USING SPATIAL INFORMATION TO SUPPORT DECISIONS ON SAFEGUARDS AND MULTIPLE BENEFITS FOR REDD+

ASSESSING THE RELATIVE IMPORTANCE OF FORESTS FOR WIND EROSION CONTROL

QGIS v 2.18

UN-REDD PROGRAMME

Food and Agriculture Organization of the United Nations

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The UN-REDD Programme is the United Nations Collaborative initiative on Reducing Emissions from Deforestation and forest Degradation (REDD) in developing countries. The Programme was launched in September 2008 to assist developing countries prepare and implement national REDD+ strategies, and builds on the convening power and expertise of the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP) and the United Nations Environment Programme (UNEP).

The United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC) is the specialist biodiversity assessment centre of the United Nations Environment Programme (UNEP), the world's foremost intergovernmental environmental organisation. The Centre has been in operation for over 30 years, combining scientific research with practical policy advice.

Prepared by Xavier de Lamo, Yara Shennan-Farpón and Corinna Ravilious.

We welcome comments on any errors or issues. Should readers wish to comment on this document, they are encouraged to get in touch via: ccb@unep-wcmc.org.

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Contents

1. Introduction

REDD+ has the potential to deliver multiple benefits beyond carbon. For example, it can promote biodiversity conservation and secure ecosystem services from forests such as water regulation and non-timber forest products. Some of the potential benefits from REDD+, such as biodiversity conservation, can be enhanced through identifying areas where REDD+ actions might have the greatest impact using spatial analysis.

Open Source GIS software can be used to undertake spatial analysis of datasets of relevance to multiple benefits and environmental safeguards for REDD+. Open-source software is released under a license that allow software to be freely used, modified, and shared (http://opensource.org/licenses). Therefore, using open source software has great potential in building sustainable capacity and critical mass of experts with limited financial resources.

The capacity of forest to control soil erosion is also regarded as a key potential REDD+ benefit. Wind erosion, in particular, constitutes a key component in soil degradation processes in arid areas; as it can cause degradation of sedimentation crusts on the surface of stripped soils, as well as reducing the capacity of soils to store nutrients and water (FAO 1996). Even though the importance of the contributing factors are locally dependent, it is widely recognized that the amount of soil loss by wind erosion at a regional scale is mainly dependent on four key factors: climate, soil, topography and vegetation cover (Shao & Leslie 1997).

This tutorial provides a methodology to conduct a preliminary spatial assessment of the relative importance of forest in protecting against wind erosion by mapping these key factors, using Paraguay as a study area. The analysis is undertaken by using an overlay approach, where data on wind speed, precipitation, evapotranspiration, soil characteristics and topographical complexity are generated and combined with forest data. The method described here is partly based on the USDA's Universal Wind Erosion Equation (Wooddruf & Siddoway, 1965), as well as on Mezosi *et al.* (2015), Tsogtbaarar & Khudulmur (2014), and FAO (1979).

This method is not designed to predict exact locations of wind erosion occurrence or making quantitative estimates of potential soil erosion – it serves to assess the role of forests to wind erosion control based on the general sensitivity of the land to wind erosion, taking into account the dominant/general climate, soil and topographical conditions of the area. The resulting map may be suitable for regional land use management and identify wind erosion-prone areas, where more detailed quantitative risk mapping may be needed.

The analysis runs entirely from QGIS version 2.18, R Software and R Studio, which needs to be installed in order to execute this analysis.

2. Methodology

The first step will be to prepare, download and process all the necessary layers in order to have the required variables to estimate the relative importance of forest for wind erosion control. Using the formula from Woodruff and Siddoway (1965) as a starting point, we have designed and adapted a formula which uses an overlay approach to calculate the importance of forest for wind erosion control at a regional scale as a function of 4 thematic layers' parameters:

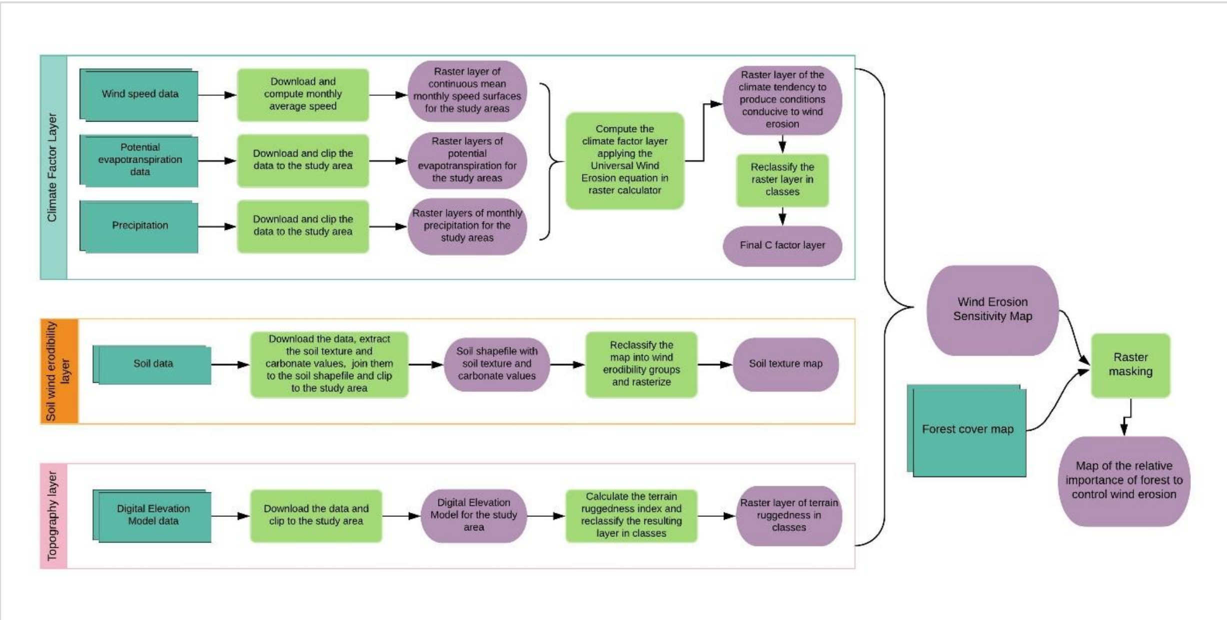
Climate: Wind speed and humidity are the main climatic controlling factors. It is generally assumed that wind speed at values above 6 – 9 m/s wind erosion occurs (Mezosi *et al.* 2015)**.** Similarly, the sensitivity to wind erosion increase with aridity, as humid soil particles are more resistant to be displaced by wind (Shao & Leslie 1997).

Soil characteristics: Texture and gran size distribution are assumed to determine soil erosion sensitivity. Coarse-textured soils, such as sandy soils, are known to be more prone to wind erosion than fine-textured ones, such as clay soils (Fryrear *et al.* 1998).

Topography: The more "rough" the surface is, the lower is the wind speed, and hence the wind erodibility will decrease (Shao 2008).

Vegetation cover: Vegetation acts as a protection layer that prevents the wind to displace soil particles. The density of the vegetation determines the level of protection.

The method described in this document goes through the steps required to develop the spatial layers for the first three factors listed above. A final map showing the relative importance of forest for wind erosion control, is produced by combining all the layers developed. This method assumes that the user has a forest cover layer available for analysis, which is utilized in this tutorial as a substitute of the vegetation cover.
Below an image showing the workflow including the steps required to carry out this analysis.



3. Prepare the climate, soil characteristics and topography layers.

3.1. Create the Climate factor (C') layer

Climate erosivity is assessed in this method using the formula suggested by FAO (1979) for the Universal Wind Erosion Equation (Wooddruf & Sidoway, 1965):

$$C = \frac{1}{100} \times \sum_{i=1}^{12} u^3 \left(\frac{PETi - Pi}{PETi}\right) d$$

Where:

u = monthly average wind speed (m/s)
PETi = monthly potential evaporation (mm)
Pi = monthly average precipitation (mm)
d = the number of days in a month.

Spatial layers will be developed for each parameter included in the equation above, and will then be used as input layers in Raster Calculator to produce a climate erosivity map.

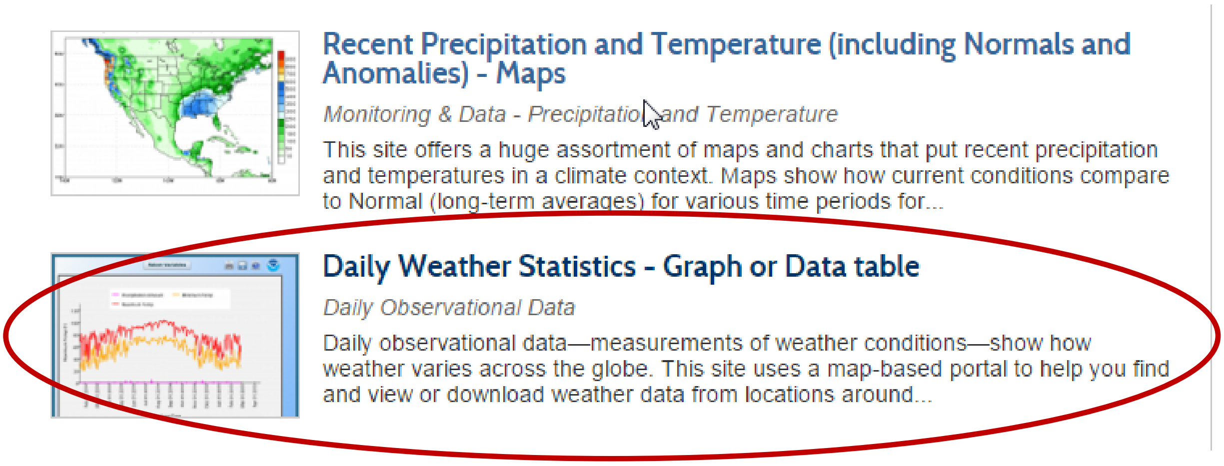
3.1.1. Compute the monthly average wind speed layer (u)

Twelve layers, representing monthly average wind speed values for the area of interest, will be developed for the *"u"* component of the formula. If no spatial modelled surface for wind velocity are available for your study area, you can develop one using daily wind speed station data from NOAA's National Climatic Data Center website. This data will be used in this tutorial to create average wind speed maps for each month of the year in the study area, by using geostatistical methods in QGIS and statistical analyses in RStudio.

