userR! 2021 afrimapr tutorial session one: Introduction to spatial data

07 July 2021

This is a tutorial developed for useR! 2021 on mapping spatial data in R using African data. It is aimed at participants with limited R and GIS experience.

The tutorial is based on the afrilearnr package containing tutorials to teach spatial data skills in R with African data. It is part of the afrimapr project, which is funded through the Wellcome Trust's Open Research Fund and Data for Science and Health.

The tutorial has been adapted for useR! 2021 - please see the online tutorials for more detailed information and lessons.

PDFs of the tutorials have been included in the project documents folder. To get your own pdf of this tutorial, click on `Knit` in the RStudio toolbar and select `Knit to PDF`. Alternatively, `Knit to HTML` and once the html page has opened, click `Open in Browser` and then print a pdf from the browser window.

A. Outline of this tutorial session

This is an entry level introduction to spatial data in R using examples from Africa. It is aimed at participants with limited R and GIS experience.

Learning outcomes

By the end of this session, you would have learnt how to store and handle spatial data, and how to make static and interactive maps. Specifically, you will be able to:

- recall R functions that are used in mapping
- understand the classification of different spatial data types
- use packages in R to work with raster and vector data (sf and raster)
- create static and interactive maps using the tmap package and example data available from the afrilearndata package
- overlay several data types (layers) on a map
- learn how to change the colour palette to represent data on a map e.g. population density

Please do reach out after the course to the trainers and other participants to address any difficulties you may come across.

B. Loading packages and data

Packages in R contain extra methods and data to add to base R. Think of it like a mobile phone that comes with all of the base programmes that someone will need, but each person can then choose which apps to install to be able to do more specific tasks. In R, think of extra packages as apps you might install on your phone.

We will be loading a package called `afrilearndata` containing example data for us to look at.

We will also use packages that allow us to deal with spatial data. Cities, highways and boundaries are examples of point, line and polygon data termed **vector data**, while data such as gridded population density are termed **raster data**.

The packages sf and raster allow us to deal with vector and raster data.

Using an R package requires a 2 step process:

1. install.packages is needed only once to install a package from the internet
2. library([package_name]) is needed each time you start a new R session

To check that the packages have been installed, try running the library commands below. If they have been installed, nothing should happen. Not very interesting but a good check and a good reminder that this is what you will need to do each time you start a new R session.

If you happen to get messages indicating any of the packages are not installed, you can use install.packages to install them. For the purposes of this useR! 2021 tutorial, the packages have been installed into the R Studio Cloud project. Because we have already installed the packages for you, you only have to run the code below to load the packages into this working environment (see step 2 above). However, if you run this tutorial locally on your own computer, you will need to install these packages if you haven't already done so. You can find a script that will install all the necessary packages in the project main directory packages_and_data.R.

```
#### SECTION B: LOADING PACKAGES AND DATA ----

# for vector data handling
library(sf)

# for raster data handling
library(raster)

# example spatial data for Africa
library(afrilearndata)

# for static and interactive mapping
library(tmap)

# to create RasterLayer object
library(rgdal)
```

C. Spatial data overview

- Cities, highways and boundaries are examples of point, line and polygon data termed **vector data**. Vector data typically represents discrete objects e.g. fire hydrants, roads, dams, airports, countries. Vector data can typically be thought of as tabular data with a column for coordinates and other columns with attributes.
- **Raster data** is continuous data, which does not have clear and definable boundaries, but rather shows varying information such as gridded population density, temperature, precipitation, elevation. It's a grid of regularly sized pixels.

We will start by looking at these spatial data for Africa, shown in the map below, using data from the afrilearndata package, which is part of the afrimapr project. These include:

1. Capital city locations (points) africapitals
2. A highway network (lines) afrihighway
3. Country boundaries (polygons) africountries
4. Population density (gridded or raster data) afripop2020

Let's first take a look at the data:

```
# View the data

#View(afripop2020)
```

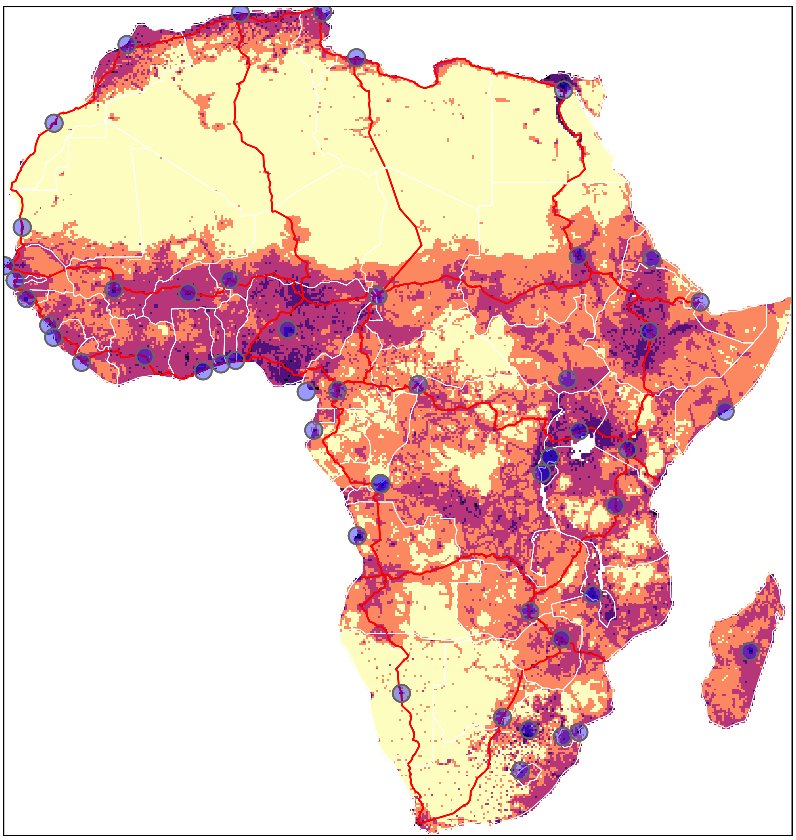
```r
#View(africountries)
#View(afrihighway)
#View(africapitals)
```

Now, to view these data on a map:

```r
# first tmap map
# **explain why we are using tmap here?**

tmap_mode("plot")

tmap::tm_shape(afripop2020) +
  tm_raster(palette = rev(viridisLite::magma(5)), breaks=c(0,2,20,200,2000,25000)) +
  tm_shape(africountries) +
  tm_borders("white", lwd = .5) +
  tm_shape(afrihighway) +
  tm_lines(col = "red") +
  tm_shape(africapitals) +
  tm_symbols(col = "blue", alpha=0.4, scale = .6 )+
  tm_legend(show = FALSE)
```



In R there is often more than one package that does the same thing. Which one is 'best' for you can depend on preference and context and can change over time. This is true for R spatial operations.

