Producing land cover change maps and statistics

Guide on advanced use of QGIS and RStudio

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Acknowledgments:

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Contents

Scope and purpose

This guide shows how to produce land cover change maps and statistical tables using open-source software Quantum Geographic Information System (QGIS) and code in RStudio.

The land cover change guide released in OCTOBER 2020 by ESCAP – Producing land cover change maps and statistics: Step by step guide on the use of QGIS and RStudio shows the user how to produce maps and statistical tables of land cover changes over a time interval. The current guide shows the user how to generate the same maps and tables using more powerful RStudio scripts. You do not need to go through the earlier released guide before taking on the present guide. You may wish to preview that guide to see how maps can be produced using QGIS.

Maps and statistical tables are generated in accordance with the land cover categories of the System of Environmental-Economic Accounting (SEEA).

The guide takes you through 3 steps:

Step 1: Download the necessary data 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: Generate land cover change maps and statistical tables using QGIS and scripts in RStudio – **Generating land cover change maps and statistical tables**

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 (users are encouraged to download the latest available versions of the programs).

For illustrative purposes, the guide uses select open-source data for a specific geographical area, the Ganga Brahmaputra River Basin in India. You can generate your own maps and statistical tables and choose other data which suit your purpose and the geographical area of your interest; 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!

Step 1 – Data downloading

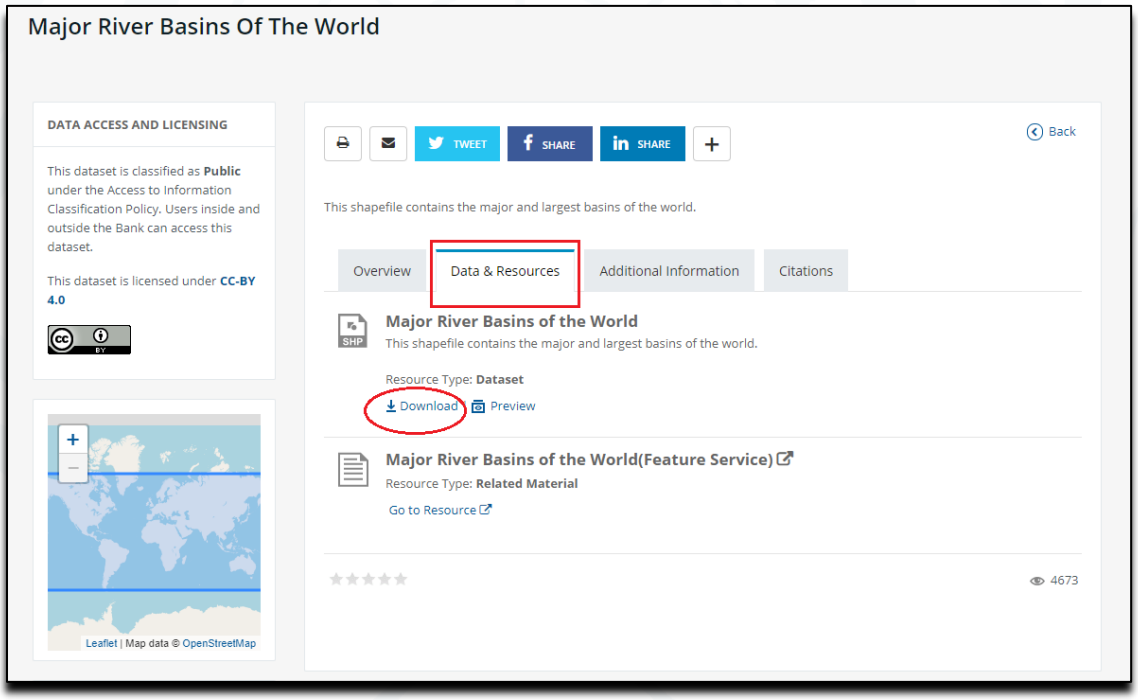
In this section, we will show how to download both raster datasets and vector datasets for use in developing the land cover change maps.

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



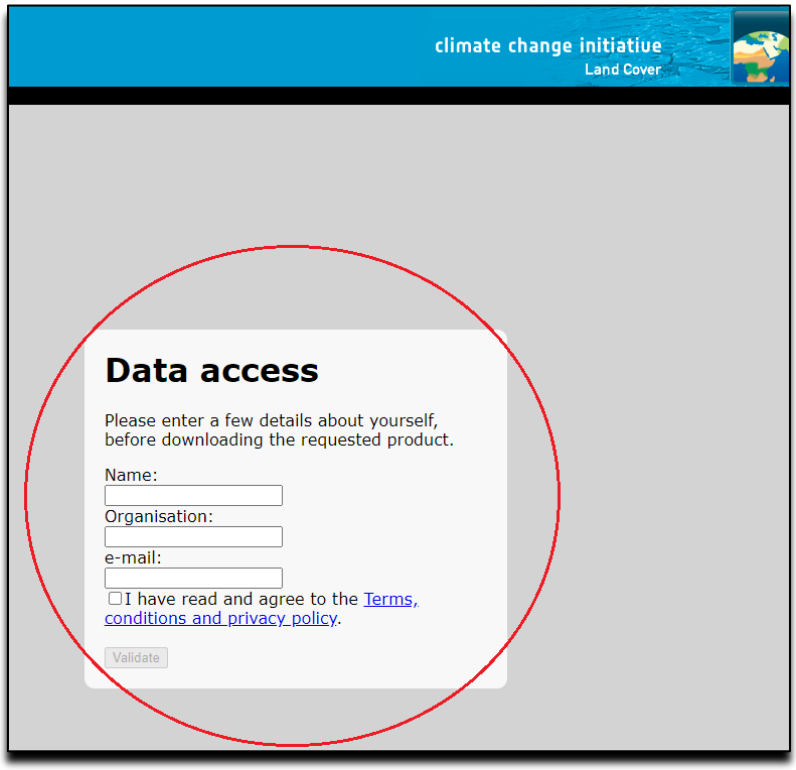
[1] The **shapefile** format is a geospatial vector data format for geographic information system (GIS) software. It is developed and regulated by Esri as a mostly open specification for data interoperability among Esri and other GIS software products. The shapefile format can spatially describe vector 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 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

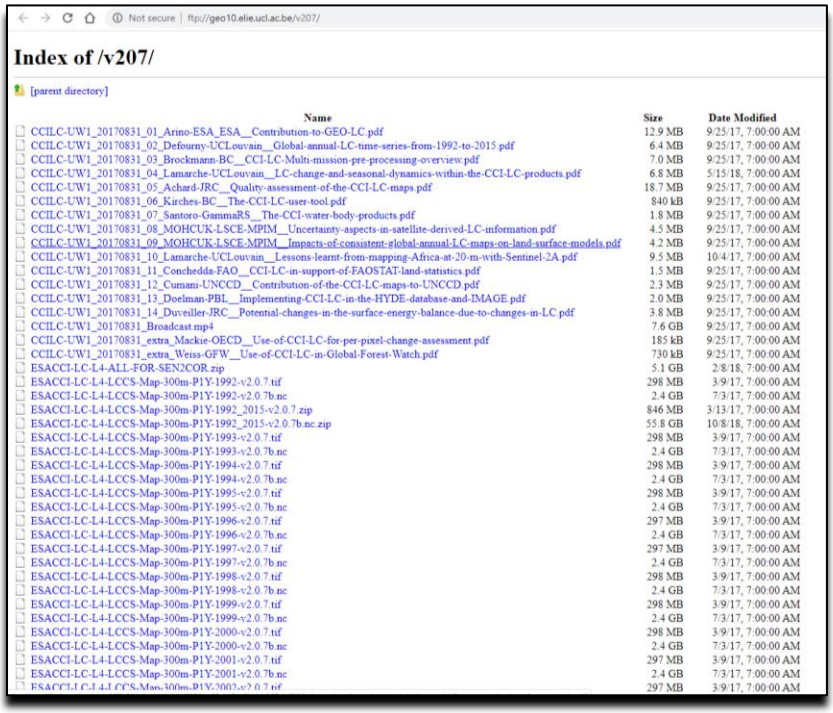
ESACCI-LC for Sen2Cor data package
54 tif files, zip compression - 5.1Go
Rem: includes LC maps, water bodies v4 and snow products

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)

Please note that you may have to open this link in a browser other than Chrome. For this exercise, we used Internet Explorer and Microsoft Edge.

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
CCILC-UW1_20170831_05_Achard-JRC__Quality-assessment-of-the-CCI-LC-maps.pdf	18.7 MB	9/25/17, 7:00:00 AM
CCILC-UW1_20170831_06_Kirches-BC__The-CCI-LC-user-tool.pdf	840 kB	9/25/17, 7:00:00 AM
CCILC-UW1_20170831_07_Santoro-GammaRS__The-CCI-water-body-products.pdf	1.8 MB	9/25/17, 7:00:00 AM
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CCILC-UW1_20170831_extra_Weiss-GFW__Use-of-CCI-LC-in-Global-Forest-Watch.pdf	730 kB	9/25/17, 7:00:00 AM
ESACCI-LC-L4-ALL-FOR-SEN2COR.zip	5.1 GB	2/8/18, 7:00:00 AM
ESACCI-LC-L4-LCCS-Map-300m-P1Y-1992-v2.0.7.tif	298 MB	3/9/17, 7:00:00 AM
ESACCI-LC-L4-LCCS-Map-300m-P1Y-1992-v2.0.7b.nc	2.4 GB	7/3/17, 7:00:00 AM
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ESACCI-LC-L4-LCCS-Map-300m-P1Y-1993-v2.0.7b.nc	2.4 GB	7/3/17, 7:00:00 AM
ESACCI-LC-L4-LCCS-Map-300m-P1Y-1994-v2.0.7.tif	298 MB	3/9/17, 7:00:00 AM
ESACCI-LC-L4-LCCS-Map-300m-P1Y-1994-v2.0.7b.nc	2.4 GB	7/3/17, 7:00:00 AM
ESACCI-LC-L4-LCCS-Map-300m-P1Y-1995-v2.0.7.tif	298 MB	3/9/17, 7:00:00 AM
ESACCI-LC-L4-LCCS-Map-300m-P1Y-1995-v2.0.7b.nc	2.4 GB	7/3/17, 7:00:00 AM
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
ESACCI-LC-L4-LCCS-Map-300m-P1Y-1997-v2.0.7b.nc	2.4 GB	7/3/17, 7:00:00 AM
ESACCI-LC-L4-LCCS-Map-300m-P1Y-1998-v2.0.7.tif	298 MB	3/9/17, 7:00:00 AM
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 between 1995 and 2015 inclusive as we are comparing the land cover changes from year to year along the Ganga Bhramaputra River Basin for that 20-year period.
   Example:
   ESACCI-LC-L4-LCCS-Map-300m-P1Y-1995-v2.0.7.tif
   ESACCI-LC-L4-LCCS-Map-300m-P1Y-1996-v2.0.7.tif
   ESACCI-LC-L4-LCCS-Map-300m-P1Y-1997-v2.0.7.tif
   …
   …
   …
   ESACCI-LC-L4-LCCS-Map-300m-P1Y-2013-v2.0.7.tif
   ESACCI-LC-L4-LCCS-Map-300m-P1Y-2014-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.

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 and extracting the data relevant to mapping land cover change.

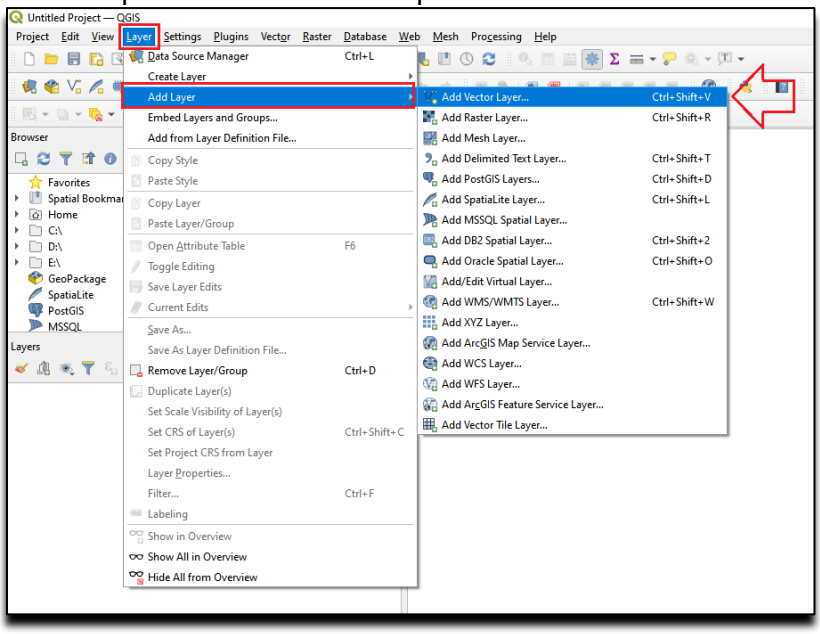
2.1 Loading vector data into QGIS

For this exercise, we created a new folder named "Data Pre-Processing". You may use this folder name or choose your own name and location.