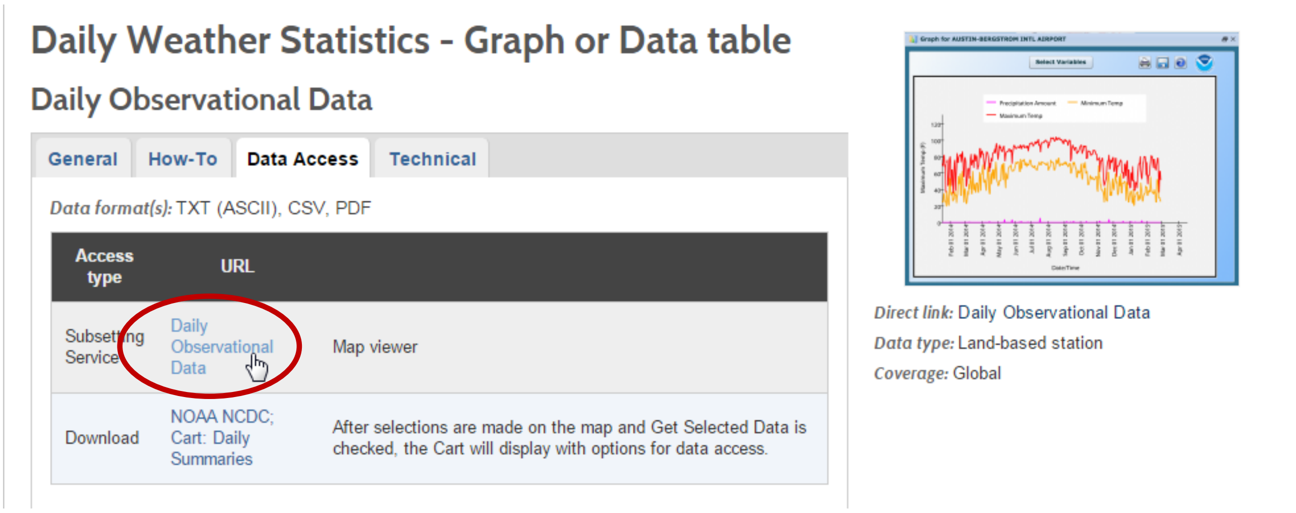
Steps to download the daily wind speed data

1. Go to: https://www.climate.gov/maps-data, and then click on to ***Dataset Gallery*** on the top of the page***.***

2. On the left side of the page, under ***Refine by Coverage***, click on ***Global*** and then search for ***Daily Weather Statistics (Graph or Data table).***

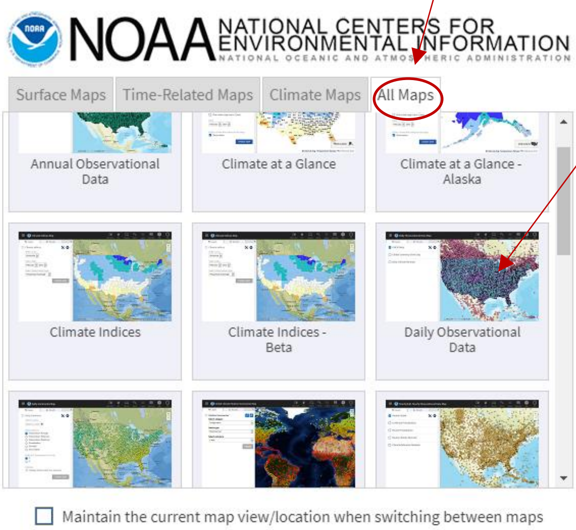


3. *Go to* ***Data Access*** and click on the link under ***Daily Observational Data*** in the ***Subsetting Service Row.***

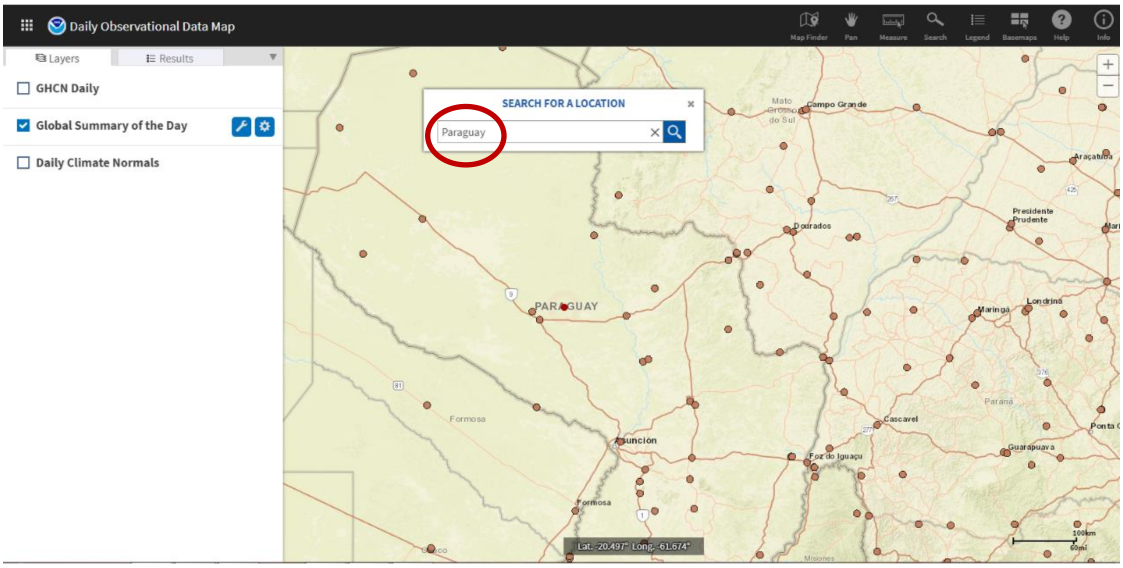


Access type	URL	
Subsetting Service	Daily Observational Data	Map viewer
Download	NOAA NCDC; Cart: Daily Summaries	After selections are made on the map and Get Selected Data is checked, the Cart will display with options for data access.

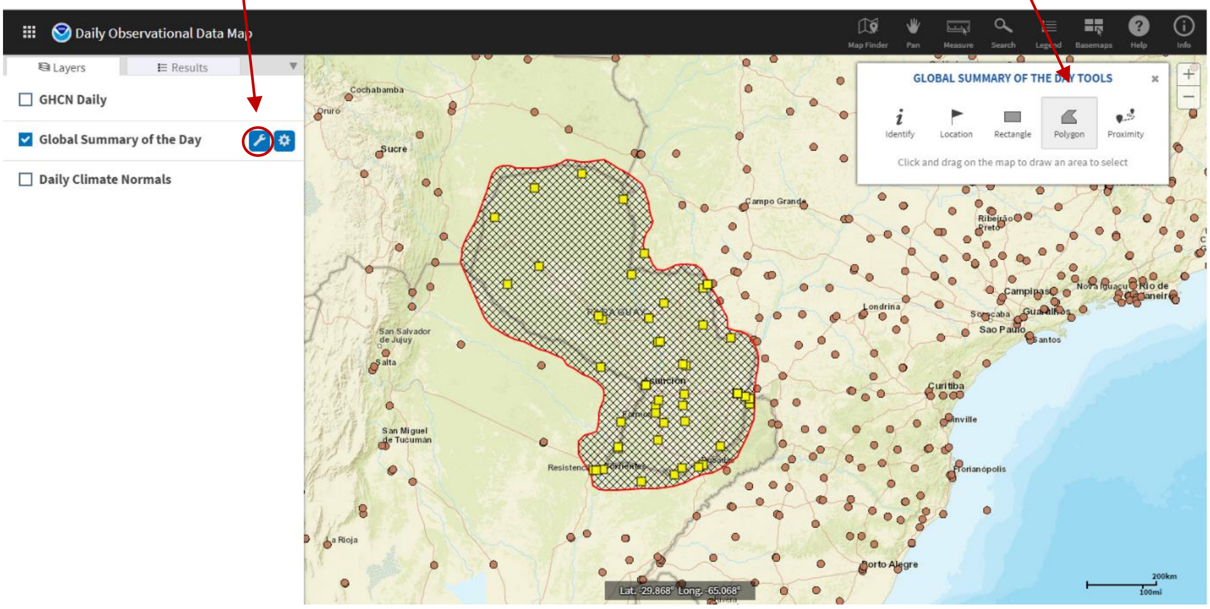
4. A pop up window will open, click on **All Maps** and then on **Daily Observational Data.** A map viewer will automatically open.



