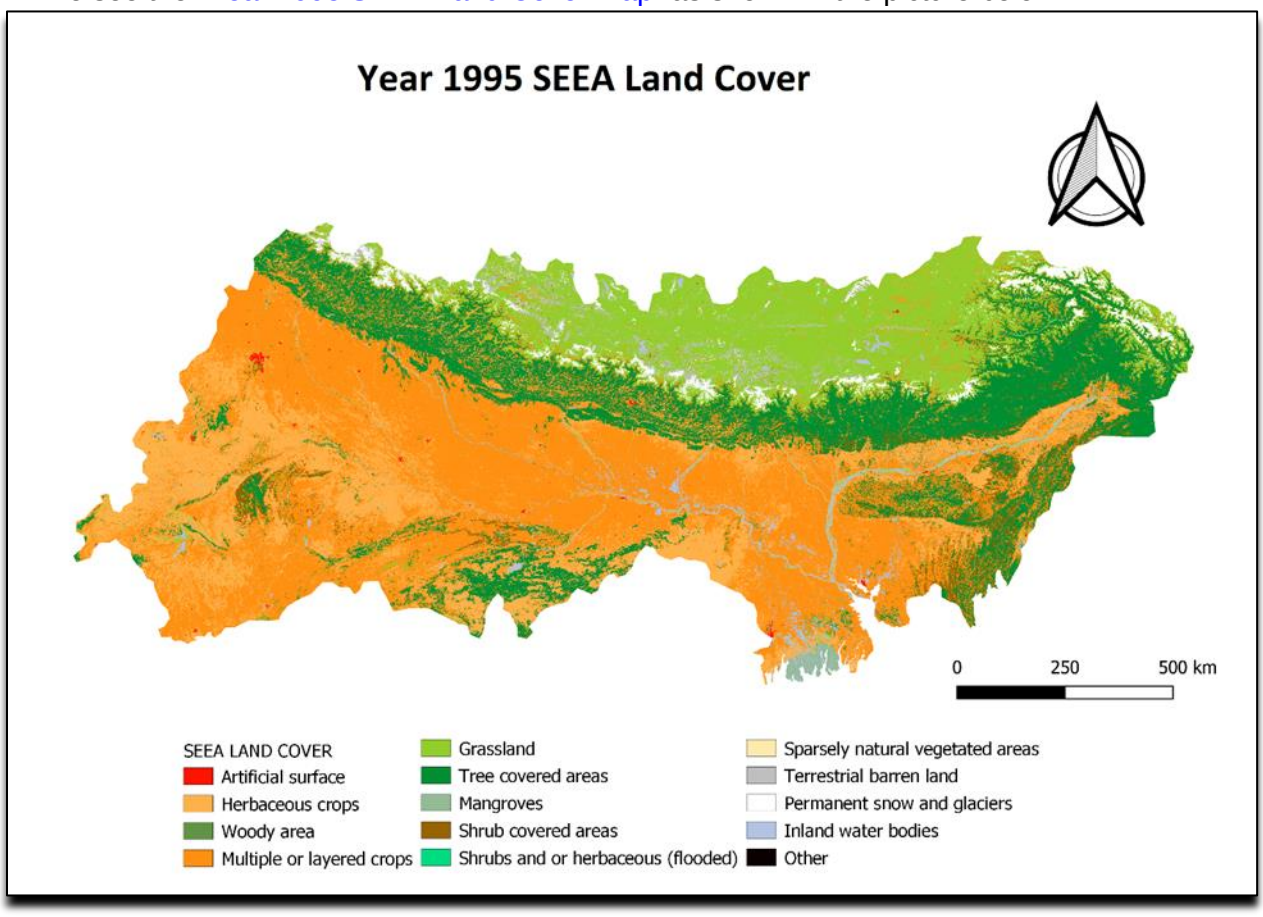
16. On the toolbar at the left of the interface, click "Adds a new Title to the layout"
17. Click on the top left-hand corner of the map and draw a rectangle with the cursor
18. On the toolbar at the right of the interface, click on "Item Properties"
19. Complete "Label" under "Item Properties" as "Year 1995 SEEA Land Cover Map"



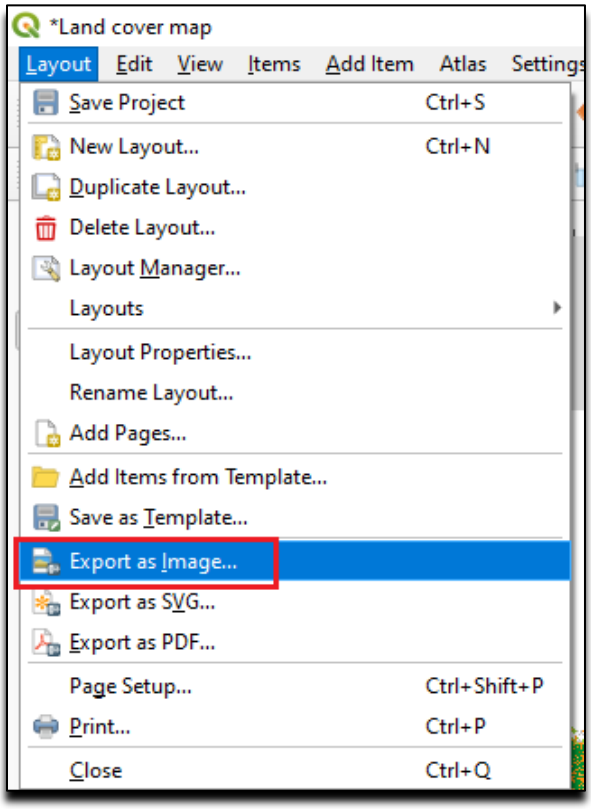
20. Under “Appearance”, edit “Font” and other characteristics as outlined in the picture below:



We see the “Year 1995 SEEA Land Cover Map” as shown in the picture below:



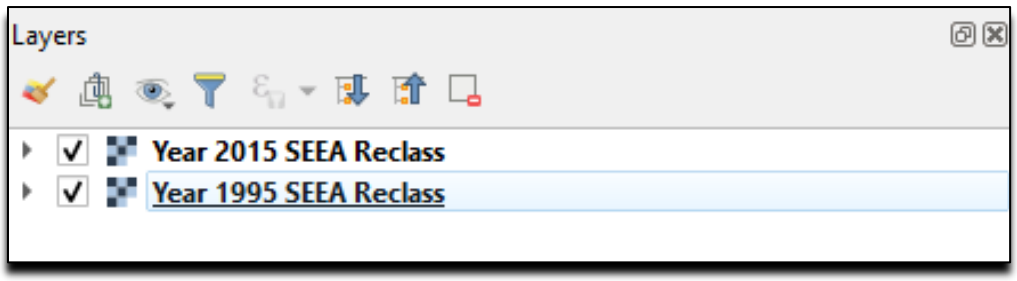
21. On the taskbar at the top of the interface, click "Layout" button and Select on the "Export as Image" as shown in the picture below:



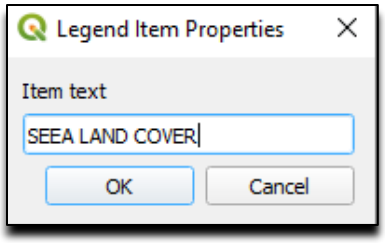
22. Save under proposed name and proposed format

The following steps show how to prepare the 2015 map:

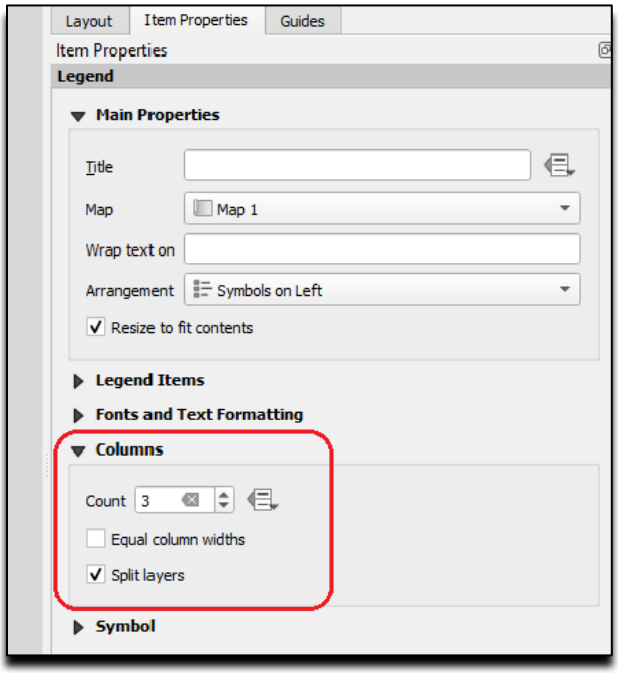
23. Go to the "Layers" Panel and place the "Year 2015 SEEA Reclass" on top of "Year 1995 SEEA Reclass" as shown in the picture below:



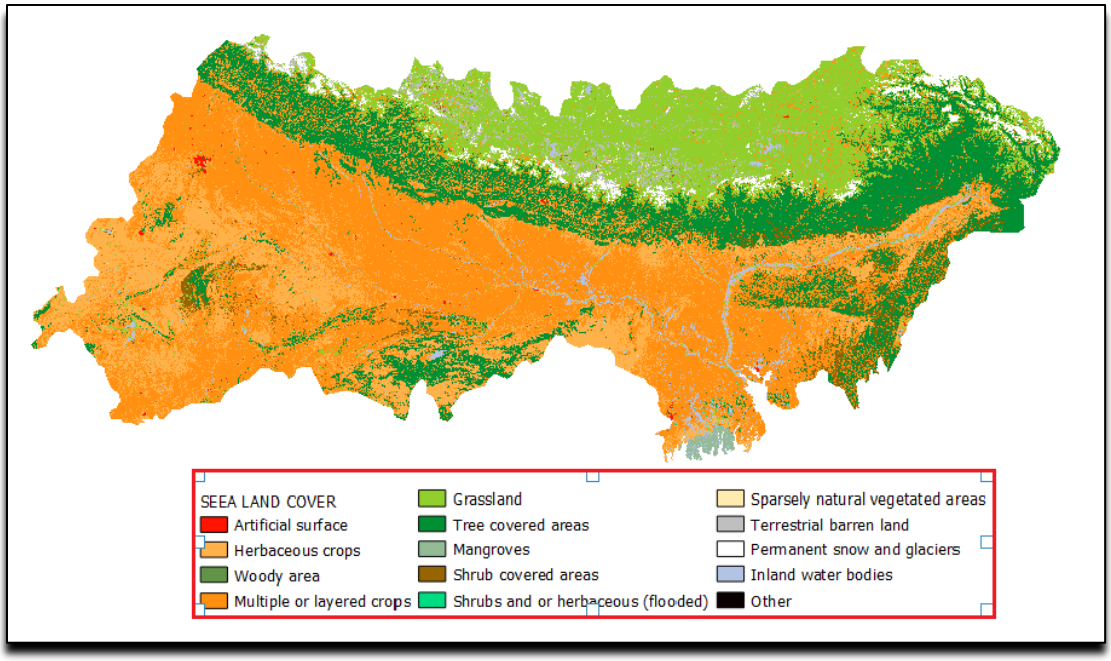
24. Continuing, double-click on the file "Year 2015 SEEA Reclass" and Rename as "SEEA LAND COVER" and Click "Ok" as shown in the image below:



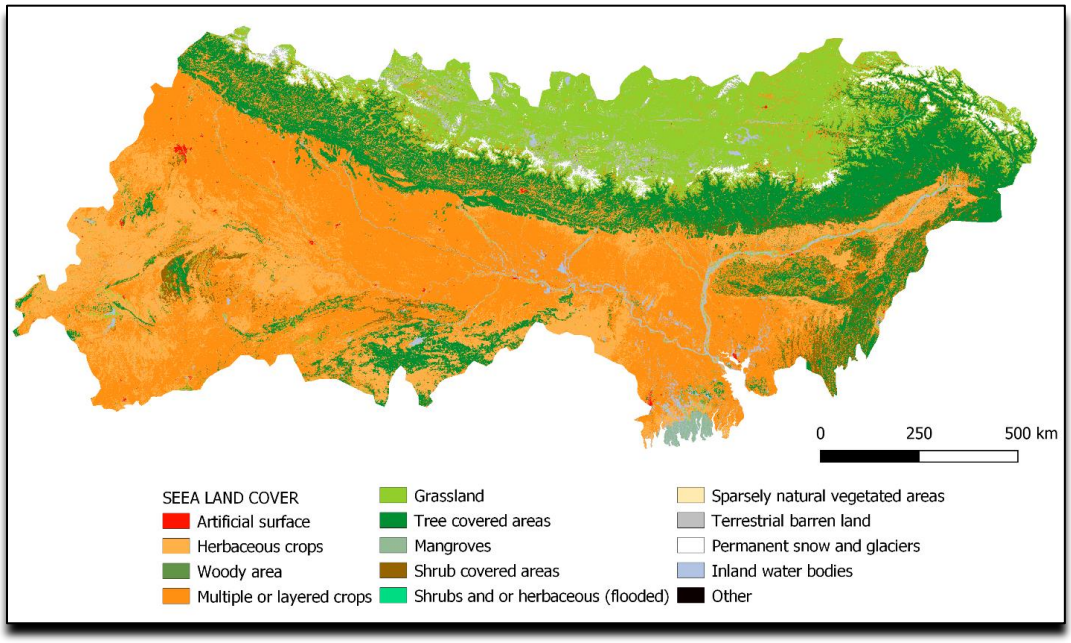
25. Scroll down to "Columns" and change the Count to 3 and select the Split layers as shown in the picture below:



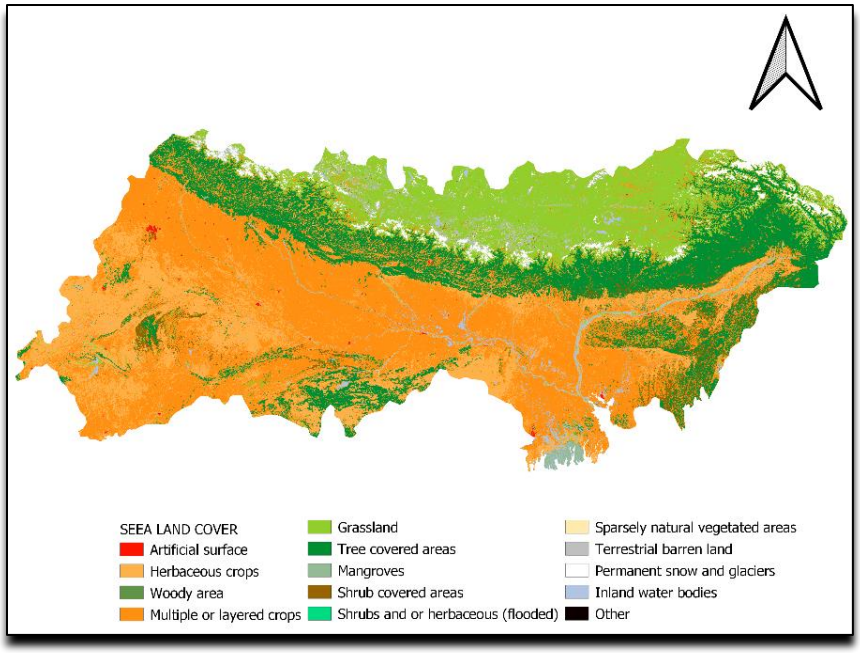
The legend will appear on the map, and can be shifted to the position of your choosing by clicking on the legend in the picture as below:



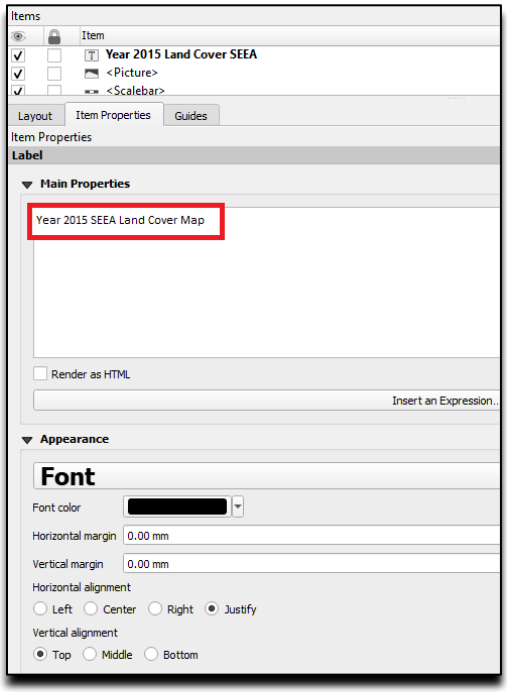
26. On the toolbar at the left of the interface, click "Adds a new Scale Bar to the layout" 
27. For the scale to appear on the map, click on the map and draw a rectangle with the cursor, and the following image will appear:



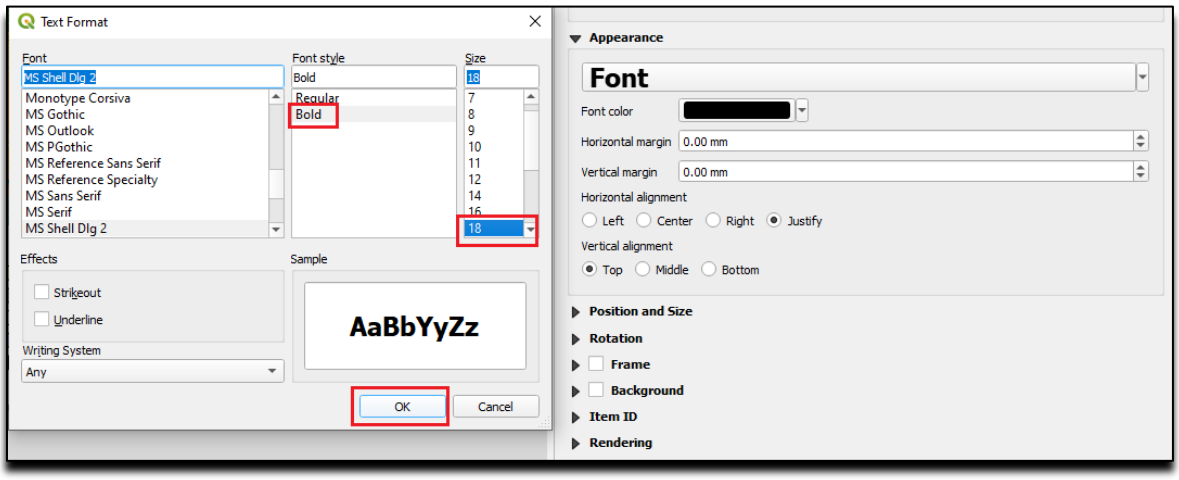
28. On the toolbar at the left of the interface, click "Adds a new North Arrow to the layout" 
29. Click on the top right-hand corner of the map and draw a rectangle with the cursor, and the north arrow will show on the map similarly to the picture below:



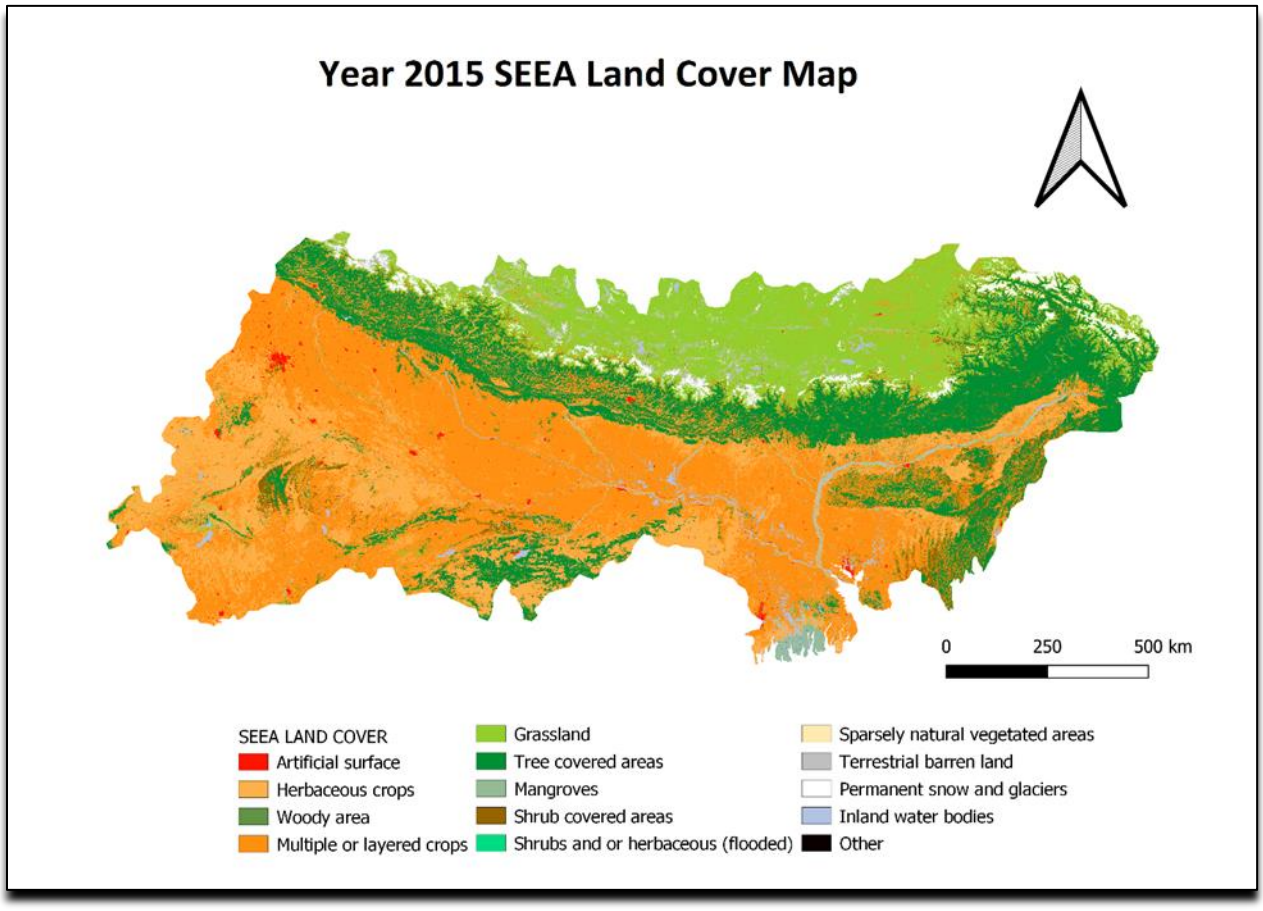
30. On the toolbar at the left of the interface, click "Adds a new Title to the layout"
31. Click on the top left-hand corner of the map and draw a rectangle with the cursor
32. On the toolbar at the right of the interface, click on "Item Properties"
33. Complete "Label" under "Item Properties" as "Year 2015 SEEA Land Cover Map"



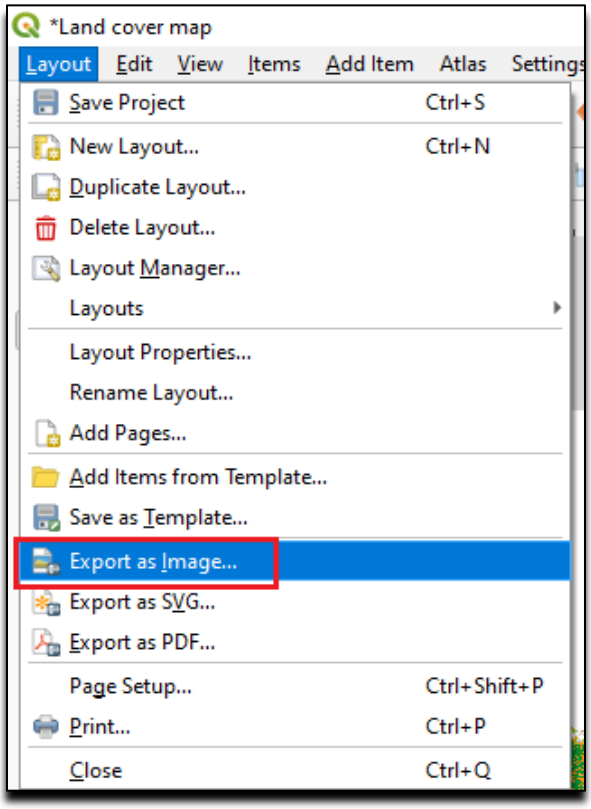
34. Under “Appearance”, edit “Font” and other characteristics as outlined in the picture below:



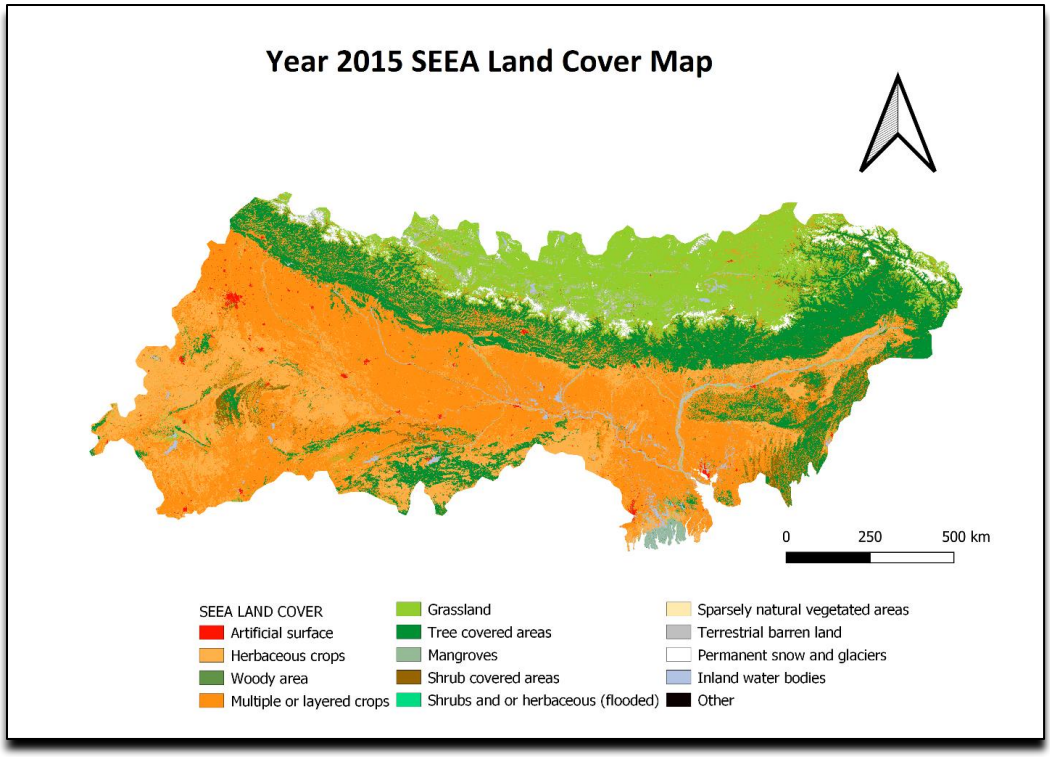
We see the “Year 2015 SEEA Land Cover Map” as shown in the picture below:



35. On the taskbar at the top of the interface, click “Layout” button and Select on the “Export as Image” as shown in the picture below:



36. Save under proposed name and proposed format
37. Click “Layout” and click “Export as Image” as seen in the picture below:



You have completed Step 3 – Data processing and visualization! Almost finished!