In R the `sf` package deals with vector data (points, lines and polygons), and the `raster` package deals with raster data.

There are other packages too but we don't need those for now.

D. Spatial data objects

We are going to take a look at the spatial data objects used to create the map shown above.

We call them 'objects' because the data are already stored in R. This is also to make clear the difference from a 'file' that is stored elsewhere on your computer. A 'file' can be read into an R 'object' and we will come to that later.

In R there are various functions that can help us explore what an object contains. There is some overlap between them, but we find these particularly useful:

1. str() structure of the object, displays both names and values
2. head() displays the first few rows of data with the column names
3. names() gives just column names
4. class() gives the class of the object, that is broadly what sort of object it is

Have a look at the outputs for `africapitals` (uncomment the later lines to see their outputs) :

```
# sf-points-str

str(africapitals)
```

```
## Classes 'sf' and 'data.frame':   50 obs. of  5 variables:
##  $ capitalname: chr  "Abuja" "Accra" "Addis Abeba" "Algiers" ...
##  $ countryname: chr  "Nigeria" "Ghana" "Ethiopia" "Algeria" ...
##  $ pop        : int  178462 2029143 2823167 2029936 1463754 578860 1342519 547668 34388 404119 ...
##  $ iso3c      : chr  "NGA" "GHA" "ETH" "DZA" ...
##  $ geometry   :sfc_POINT of length 50; first list element:  'XY' num  7.17 9.18
##  - attr(*, "sf_column")= chr "geometry"
##  - attr(*, "agr")= Factor w/ 3 levels "constant","aggregate",..: NA NA NA NA
##   ..- attr(*, "names")= chr [1:4] "capitalname" "countryname" "pop" "iso3c"
```

```
# sf-points-head

head(africapitals)
```

```
## Simple feature collection with 6 features and 4 fields
## Geometry type: POINT
## Dimension:     XY
## Bounding box:  xmin: -0.2 ymin: -18.89 xmax: 47.51 ymax: 36.77
## Geodetic CRS:  WGS 84
##       capitalname countryname     pop iso3c             geometry
## 280         Abuja     Nigeria  178462   NGA    POINT (7.17 9.18)
## 308         Accra       Ghana 2029143   GHA    POINT (-0.2 5.56)
## 382   Addis Abeba    Ethiopia 2823167   ETH   POINT (38.74 9.03)
## 996       Algiers     Algeria 2029936   DZA   POINT (3.04 36.77)
## 1584 Antananarivo  Madagascar 1463754   MDG POINT (47.51 -18.89)
## 2193       Asmara     Eritrea  578860   ERI  POINT (38.94 15.33)
```

```
# sf-points-names

names(africapitals)
```

```
## [1] "capitalname" "countryname" "pop"         "iso3c"       "geometry"
```

```
# sf-points-class

class(africapitals)
```

```
## [1] "sf"         "data.frame"
```

These show us that `africapitals` is of class `sf` and `data.frame` and contains a series of columns including ones named: 'capitalname', 'countryname' and 'geometry'.

`data.frame`, often referred to as just dataframe, is the most common object type in R certainly for new users. Dataframes store data in rows and named columns like a spreadsheet.

`sf` objects are a special type of dataframe with a column called 'geometry' that contains the spatial information, and one row per feature. In this case the features are points.

If you look at the output from the `str()` command above you should see that the first value in the geometry column has the coordinates 7.17 9.18. Because the capitals data are points, they just have a single coordinate pair representing the longitude and latitude of each capital.

E. First maps with `tmap`

There are a number of packages for making maps that extend what is available from `sf`.

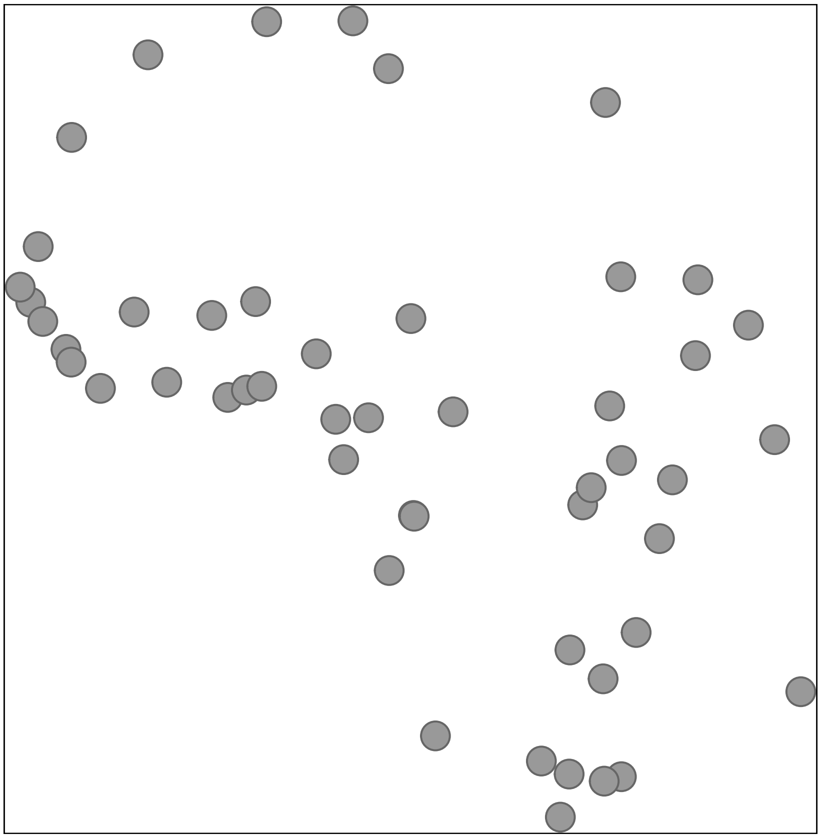
Package `tmap` is a good place to start; it offers both static and interactive mapping.

Vector data: points We can start with static plots of the capitals (points).