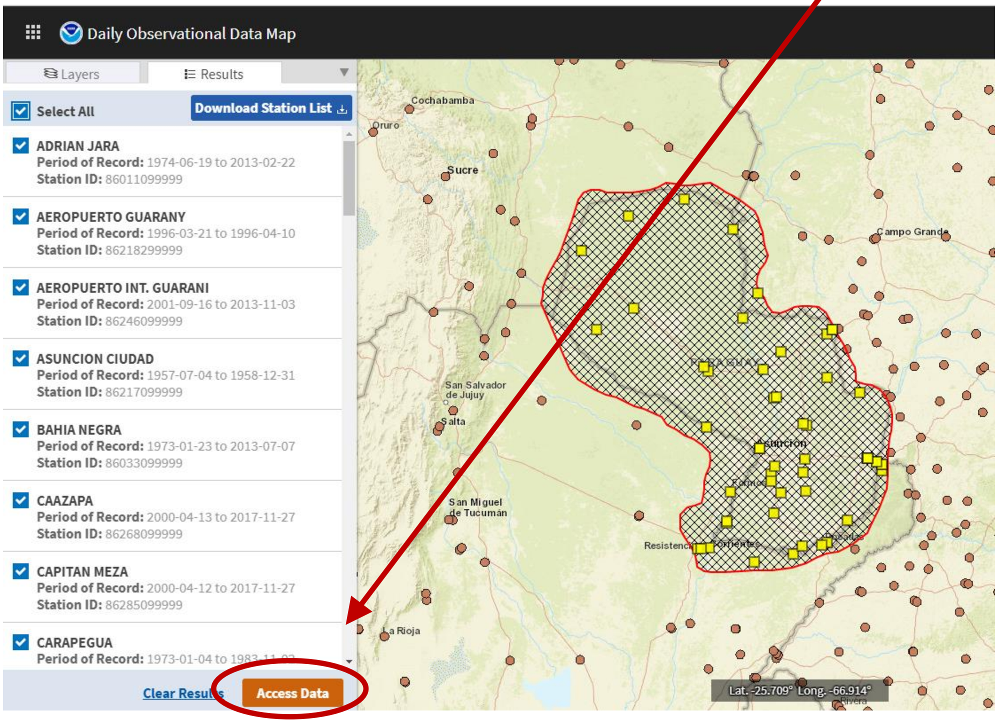
5. Once the map viewer is open, **Search** for a location, Paraguay in this case, and tick the box next to **Global Summary of the Day** on the left side of the map.



6. Click on the **tools icon** next to **Global Summary of the Day** and then to **Polygon** to select the area of interest. This will allow you to draw a polygon and select the weather stations for your area of interest. For a more accurate execution of the interpolation that will be carried out later on, it is advised to also select weather station in the surrounding area of our area of interest. In this example, we will draw a polygon around Paraguay.

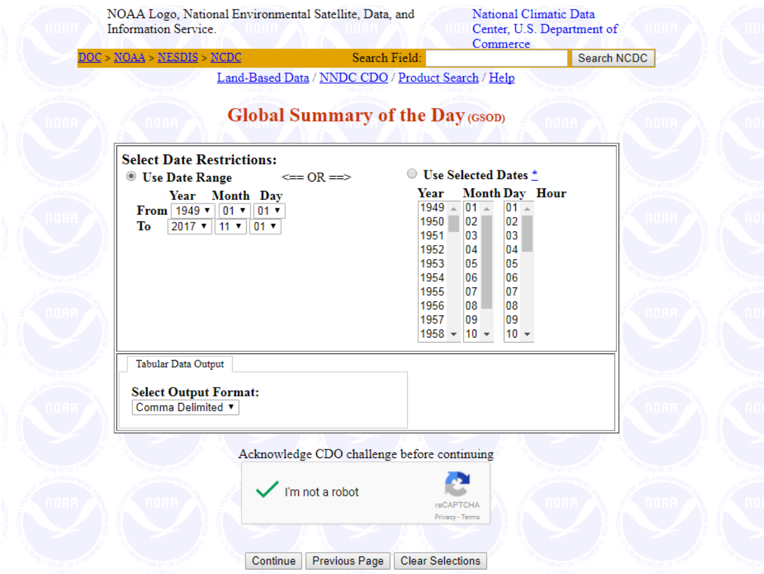


7. On the left side of the map the list of the stations included in the polygon will appear. Select just the stations with at least five years of data and then click on **Access Data** at the bottom.

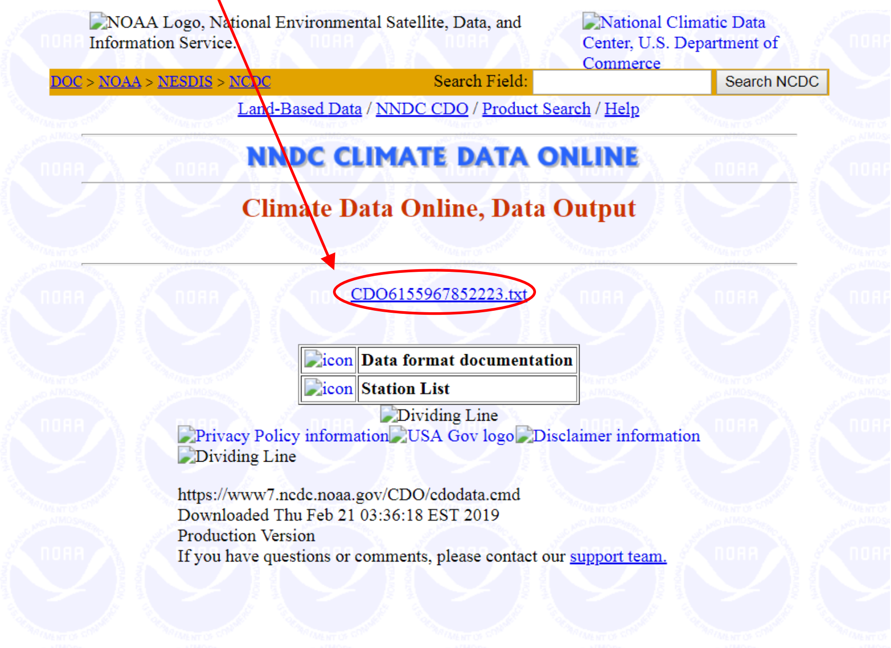


In the following window, click on ***"Agree"***.

8. In the next window, you will be asked to select the date range of the weather records of the station selected. Select 01/01/1949 and leave the date in the "To" row as it is. Select ***"comma delimited"*** under ***"Select output format".*** Mark the box under "I am not a robot" and then click continue.



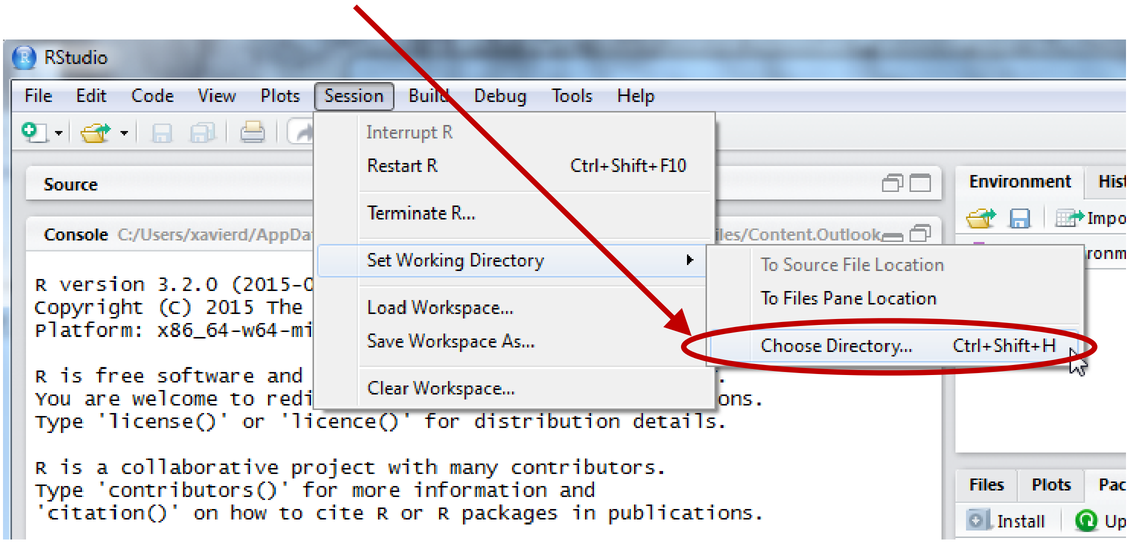
9. The dataset of the records selected will then available for download as a csv. Click on the link to the text file and select ***"Save link as"*** and save it in your working file ("data_downloaded.txt").



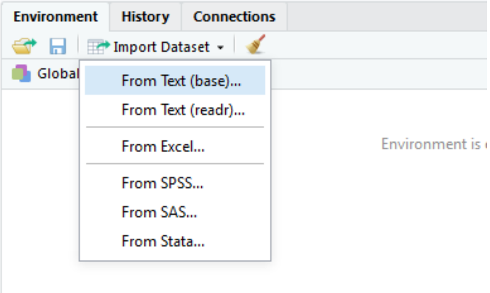
Steps to compute historical monthly wind speed averages from the daily wind speed data

Now that we have downloaded all the required data, we need to compute historical monthly wind speed averages from it. We will use R Software and R Studio (an R user interface) to do this.

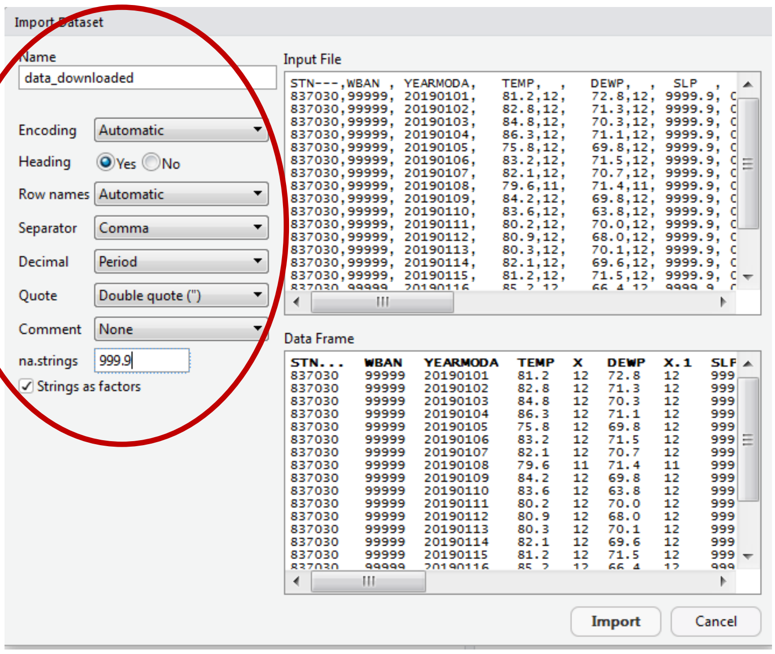
1. Open **R Studio** and set your working directory by going to **Session > Set Working Directory > Choose Directory.** Select the folder in which you have saved the weather data.