Open QGIS Desktop with GRASS, and:

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

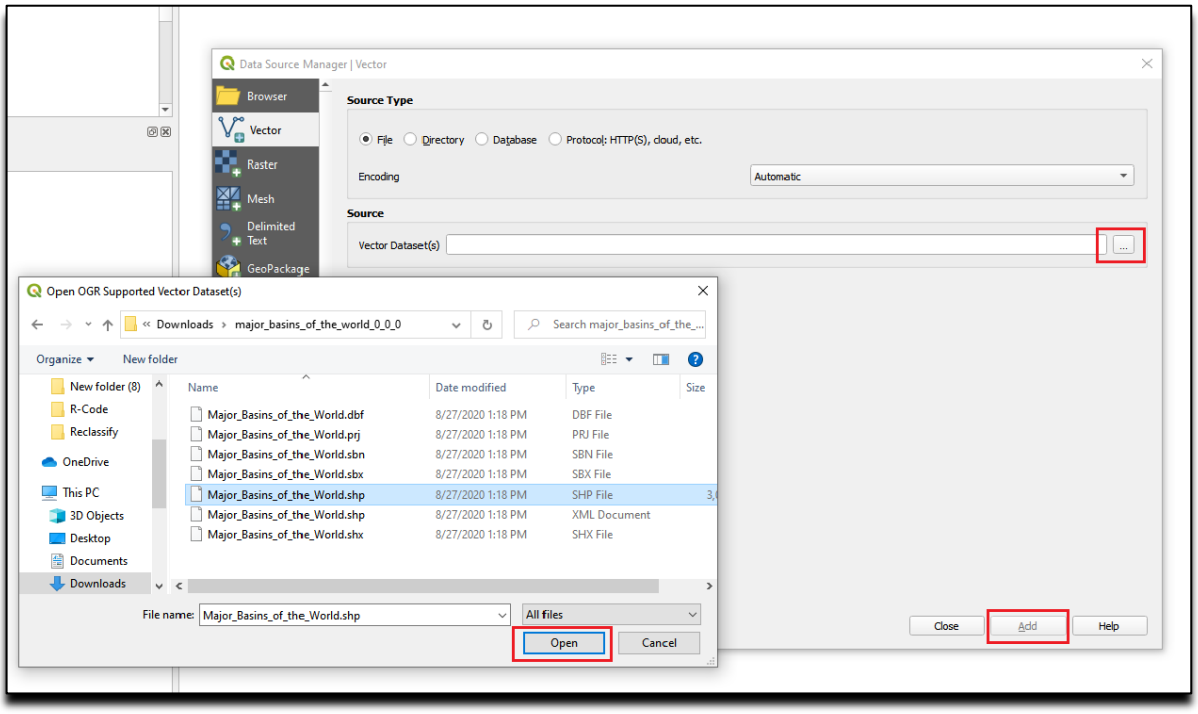
These steps are indicated in the picture shown below:



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

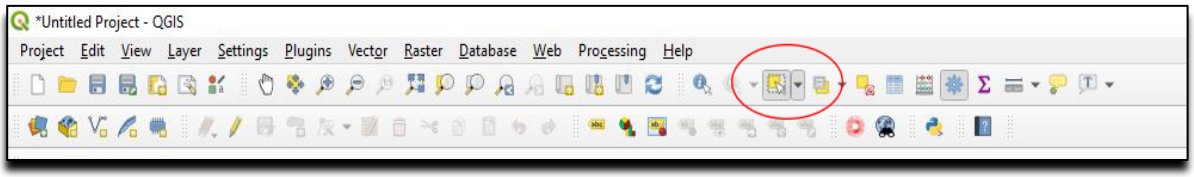
4. Next, Click the Browse button  and select the file "Major Basins of the World" in .shp file format
5. Click "Open"
6. Click "Add" and close the window

These steps are shown in the picture below:

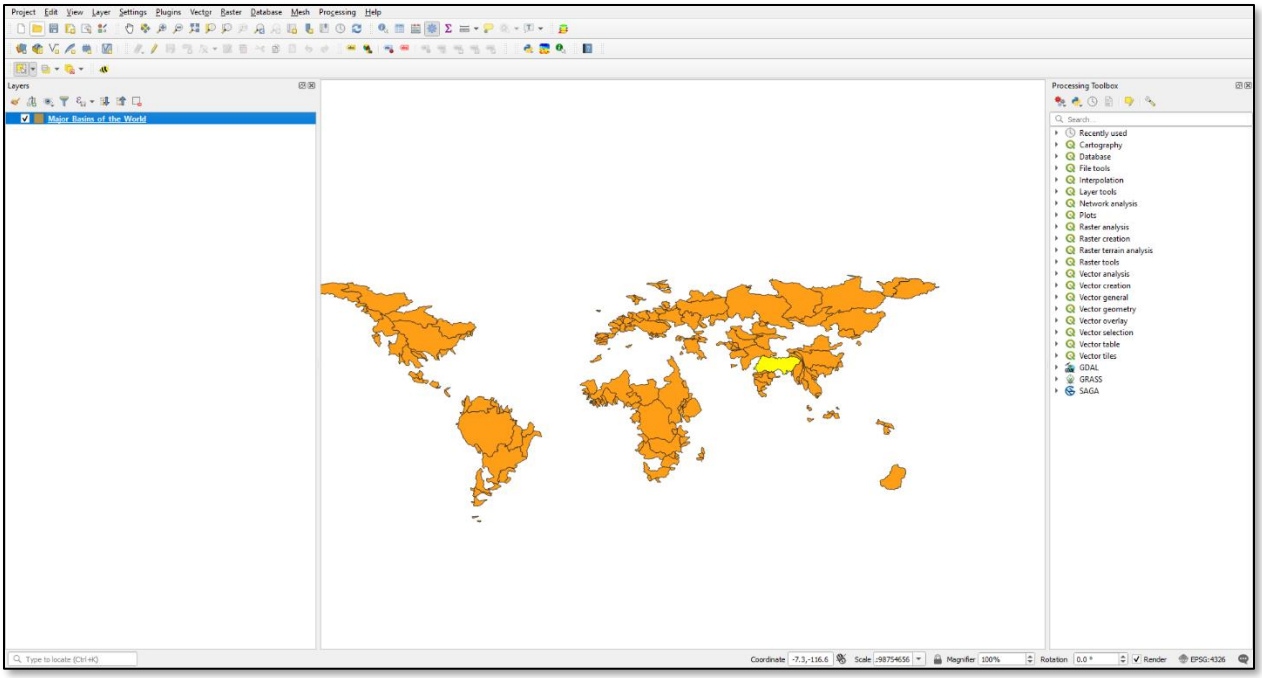


2.2 Extracting shape file for chosen area (Ganga Bhramaputra River Basin)

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

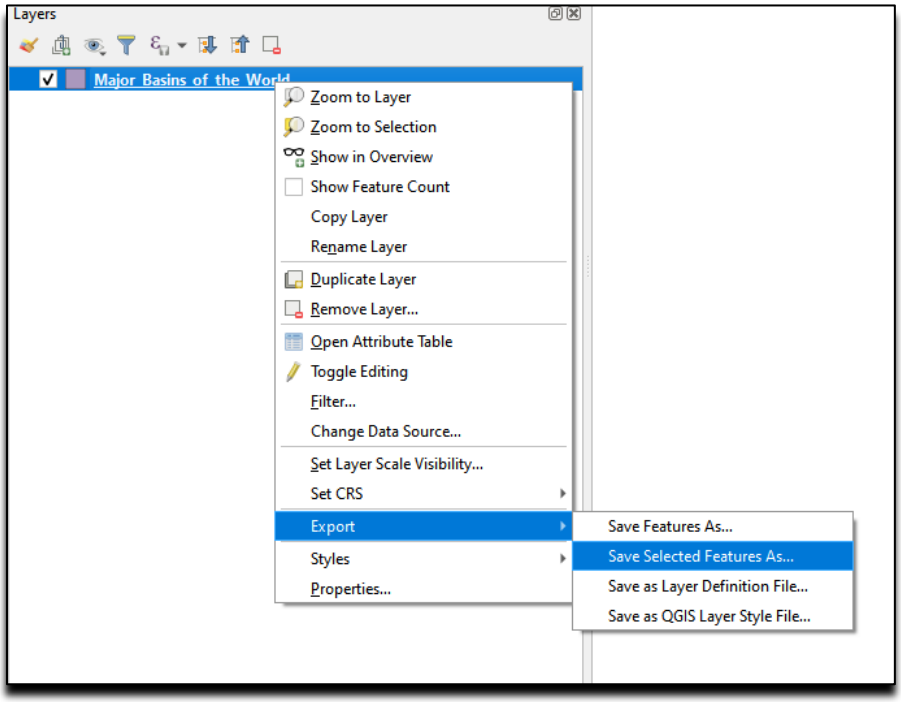


2. In the map that appears on the Map Panel of the QGIS Interface, click on your chosen region to highlight it. In this exercise, we selected the Ganga Bhramaputra River Basin in Shape File Form (.shp) and an image like the one below appears:

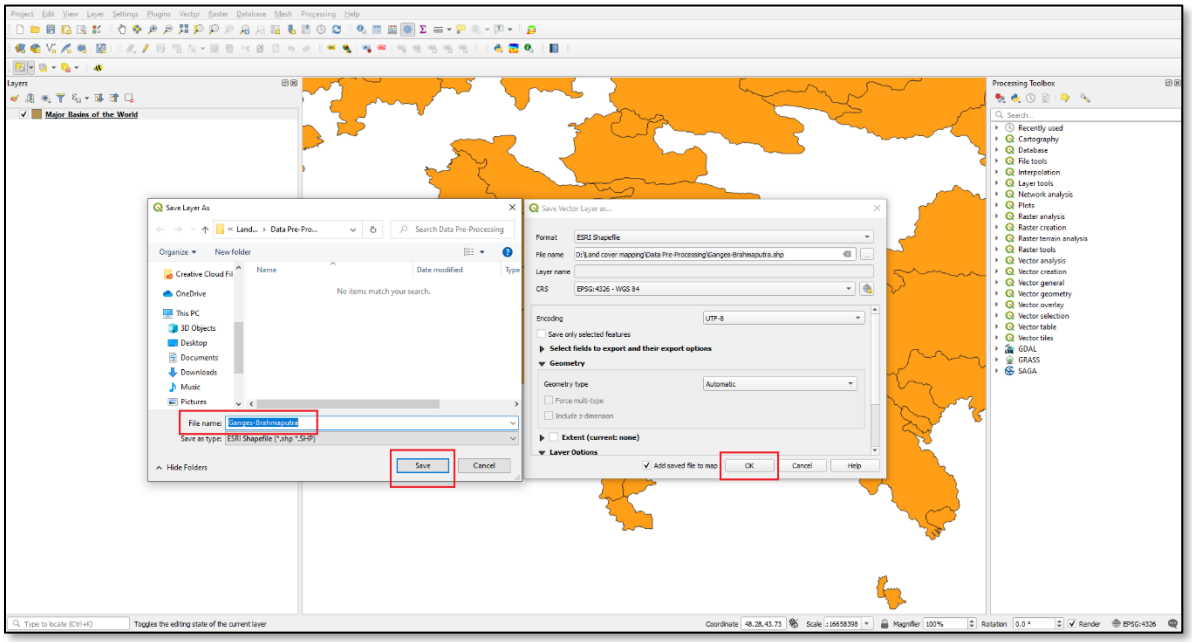


3. In the left bottom panel (called the layer panel) of the QGIS interface, right click on the file "Major River Basins in the World"
4. Select "Export"
5. Select "Save Selected Feature As"

These steps are highlighted in the picture below:



6. Next, select "Browse" and open the folder "Data Pre-Processing" (or the folder that you named)
7. Give a name to the file. For this exercise, we named 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"



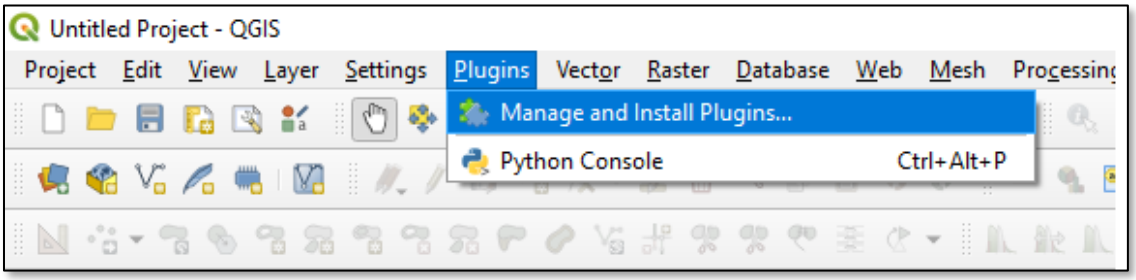
10. In the Layer Panel, right-click on "Major River Basins of the World"
11. Click "Remove Layer"

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

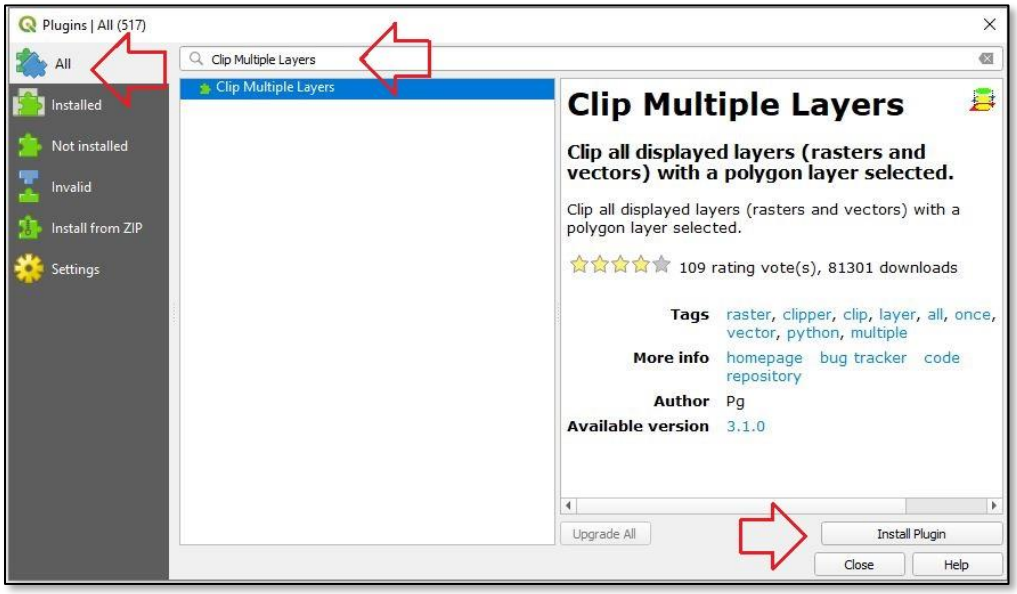
2.3 Clipping all displayed layers

The next steps clip the layers for use in producing the land cover maps and statistical tables. These steps include downloading the Clip Multiple Layers plug-in:

1. On the QGIS toolbar, click on "Plugins"
2. Click on "Manage and Install Plugins"



3. When the Plugins window appears, scroll down and click "All"
4. In the Search bar, type "Clip Multiple Layers" and select the option as shown in the picture below
5. Click "Install Plugin" and "Close"