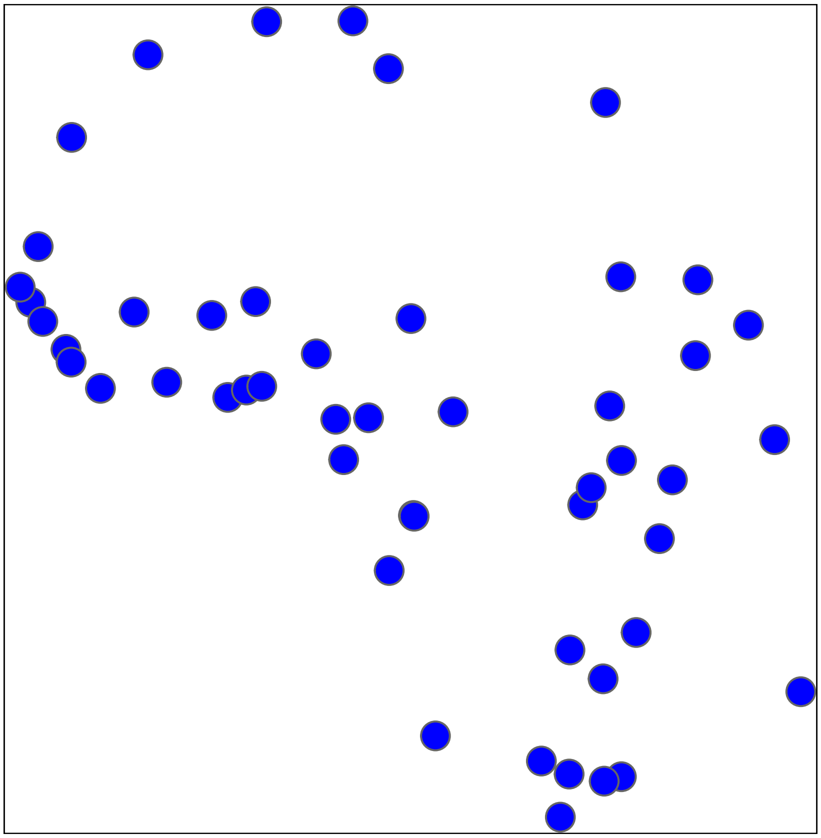
In `tmap`, `tm_shape([object_name])` defines the data to be used. Then `+` to add code that defines how the data are displayed, e.g. `tm_symbols()` for points. Extra arguments can be specified to modify the data display.

See how to set colour with `tm_symbols(col = "blue")` and `col=[column_name]` to set the colour of each point according to the data value stored in a column (in the code chunk below, remove the # from the line you want to run, and add the # to comment out the lines you don't want to run).

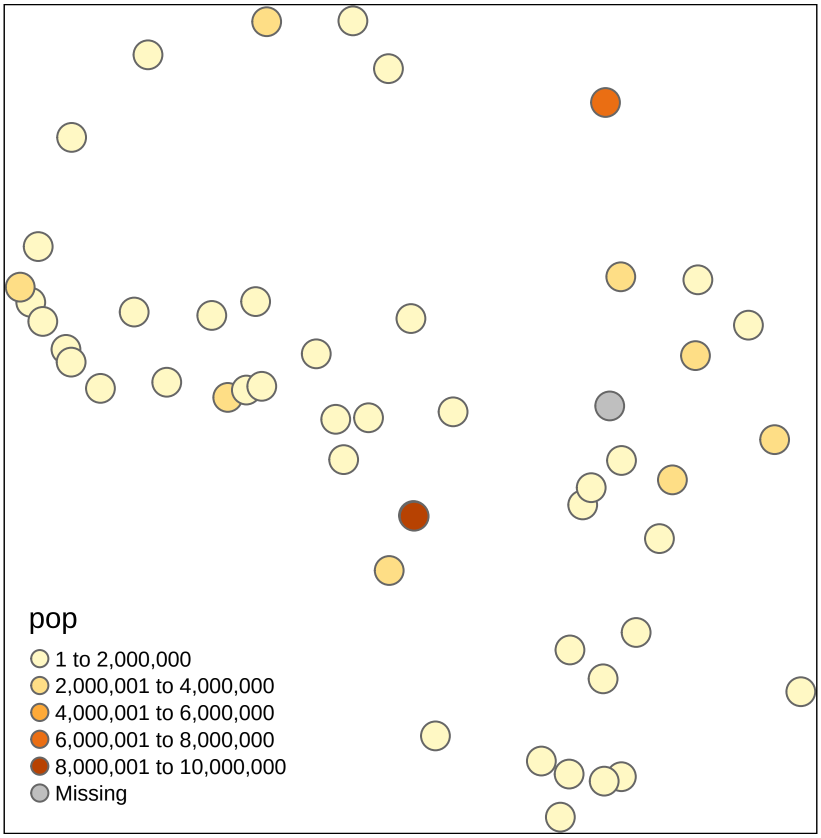
```
# tmap-points1a
tmap_mode('plot')
tm_shape(africapitals) +
   tm_symbols()
```



```
# tmap-points1b
tmap_mode('plot')
tm_shape(africapitals) +
   tm_symbols(col = "blue")
```

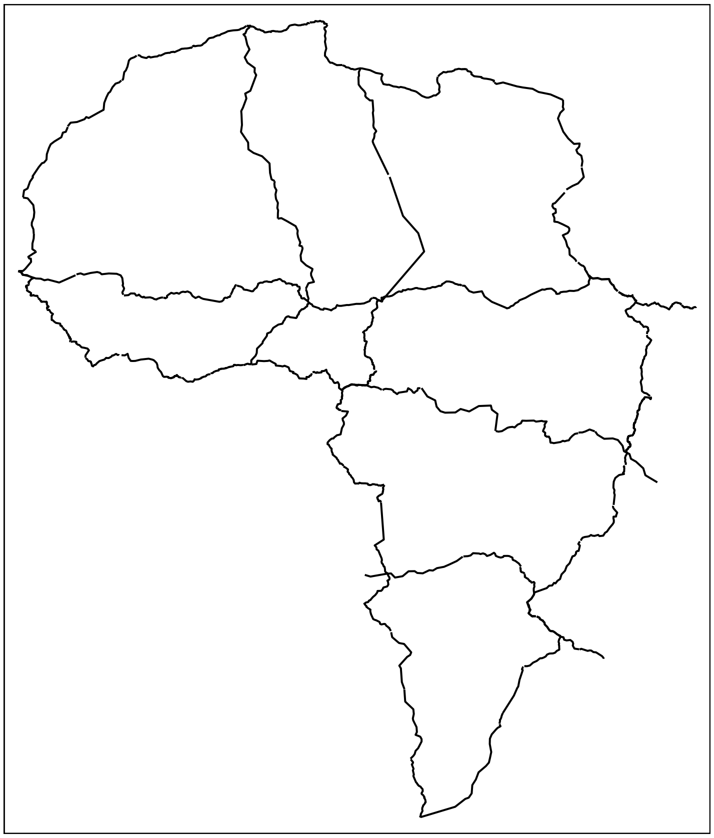


```
# tmap-points1c
tmap_mode('plot')
tm_shape(africapitals) +
  tm_symbols(col = "pop")
```