2. Now we are going to import the weather dataset file, "data_downloaded.txt". Under the 'Environment' tab in R studio window, click on ***"Import Dataset"*** and select **"From Text (base)"**



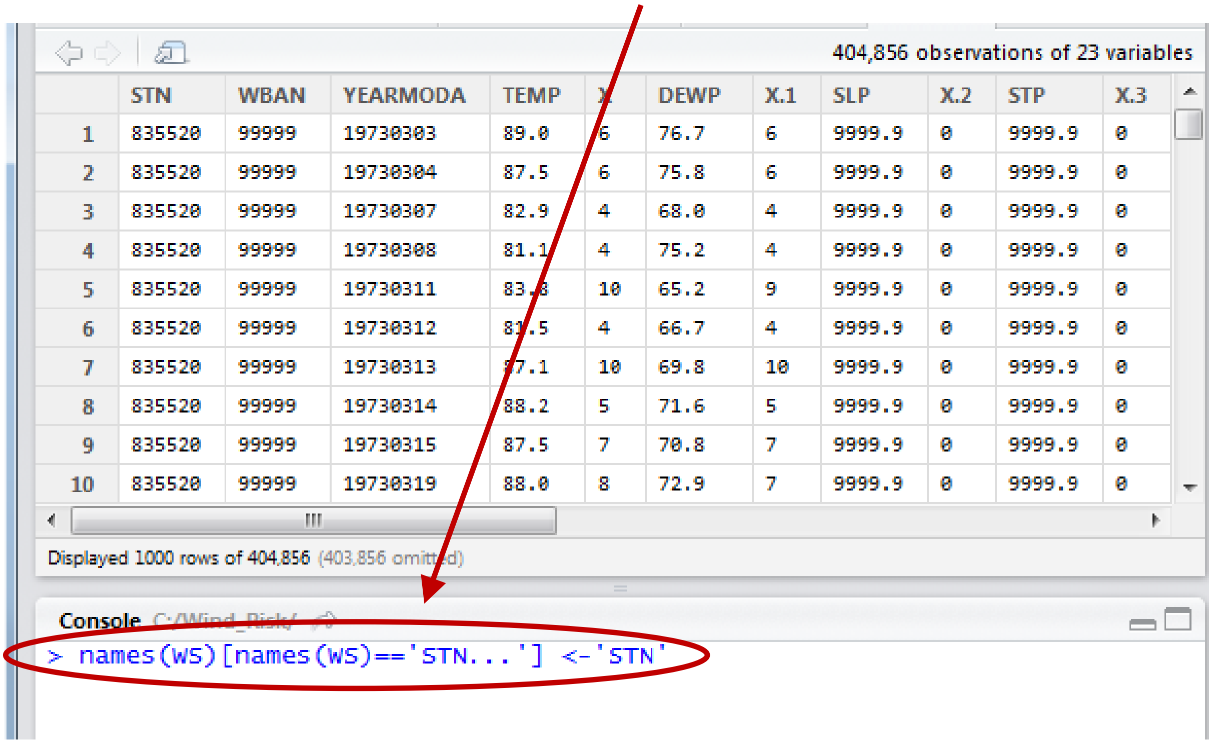
3. Select the dataset and ensure that the "***Separator***" is set as *"Comma"*, "***Decimal***" is set as *"Period"* and ***"na.strings"*** to *"999.9"*, which is the value to which our dataset assigns the missing values. Then click ***"Import".*** You can change the name of the dataset to something easier to work with (for example, WS).



You are now able to see the dataset in the viewer window. We are now going to select from the dataset our parameters of interest: the Station Code Number ("STN…"), the date of the observations ("YEARMODA") and the mean wind speed value ("WDSP").

4. Change the name of the station name column (STN…) to something simpler to work with (fnamWSor example: STN). To do that, write the following formula in the console window:

```
names(WS)[names(WS)=='STN...']<-'STN'
```

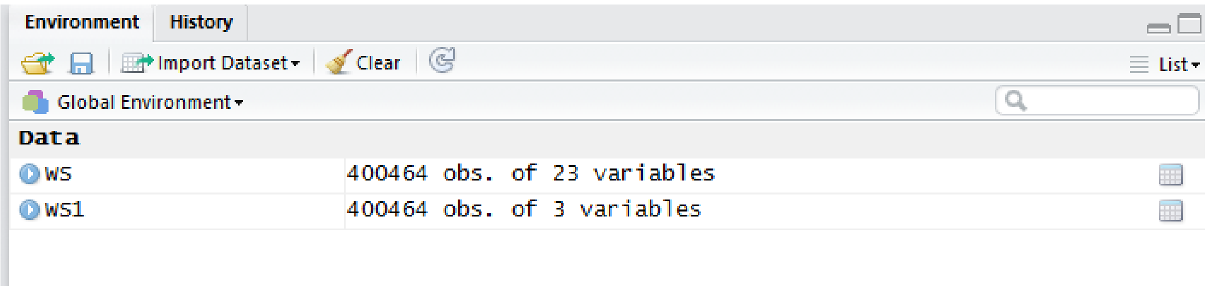


	STN	WBAN	YEARMODA	TEMP	X	DEWP	X.1	SLP	X.2	STP	X.3
1	835520	99999	19730303	89.0	6	76.7	6	9999.9	0	9999.9	0
2	835520	99999	19730304	87.5	6	75.8	6	9999.9	0	9999.9	0
3	835520	99999	19730307	82.9	4	68.0	4	9999.9	0	9999.9	0
4	835520	99999	19730308	81.1	4	75.2	4	9999.9	0	9999.9	0
5	835520	99999	19730311	83.8	10	65.2	9	9999.9	0	9999.9	0
6	835520	99999	19730312	81.5	4	66.7	4	9999.9	0	9999.9	0
7	835520	99999	19730313	87.1	10	69.8	10	9999.9	0	9999.9	0
8	835520	99999	19730314	88.2	5	71.6	5	9999.9	0	9999.9	0
9	835520	99999	19730315	87.5	7	70.8	7	9999.9	0	9999.9	0
10	835520	99999	19730319	88.0	8	72.9	7	9999.9	0	9999.9	0

5. Now, we are going to create a new data frame (WS1) containing only the three variables of interest (STN, YEARMODA and WDSP). To do that, write the following command in the console.

```
WS1<-WS[c("STN","YEARMODA","WDSP")]
```

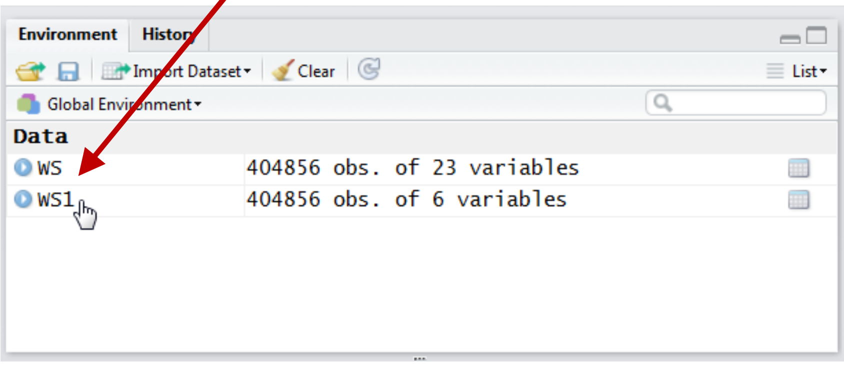
You should now see the following datasets (WS and WS1) in the Global Environment tab:



6. For computational purposes, the variable for the date of the observation (*YEARMODA*) must be split into three: year, month and day of observation. To do this, write the following formula into the Console window:

```
WS1$YEARMODA <- as.Date(as.character(WS1$YEARMODA), format='%Y%m%d')
WS1$YEAR <- format(WS1$YEARMODA, '%Y')
WS1$MONTH <- format(WS1$YEARMODA, '%m')
WS1$DAY <- format(WS1$YEARMODA, '%d')
```

Right click on the **WS1** data frame in **RStudio's data window** to see the changes made in the data frame.



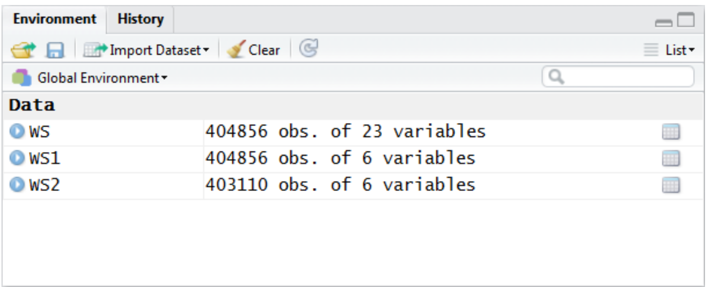
The WS1 dataset now shows the new variables created, YEAR, MONTH and DAY:

	STN	YEARMODA	WDSP	YEAR	MONTH	DAY
1	835520	1973-03-03	3.9	1973	03	03
2	835520	1973-03-04	2.9	1973	03	04
3	835520	1973-03-07	2.0	1973	03	07
4	835520	1973-03-08	999.9	1973	03	08
5	835520	1973-03-11	0.6	1973	03	11
6	835520	1973-03-12	2.9	1973	03	12
7	835520	1973-03-13	4.0	1973	03	13
8	835520	1973-03-14	4.5	1973	03	14

7. The WS dataset contains some no data values (recorded as 999.9). We need to remove these values from the dataset before any other calculation is made. A new data frame will be created (WS2), containing only valid observations. To do that, write the following command in the console:

```
WS2<- subset(WS1,WDSP!='999.9')
```

Note that you can now see WS2 in the Data window. The number of observations (obs.) included in WS2 has been reduced compared to WS1.