Step 4 – Producing land cover change statistics

The steps in this section show how to develop the following using Reclassified data in QGIS and RStudio:

- Land cover change matrix
- Table showing percentage change in land cover

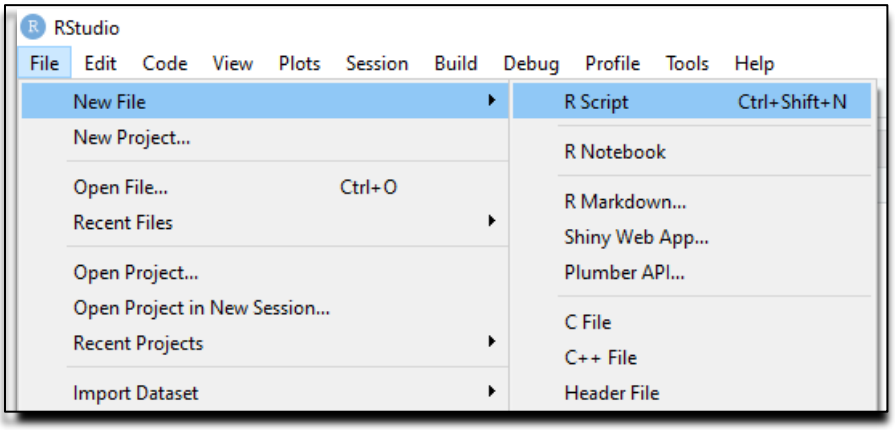
R and RStudio are open source and, like QGIS, can be downloaded and install free of cost. More information on how to download R and RStudio are provided in the Appendix to this guide.

Description of the commands used in RStudio are prefaced by the hashtag symbol (#).

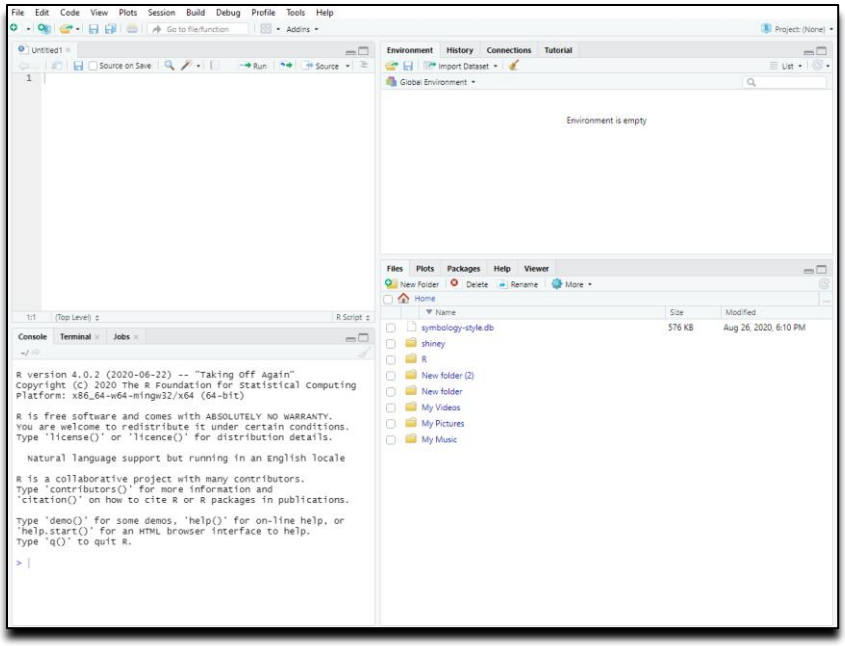
4.1 Setting up RStudio and installation of the prerequired libraries

The steps in this section show how to set up RStudio and install the libraries required for the exercise:

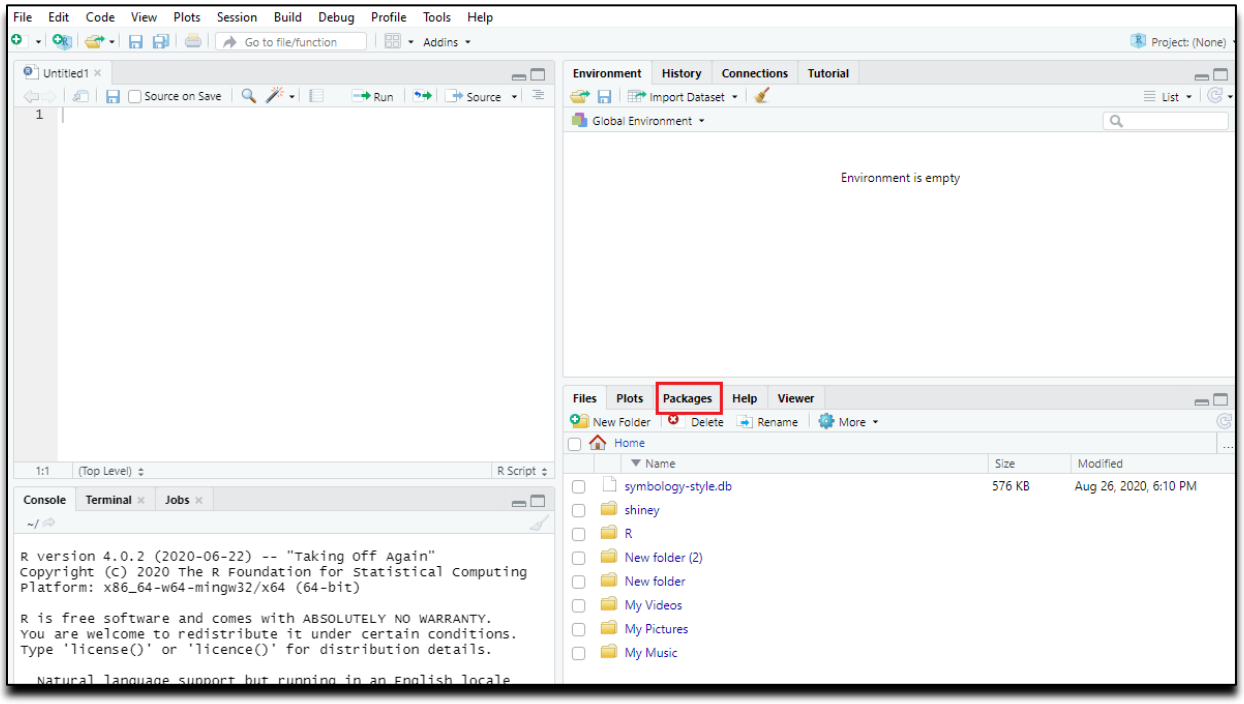
1. Open RStudio
2. Click on "New File" and select "R Script" as shown in the image below:



The resulting interface of RStudio is shown in the picture below:



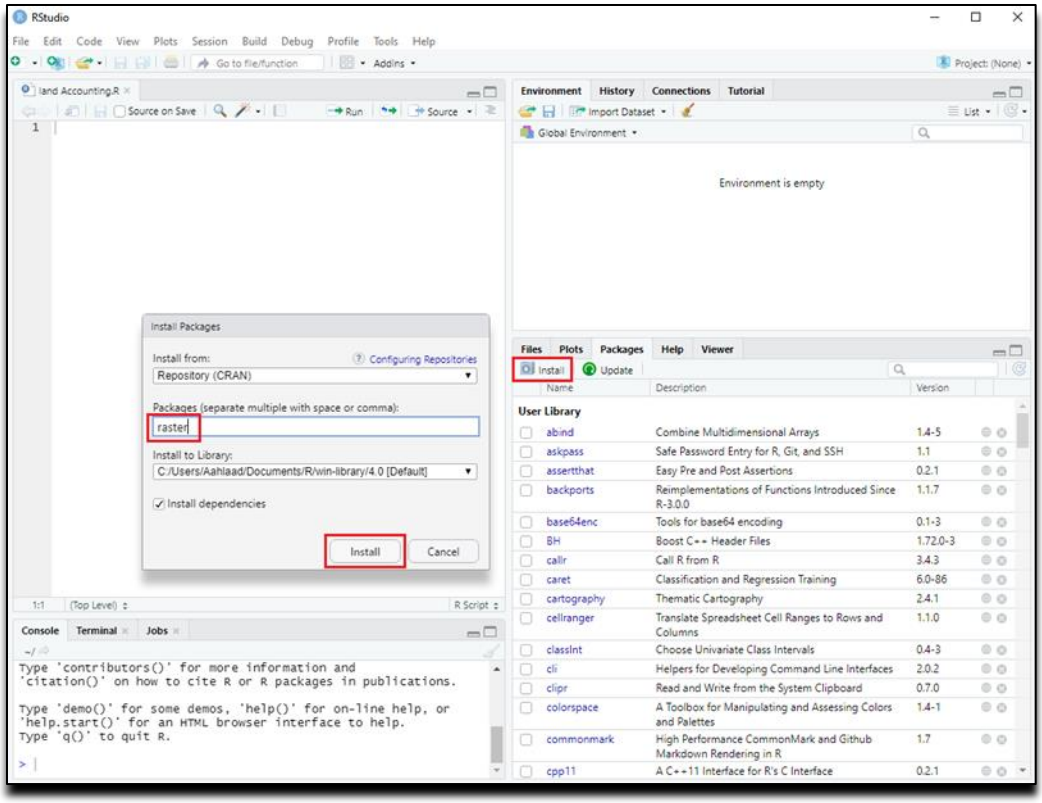
3. Click “File”
4. Click “Save As” and save with the name of your choosing.
   For this exercise, we save the File as “Reclassify folder”
5. Click on “Packages” as shown in the picture below:



6. Select “Install”
7. In the window that appears, search for “raster”

8. Click "Install dependencies"
9. Click "Install"

These steps are shown in the picture below:



10. Next, type library(raster) in the Accounting window as shown in the picture below and click "Run"
    Ignore the warning message.

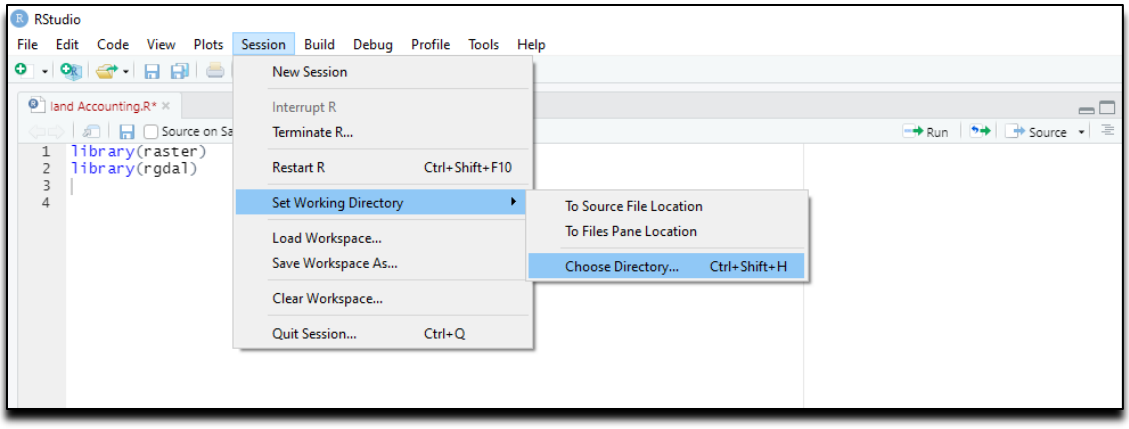
#The command library(raster) allows the user to load image format files and is part of the built-in RStudio syntax

After installing the raster library, repeat Steps 1 – 10 to install the **rgdal library** by replacing 'raster' with 'rgdal'.

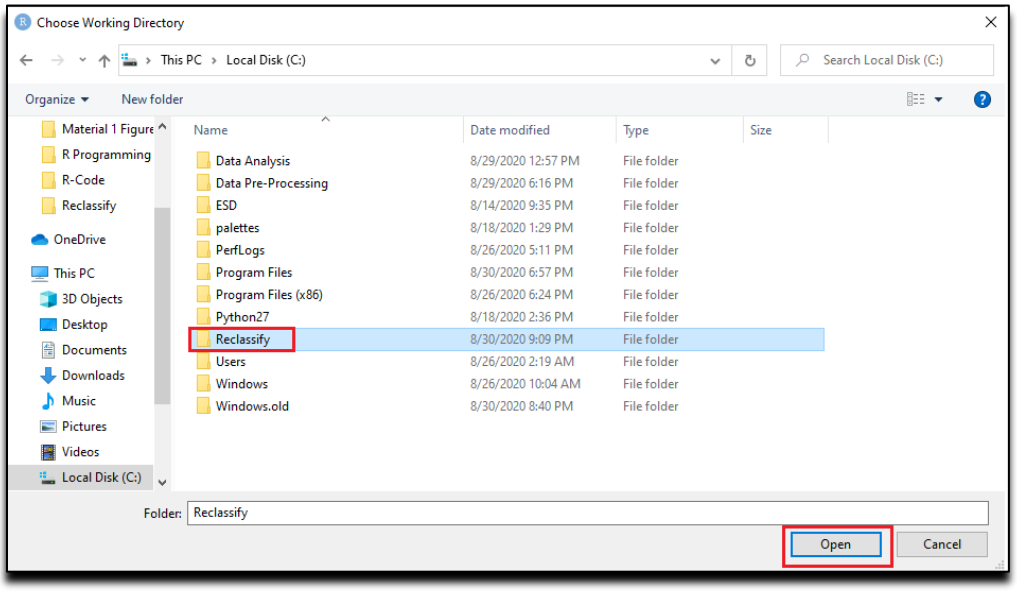
4.2 Defining inputs

The steps in this section show how to define the Working Directory in RStudio as the directory where the raster image files are saved.