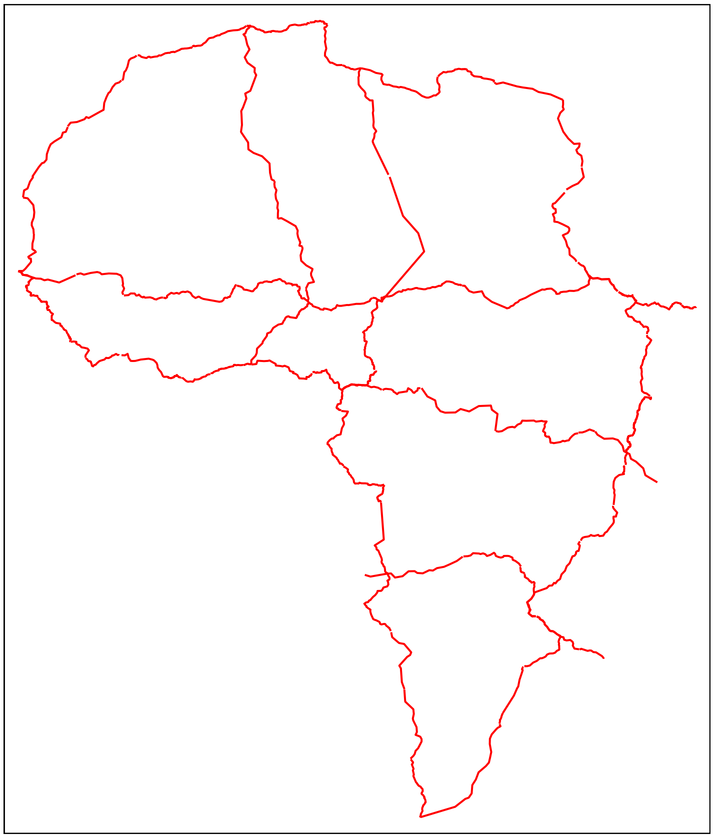


Vector data: lines The highway network (lines) can be plotted using the same `tm_shape([object_name])` to start, then adding `tm_lines()` to display the lines. See other options for colouring lines (as above, remove the # from the line you want to run, and add the # to comment out the lines you don't want to run).

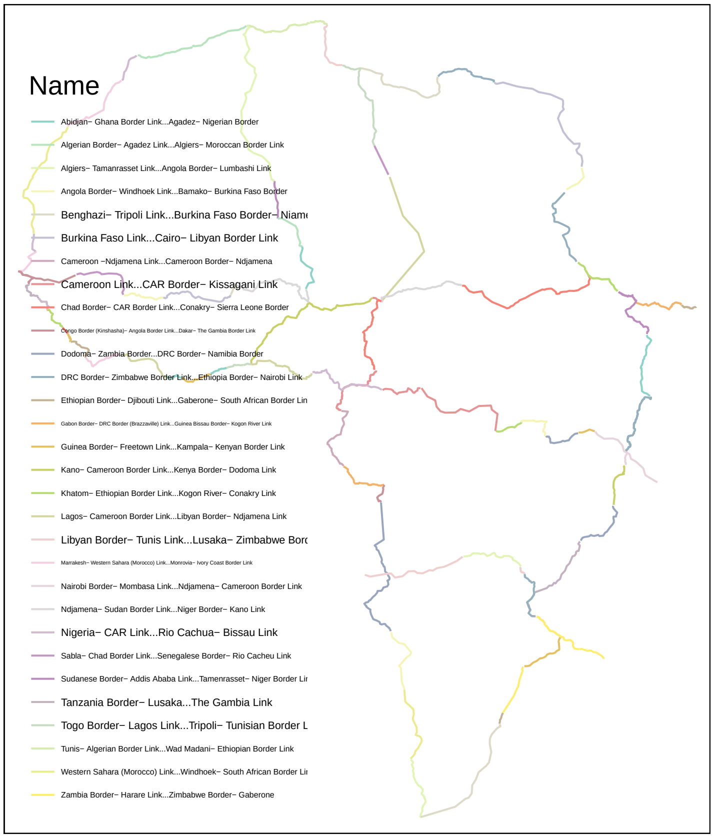
```
# tmap-lines1a
tmap_mode('plot')
tm_shape(afrihighway) +
  tm_lines()
```



```
# tmap-lines1b
tmap_mode('plot')
tm_shape(afrihighway) +
    tm_lines(col = "red")
```

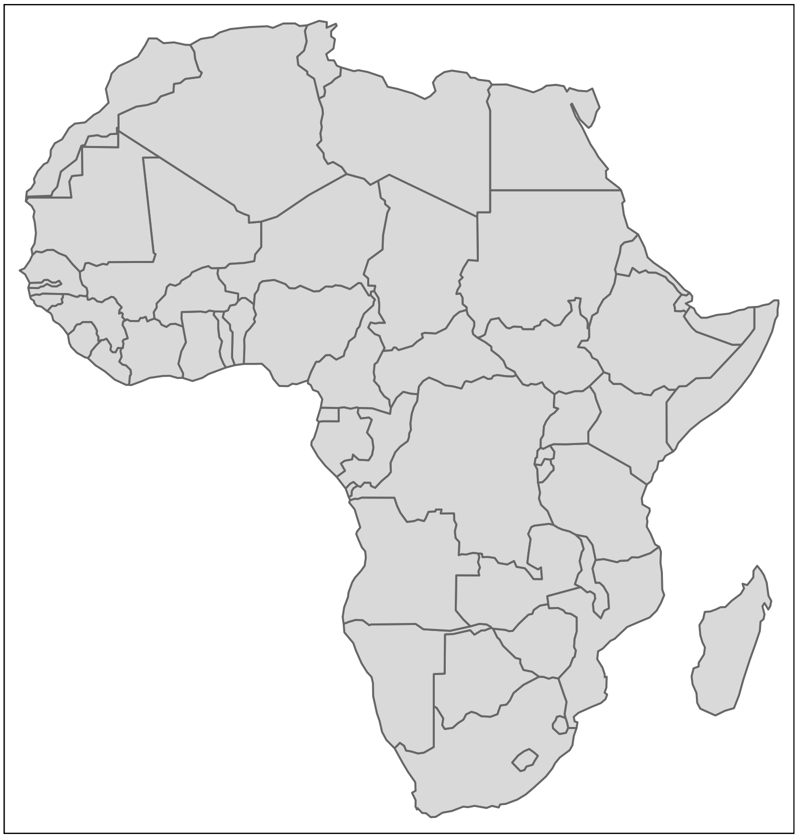


```
# tmap-lines1c
tmap_mode('plot')
tm_shape(afrihighway) +
   tm_lines(col = "Name")  # use a column name from the object
```