8. In the 'metadata' txt file downloaded in Step 8 of the section "Steps to download the daily wind speed data", you will see that wind speed values are in tenths of a knot (0.1 knots). The formula requires these values to be converted to meters per second (m/s). To convert these values to m/s and store them in a new column called 'WDSP_MS', write the following command in the console:

```
WS2$WDSP_MS <- with(WS2, WDSP*0.514444)
```

In the WS2 data tab you can now see a new column 'WDSP_MS' with new values for wind speed in m/s:

403,110 observations of 7 variables

	row.names	STN	YEARMODA	WDSP	YEAR	MONTH	DAY	WDSP_MS
1	1	835520	1973-03-03	3.9	1973	03	03	2.0063316
2	2	835520	1973-03-04	2.9	1973	03	04	1.4918876
3	3	835520	1973-03-07	2.0	1973	03	07	1.0288880
4	5	835520	1973-03-11	0.6	1973	03	11	0.3086664
5	6	835520	1973-03-12	2.9	1973	03	12	1.4918876
6	7	835520	1973-03-13	4.0	1973	03	13	2.0577760
7	8	835520	1973-03-14	4.5	1973	03	14	2.3149980
8	9	835520	1973-03-15	2.5	1973	03	15	1.2861100

We can now compute mean monthly wind speed values for each of the stations of the dataset.

Steps to compute mean monthly wind speed values

1. We will carry out this operation using a **dplyr** package, which is not included in the core R software. To install and load the **dplyr** package, write the following formula in the Console tab:

```
install.packages("dplyr")
```

The download process will start automatically. Once the process is finished, you should see the text below in the Console window:

```
package ‘assertthat’ successfully unpacked and MD5 sums checked
package ‘R6’ successfully unpacked and MD5 sums checked
package ‘Rcpp’ successfully unpacked and MD5 sums checked
package ‘magrittr’ successfully unpacked and MD5 sums checked
package ‘lazyeval’ successfully unpacked and MD5 sums checked
package ‘DBI’ successfully unpacked and MD5 sums checked
package ‘BH’ successfully unpacked and MD5 sums checked
package ‘dplyr’ successfully unpacked and MD5 sums checked

The downloaded binary packages are in
        C:\Users\yaras\AppData\Local\Temp\RtmpQV1ak4\downloaded_packages
```

This will also show you the directory of the downloaded package on your computer.

```
library ("dplyr")
```

2. Once the package is loaded, write the following command in the console:

```
> WS3<- WS2 %>%
+ group_by(STN,MONTH)%>%
+ summarize(mean_wdsp=mean(WDSP_MS))
```

This will calculate monthly average wind speed for each of the weather stations in the data frame and store the values in a new data frame called WS3. The new data frame will then look like this. In order to see the WS3 data frame, click on WS3 in the Global Environments window:

728 observations of 3 variables

	STN	MONTH	mean_wdsp
1	835520	01	2.2755391
2	835520	02	2.2527654
3	835520	03	2.0482009
4	835520	04	2.3552663
5	835520	05	2.6584370
6	835520	06	2.8245274
7	835520	07	2.9526125
8	835520	08	3.2044409

Add the geographical coordinates of the weather stations into the dataset

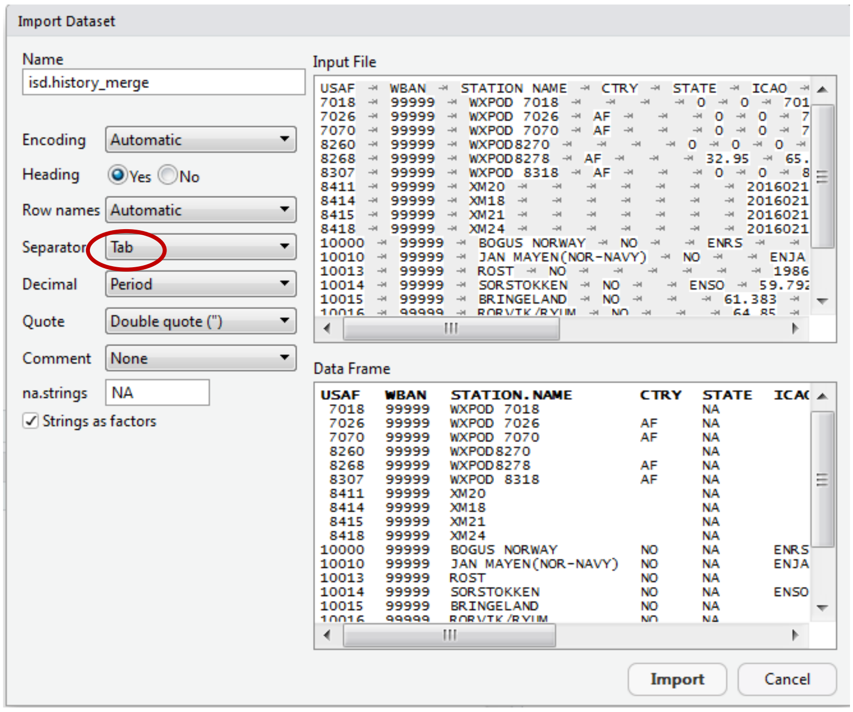
We now have the average wind speed values we were looking for, but before exporting the dataset we need to add further information in order to be able to perform the interpolation in QGIS. First, we need to add the geographical coordinates of each station. To do that, follow these steps:

1. Download the coordinate system data from this link: http://www1.ncdc.noaa.gov/pub/data/noaa/

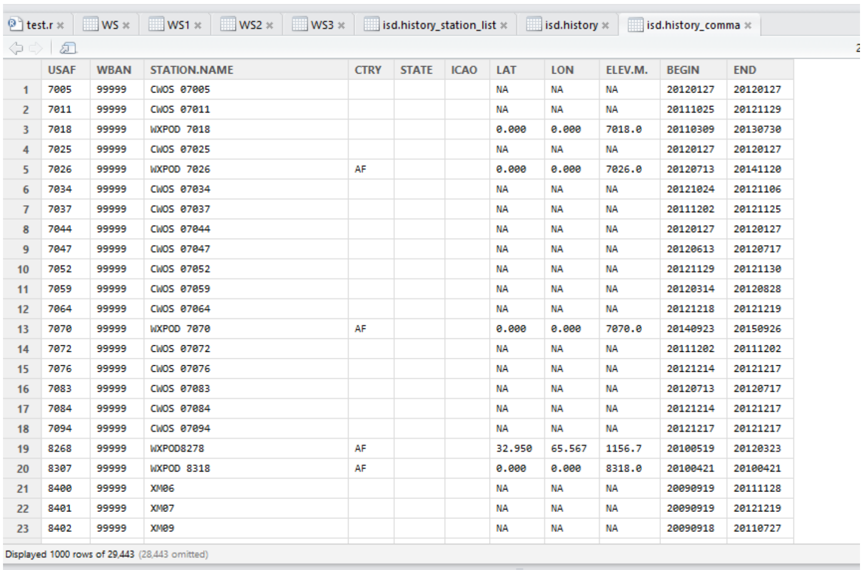
This website will provide access to many datasets and folders grouped into different years. Select the file called 'isd_history.csv' (or click here to download the data directly: http://www1.ncdc.noaa.gov/pub/data/noaa/isd-history.csv). The data is downloaded as a .csv file, comma delimited, which can be opened and viewed in R or Excel.

2. Open the csv data set, and save it as a text file, e.g. 'isd.history-merge.txt'.

3. In R, use the Import button to import the txt file. Use the parameters as shown in the image below:



You should now see the data in the data viewing window (top left), like this:



	USAF	WBAN	STATION.NAME	CTRY	STATE	ICAO	LAT	LON	ELEV.M.	BEGIN	END
1	7005	99999	CWOS 07005				NA	NA	NA	20120127	20120127
2	7011	99999	CWOS 07011				NA	NA	NA	20111025	20121129
3	7018	99999	WXPOD 7018				0.000	0.000	7018.0	20110309	20130730
4	7025	99999	CWOS 07025				NA	NA	NA	20120127	20120127
5	7026	99999	WXPOD 7026	AF			0.000	0.000	7026.0	20120713	20141120
6	7034	99999	CWOS 07034				NA	NA	NA	20121024	20121106
7	7037	99999	CWOS 07037				NA	NA	NA	20111202	20121125
8	7044	99999	CWOS 07044				NA	NA	NA	20120127	20120127
9	7047	99999	CWOS 07047				NA	NA	NA	20120613	20120717
10	7052	99999	CWOS 07052				NA	NA	NA	20121129	20121130
11	7059	99999	CWOS 07059				NA	NA	NA	20120314	20120828
12	7064	99999	CWOS 07064				NA	NA	NA	20121218	20121219
13	7070	99999	WXPOD 7070	AF			0.000	0.000	7070.0	20140923	20150926
14	7072	99999	CWOS 07072				NA	NA	NA	20111202	20111202
15	7076	99999	CWOS 07076				NA	NA	NA	20121214	20121217
16	7083	99999	CWOS 07083				NA	NA	NA	20120713	20120717
17	7084	99999	CWOS 07084				NA	NA	NA	20121214	20121217
18	7094	99999	CWOS 07094				NA	NA	NA	20121217	20121217
19	8268	99999	WXPOD8278	AF			32.950	65.567	1156.7	20100519	20120323
20	8307	99999	WXPOD 8318	AF			0.000	0.000	8318.0	20100421	20100421
21	8400	99999	XM06				NA	NA	NA	20090919	20111128
22	8401	99999	XM07				NA	NA	NA	20090919	20121219
23	8402	99999	XM09				NA	NA	NA	20090918	20110727