1. Click on "Session"
2. Select "Set Working Directory" and select "Choose Directory" as show in the image below:

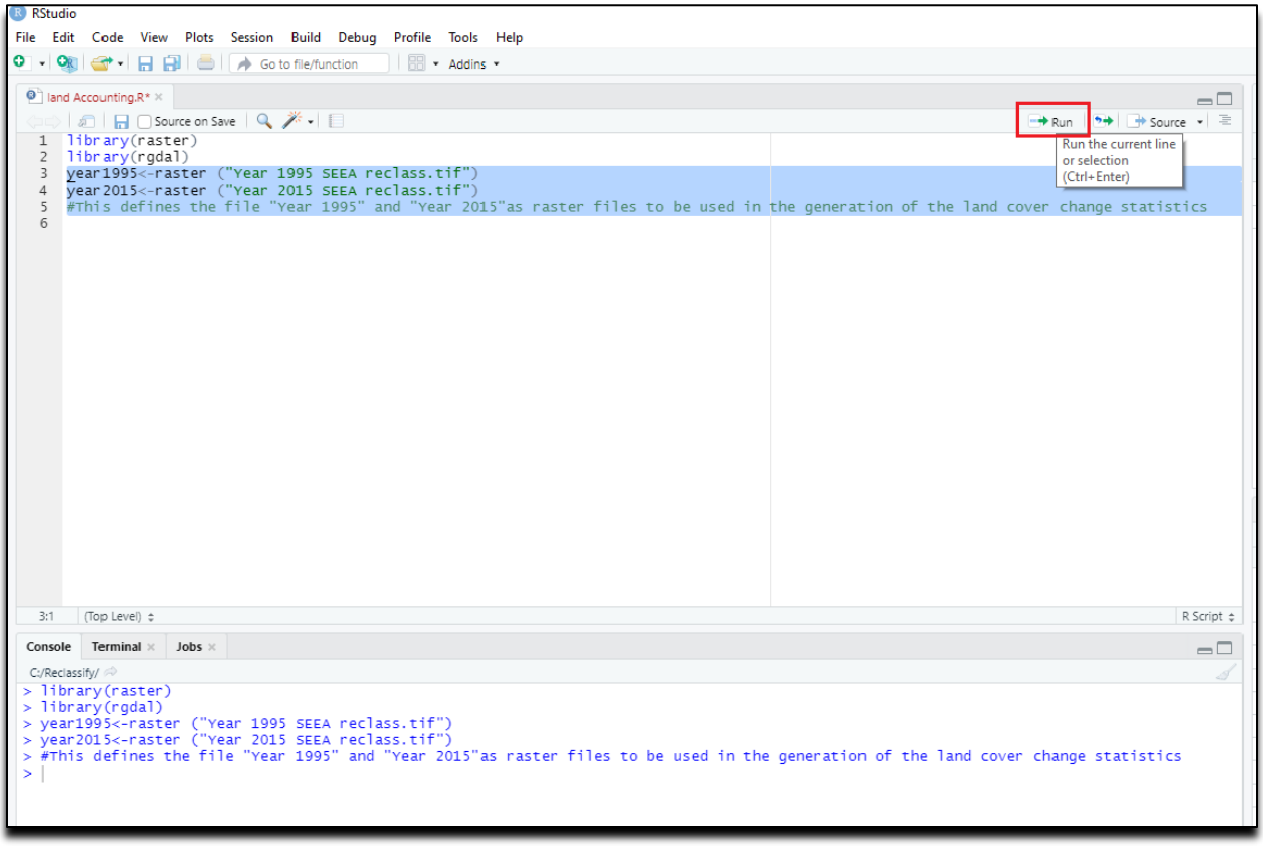


3. In the new window that appears, go to the Folder where the raster image files (*.tif) were saved. Select that Folder and Click "Open".
   For the exercise in this guide, we saved the *.tif files in a folder called "Reclassify" as shown in the picture below:



4. Next, type the following commands and click "Run" as shown in the picture below:
   year1995<-raster ("Year 1995 SEEA reclass.tif")
   #The command defines "Year 1995 SEEA reclass.tif" as a raster file to be used in the generation of the Land Cover Change Statistics
   year2015<-raster ("Year 2015 SEEA reclass.tif")

#The command defines "Year 2015 SEEA reclass.tif" as a raster file to be used in the generation of the Land Cover Change Statistics



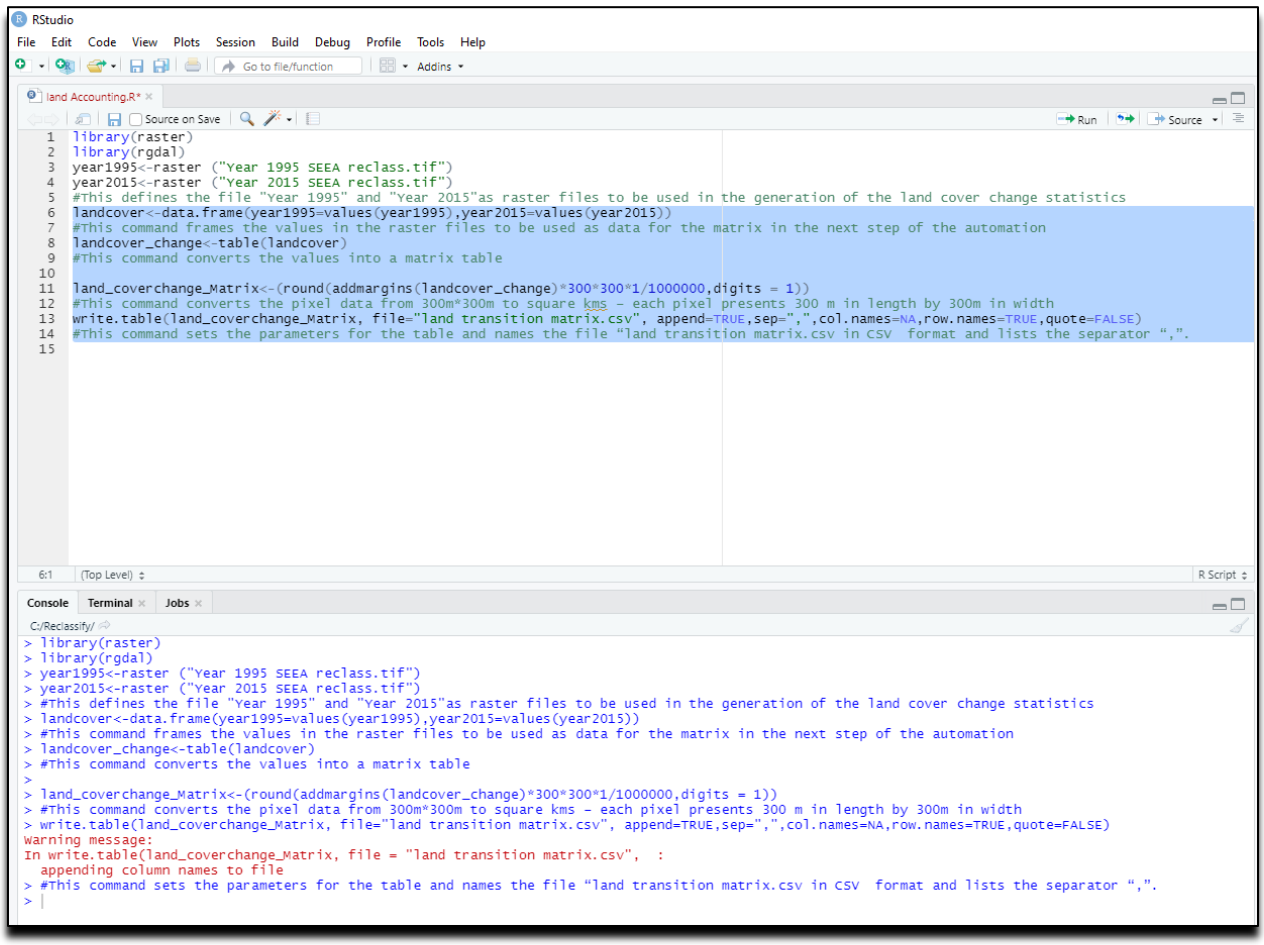
4.3 Generating land cover change transition matrix

The steps in this section show how to generate the transition matrix showing the land cover change from 1995 to 2015:

1. Type the following commands and click "Run" as shown in the picture below:
   landcover<-data.frame(year1995=values(year1995),year2015=values(year2015))
   #This command frames the values in the raster files to be used as data for the matrix in the next step of the automation
   landcover_change<-table(landcover)
   #This command converts the values into a matrix table

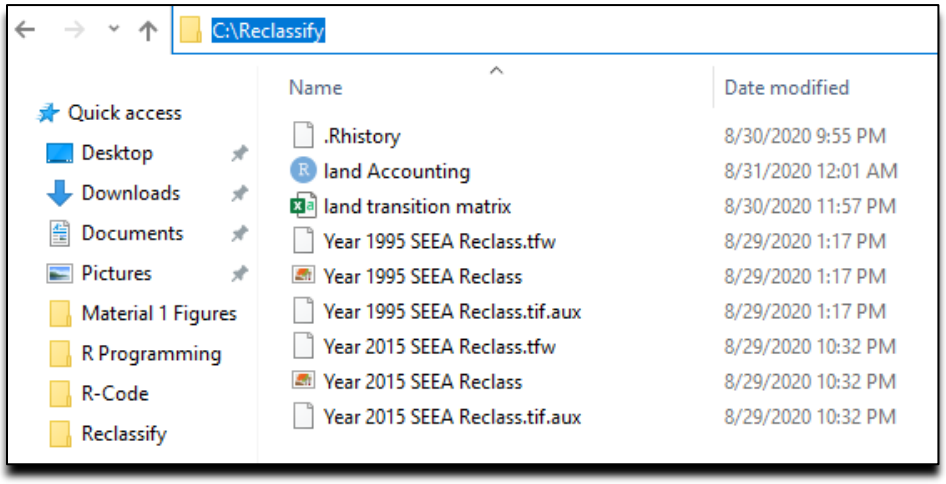
   land_coverchange_Matrix<-
   (round(addmargins(landcover_change)*300*300*1/1000000,digits = 1))
   #This command converts the pixel data from 300m*300m to square kms – each pixel presents 300 m in length by 300m in width
   write.table(land_coverchange_Matrix,file="land transition
   matrix.csv",append=TRUE,sep=",",col.names=NA,row.names=TRUE,quote=FALSE)

#This command sets the parameters for the table and names the file "land transition matrix.csv in CSV[8] format and lists the separator ",".



[8] A comma-separated values (CSV) file is a delimited text file that uses a comma to separate values.

In the exercise in this guide, the resulting land transition matrix is saved as seen in the picture below:



This table can be further formatted in the resulting .csv file or saved as Excel Files, and formatted as desired. For the exercise in this guide, we formatted the results as follows:

Land Cover Change Matrix - Ganges Brahmaputra River Basin

Year 1995 Land Cover in square km	Year 2015 Land Cover in square km														
	1	2	3	4	5	6	7	8	9	10	11	12	13	Sum – Year 1995
1	2,975.50	-	-	-	-	-	-	-	-	-	-	-	-	2,975.50
2	2,873.40	298,789.80	0.60	113.00	284.30	665.50	23.80	12.20	0.40	2.50	108.10	-	546.60	303,420.20
3	5.50	-	2,375.70	0.20	0.30	2.90	-	-	-	-	-	-	-	2,384.60
4	3,773.70	21.50	0.70	673,849.60	1,879.10	4,375.10	39.10	23.10	0.40	11.90	133.30	-	400.40	684,508.00
5	289.00	807.90	0.40	819.90	293,469.90	251.50	4.00	2.10	0.60	223.40	900.50	-	623.20	297,392.40
6	85.60	1,385.90	27.80	5,369.90	100.70	325,296.30	0.50	525.00	20.10	-	1.00	-	27.90	332,840.70
7	2.50	11.20	-	18.10	0.90	18.20	5,341.00	0.10	0.10	-	-	-	102.90	5,494.90
8	50.70	1,720.00	59.30	2,669.80	78.60	8,376.60	26.60	24,573.20	1.00	0.10	2.40	-	9.20	37,567.30
9	0.20	-	-	2.40	-	8.90	0.20	-	667.20	-	-	-	1.40	680.30
10	5.00	2.70	-	3.20	689.00	-	-	-	-	1,673.60	11.70	-	5.10	2,390.50
11	3.90	43.10	-	30.00	4,589.90	-	-	1.60	-	209.60	23,205.80	-	14.80	28,098.60
12	-	-	-	-	-	-	-	-	-	-	-	32,579.00	-	32,579.00
13	68.70	161.80	0.20	125.50	324.40	84.60	19.20	1.10	2.20	13.40	304.80	-	31,610.90	32,716.80
Sum – Year 2015	10,133.60	302,944.00	2,464.70	683,001.60	301,417.10	339,079.50	5,454.30	25,138.30	692.10	2,134.50	24,667.70	32,579.00	33,342.30	1,763,048.70