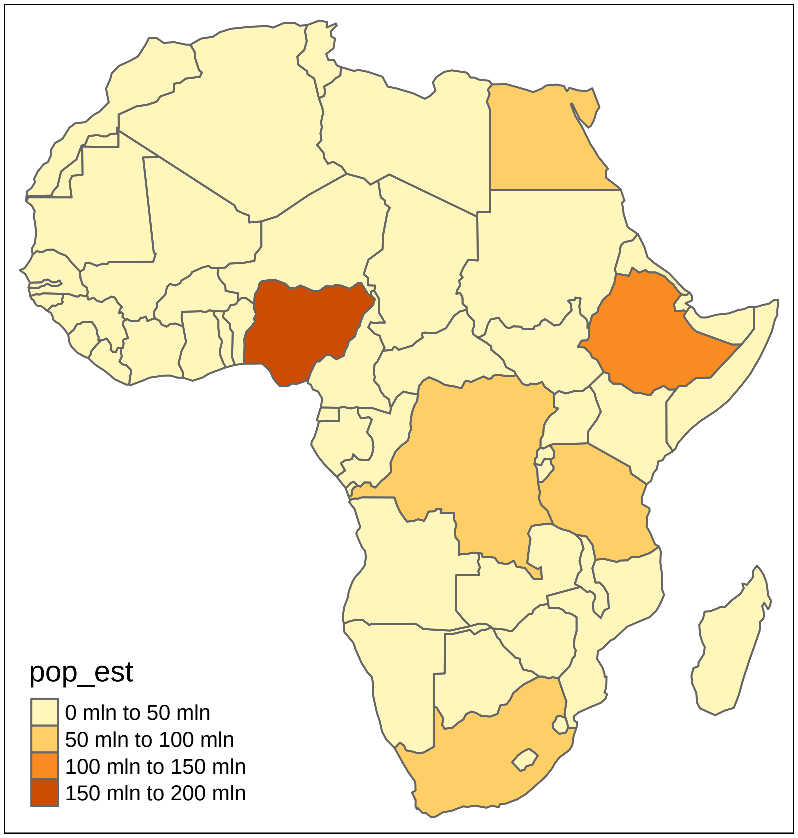


Vector data: polygons Countries (polygons) can similarly be mapped using `tm_shape` and `tm_polygons`. Similar to above, see other options for colouring countries.

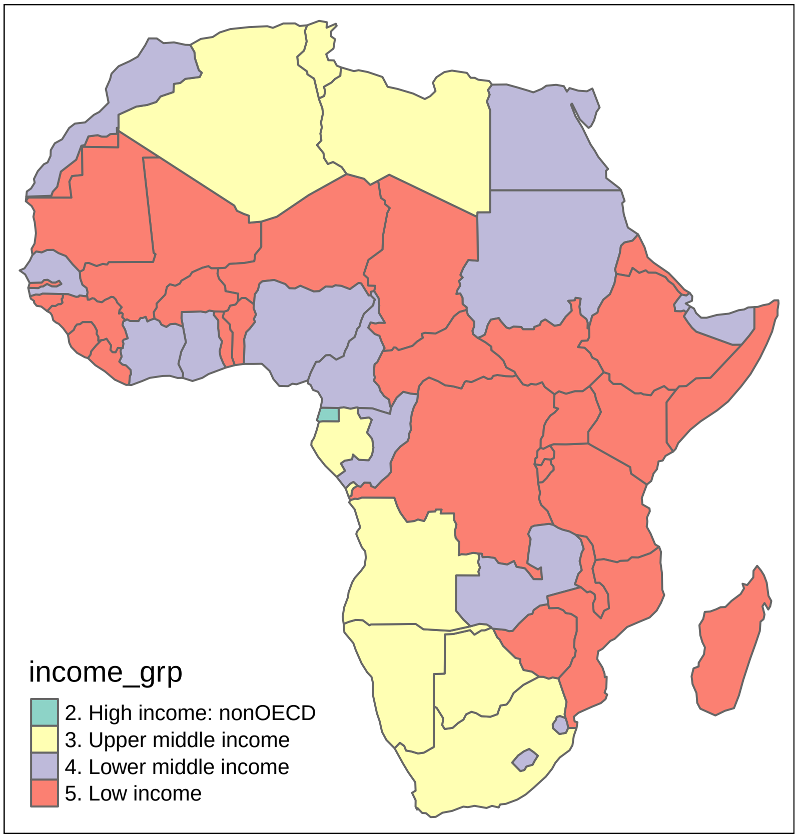
```
# tmap-polygons-1a
tmap_mode('plot')
tm_shape(africountries) +
     tm_polygons()
```



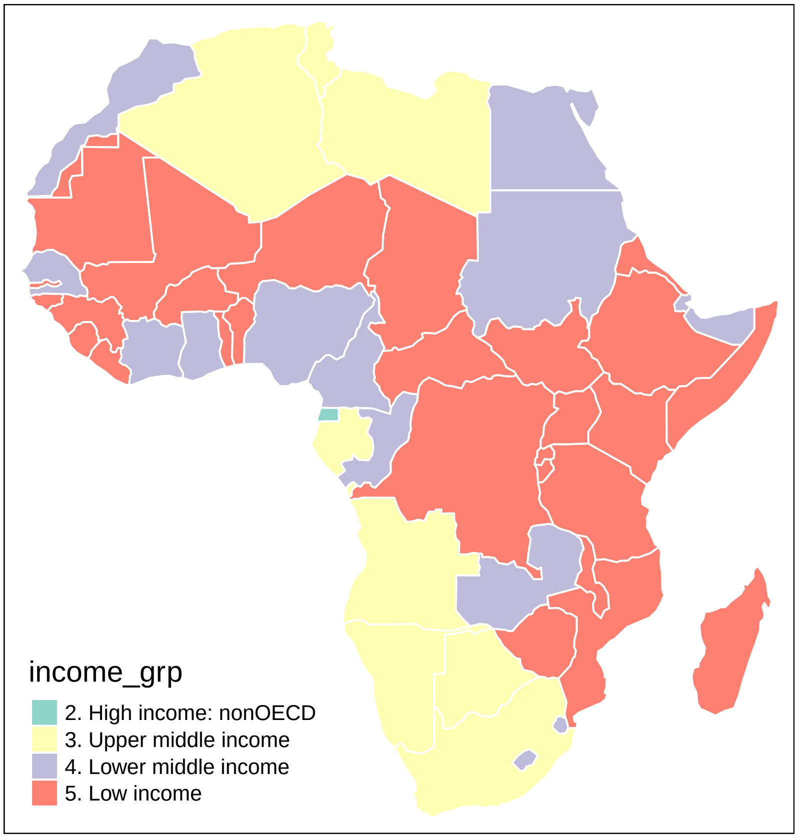
```r
# tmap-polygons-1b
tmap_mode('plot')
tm_shape(africountries) +
      tm_polygons(col="pop_est")
```




```
# tmap-polygons-1c
tmap_mode('plot')
tm_shape(africountries) +
      tm_polygons(col="income_grp")
```




```r
# tmap-polygons-1d
tmap_mode('plot')
tm_shape(africountries) +
  tm_polygons(col="income_grp", border.col = "white")
```