Displayed 1000 rows of 29,443 (28,443 omitted)

4. The station coordinate file ('isd.history-merge.txt') containing information of each station (its name, the country where is located and the geographic coordinates LAT and LONG) has now to be merged with the data frame containing information on mean_wdsp. R will use the station code, STN, as the union element from the 'WS3' data frame and the station code USAF from the 'isd.history-merge.txt' data frame. In order to perform this step write in the console window the command shown below:

```
> WS4<-merge(WS3,isd.history_merge,by.x="STN",by.y="USAF",all=FALSE)
```

This will create a new data frame, WS4, using the Station Code as a common key variable. The new dataset will look something similar to this:

728 observations of 7 variables

	STN	MONTH	mean_wdsp	STATION.NAME	CTR	LAT	LON
1	835520	01	2.2755391	CORUMBA INTL	BR	-19.012	-57.673
2	835520	02	2.2527654	CORUMBA INTL	BR	-19.012	-57.673
3	835520	03	2.0482009	CORUMBA INTL	BR	-19.012	-57.673
4	835520	04	2.3552663	CORUMBA INTL	BR	-19.012	-57.673
5	835520	05	2.6584370	CORUMBA INTL	BR	-19.012	-57.673
6	835520	06	2.8245274	CORUMBA INTL	BR	-19.012	-57.673
7	835520	07	2.9526125	CORUMBA INTL	BR	-19.012	-57.673
8	835520	08	3.2044409	CORUMBA INTL	BR	-19.012	-57.673
9	835520	09	3.2568618	CORUMBA INTL	BR	-19.012	-57.673
10	835520	10	2.9672184	CORUMBA INTL	BR	-19.012	-57.673

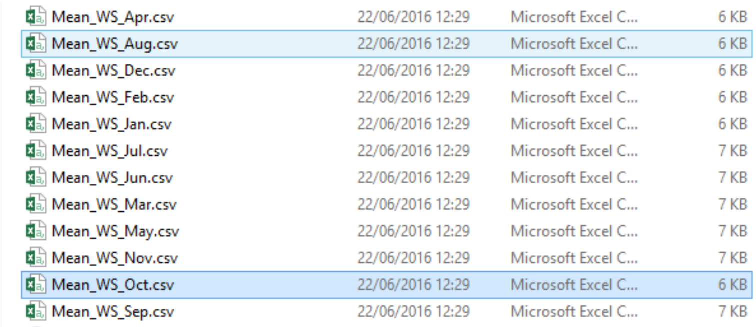
5. To facilitate the steps of the analysis performed with QGIS, we now need to split the dataset into one file for each month. To do that, write the following commands in the console:

```
WS_Jan <-subset(WS4,MONTH=='01')
WS_Feb <-subset(WS4,MONTH=='02')
WS_Mar <-subset(WS4,MONTH=='03')
WS_Apr <-subset(WS4,MONTH=='04')
WS_May <-subset(WS4,MONTH=='05')
WS_Jun <-subset(WS4,MONTH=='06')
WS_Jul <-subset(WS4,MONTH=='07')
WS_Aug <-subset(WS4,MONTH=='08')
WS_Sep <-subset(WS4,MONTH=='09')
WS_Oct <-subset(WS4,MONTH=='10')
WS_Nov <-subset(WS4,MONTH=='11')
WS_Dec <-subset(WS4,MONTH=='12')
```

Finally, export the datasets created through the following commands:

```
write.csv(WS_Jan, file='Mean_WS_Jan.csv')
write.csv(WS_Feb, file='Mean_WS_Feb.csv')
write.csv(WS_Mar, file='Mean_WS_Mar.csv')
write.csv(WS_Apr, file='Mean_WS_Apr.csv')
write.csv(WS_May, file='Mean_WS_May.csv')
write.csv(WS_Jun, file='Mean_WS_Jun.csv')
write.csv(WS_Jul, file='Mean_WS_Jul.csv')
write.csv(WS_Aug, file='Mean_WS_Aug.csv')
write.csv(WS_Sep, file='Mean_WS_Sep.csv')
write.csv(WS_Oct, file='Mean_WS_Oct.csv')
write.csv(WS_Nov, file='Mean_WS_Nov.csv')
write.csv(WS_Dec, file='Mean_WS_Dec.csv')
```

This will create a separate csv file for each of the months, which will also be saved in the workspace directory folder.

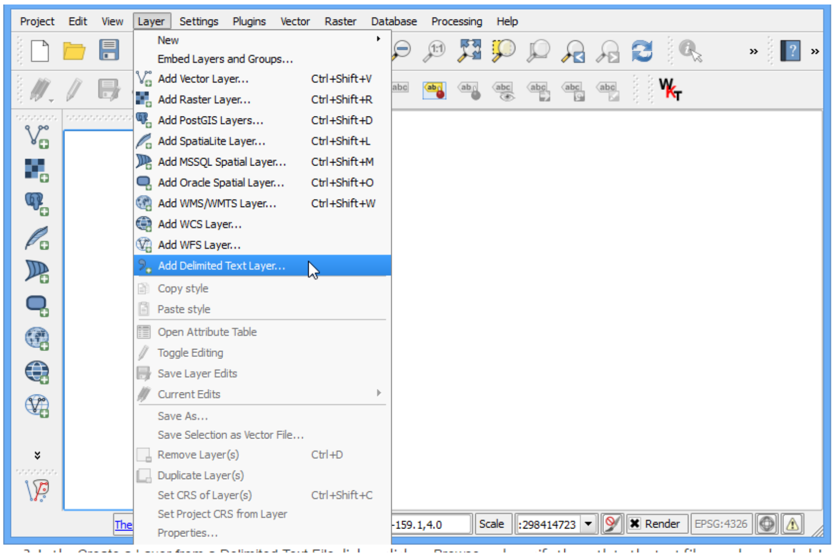


Develop continuous mean monthly wind speed surfaces for the study area

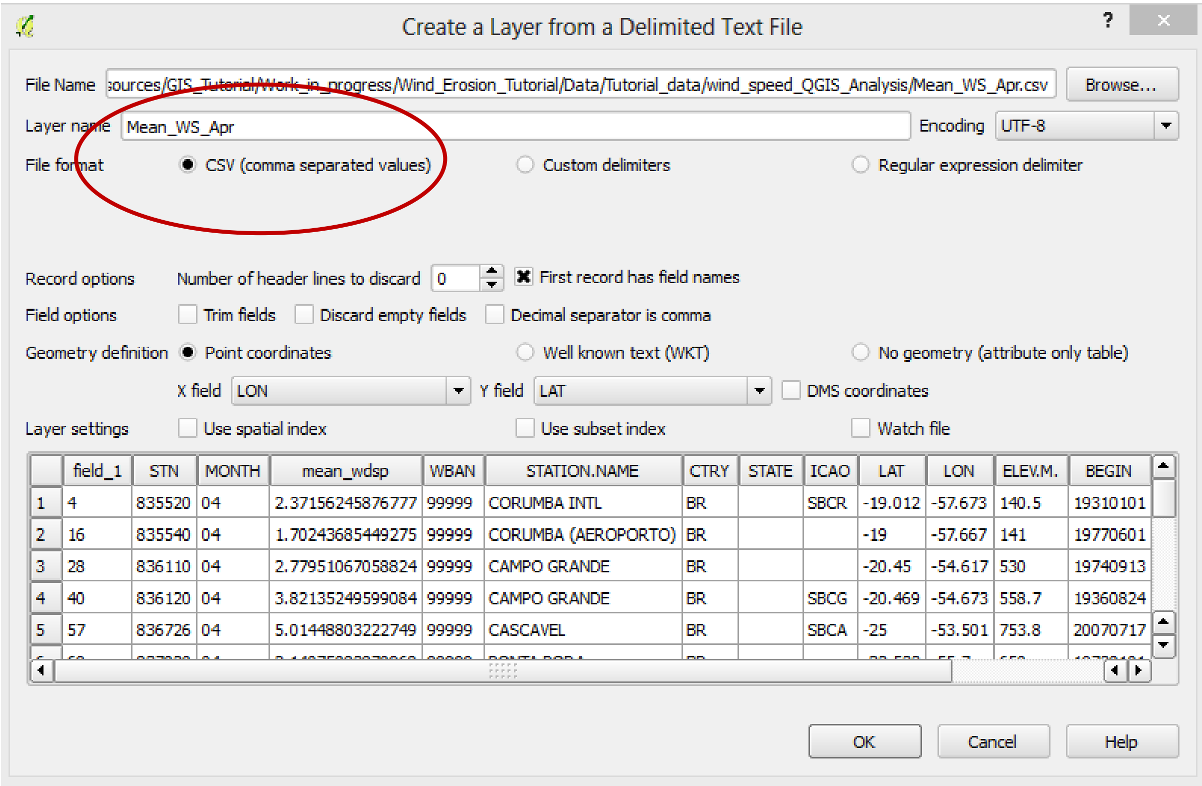
To develop a final climate layer covering the whole area of interest, is now necessary to estimate the average wind speed for the zones where weather stations are missing. To perform this analyses, we need to interpolate wind speed values for all the study area using geostatistical techniques. The preliminary step requires to import all the datasets exported in the previous step and convert them into point shapefiles using QGIS.