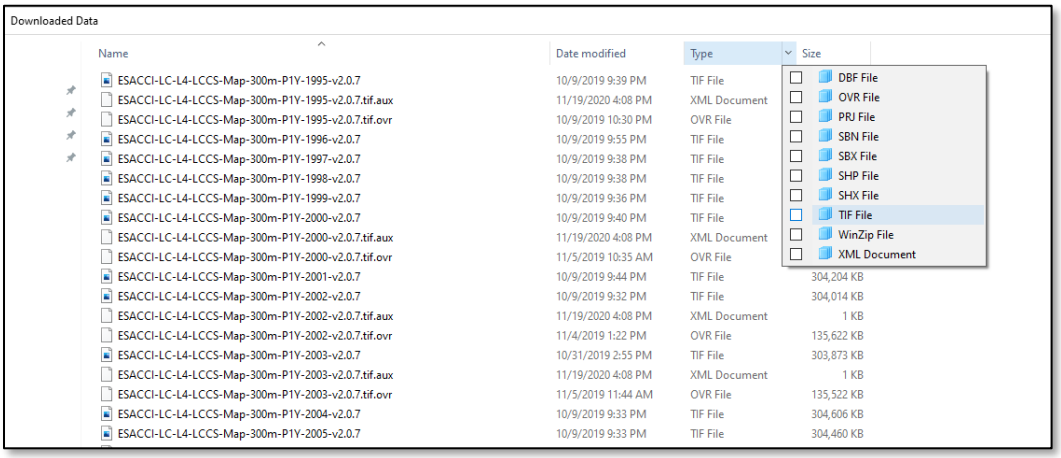


6. The Clip Multiple Layers plug-in is now activated, and should be visible on the main toolbar

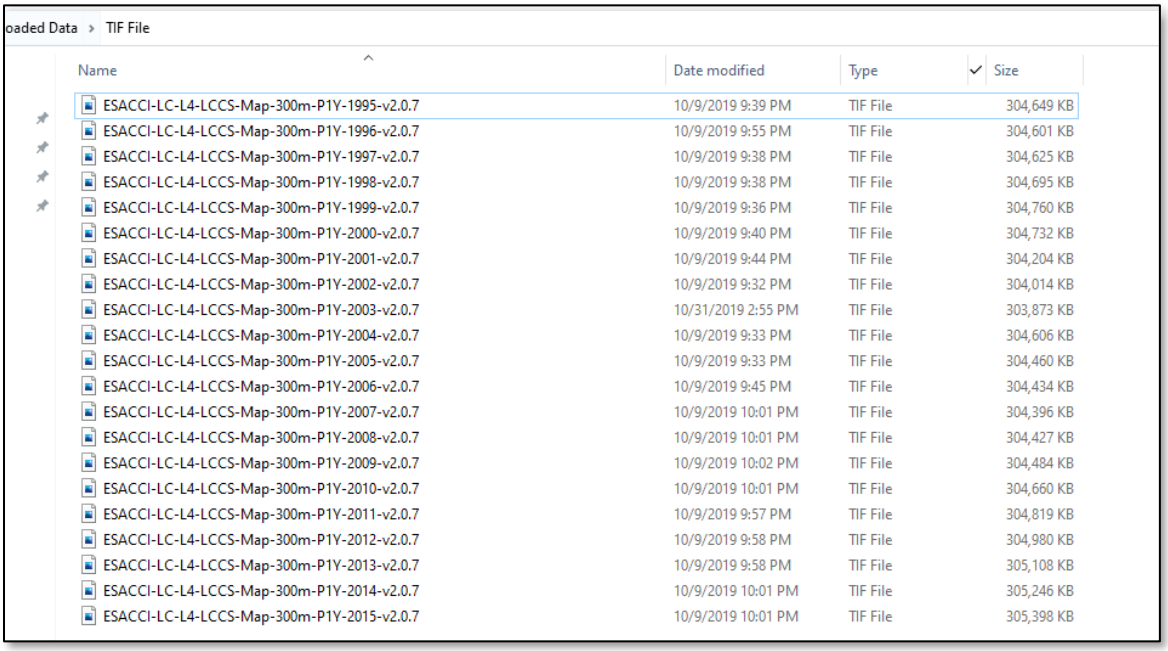
2.4 Adding ESA land cover data to QGIS

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

1. Go to the "Downloaded Data" folder (or the equivalent folder as named by the user)
2. Click "Type" and select "TIF File"

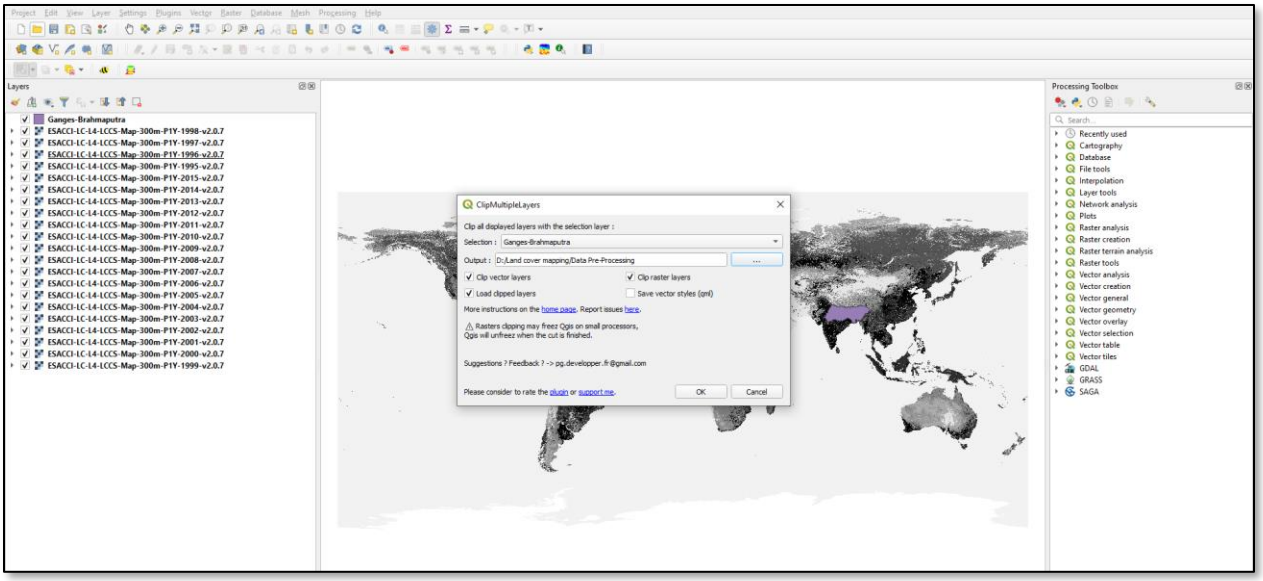


3. Select and highlight all the TIF Files as in the picture below, and drag and drop the TIF Files into QGIS

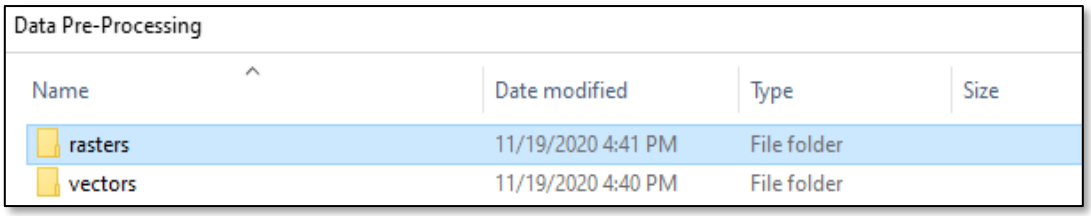


4. In QGIS, click "Clip Multiple Layers" as in the picture below:

5. In the window that appears, define "Selection" as Ganges-Brahmaputra.shp
6. Click on "Browse"  and save the output in the desired location. For this exercise, we save this file in "Data Pre-processing"
7. Click "OK"



Now we are going to clip all the layers from 1995 to 2015. Once you have clipped these layers, you should see the outputs appearing in the Data Pre-Processing Folder as individual folders named rasters and vectors as shown in the picture below:



2.5 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	

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.

1. Open "Excel" (for Windows)
2. Copy Text as follows:

V1	V2	V3
-0.1	0.1	0
0.2	11.1	2
11.9	12.1	3
19.9	40.1	4
49.9	90.1	6
99.9	110.1	4
119.9	122.1	8
129.9	130.1	5
139.9	140.1	9
149.9	153.1	10
159.9	170.1	7
179.9	180.1	9
189.9	190.1	1
199.9	202.1	11
209.9	210.1	13
219.9	220.1	12

With **V1** = lower limit of the range of ESA Land Cover Values
V2 = upper limit of the range of ESA Land Cover Values
V3 = SEEA Land Cover Classifications that the ESA Land Cover Values map onto

3. Save as "SEEA_Classes.csv" in a folder named "rasters" and click "Close"

This file will be used in RStudio to automatically reclass all the clipped raster images in RStudio.

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

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

Step 3 – Generating land cover change maps and statistical tables

This step shows how to automatically generate temporal land cover change maps and statistical tables in RStudio, using the data processed in QGIS.

This guide makes use of more advanced codes in RStudio than the earlier guide.

In this guide, the temporal land cover change maps are generated using RStudio and not QGIS as in the previous guide. QGIS is now only used to process the data, and the definitions and code are developed in RStudio to produce temporal maps and statistical tables.

Generating the maps in RStudio, in addition to the statistical tables, involves installing more packages and downloading more libraries.

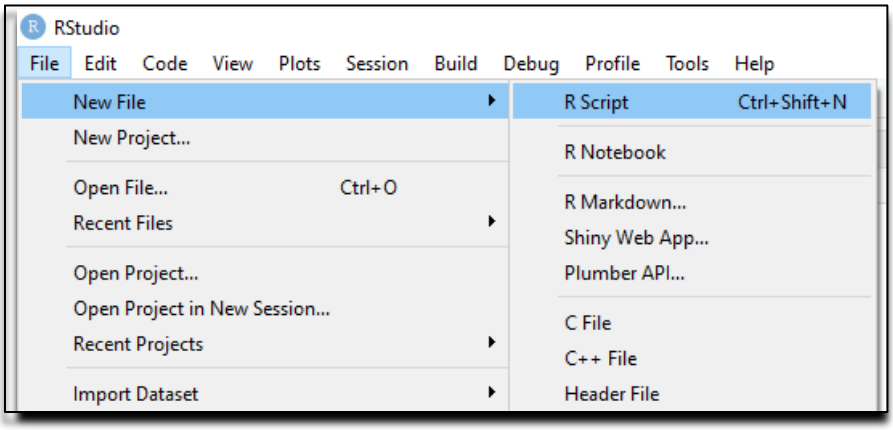
This guide will show how to install the required packages and libraries.

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

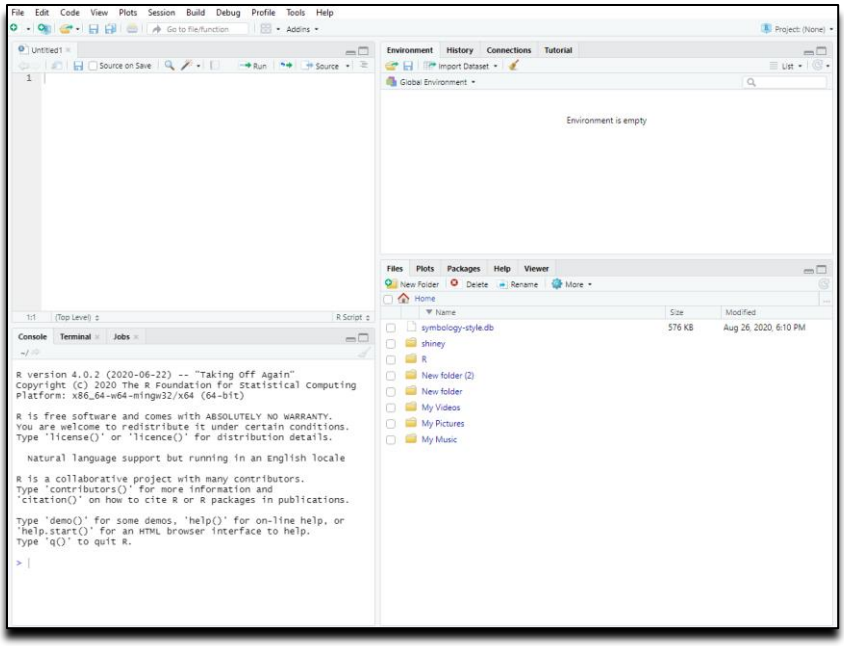
Description of the commands used in RStudio are prefaced by the hashtag symbol (#).

3.1 Setting up RStudio and installation of the prerequired libraries

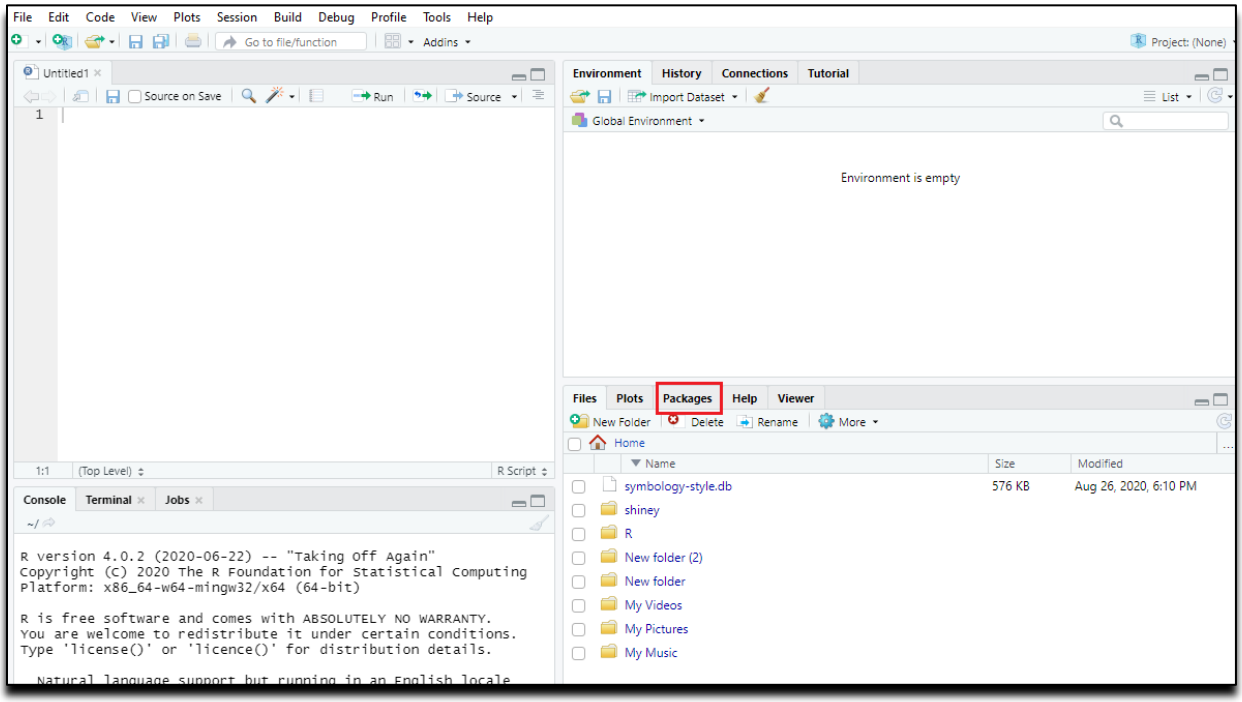
1. The steps in this section show how to set up RStudio and install the libraries required for the exercise. Open RStudio
2. Click on "New File" and select "R Script" as shown in the image below:



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



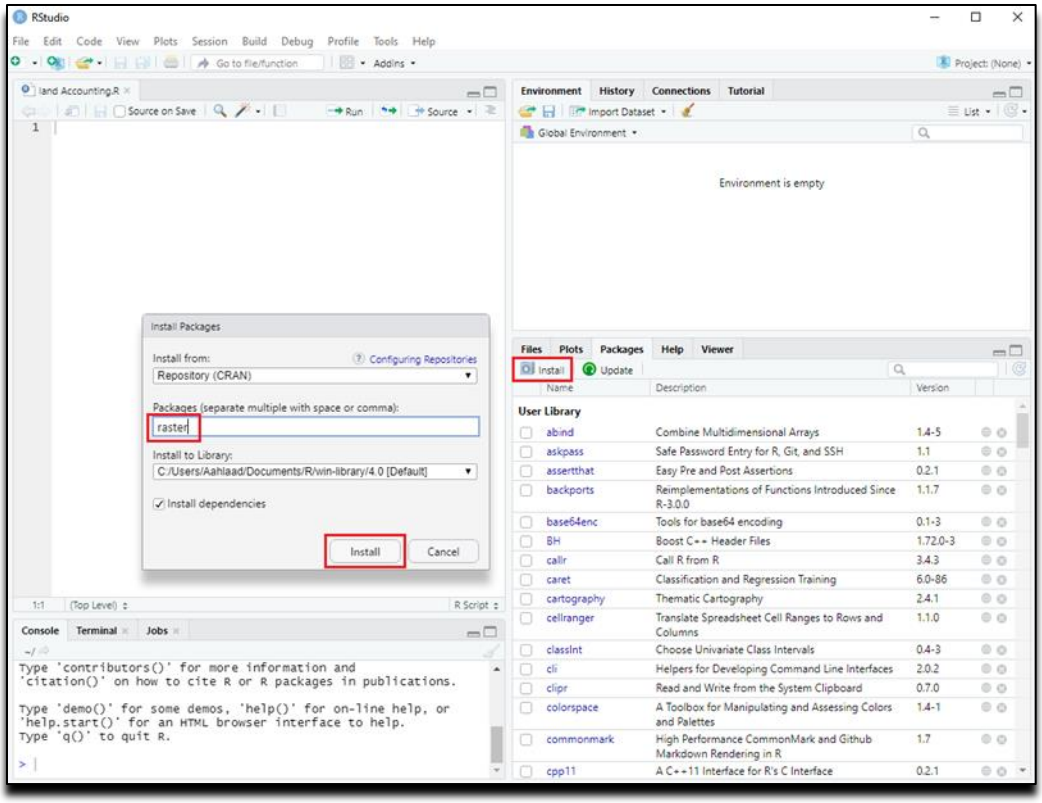
3. Click “File”
4. Click “Save As” and save with the name of your choosing.
   For this exercise, we save the File as “Reclassify folder”
5. Click on “Packages” as shown in the picture below:



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 window as shown in the picture above 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 several libraries in RStudio, by replacing 'raster' with the following terms:

- 'sp'
- 'RStoolbox'
- 'cartography'
- "MASS'
- 'tmap'
- 'tmaptools'
- 'rgdal'
- 'sf'
- ***vctrs***

For some older versions of RStudio, you may need to include vctrs as listed above

NB. The user can also install all packages at once by typing the following commands into RStudio and clicking run as in the picture below:

install.packages("raster")

install.packages("sp")

install.packages("sf")

install.packages("RStoolbox")

install.packages("cartography")

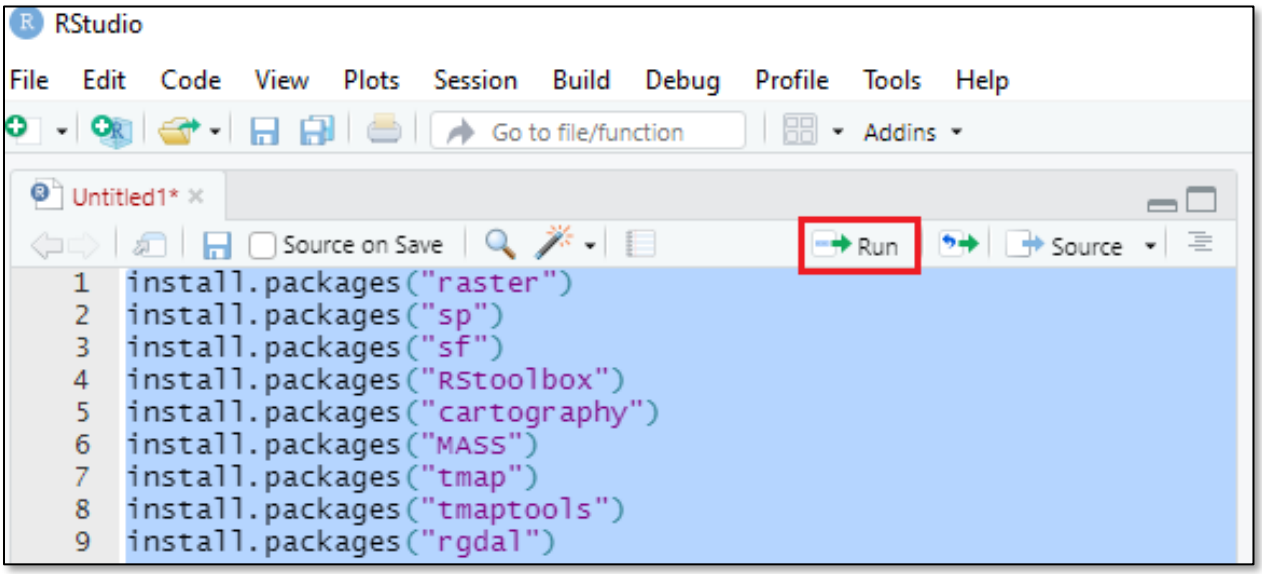
install.packages("MASS")

install.packages("tmap")

install.packages("tmaptools")

install.packages("rgdal")

For some older versions of RStudio, you may need to include install.packages ("vctrs")



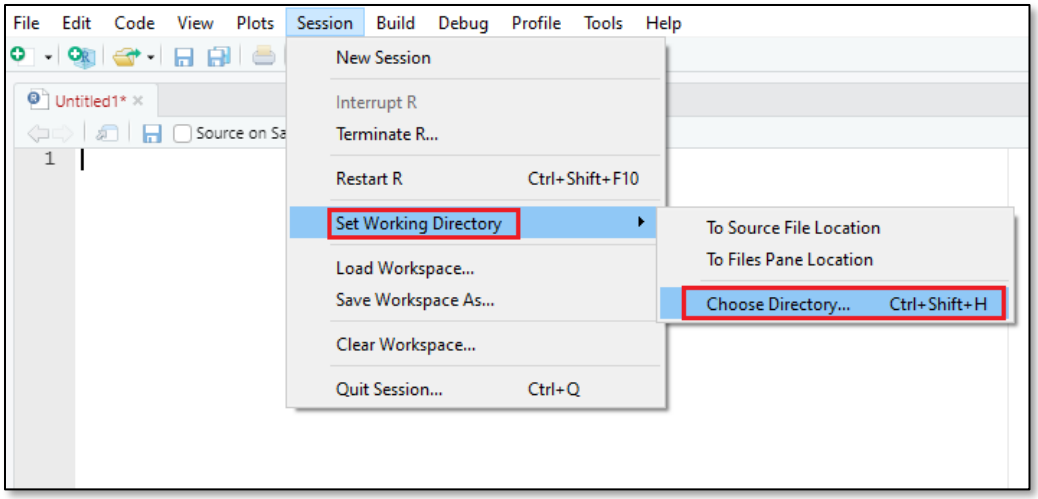
Please note that it is important to select all commands (highlight as in the picture above) and then click "Run" for the commands to run.

3.2 Defining directory and libraries

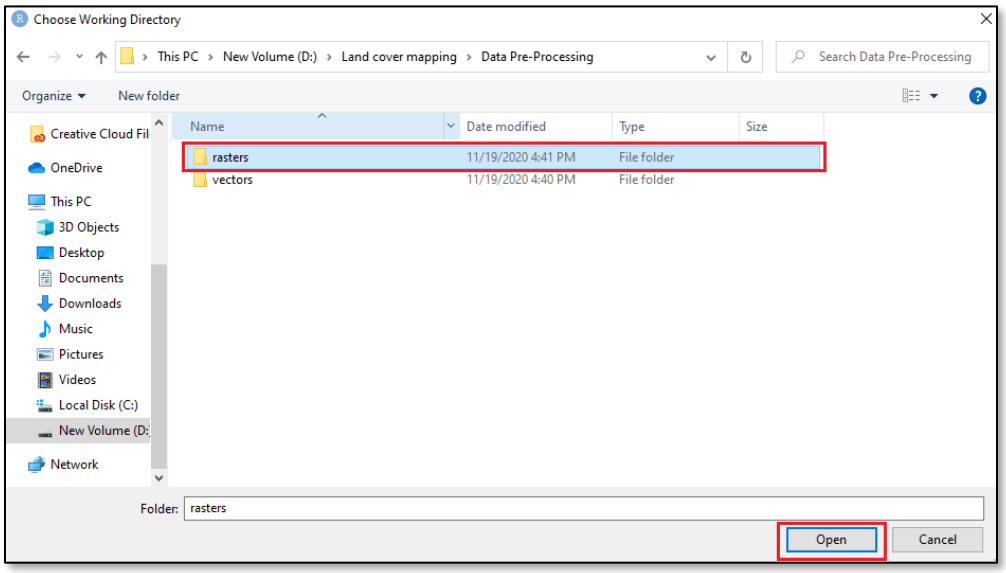
The steps in this section show the following:

- How to define the Working Directory in RStudio as the directory where the raster image files are saved
- How to define the libraries needed in RStudio

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



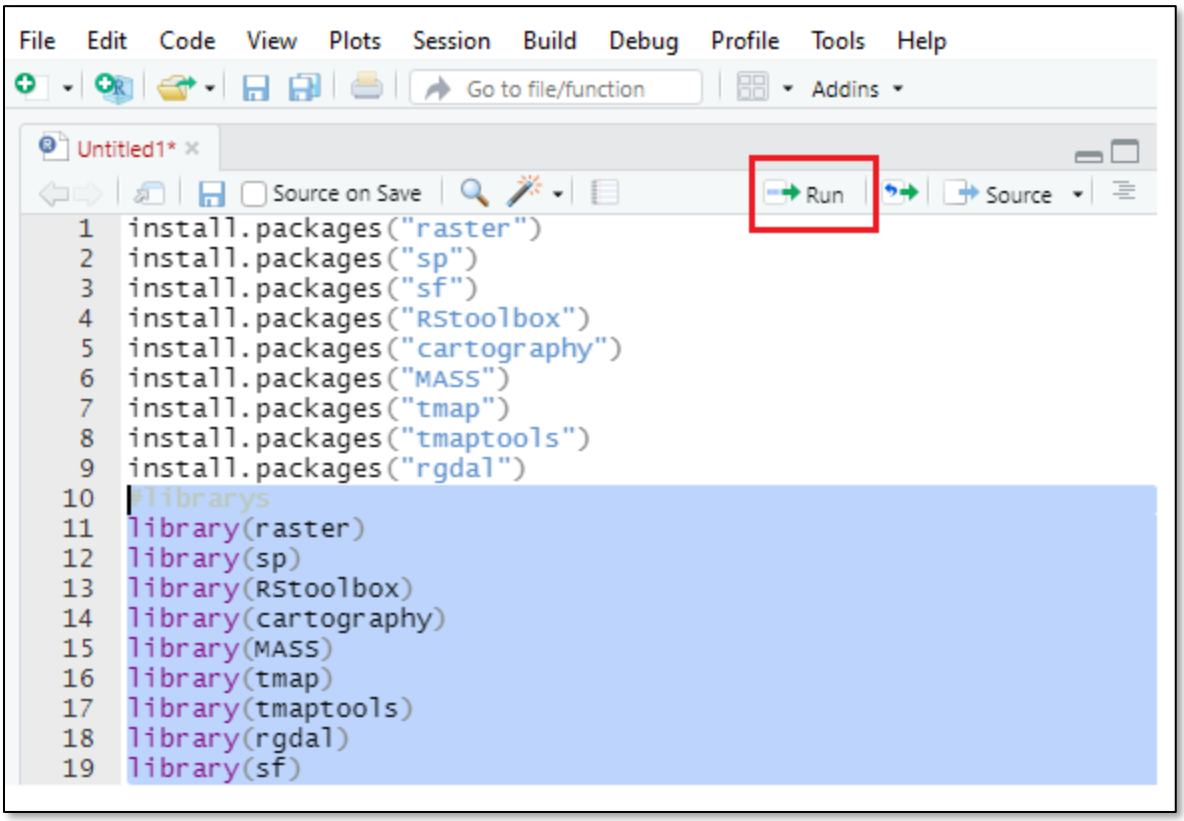
3. In the new window that appears, go to the Folder where the raster image files (*.tif) were saved. Select that Folder and Click "Open".



4. Next, type the following libraries in the command panel in RStudio and click "Run" as shown in the picture below:

```
library(raster)
library(sp)
library(RStoolbox)
library(cartography)
library(MASS)
library(tmap)
library(tmaptools)
library(rgdal)
library(sf)
```

These commands are used for reasons such as loading raster images, producing maps with all map elements, tools and styles built into RStudio.



3.3 Defining inputs

The commands in this next section define the inputs needed to run code in RStudio to automatically generate the temporal land change matrices.

Type the following commands in RStudio, highlight them, and click "Run":

```
Classes<-read.csv("SEEA_Classes.csv")
```
#This command defines the SEEA Reclassification done in QGIS for use in RStudio#

```
landcover1995<-raster("clip_ESACCI-LC-L4-LCCS-Map-300m-P1Y-1995-v2.0.7.tif")
```
#This command defines the landcover1995 file into a raster file for use in RStudio

```
r.list <- list.files(getwd(), "tif$")
```
#This command loads all the image files and defines it as "r.list"#

```
LandCoverClasses<-
c("Artificialsurface","Herbaceouscrops","Woodyarea","Multipleorlayeredcrop",
"Grassland","Treecoveredareas","Mangrove",
                "Shrubcoverareas","Shrubsandorherbaceousareas",
"Sparselynaturalvegetatedareas","Terrestrialbarrenland",
```

"PermanentsnowandGlacier","Inlandwaterbodies")

#This command defines the names of the SEEA Land Cover Classes#

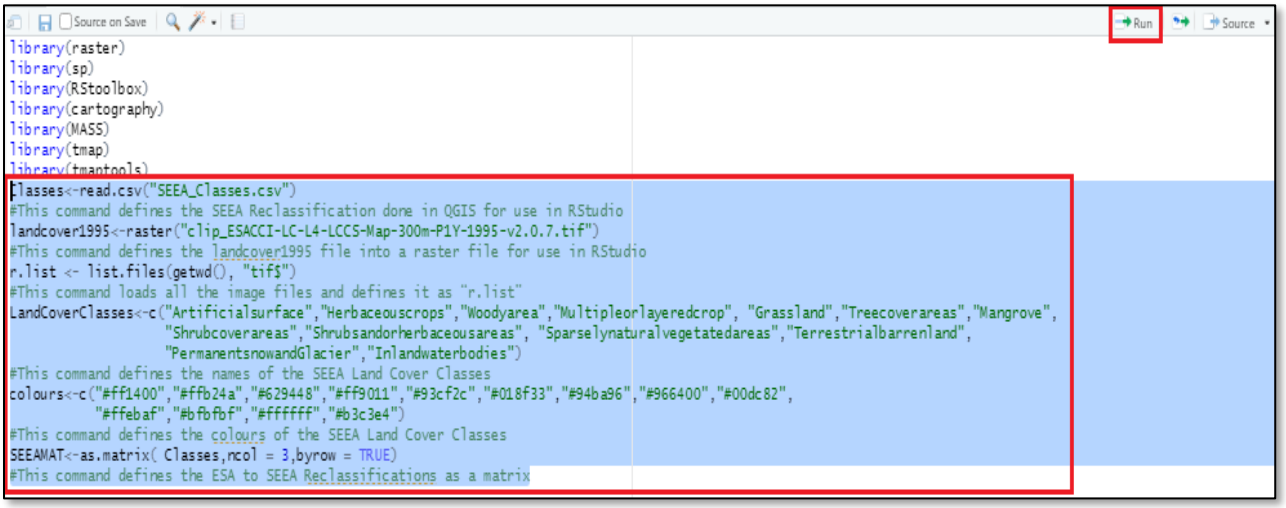
colours<-
c("#ff1400","#ffb24a","#629448","#ff9011","#93cf2c","#018f33","#94ba96","#966400","#00dc82",

"#ffebaf","#bfbfbf","#ffffff","#b3c3e4")

#This command defines the colours of the SEEA Land Cover Classes#

SEEAMAT<-as.matrix(Classes,ncol = 3,byrow = TRUE)
#This command defines the ESA to SEEA Reclassifications as a matrix#

These steps are shown in the picture below:



3.4 Generating land cover change maps and statistical tables

The commands in this next section are typed in RStudio and these commands generate the land cover change maps and statistical tables automatically.