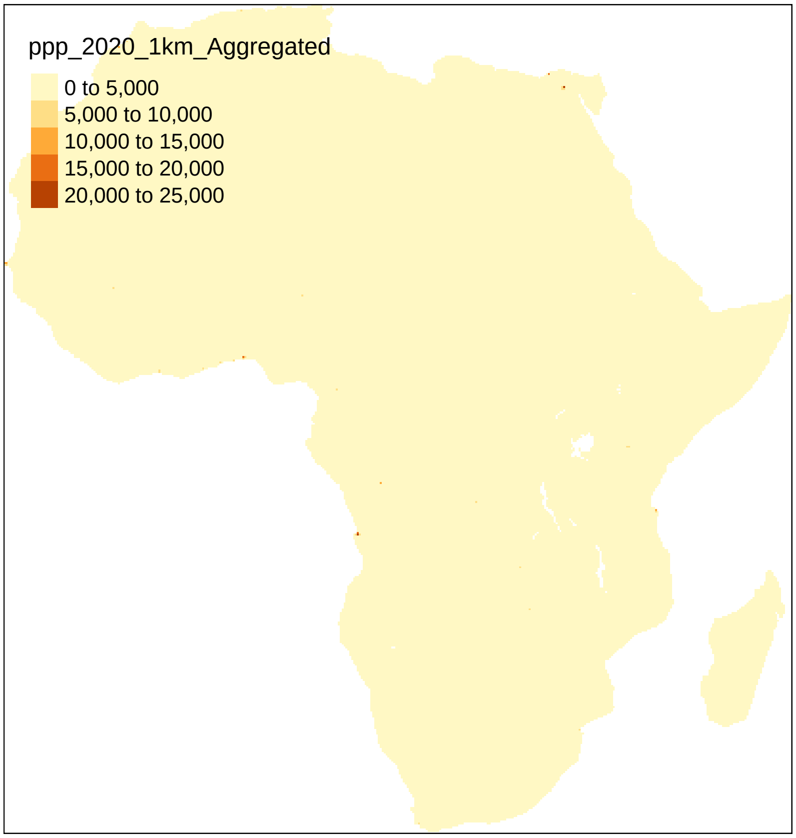


Raster data Gridded (raster) data can represent e.g. remotely sensed or modelled data.

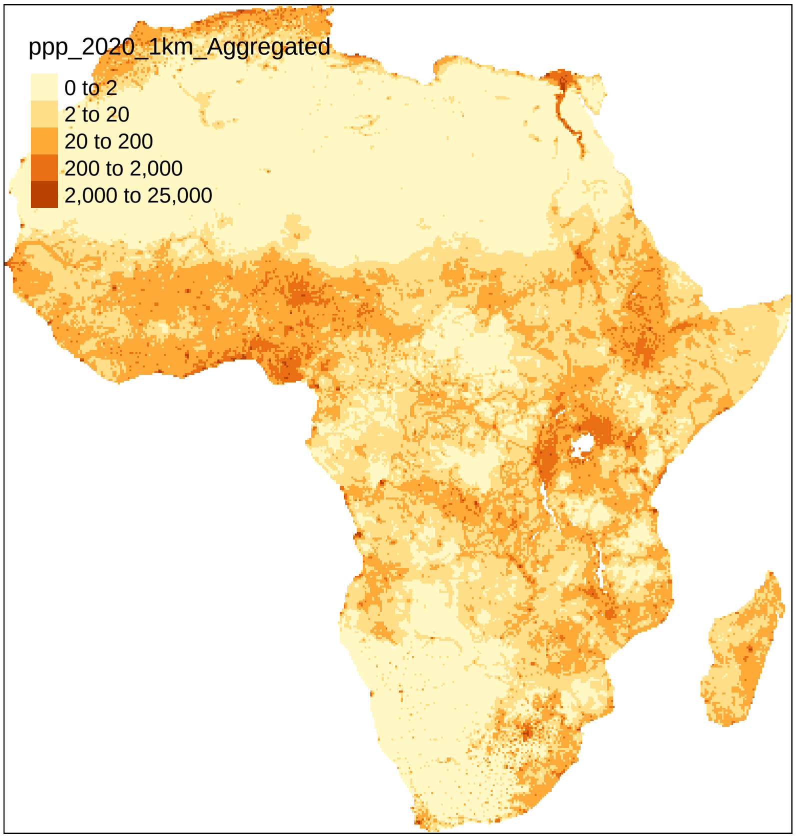
It can be displayed with `tm_shape([object_name])` and `tm_raster`. Here we specify the `breaks` or cutoffs to the different colour bands because the data is continuous rather than discrete.

In this example, if you use the default breaks by not specifying any arguments with `tm_raster()`, the map looks entirely one colour. This is because there are few very high density cells and a majority of cells with very low values. This is a common issue with population data. The default (equal-interval) classification doesn't work well; most of the map falls in the lowest category. If you look very closely you can see a few very high value cells e.g. in Lagos and Cairo.

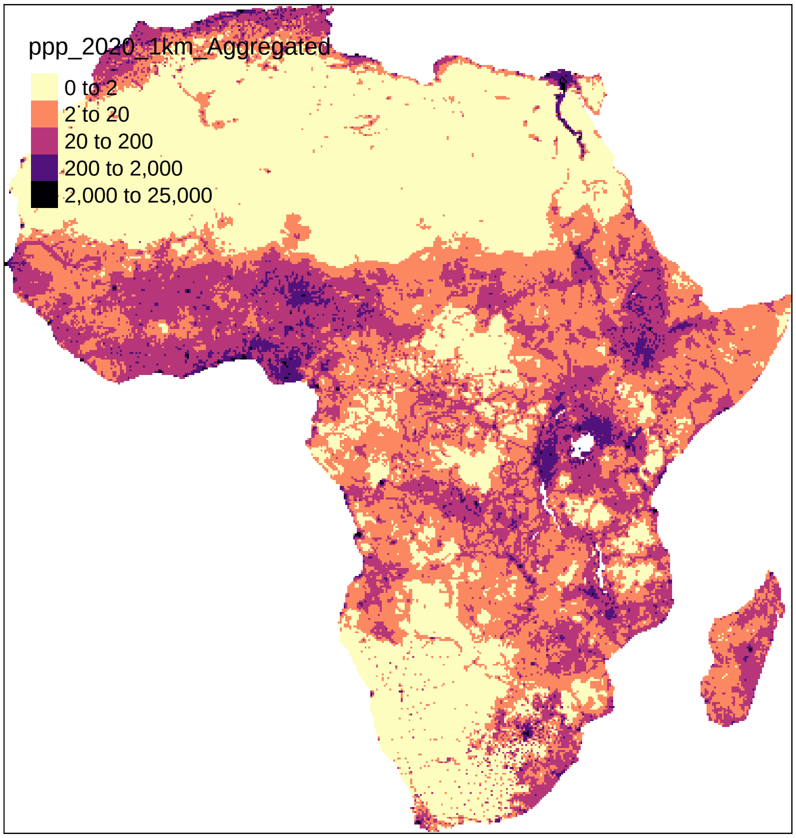
```
# tmap-raster1a
tmap_mode('plot')
tm_shape(afripop2020) +
  tm_raster()
```




```
# tmap-raster1b
tmap_mode('plot')
tm_shape(afripop2020) +
  tm_raster(breaks=c(0,2,20,200,2000,25000))
```




```r
tmap_mode('plot')
#changing the colour palette
tm_shape(afripop2020) +
  tm_raster(palette = rev(viridisLite::magma(5)), breaks=c(0,2,20,200,2000,25000))
```