Follow the steps below, repeating them for every file of monthly wind speeds. At the end of the process you will have 12 separate files:

1. Select **'Layer' > 'Add Layer' > 'Add delimited text layer'**, as shown below:

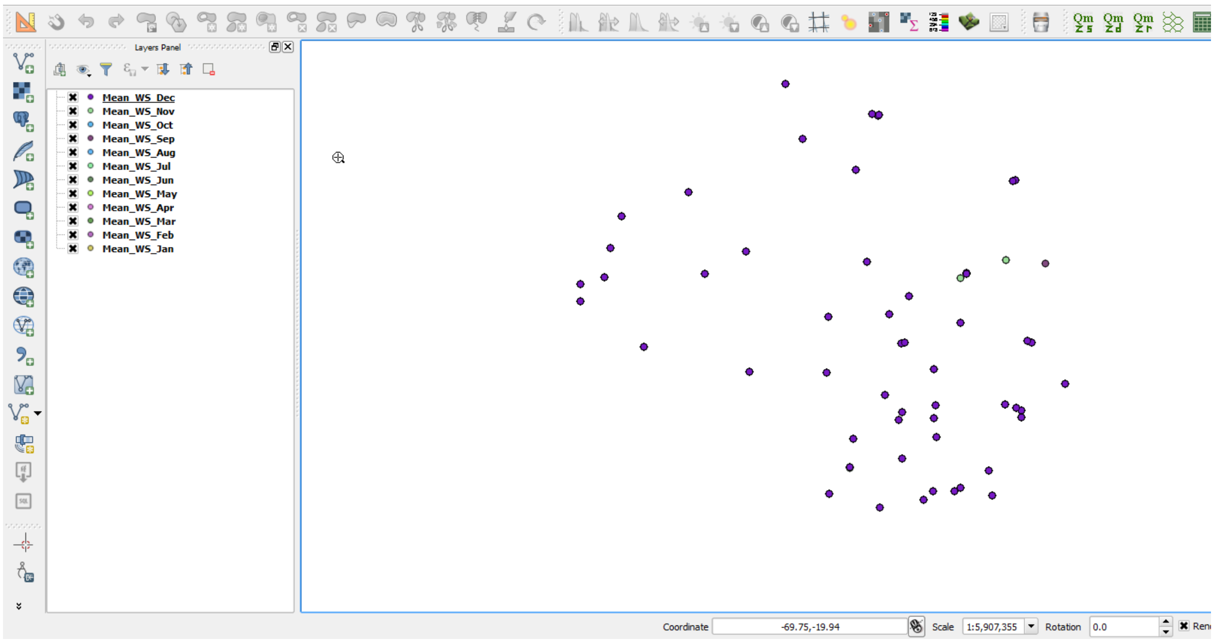


Select the parameters, using the CSV format (change the input layer name for each monthly dataset, e.g. "Mean_WS_Jan", "Mean_WS_Feb", etc.) as shown in the image below, and then click OK:

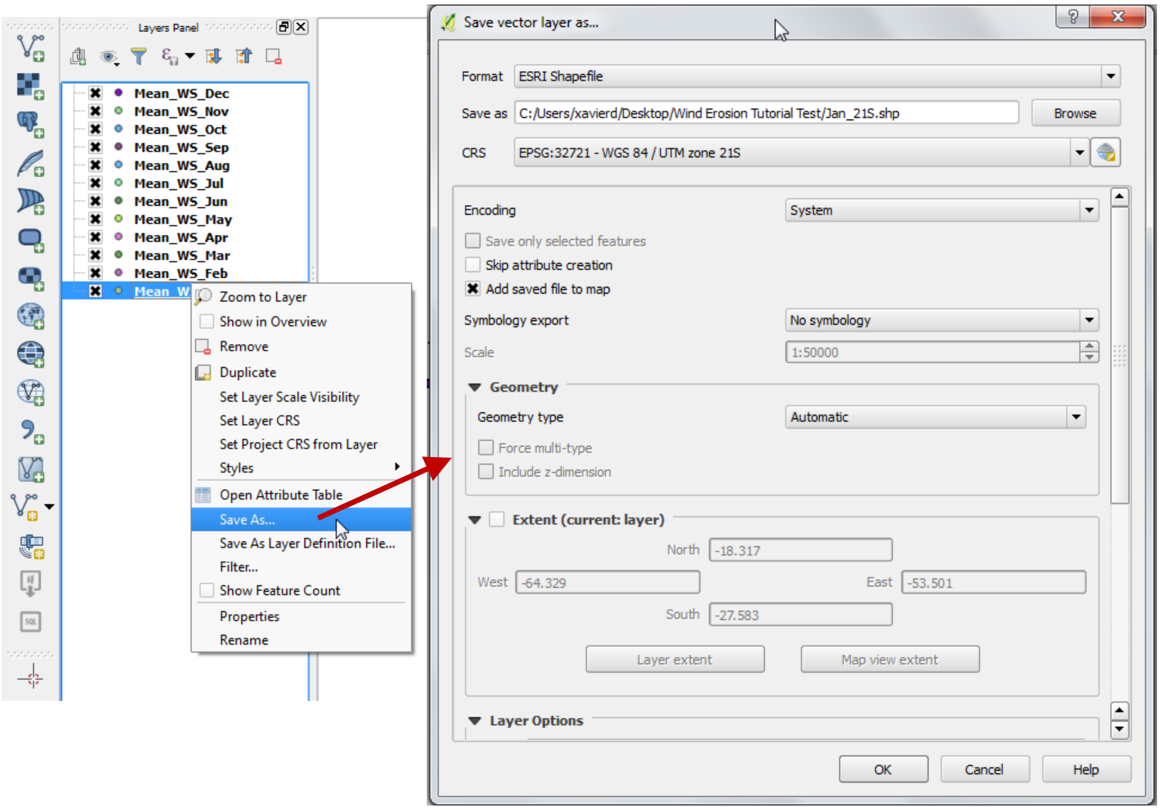


2. A Coordinate Reference System Selector will appear asking you to select a coordinate reference system. Since the wind speed coordinates are in latitudes and longitudes, you should select WGS 84. Click OK.

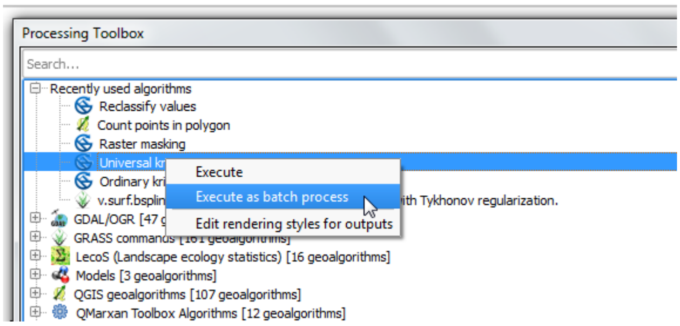
You should now have the point data loaded in QGIS, as in the image below:



3. The layers need now to be projected into a projected coordinate system. Right click on each layer and select "Save As…" a window will automatically appear. Select the folder to which you want to save the file, give it a name and select an appropriate projected coordinate system for your study area, in this case we will select WGS 84 UTM Zone 21S. Repeat for all twelve layers.

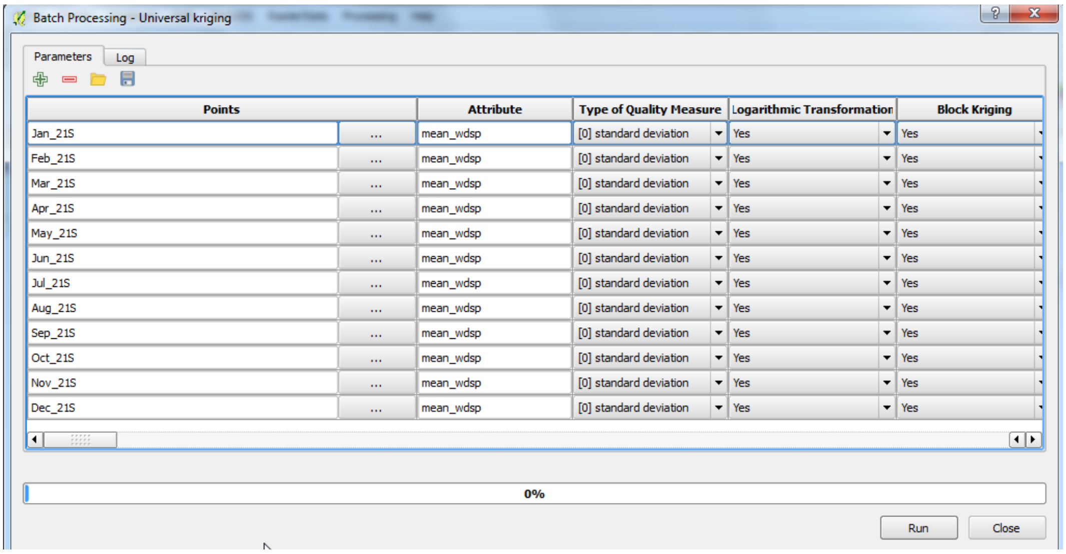


4. We are now going to apply the Universal Kriging technique to interpolate the monthly mean wind speed values. This particular technique has been chosen since is considered one of the most accurate techniques to spatially interpolate this kind of variable (Luo *et al.* 2007). To perform this analysis go to the processing toolbox and search for SAGA's Universal Kriging tool. Right click and select "Execute as batch process".