1	Artificial surface
2	Herbaceous crop
3	Woody area
4	Multiple or Layered crop
5	Grassland
6	Tree cover areas
7	Mangrove
8	Shrub cover areas
9	Shrubs and or herbaceous areas
10	Sparsely natural vegetated areas
11	Terrestrial barren land
12	Permanent snow and glacier
13	In land water Bodies

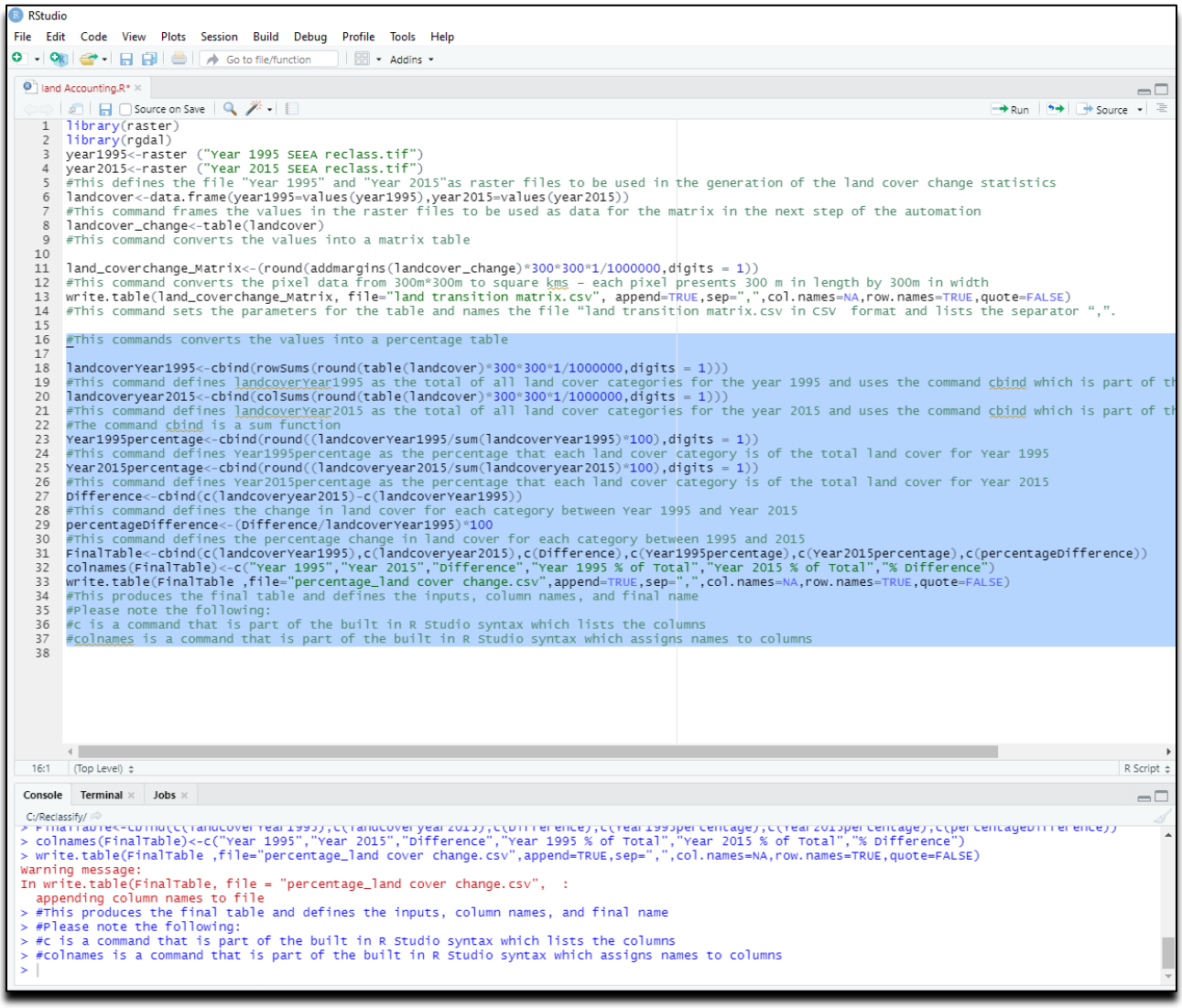
4.4 Generating percentage of land cover change table

The steps in this section show how to generate the table showing the percentage changes in Land Cover from 1995 to 2015:

1. Type the following commands and click "Run" as shown in the picture below:

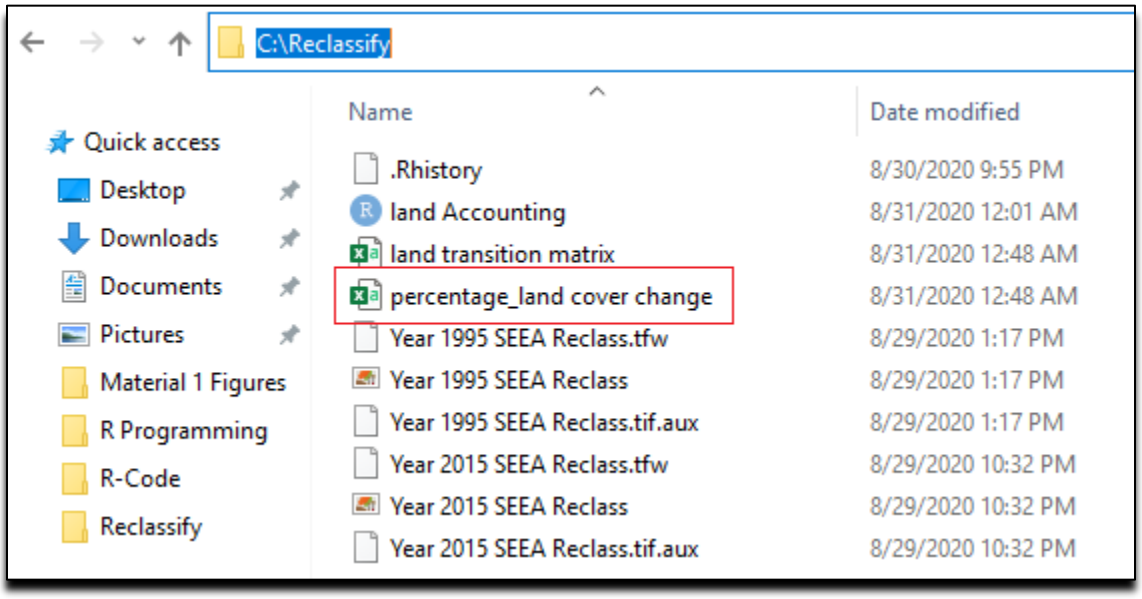
```
landcoverYear1995<-cbind(rowSums(round(table(landcover)*300*300*1/1000000,digits = 1)))
#This command defines landcoverYear1995 as the total of all land cover categories for the year 1995 and uses the command cbind which is part of the built-in RStudio syntax
landcoveryear2015<-cbind(colSums(round(table(landcover)*300*300*1/1000000,digits = 1)))
#This command defines landcoverYear2015 as the total of all land cover categories for the year 2015 and uses the command cbind which is part of the built-in RStudio syntax
#The command cbind is a sum function
Year1995percentage<-
cbind(round((landcoverYear1995/sum(landcoverYear1995)*100),digits = 1))
#This command defines Year1995percentage as the percentage that each land cover category is of the total land cover for Year 1995
Year2015percentage<-
cbind(round((landcoveryear2015/sum(landcoveryear2015)*100),digits = 1))
#This command defines Year2015percentage as the percentage that each land cover category is of the total land cover for Year 2015
Difference<-cbind(c(landcoveryear2015)-c(landcoverYear1995))
#This command defines the change in land cover for each category between Year 1995 and Year 2015
percentageDifference<-(Difference/landcoverYear1995)*100
#This command defines the percentage change in land cover for each category between 1995 and 2015
FinalTable<-
cbind(c(landcoverYear1995),c(landcoveryear2015),c(Difference),c(Year1995percentage),c(Year2015percentage),c(percentageDifference))
colnames(FinalTable)<-c("Year 1995","Year 2015","Difference","Year 1995 % of Total","Year 2015 % of Total","% Difference")
write.table(FinalTable ,file="percentage_land cover change.csv",append=TRUE,sep=",",col.names=NA,row.names=TRUE,quote=FALSE)
#This produces the final table and defines the inputs, column names, and final name
#Please note the following:
#c is a command that is part of the built in RStudio syntax which lists the columns
```

#colnames is a command that is part of the built in RStudio syntax which assigns names to columns



Ignore the Warning message

In the exercise in this guide, the resulting table showing the percentage change in land cover is saved as seen in the picture below:



This table can be further formatted in the resulting .csv files or saved as Excel Files, and formatted as desired. For the exercise in this guide, we formatted the results as follows:

Table showing Land Cover Changes Among Categories						
	Year 1995	**Year 2015**	**Difference**	**Year 1995 % of Total**	**Year 2015 % of Total**	**% Difference between 1995 and 2015**
1	2,975.50	10,133.70	7,158.20	0.20%	0.60%	241%
2	303,420.20	302,943.90	(476.30)	17.20%	17.20%	0%
3	2,384.60	2,464.70	80.10	0.10%	0.10%	3%
4	684,507.90	683,001.60	(1,506.30)	38.80%	38.70%	0%
5	297,392.40	301,417.10	4,024.70	16.90%	17.10%	1%
6	332,840.70	339,079.60	6,238.90	18.90%	19.20%	2%
7	5,495.00	5,454.40	(40.60)	0.30%	0.30%	-1%
8	37,567.50	25,138.40	(12,429.10)	2.10%	1.40%	-33%
9	680.30	692.00	11.70	0.00%	0.00%	2%
10	2,390.30	2,134.50	(255.80)	0.10%	0.10%	-11%
11	28,098.70	24,667.60	(3,431.10)	1.60%	1.40%	-12%
12	32,579.00	32,579.00	-	1.80%	1.80%	0%
13	32,716.80	33,342.40	625.60	1.90%	1.90%	2%

1	**Artificial surface**
2	**Herbaceous crop**
3	**Woody area**
4	**Multiple or Layered crop**
5	**Grassland**
6	**Tree cover areas**
7	**Mangrove**
8	**Shrub cover areas**
9	**Shrubs and or herbaceous areas**
10	**Sparsely natural vegetated areas**
11	**Terrestrial barren land**
12	**Permanent snow and glacier**
13	**In land water Bodies**

You have completed Step 4 of 4! Well done on producing your visualizations and statistics! We wish you good luck as you continue the journey ahead.

Appendix

The Appendix gives a brief overview of QGIS and R and RStudio, which are the open source programs used in the exercise outlined in this guide; and shows how to download and install these programs for use.

A. QGIS

QGIS is a cross-platform desktop geographic information system that supports viewing, editing and analysis of geospatial data.

We used the most recent version of QGIS available, and we advise that you do the same. However, while most versions of QGIS will work, we recommend that you use QGIS version 3.10 and above, with the following plugins:

- GRASS – Geographic Resource Analysis Support System
- SAGA – System of Automated Geoscientific Analysis
- GDAL – Geographic Data Abstraction Library

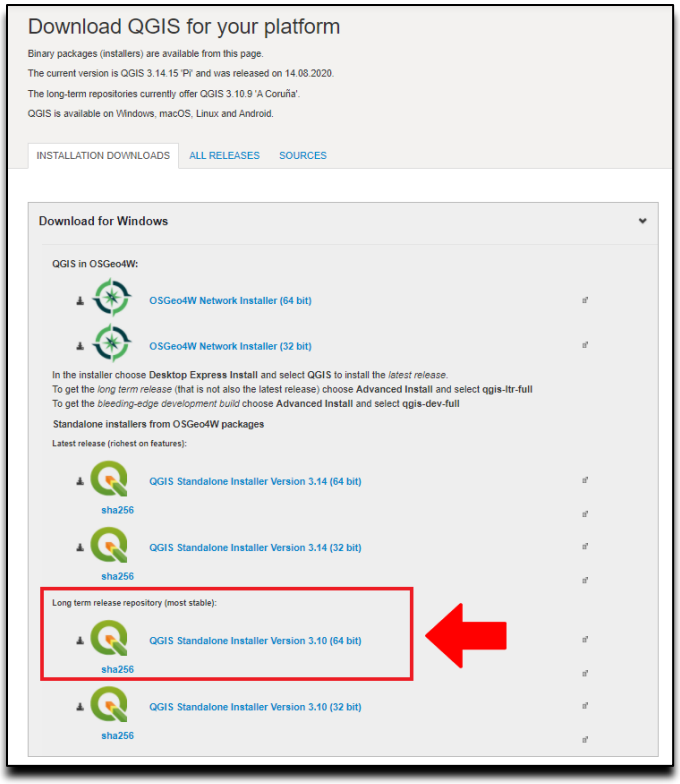
Downloading and Installing QGIS

1. Go to the QGIS website (https://qgis.org/en/site/forusers/download.html)

We used the most recent version of QGIS available and we advise that you do the same. However, while most versions of QGIS will work, we recommend that you use QGIS version 3.10 and above, with the following plugins:

- GRASS – Geographic Resource Analysis Support System
- SAGA – System of Automated Geoscientific Analysis
- GDAL – Geographic Data Abstraction Library