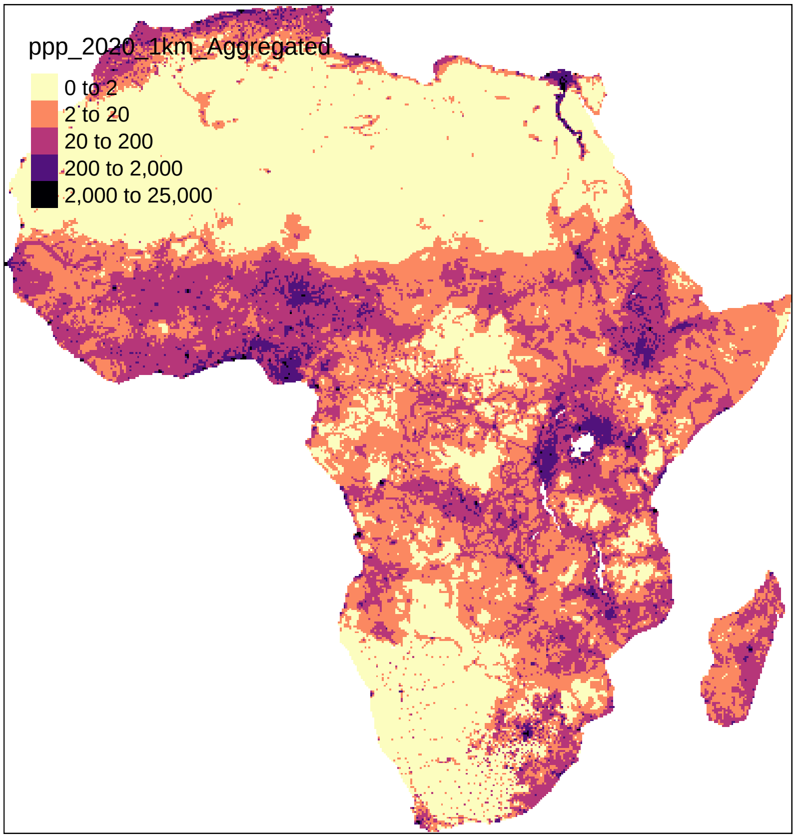
F. Mapping multiple 'layers'

In the previous section, we showed how to make maps of individual data objects. Those sections of code can be combined to create multiple 'layer' maps as shown in the example below.

`tmap` (and other map packages) use the `+` symbol to combine layers. See the maps below where another layer is added for each map.

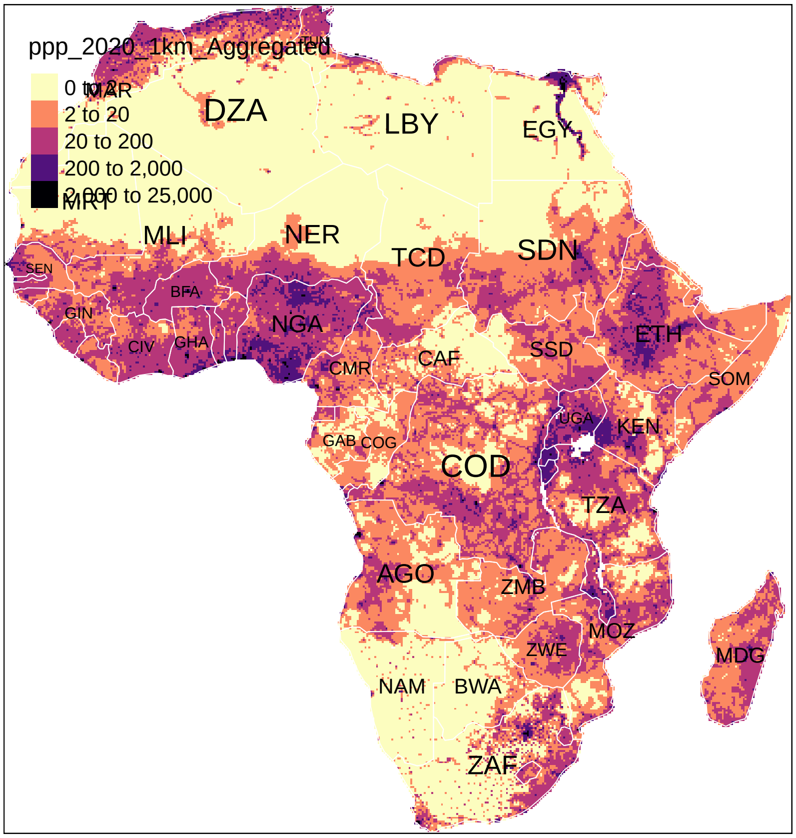
```
# tmap-vector-raster1a

tmap_mode('plot')
tmap::tm_shape(afripop2020) +
  tm_raster(palette = rev(viridisLite::magma(5)), breaks=c(0,2,20,200,2000,25000))
```