Admittedly, this code is lengthy, but this code encapsulates all the libraries, directories and definitions defined in the previous steps. Typing all this code into RStudio and clicking "Run" will produce the function which will then be used to generate land cover change maps and statistical tables automatically.

Type the following commands in RStudio, highlight them and click "Run":

LandMatrix<-function(SEEAClasses ,FirstYear,ListFiles, SEEAcolores,legendclasses)

#This command defines the land cover change matrices and tables as a function in RStudio#

```
{


  SEEAMAT<-as.matrix( SEEAClasses ,ncol = 3,byrow = TRUE)
  year1995Reclass<-reclassify(FirstYear,SEEAMAT)
  for( i in ListFiles){
    r <- raster(i)
    landcoverreclass<-reclassify(r,SEEAMAT)
    v<-
data.frame(year1995Reclass=values(year1995Reclass),landcoverreclass=values(landco
verreclass))
    n<-table(v)
    m<-(round(addmargins(n)*300*300*1/1000000,digits = 1))
    row.names(m)[row.names(m)=="1"]<-"Artificialsurface"
    row.names(m)[row.names(m)=="2"]<-"Herbaceouscrops"
    row.names(m)[row.names(m)=="3"]<-"Woodyarea"
    row.names(m)[row.names(m)=="4"]<-"Multipleorlayeredcrop"
    row.names(m)[row.names(m)=="5"]<-"Grassland"
    row.names(m)[row.names(m)=="6"]<-"Treecoveredareas"
    row.names(m)[row.names(m)=="7"]<-"Mangrove"
    row.names(m)[row.names(m)=="8"]<-"Shrubcoverareas"
    row.names(m)[row.names(m)=="9"]<-"Shrubsandorherbaceousareas"
    row.names(m)[row.names(m)=="10"]<-"Sparselynaturalvegetatedareas"
    row.names(m)[row.names(m)=="11"]<-"Terrestrialbarrenland"
    row.names(m)[row.names(m)=="12"]<-"Permanentsnowandglacier"
    row.names(m)[row.names(m)=="13"]<-"Inlandwaterbodies"
    row.names(m)[row.names(m)=="14"]<-"Ocean"
    colnames(m)[colnames(m)=="1"]<-"Artificialsurface"
    colnames(m)[colnames(m)=="2"]<-"Herbaceouscrops"
    colnames(m)[colnames(m)=="3"]<-"Woodyarea"
    colnames(m)[colnames(m)=="4"]<-" Multipleorlayeredcrop"
```

```
    colnames(m)[colnames(m)=="5"]<-"Grassland"
    colnames(m)[colnames(m)=="6"]<-"Treecoveredareas"
    colnames(m)[colnames(m)=="7"]<-"Mangrove"
    colnames(m)[colnames(m)=="8"]<-"Shrubcoverareas"
    colnames(m)[colnames(m)=="9"]<-"Shrubsandorherbaceousareas"
    colnames(m)[colnames(m)=="10"]<-"Sparselynaturalvegetatedareas"
    colnames(m)[colnames(m)=="11"]<-"Terrestrialbarrenland"
    colnames(m)[colnames(m)=="12"]<-"Permanentsnowandglacier"
    colnames(m)[colnames(m)=="13"]<-"Inlandwaterbodies"
    colnames(m)[colnames(m)=="14"]<-"Ocean"
    c<-c("Land Cover Change")
    d<-c(substr(i,start = 37,stop = 40))
    n<-paste(c,d,sep = "")

write.table(n,file="matrix.csv",append=TRUE,sep=",",col.names=NA,row.names=TRUE,
quote=FALSE)

write.table(m,file="matrix.csv",append=TRUE,sep=",",col.names=NA,row.names=TRUE,
quote=FALSE)
    a<-c("percentage")
    b<-c(substr(i,start = 37,stop = 40))
    d<-paste(b,a,sep ="")
    Year1995<-cbind(rowSums(round(table(v)*300*300*1/1000000,digits = 1)))


    OtherYears<-cbind(colSums(round(table(v)*300*300*1/1000000,digits = 1)))
    Year1995percentage<-cbind(round((Year1995/sum(Year1995)*100),digits = 1))
    OtherYearspercentage<-cbind(round((OtherYears/sum(OtherYears)*100),digits = 1))
    Difference<-cbind(c(OtherYears)-c(Year1995))
    percentageDifference<-(Difference/Year1995)*100
```

```
    FinalTable_A<-
cbind(c(Year1995),c(OtherYears),c(Difference),c(Year1995percentage),c(OtherYearsper
centage),c(percentageDifference))


    FinalTable_B<-as.matrix(FinalTable_A)


    FinalTable<-as.data.frame(FinalTable_B)


    row.names(FinalTable)[row.names(FinalTable)=="1"]<-"Artificialsurface"
    row.names(FinalTable)[row.names(FinalTable)=="2"]<-"Herbaceouscrops"
    row.names(FinalTable)[row.names(FinalTable)=="3"]<-"Woodyarea"
    row.names(FinalTable)[row.names(FinalTable)=="4"]<-"Multipleorlayeredcrop"
    row.names(FinalTable)[row.names(FinalTable)=="5"]<-"Grassland"
    row.names(FinalTable)[row.names(FinalTable)=="6"]<-"Treecoveredareas"
    row.names(FinalTable)[row.names(FinalTable)=="7"]<-"Mangrove"
    row.names(FinalTable)[row.names(FinalTable)=="8"]<-"Shrubcoverareas"
    row.names(FinalTable)[row.names(FinalTable)=="9"]<-
"Shrubsandorherbaceousareas"
    row.names(FinalTable)[row.names(FinalTable)=="10"]<-
"Sparselynaturalvegetatedareas"
    row.names(FinalTable)[row.names(FinalTable)=="11"]<-"Terrestrialbarrenland"
    row.names(FinalTable)[row.names(FinalTable)=="12"]<-"Permanentsnowandglacier"
    row.names(FinalTable)[row.names(FinalTable)=="13"]<-"Inlandwaterbodies"
    row.names(FinalTable)[row.names(FinalTable)=="14"]<-"Ocean"




    colnames(FinalTable)<-c("1992",substr(i,start = 37,stop =
40),"Difference","1992Percentage",d,"percentageDifference")
```

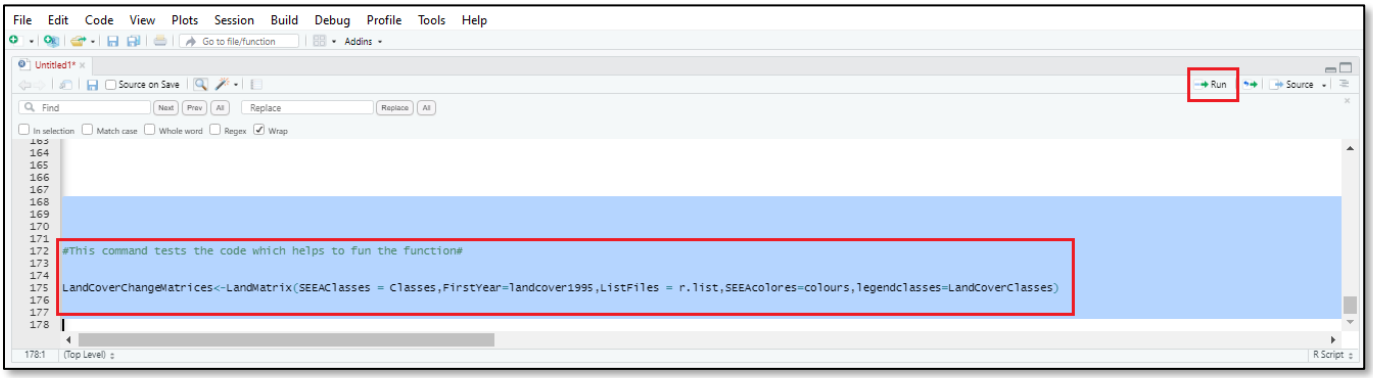
```
write.table(FinalTable,file="Change.csv",append=TRUE,sep=",",col.names=NA,row.names=TRUE,quote = FALSE)



   file_name = paste("landCover", i, ".png", sep="")



   map1=tm_shape(landcoverreclass)+
    tm_raster(style = "cat",
              labels = c("ArtificialSurface","HerbaceousCrops","WoodyCrops","MultiplelayredCrops","Grassland","TreecoveredAreas","Mangroves","Shrubcovered areas","Shrubsandorherbaceousareas","SparselyNaturalVegetated areas","TerrestrialBarrenLand","PermanentSnowAndGlaciers","InlandwaterBodies"),
palette =c("#ff1400" , "#ffb24a" , "#629448" ,"#ff9011" ,"#93cf2c" , "#018f33" ,"#94ba96" ,"#966400" ,"#00dc82" , "#ffebaf" ,"#bfbfbf" ,"#ffffff" ,"#b3c3e4"),
              title = "LandCover")+ tm_layout(main.title = "Land Cover Change",title.size = 1.5,title.position = c("right","top"))+


    tm_compass(position = c("left","bottom"))+
    tm_scale_bar(position = c("left","bottom"))+tm_layout(main.title = substr(i,start = 37,stop = 40),title.size = 1.5,title.position = c("right","top"))+tm_layout(legend.outside = TRUE)
   tmap_save(map1,file_name,height=8.5, width=11, units="in", dpi=300)
 }


}
```

#This entire command defines the function which is then used to generate output tables and land cover change maps automatically#

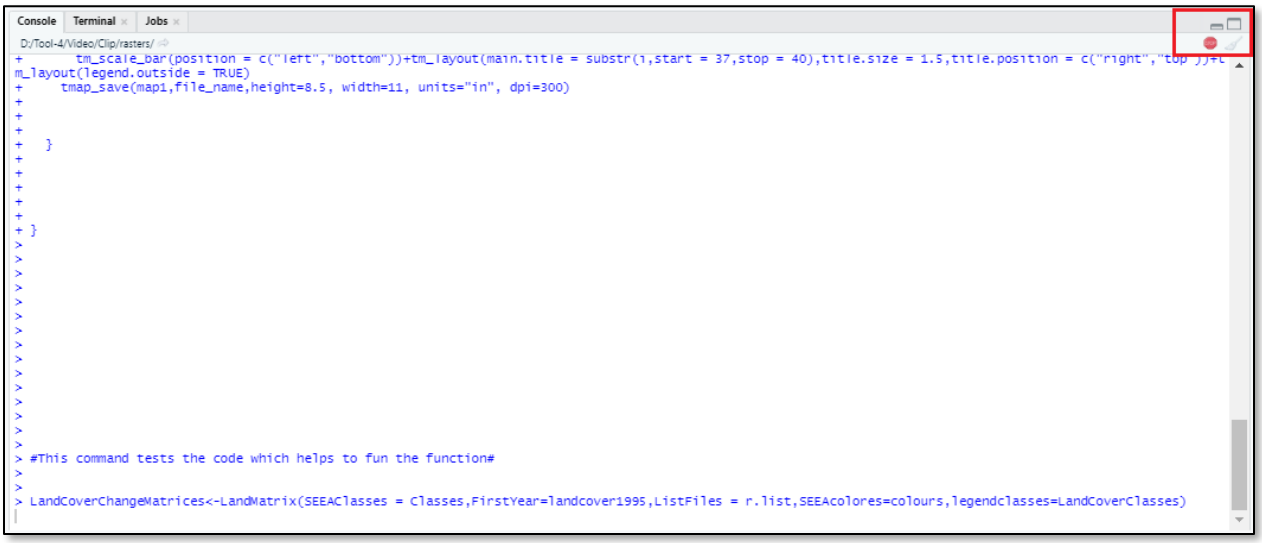
Finally, this command executes the functions in RStudio as seen in the picture below:

```
LandCoverChangeMatrices<-LandMatrix(SEEAClasses = Classes,FirstYear=landcover1995,ListFiles = r.list,SEEAcolores=colours,legendclasses=LandCoverClasses)
```

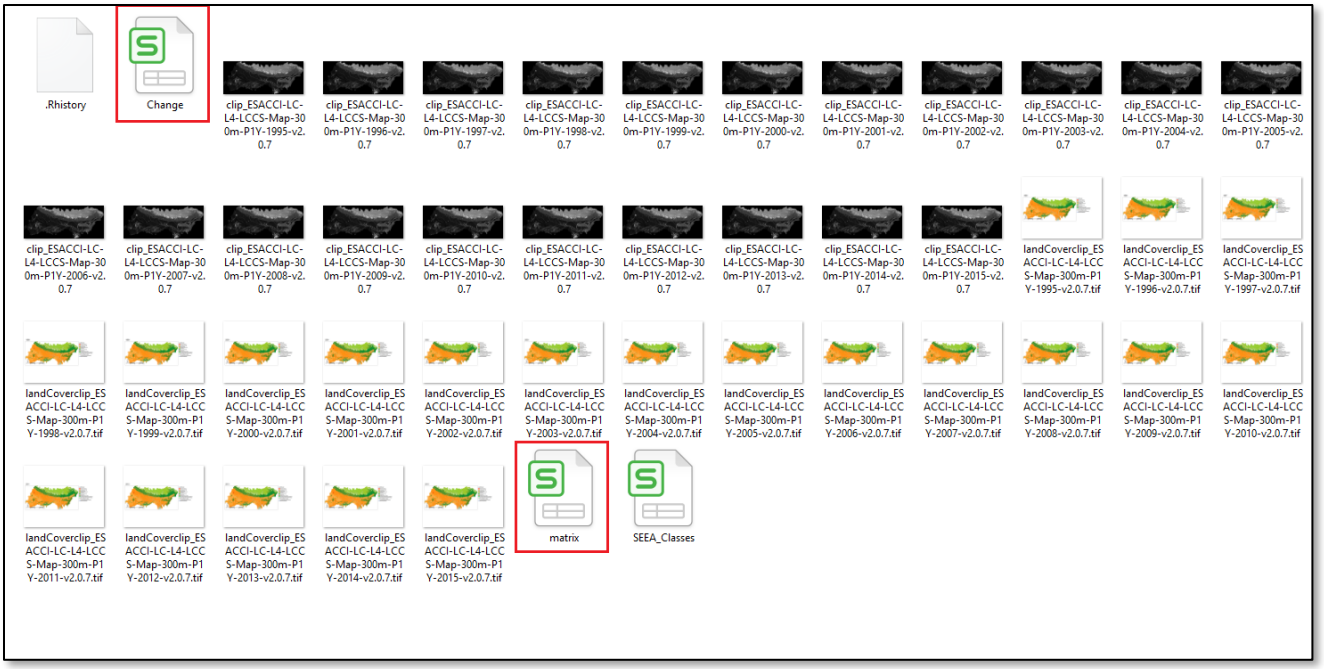
#This command executes the function using the code previously defined, and then generates the maps, matrices and tables#



The execution of this function takes about 60-90 minutes for completion, and there will be some warning messages. These warning messages serve as an indication that the execution is being performed, and the warning messages can be ignored in most cases. Please note that there is a red dot that appears in RStudio while the command is processing. When this red dot disappears, the processing is done and executed.