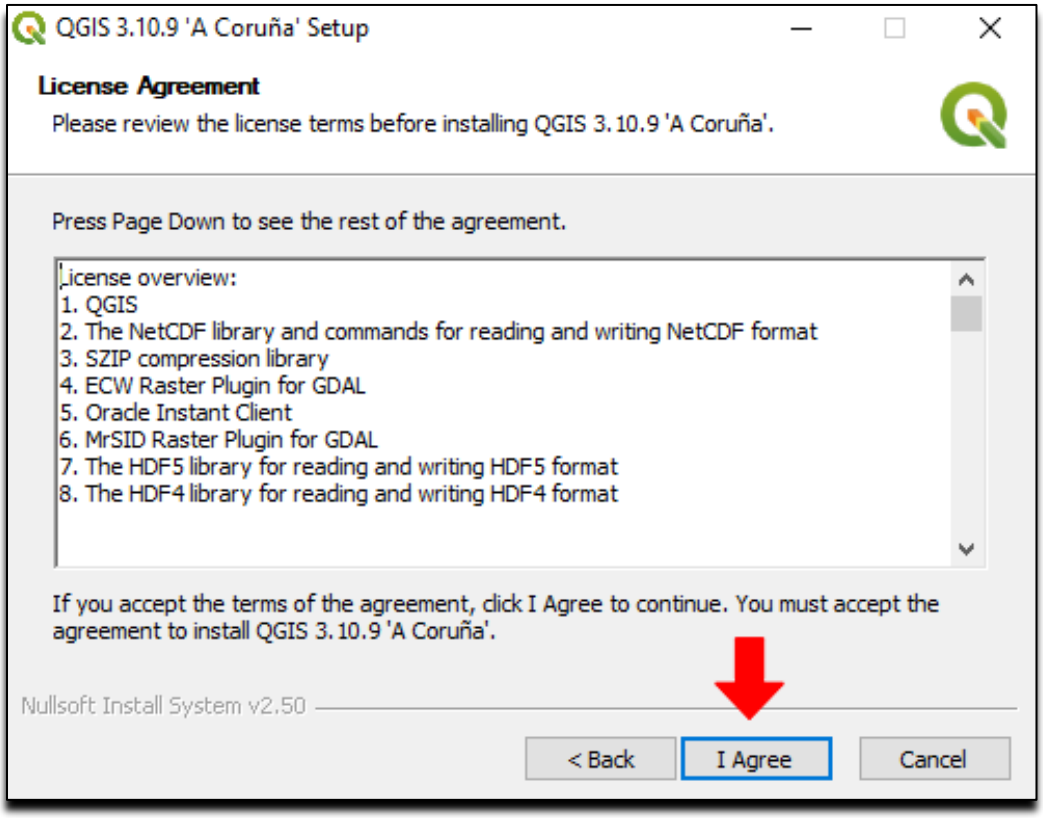
2. Download the QGIS Standalone Installer Version 3.10, and choose either the 32-bit or 64-bit based on the configuration of your individual system as suggested in the picture below:



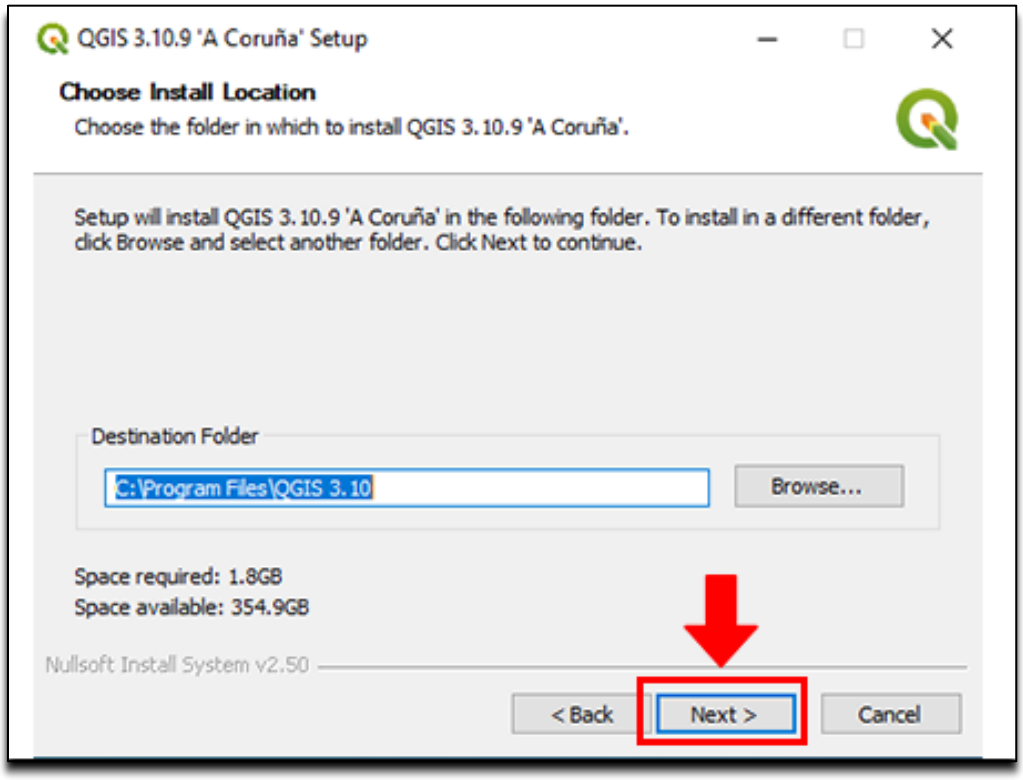
For the exercise in this guide, we used the 64-bit version, and downloaded and installed QGIS-OSGeo4W-3.10.9-1-Setup-x86_64 as shown in the picture below:

3. On the Welcome to QGIS-OSGeo4W-3.10 page, click on Next button as seen below:

4. Click on I Agree for license agreement as seen below:



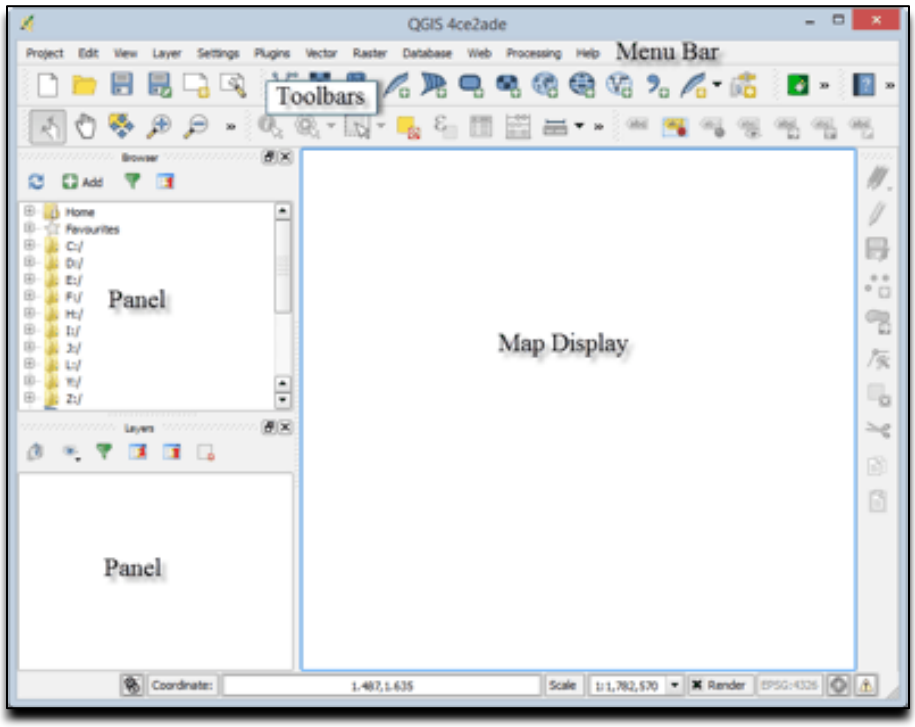
5. Click on Next in Choose Install Location, as seen in picture below:



6. Once the installation process is complete, click on Finish, as seen in the picture below. The software is now installed on your computer and ready to use.

More Characteristics of QGIS

The QGIS interface has four areas:



- Menu bar - provides access to the majority of QGIS Desktop's functionality.
- Toolbars - provide quick access to QGIS Desktop functionality; they can be arranged to either float independently or dock along the sides of the application's window.
- Panels, such as Browser, and Layers - provide a variety of functionality and can be arranged to either float independently or dock above, below, right, or left of the map display.
- Map display - shows the styled data added to the QGIS project.

The following toolbars are particularly useful, and they should be enabled:

- File - provides quick access to creating, opening, saving QGIS projects, and creating and managing print composers.
- Manage Layers - contains tools to add vector, raster, database, web service, text layers, or create new layers.
- Map Navigation - contains tools useful for panning, zooming, and refreshing the map display.

- Attributes - provides access to information, selection, field calculator, measuring, bookmarking, and annotation tools.

If you want to customize, you can:

- toggle the visibility of toolbars:

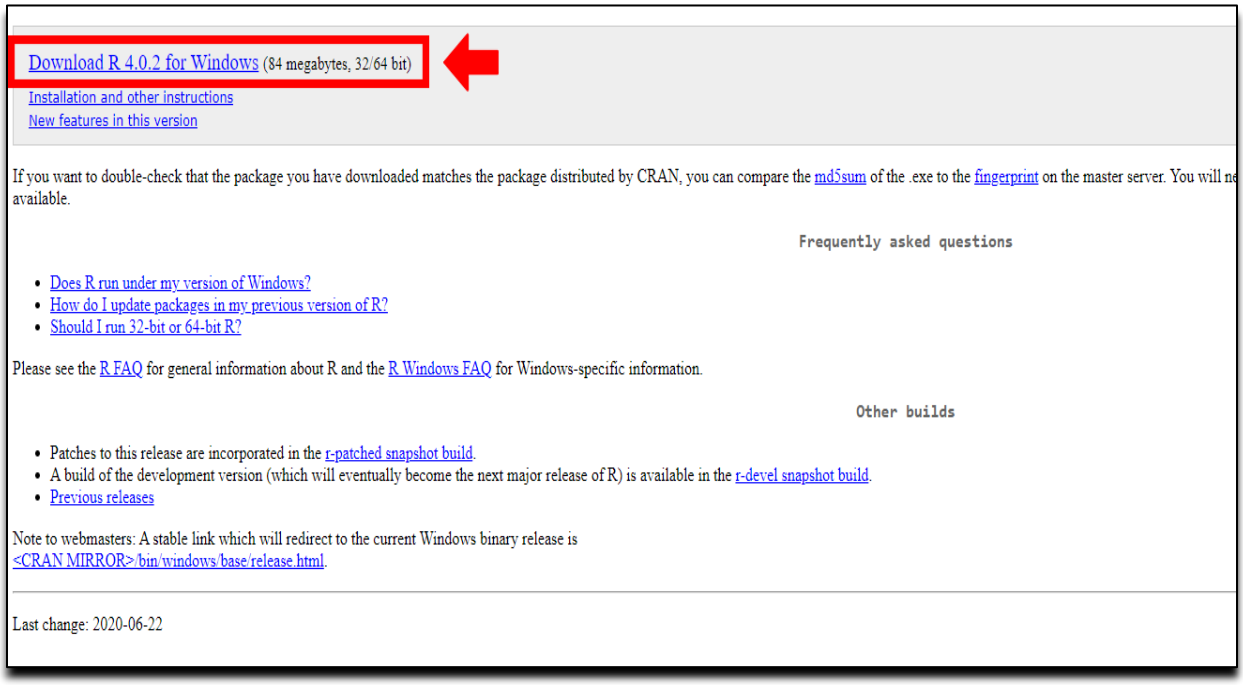
  by clicking View | Toolbars, or by right clicking the menu bar or enable toolbar button, which will open a context menu allowing you to toggle toolbar and panel visibility.
- assign shortcut to actions by clicking Settings | Configure shortcuts.
- change application options, such as interface language and rendering options by clicking Settings | Options.

B. R and RStudio

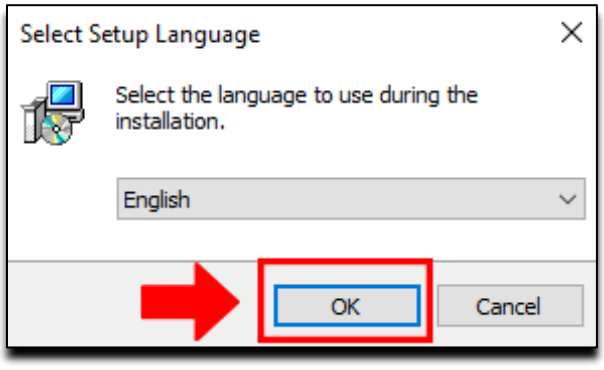
R is a programming language and free software environment for statistical computing and graphics; and RStudio is an integrated development environment for R.