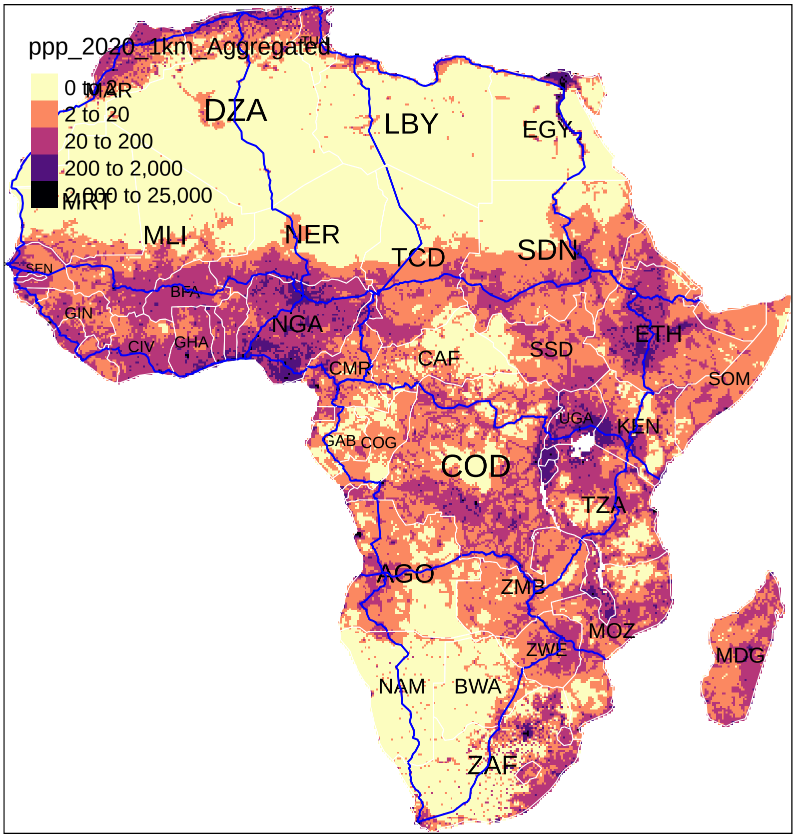

```
# tmap-vector-raster1b

tmap_mode('plot')
tmap::tm_shape(afripop2020) +
  tm_raster(palette = rev(viridisLite::magma(5)), breaks=c(0,2,20,200,2000,25000)) +
  tm_shape(africountries) +
  tm_borders("white", lwd = .5) +
  tm_text("iso_a3", size = "AREA")
```



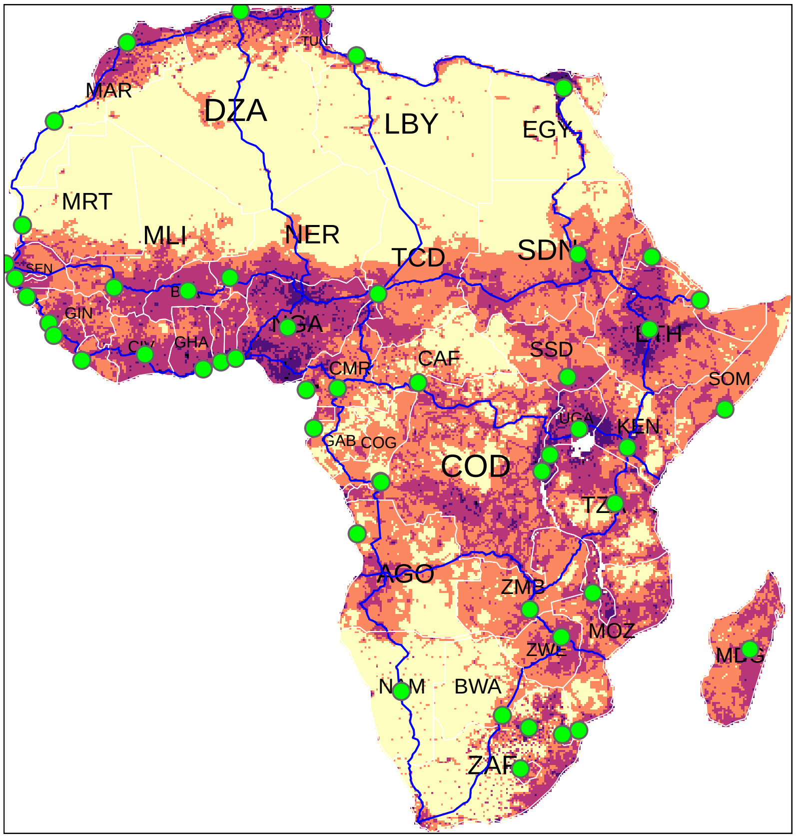

```
# tmap-vector-raster1c

tmap_mode('plot')
tmap::tm_shape(afripop2020) +
  tm_raster(palette = rev(viridisLite::magma(5)), breaks=c(0,2,20,200,2000,25000)) +
  tm_shape(africountries) +
  tm_borders("white", lwd = .5) +
  tm_text("iso_a3", size = "AREA") +
  tm_shape(afrihighway) +
  tm_lines(col = "blue")
```




```r
# tmap-vector-raster1d

tmap_mode('plot')
tmap::tm_shape(afripop2020) +
  tm_raster(palette = rev(viridisLite::magma(5)), breaks=c(0,2,20,200,2000,25000)) +
  tm_shape(africountries) +
  tm_borders("white", lwd = .5) +
  tm_text("iso_a3", size = "AREA") +
  tm_shape(afrihighway) +
  tm_lines(col = "blue") +
  tm_shape(africapitals) +
  tm_symbols(col = "green",  scale = .6 ) +
  tm_legend(show = FALSE)
```



G. Interactive maps

The maps created so far have been static. There are also great options for creating interactive maps, which are useful for web pages or reports where readers can zoom, pan and enable/disable layers.

In `tmap` you can keep the identical code that we've looked at so far and just add a single line at the beginning, `tmap_mode('view')`, to change to interactive 'view' mode. View mode will remain active for your R session and you can switch back to static `plot` mode using `tmap_mode('plot')`.

This is the identical code from the previous section but shown in view mode.

Experiment by adding and removing the # sign at the start of lines in the code below. Try to make maps:

1. without the highway network
2. without the raster population layer and with country boundaries that are visible
3. with text labels for ISO country codes

```
# tmap-interactive

tmap_mode('view')

tmap::tm_shape(afripop2020) +
  tm_raster(palette = rev(viridisLite::magma(5)), breaks=c(0,2,20,200,2000,25000)) +
  tm_shape(africountries) +
  tm_borders("white", lwd = .5) +
  tm_text("iso_a3", size = "AREA") +
  tm_shape(afrihighway) +
  tm_lines(col = "blue") +
  tm_shape(africapitals) +
```

```
  tm_symbols(col = "green",  scale = .6 ) +
  tm_legend(show = FALSE)
```

```
## QStandardPaths: XDG_RUNTIME_DIR not set, defaulting to '/tmp/runtime-rstudio-user'
## TypeError: Attempting to change the setter of an unconfigurable property.
## TypeError: Attempting to change the setter of an unconfigurable property.
```

You may want to go back to the earlier plots and see how they are modified by adding `tmap_mode('view')` before the code.

Please note that interactive maps will not render to pdf using `knit`.

Summary

Good persistence for getting this far!

We hope you've enjoyed this brief intro to mapping with R.

We've shown you :

1. storing and handling spatial data with the package `sf`
2. making static and interactive maps with package `tmap`

This is a start; there are plenty of other options (e.g. maps can also be made with the packages `mapview` and `ggplot2`).

useR! 2021: Next session

Our next session in this useR! 2021 tutorial will be an entry level outline to demonstrate getting spatial data of different types into R as a first step to mapping it. The aim is to support you getting your own data into R before making maps or other plots.

BREAK TIME OF 15 MINS

Optional exercises

to include a few exercises for learners to work through should they have the time