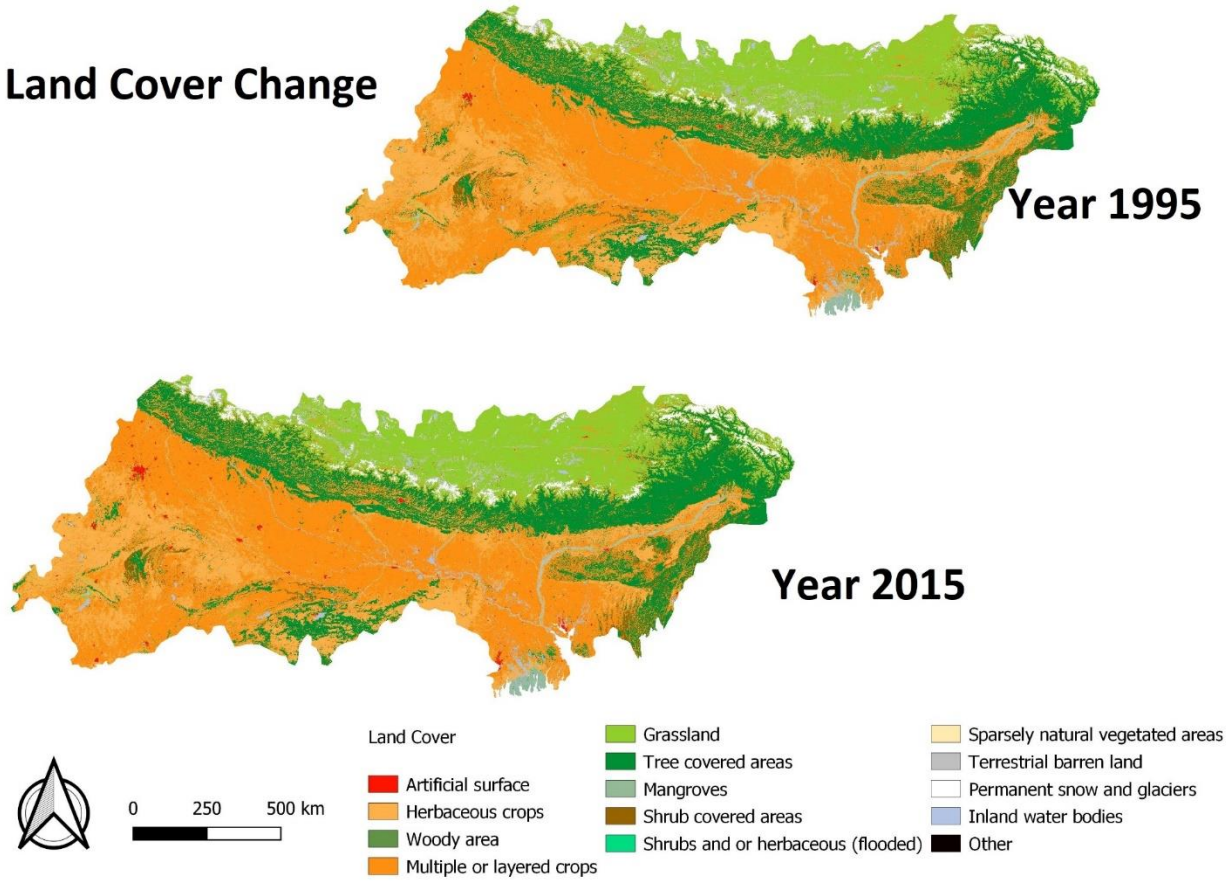


Once the execution is finished, we can see the maps and statistical tables in the Folder named "rasters" as shown in the picture below:



On the following pages, there are examples of maps, matrices and statistical tables generated using the code listed above in RStudio and formatted in Excel as required.

You have completed Step 3 of 3! Well done on producing your visualizations, maps and statistical tables! We wish you good luck as you continue the journey ahead.


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

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

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**

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

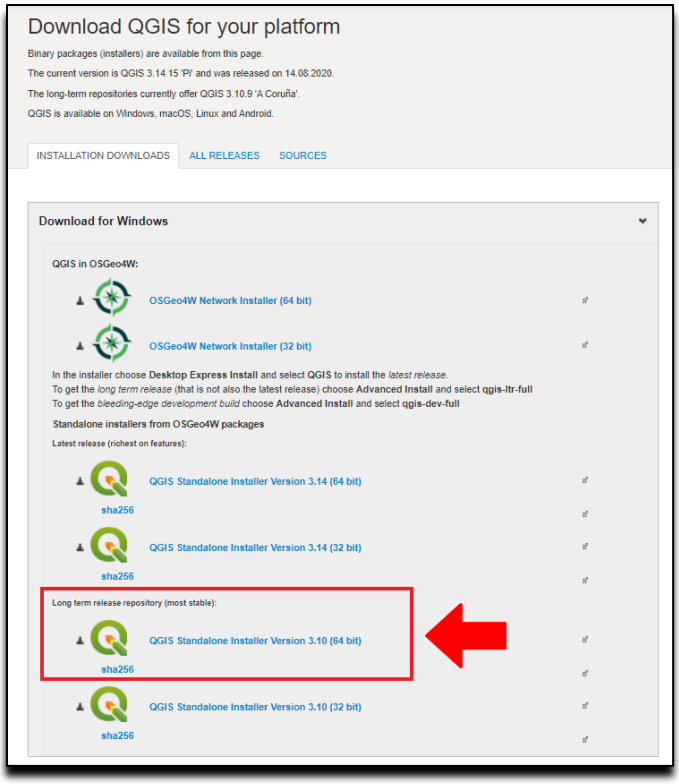
Downloading and Installing QGIS

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

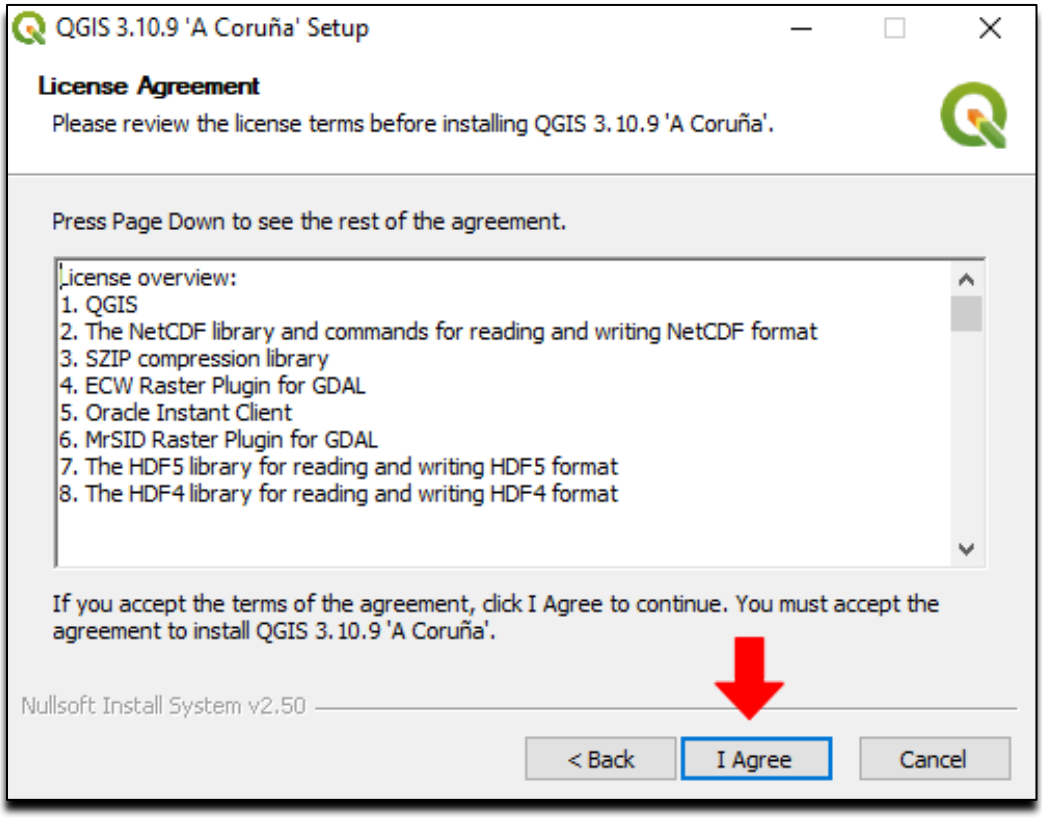
2. Download the QGIS Standalone Installer Version 3.10, and choose either the 32-bit or 64-bit based on the configuration of your individual system as suggested in the picture below:



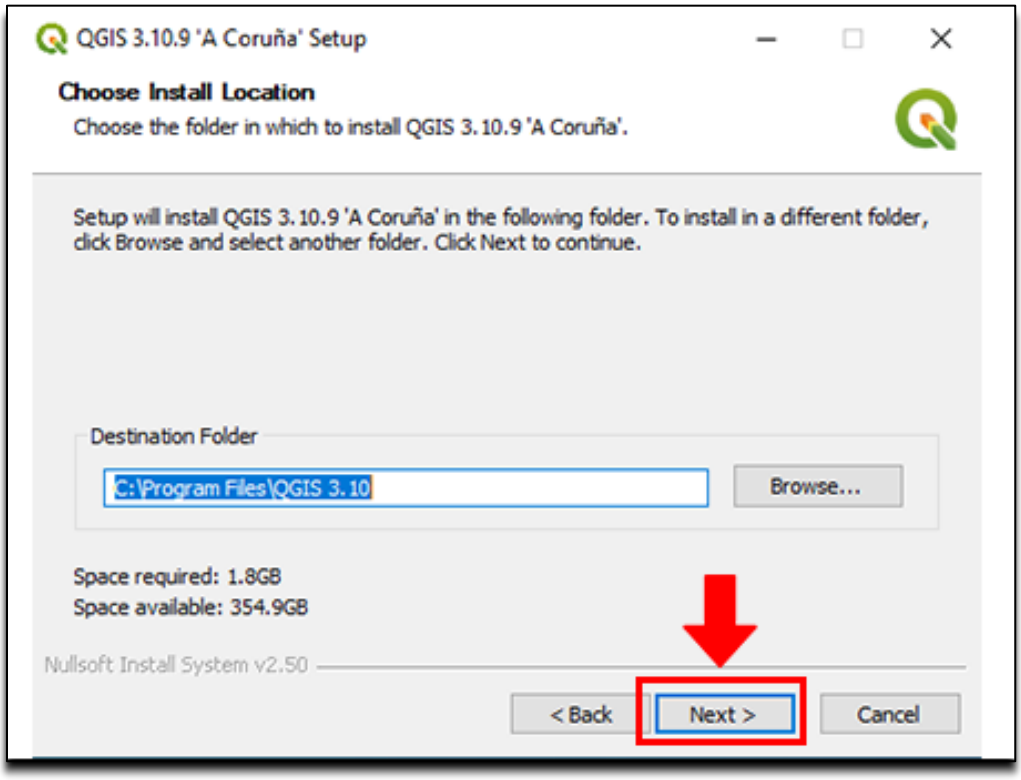
For the exercise in this guide, we used the 64-bit version, and downloaded and installed QGIS-OSGeo4W-3.10.9-1-Setup-x86_64 as shown in the picture below:

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

4. Click on I Agree for license:



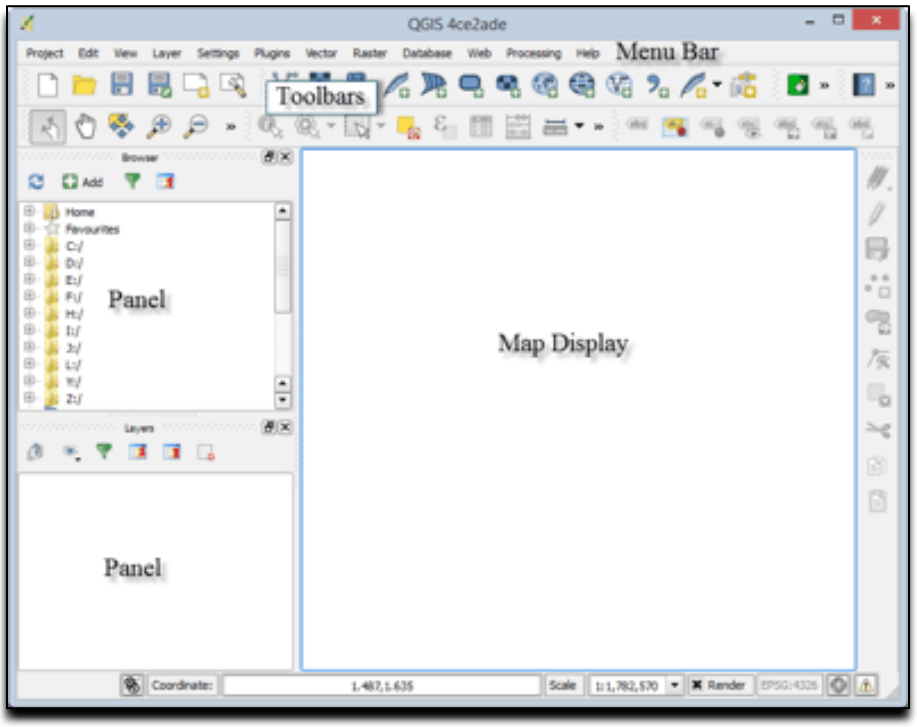
5. Click on Next in Choose Install Location:



6. Once the installation process is complete, click on Finish.
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:

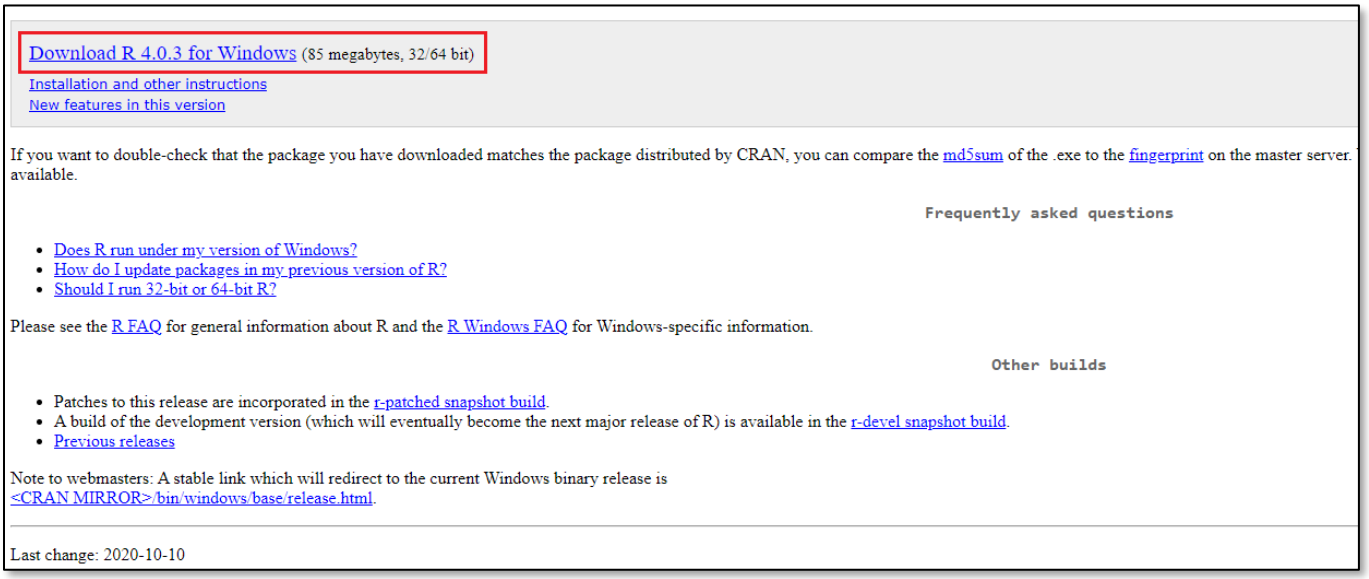
  by clicking View | Toolbars, or by right-clicking the menu bar or enable toolbar button, which will open a context menu allowing you to toggle toolbar and panel visibility.
- assign shortcut to actions by clicking Settings | Configure shortcuts.
- change application options, such as interface language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

B. R and RStudio

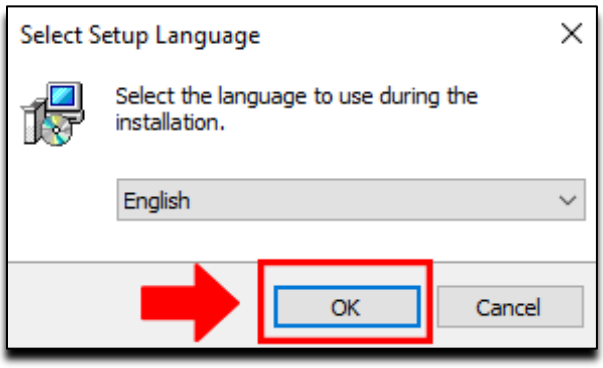
R is a programming language and free software environment for statistical computing and graphics; and RStudio is an integrated development environment for R.

Downloading and Installing R program

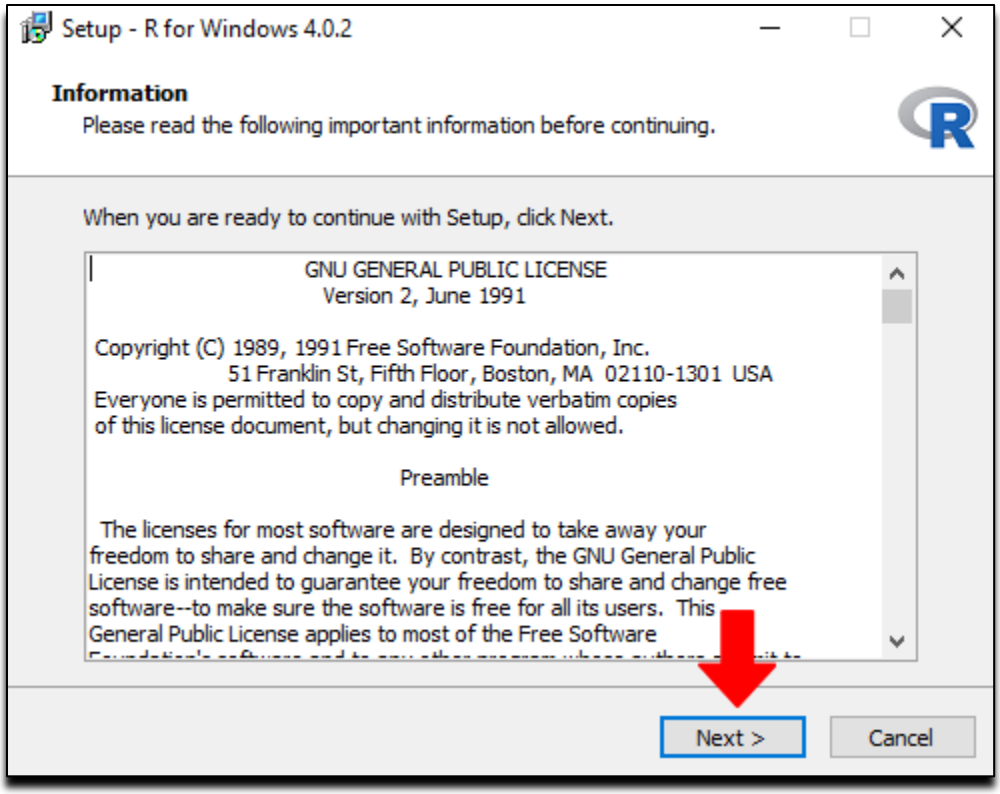
1. Go to this website (https://cran.r-project.org/bin/windows/base/), and download R as shown in the picture below:



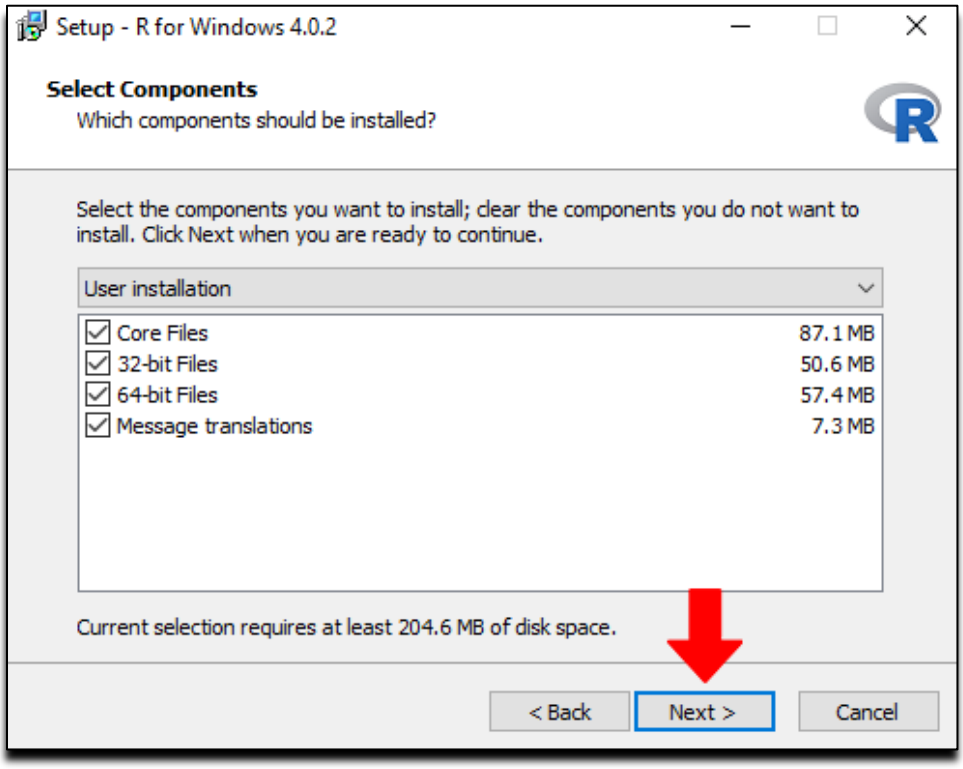
2. Define the Setup Language as English and click OK:



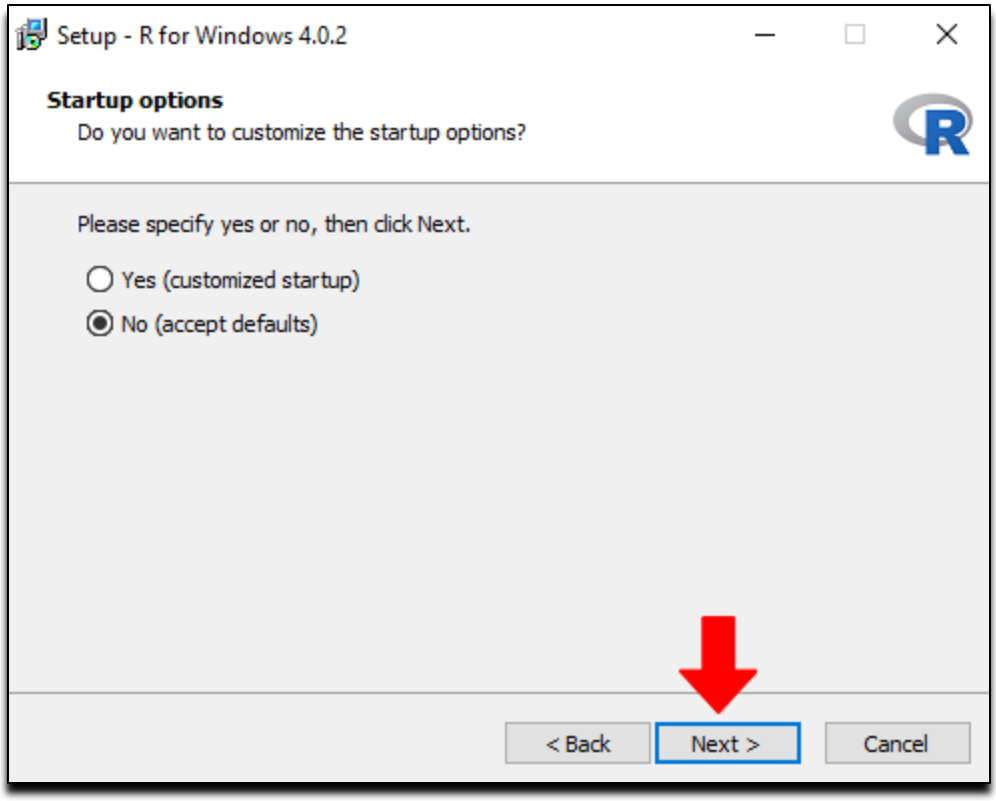
3. Click Next in the Setup Domain as shown below:



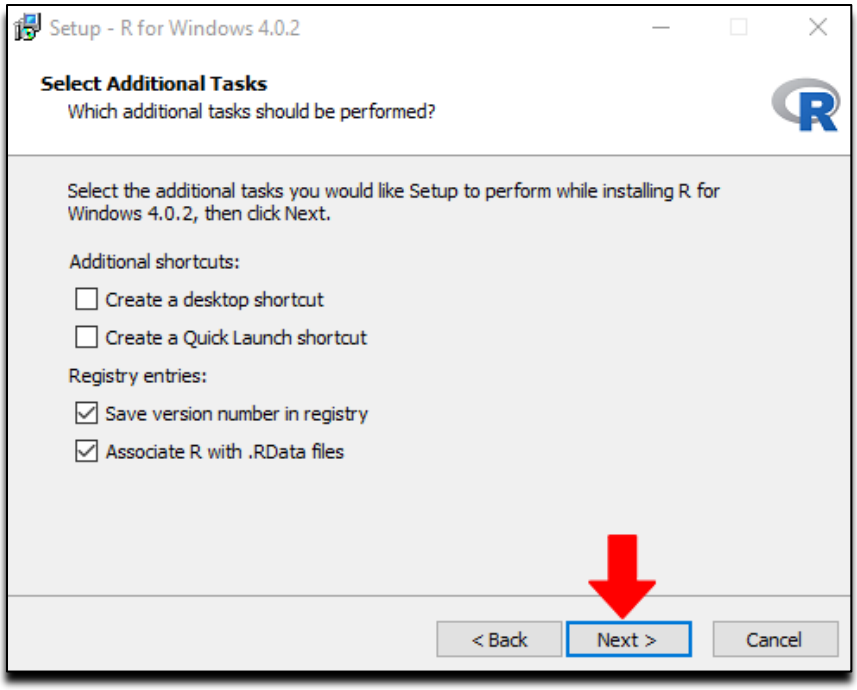
4. Select all Components and click Next:



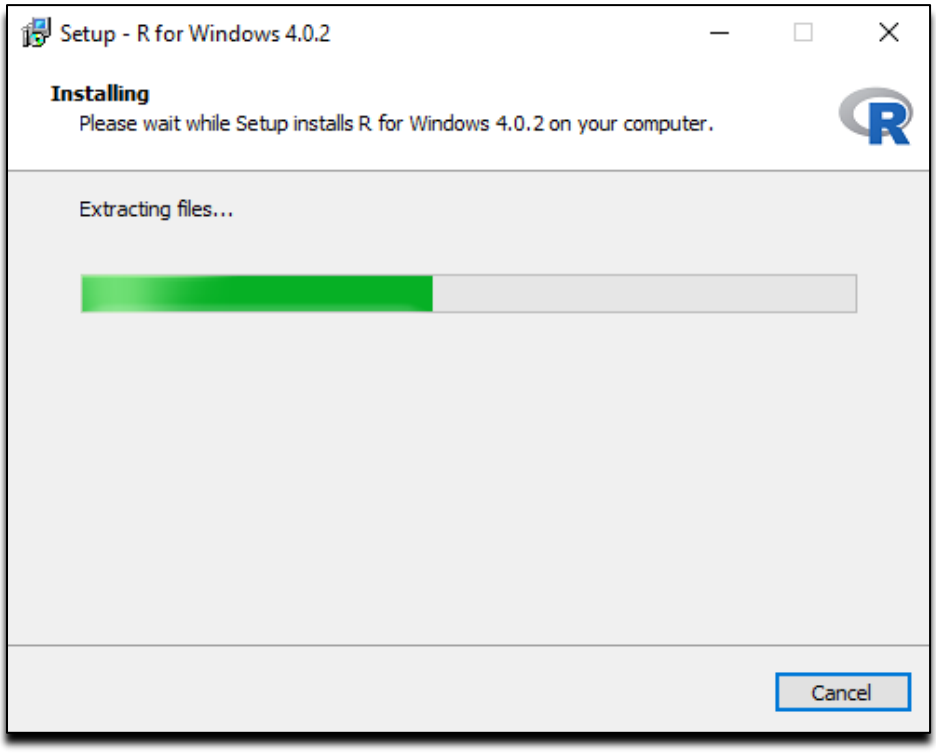
5. In Startup options, choose to accept defaults and click Next:



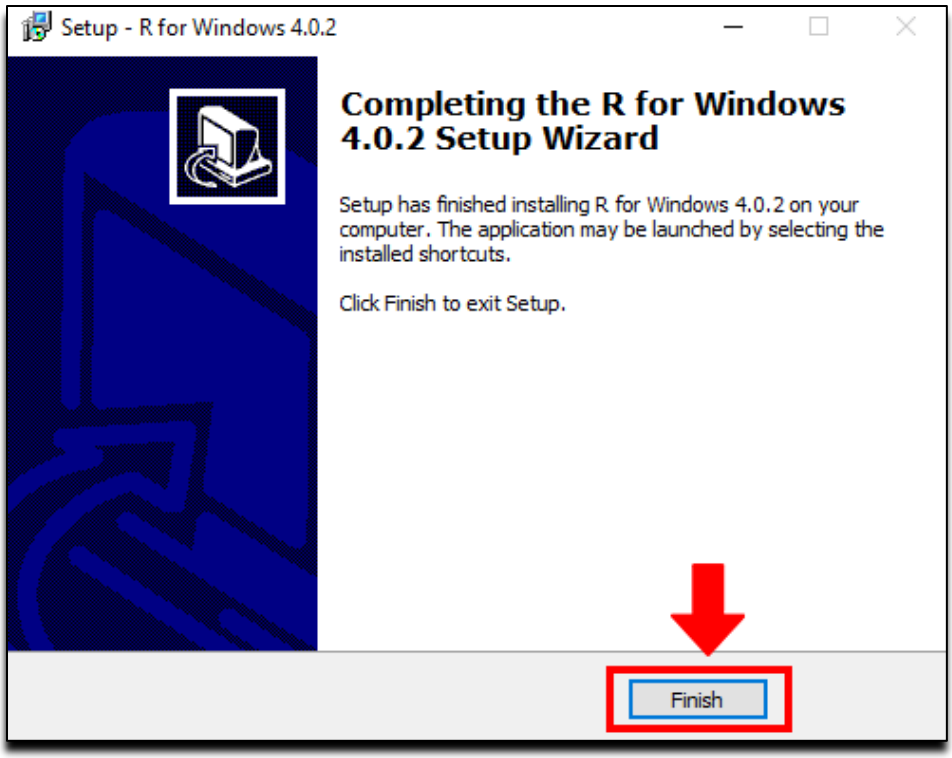
6. Select Additional Tasks; and click Next:



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:

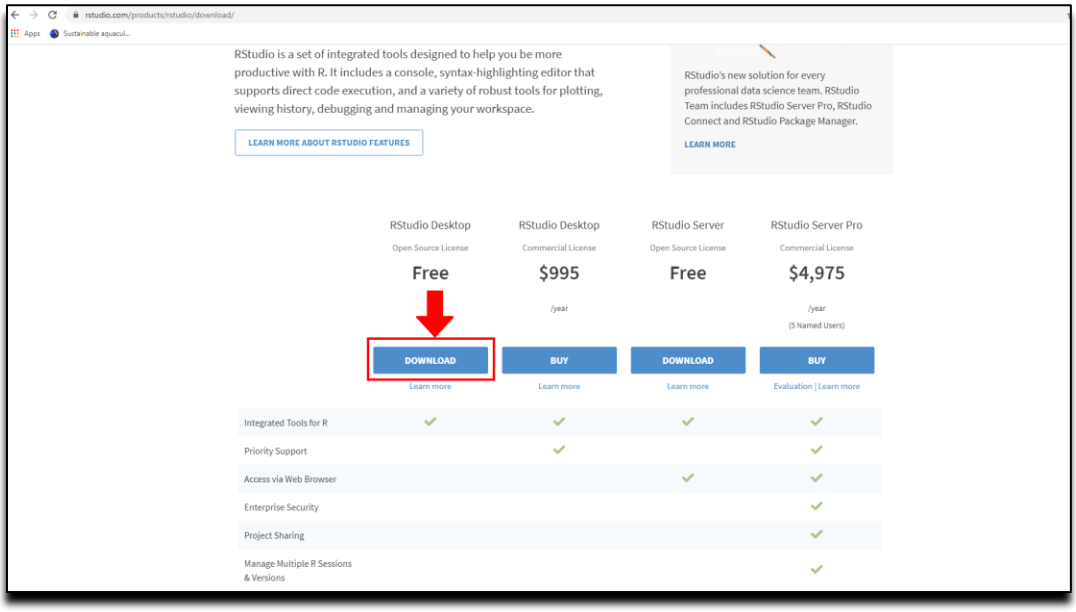


8. Once the installation process is complete, click on Finish:



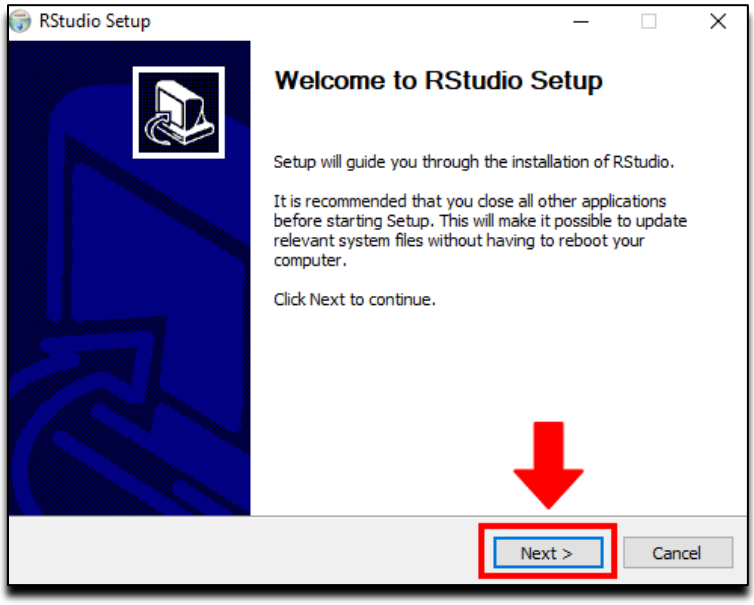
Downloading and installing RStudio (Free Version)

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:

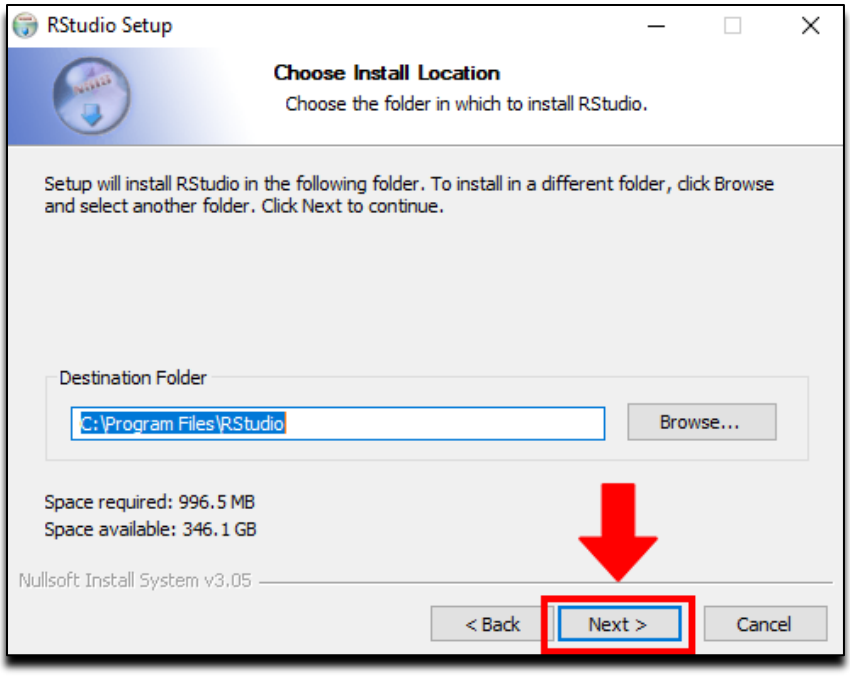


2. The version used in this guide is shown in the picture below:

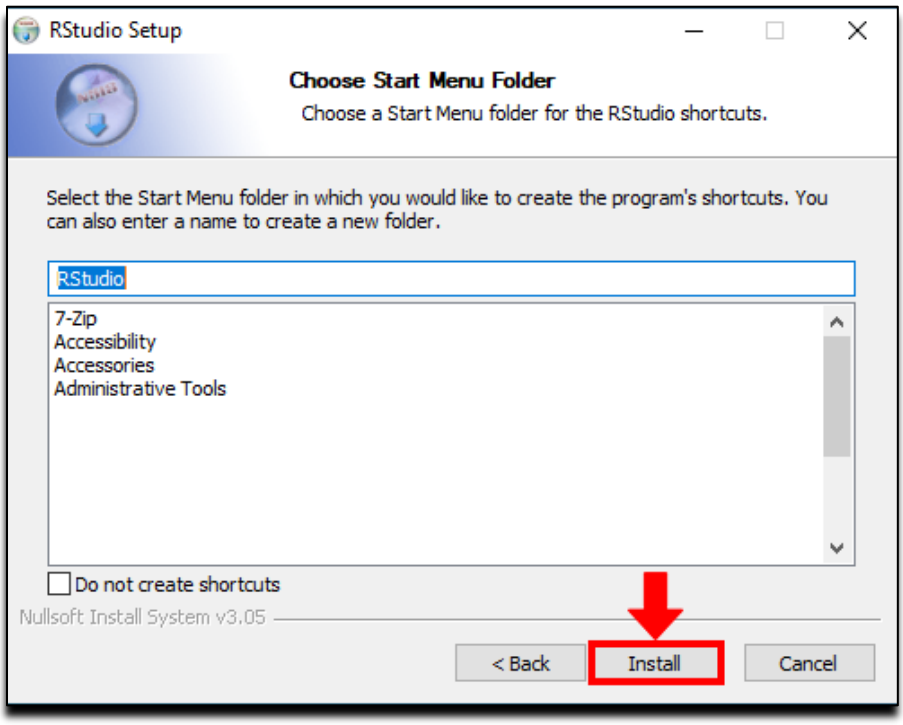
3. On the Welcome to RStudio Setup page, click Next:



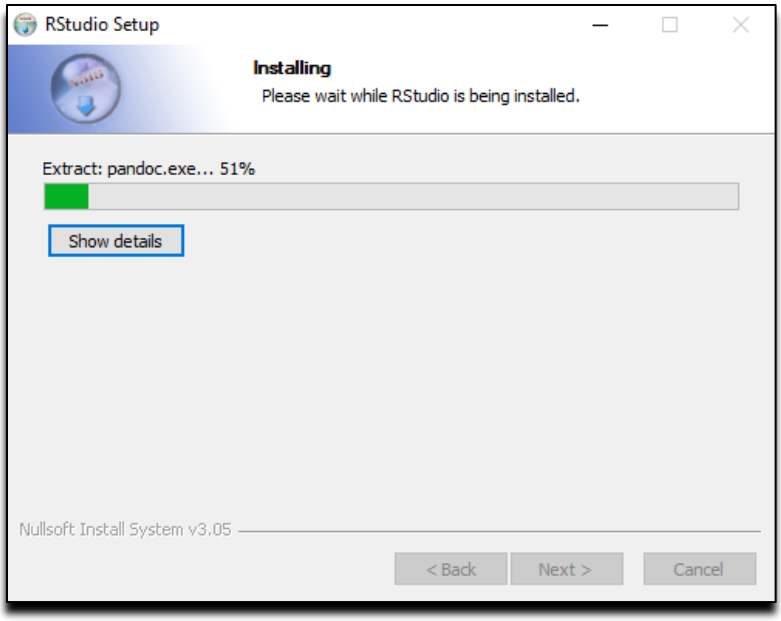
4. Choose Install Location, and click Next:



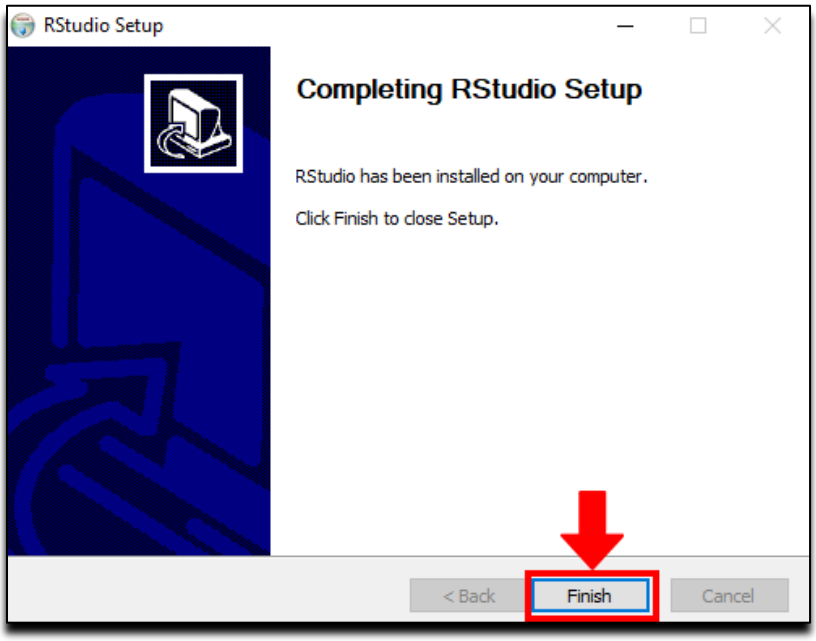
5. To initiate the installation process, click Install:



6. Please note that it will take a couple of minutes to Install the software, and the progress bar shows 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 basins in the Asia-Pacific region; the user can 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 datasets are outlined. We encourage the user to investigate and determine which datasets are most suitable.

Administrative Boundaries

This table 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/