Downloading and Installing R program

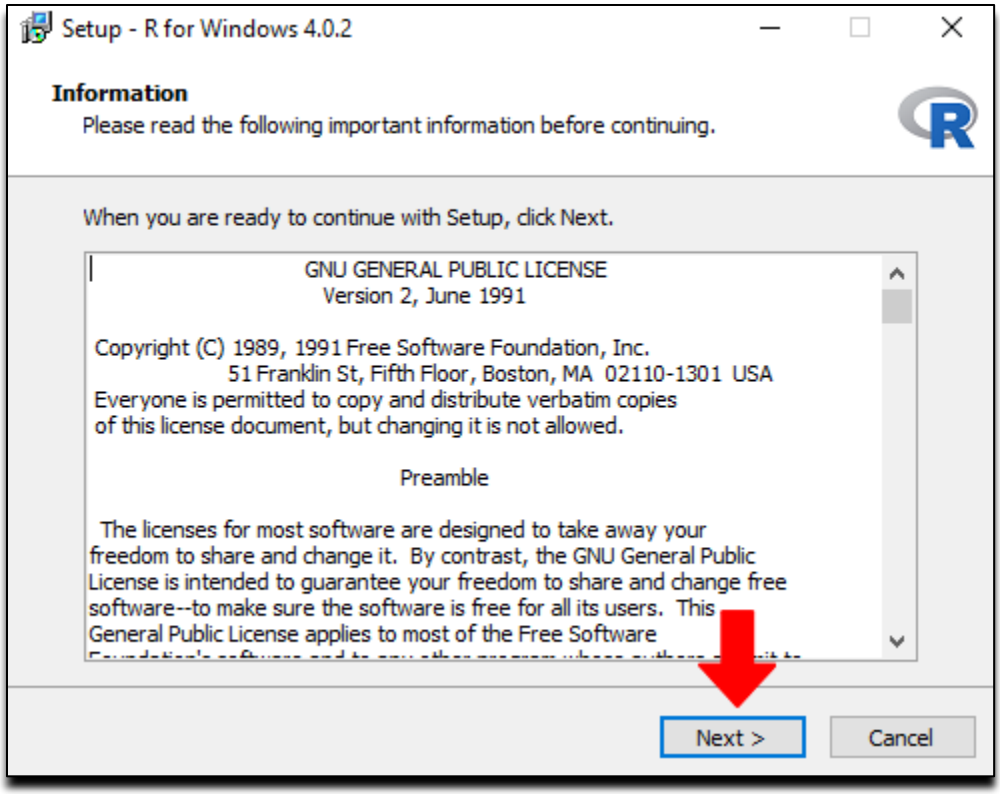
1. Go to this website (https://cran.r-project.org/bin/windows/base/), and download R as shown in the picture below:



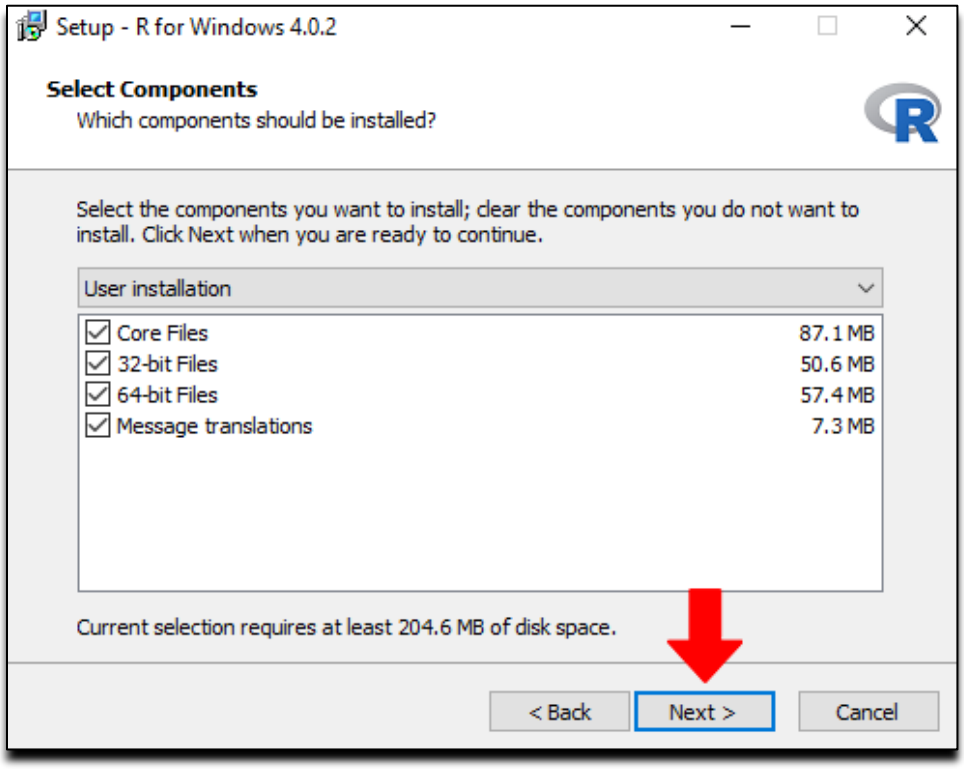
2. Define the Setup Language as English and click OK as shown in the picture below:



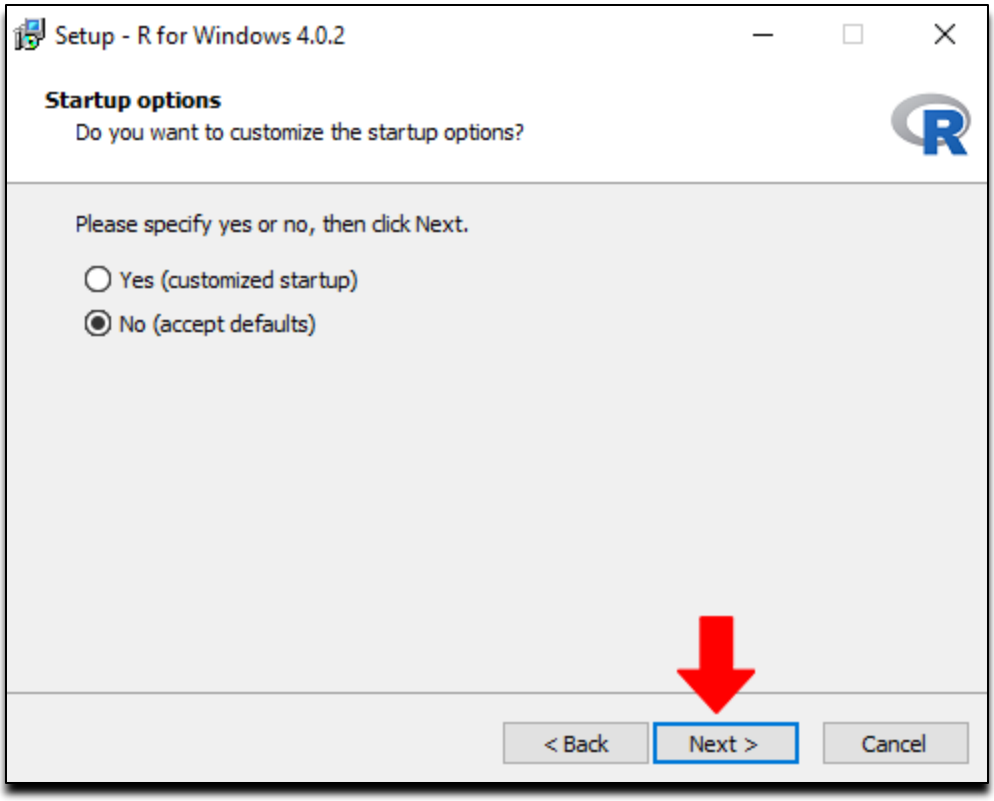
3. Click Next in the Setup Domain as shown below:



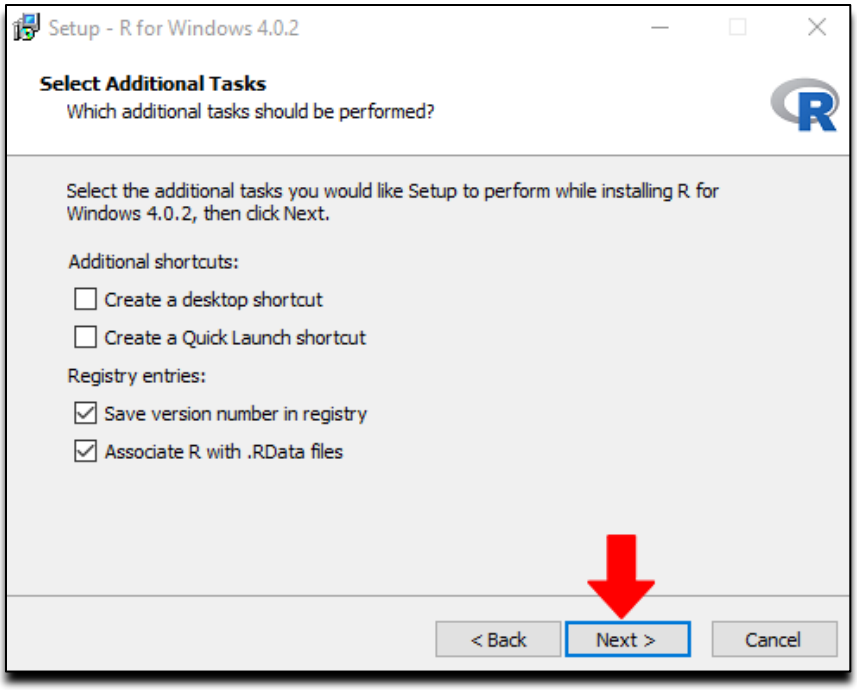
4. Select Components and click Next as shown in the picture below:



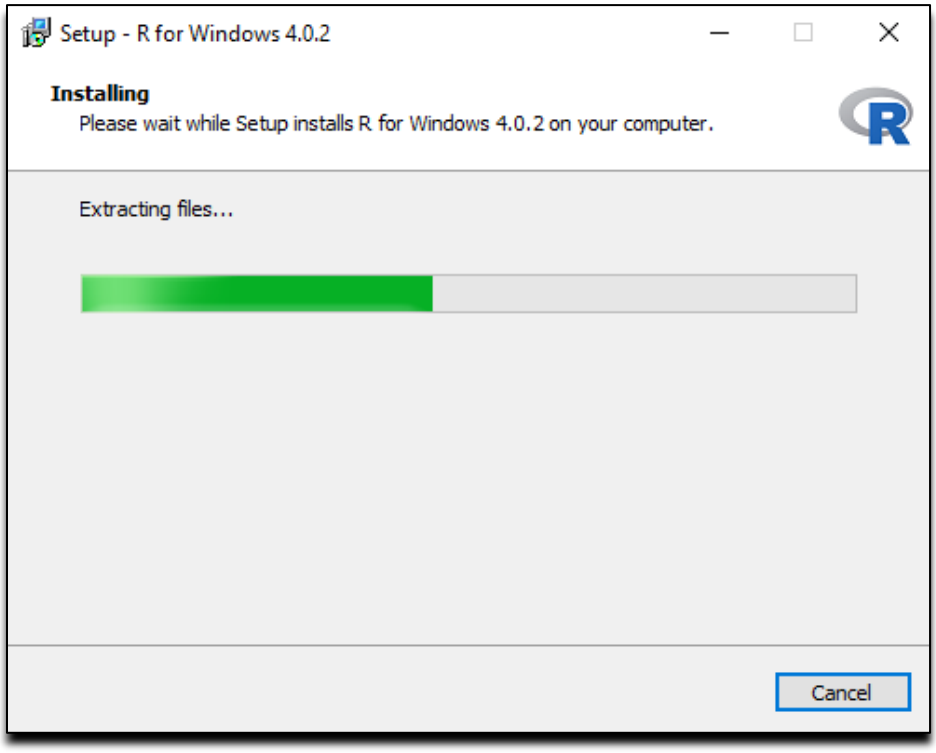
5. In Startup options, choose to accept defaults and click Next as shown in the picture below:



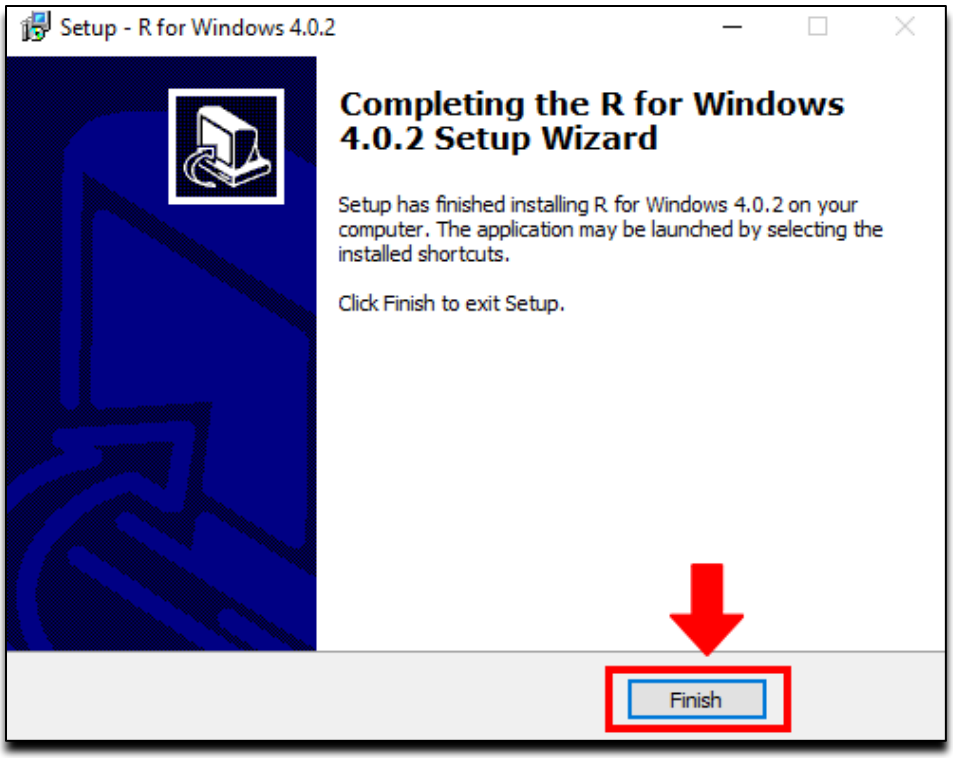
6. Select Additional Tasks; and click Next as shown below:



7. Please note that it will take a couple of minutes to Install the software, and the picture below shows on screen while the installation is taking place:

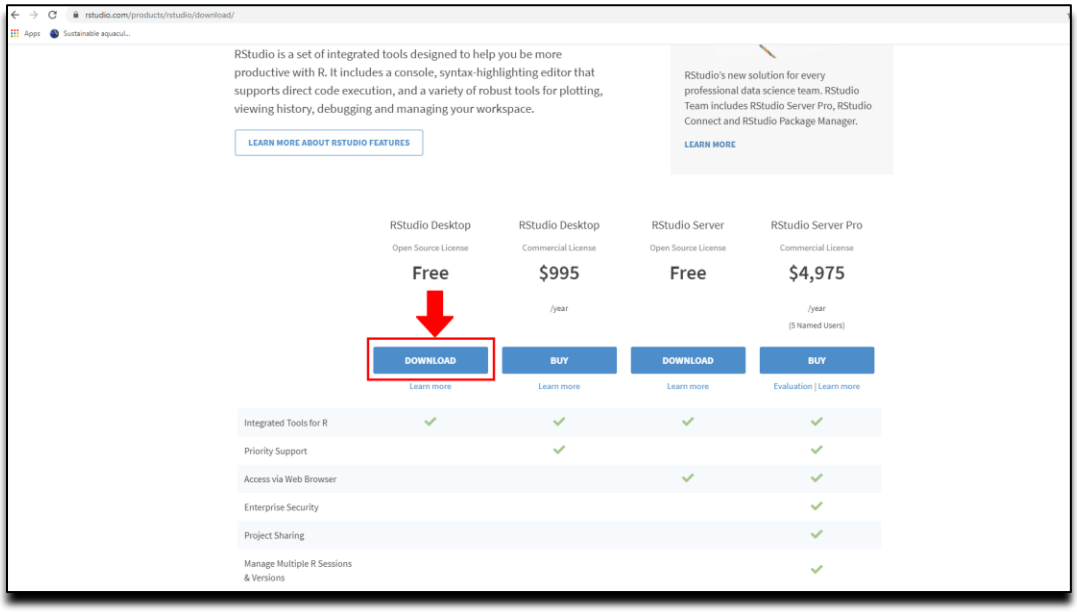


8. Once the installation process is complete, click on Finish, as seen in the picture below:



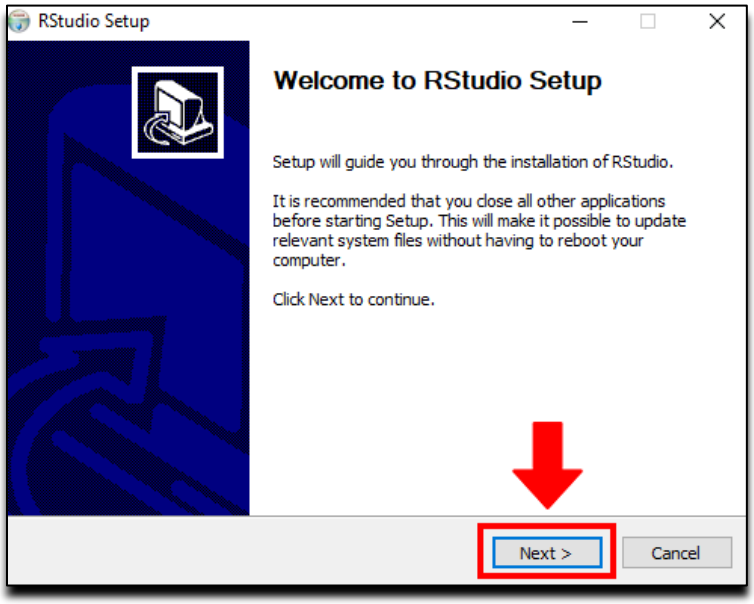
Downloading and installing RStudio (Free Version)

1. Go to this website (https://rstudio.com/products/rstudio/download/) and download the latest free version of RStudio Desktop as shown in the picture below:

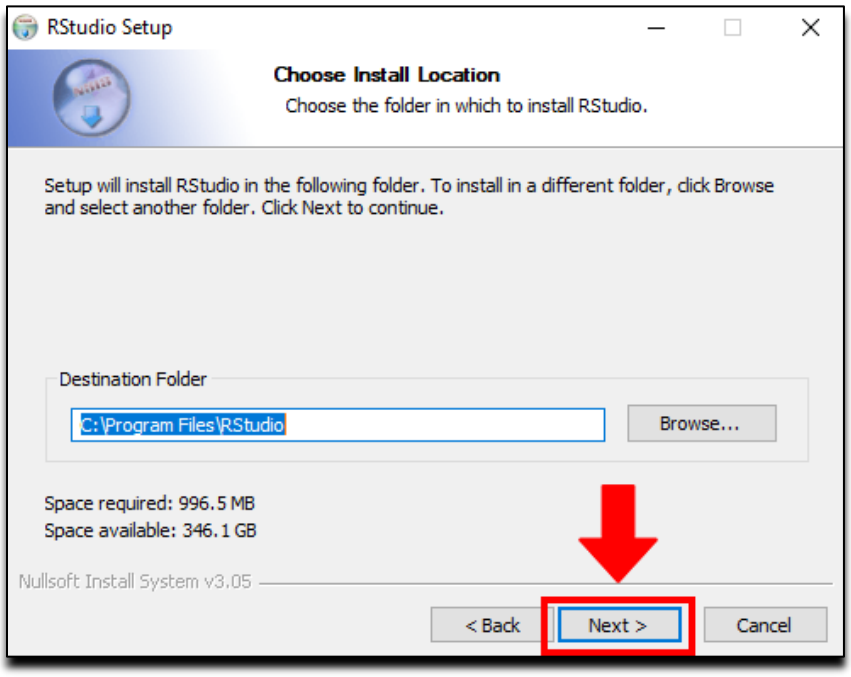


2. The version used in the exercise in this guide is shown in the picture below:

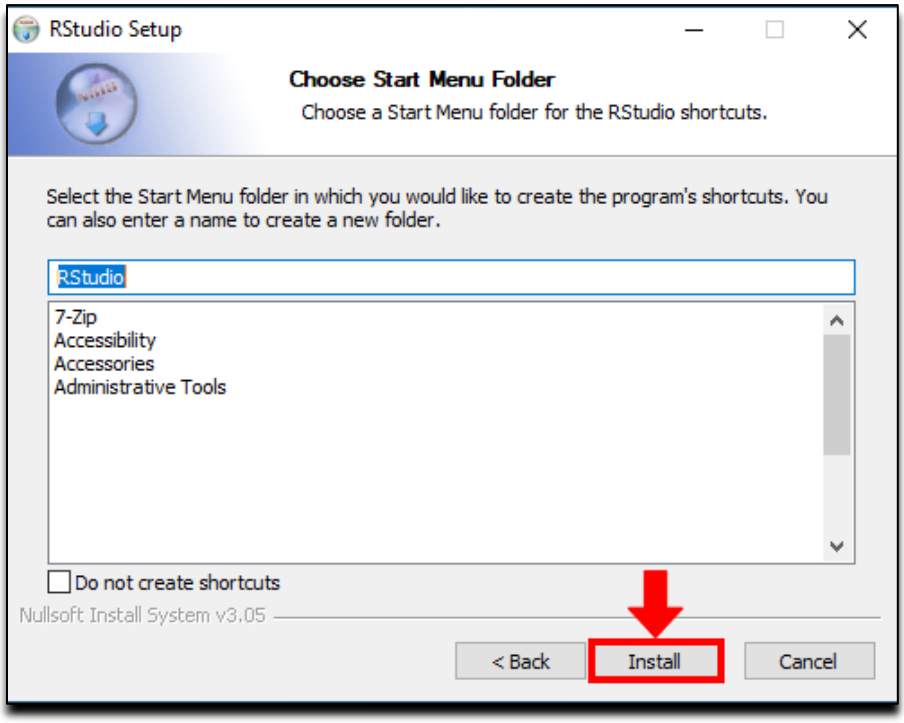
3. On the Welcome to RStudio Setup page, click Next as shown below:



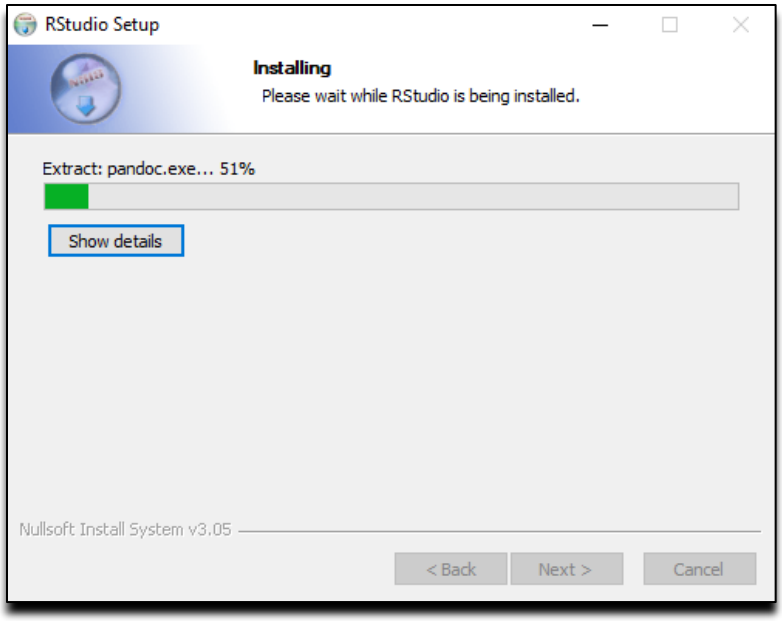
4. Choose Install Location, and click Next as shown below:



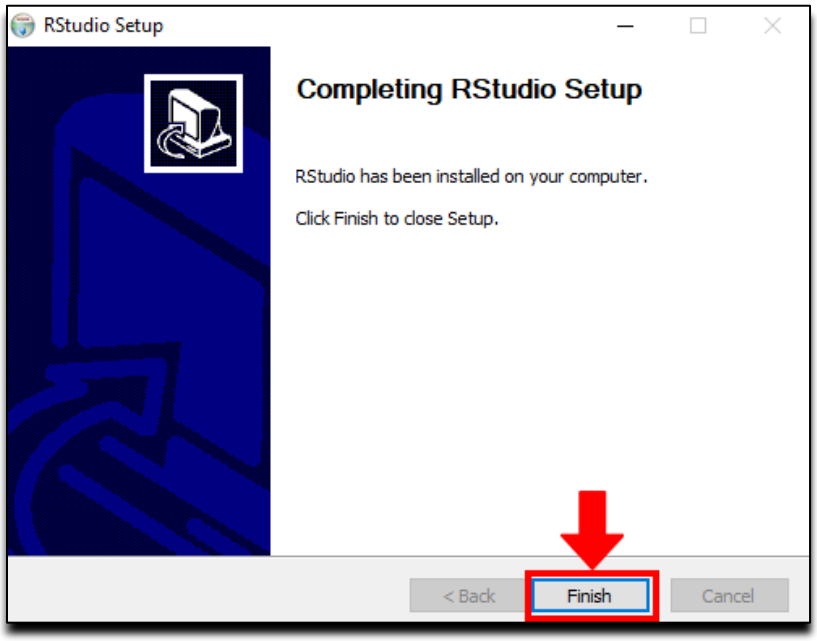
5. To initiate the installation process, click Install as shown below:



6. Please note that it will take a couple of minutes to Install the software, and the picture below shows on screen while the installation is taking place:



7. Once the installation process is complete, click on Finish, as seen in the picture below. The software is now installed on your computer and ready to use.



C. Available datasets

In this guide, the open-source data used are (1) the shape file data for the Major River Basins in the World which was downloaded from the World Bank, and (2) Tagged Image File Format Files for the Global Land Cover Data which is downloaded from the European Space Agency. The guide shows the steps to download the data, and then filter the data to process and show the land cover changes on the chosen area.

For illustration, this guide shows how to map the land cover changes along the Ganga Brahmaputra River Basin in India, as it is one of the largest river basin in the Asia-Pacific region; but the user may download similar data from the World Bank and from the European Space Agency to map land cover changes in a chosen area.

In the tables below, some of the most frequently used and most popular datasets are outlined. We encourage the user to investigate and determine which datasets are most suitable for their own uses.

Administrative Boundaries

This tables outlines sources for the administrative boundaries data that are most frequently used.

Name	Data Source
GADM – Database of Global Administrative Areas	https://gadm.org/data.html
DIVA-GIS Data	https://www.diva-gis.org/
HDX Data	https://data.humdata.org/dataset
Natural Earth Data	https://www.naturalearthdata.com/

Earth Observation Data

This table outlines earth observation data that are most frequently used. Earth Observation data outlines land cover areas and ocean and marine areas, and the data presented in the table below vary by resolution and the years available.

Sensor	Available From	Resolution	Data Source
Landsat 1 to 3	1972-1989	30M	https://earthexplorer.usgs.gov
Landsat 4-5TM	1982-2012	30M	https://earthexplorer.usgs.gov
Landsat 7	1999-Present	30M	https://earthexplorer.usgs.gov
Landsat 8	2013	30M	https://earthexplorer.usgs.gov
Aster	1999	30M	https://earthexplorer.usgs.gov
Sentinel	2015	10M	https://earthexplorer.usgs.gov
Modis	2003-Present	250M, 500M, 1km, 5Km	https://search.earthdata.nasa.gov
ESA	1992-2018	300M	ftp://geo10.elie.ucl.ac.be/v207/