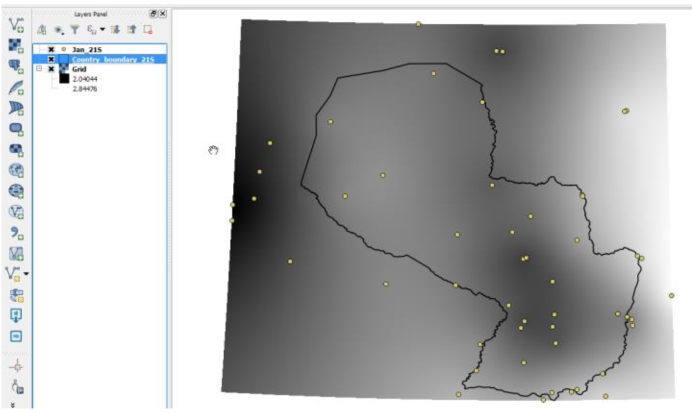


5. This action will open a new window, insert each one of the projected point shapefiles produced in the prior step. In **Attribute**, select the name of the column that contain the monthly mean wind speed values. In the **Resampling** column, choose "Inverse Distance Interpolation". In **Search Range**, choose "global". In **Number of Points,** select "All points

within search distance". In **Cell Size**, select 1000. Finally, in the **Prediction and Quality Measures** columns specify the folder in which you want to save the output files and give each file a name. Leave the other parameters as they are. (**TIP**: you can automatically fill the columns with the value of the first row by double clicking the head of the column). Then click **Run**.

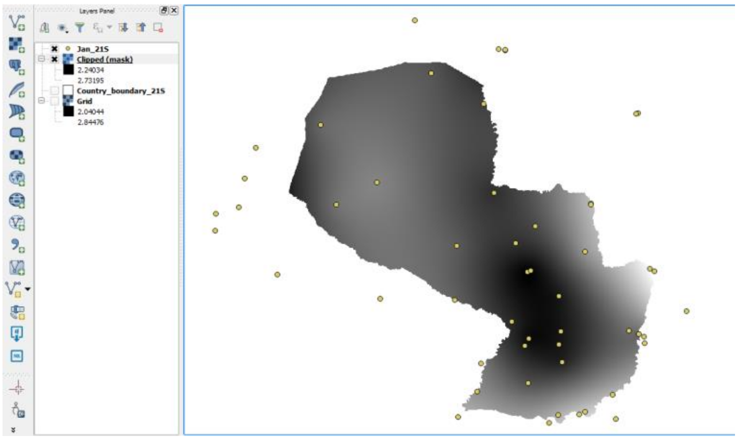


6. The layer you are interested in is the Prediction one, the second layer generated (Quality measures) just provides you with statistics on how well the prediction has been made. Interpolation does not give accurate results outside the collection area, so let's clip the resulting surfaces with the study area boundary. To do that, we need to load a shapefile of the area of interest. Click on **'Layer' > 'Add Layer' > 'Add Vector Layer'.**



7. Go to **Processing -> Toolbox** and search for **Clip raster by mask layer.** Rick click and select **"Execute as a batch process".** In the **Input layer** column, select each of the recently created wind speed raster layers, in consecutive order. In the **Mask layer** column, select the shapefile of your study area. Then, select the folder and name of the 12 clipped layers in the **Clipped (mask)** column. Select "**Yes**" under **"Crop the extent of the target dataset to the extent of**

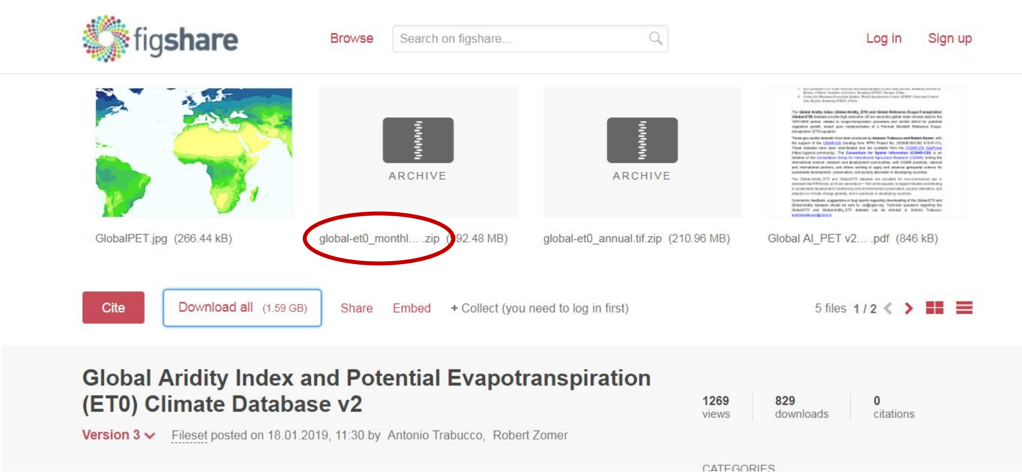
the cutline" and leave the other parameters as they are. Once done, click **Run**. The interpolated data will now be cut to the region of interest:



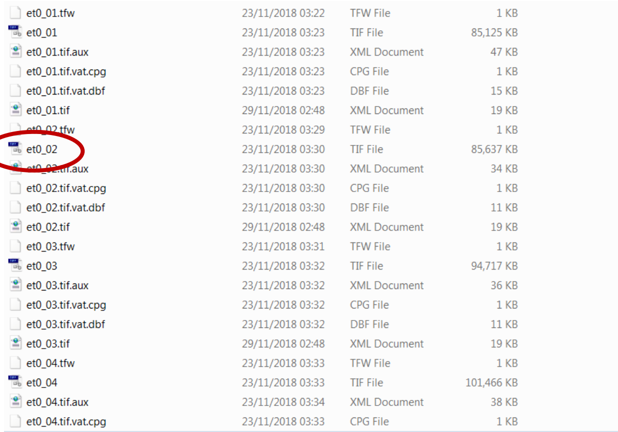
3.1.2 Extract Potential Evapotranspiration (*PETi*) data

To be able to make the calculation as per the initial formula for climate erosivity (see Page 2), we need monthly potential evaporation data *PETi* (mm).

1. PET data can be downloaded from the [CGIAR-CSI Global PET Database.]

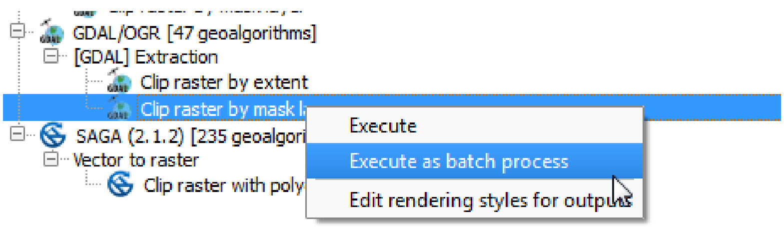


2. Select the "global_et0_monthly.tif.zip" to download and save in your working folder. Unzip the files.
3. Open the 12 raster files in QGIS. Select the 12 tif files (the number corresponds to the month).

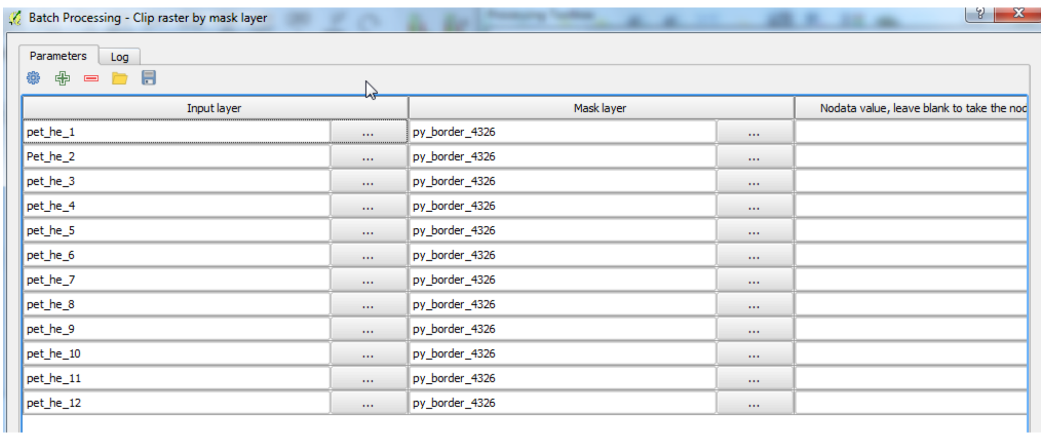


et0_01.tfw	23/11/2018 03:22	TFW File	1 KB
et0_01	23/11/2018 03:23	TIF File	85,125 KB
et0_01.tif.aux	23/11/2018 03:23	XML Document	47 KB
et0_01.tif.vat.cpg	23/11/2018 03:23	CPG File	1 KB
et0_01.tif.vat.dbf	23/11/2018 03:23	DBF File	15 KB
et0_01.tif	29/11/2018 02:48	XML Document	19 KB
et0_02.tfw	23/11/2018 03:29	TFW File	1 KB
et0_02	23/11/2018 03:30	TIF File	85,637 KB
et0_02.tif.aux	23/11/2018 03:30	XML Document	34 KB
et0_02.tif.vat.cpg	23/11/2018 03:30	CPG File	1 KB
et0_02.tif.vat.dbf	23/11/2018 03:30	DBF File	11 KB
et0_02.tif	29/11/2018 02:48	XML Document	19 KB
et0_03.tfw	23/11/2018 03:31	TFW File	1 KB
et0_03	23/11/2018 03:32	TIF File	94,717 KB
et0_03.tif.aux	23/11/2018 03:32	XML Document	36 KB
et0_03.tif.vat.cpg	23/11/2018 03:32	CPG File	1 KB
et0_03.tif.vat.dbf	23/11/2018 03:32	DBF File	11 KB
et0_03.tif	29/11/2018 02:48	XML Document	19 KB
et0_04.tfw	23/11/2018 03:33	TFW File	1 KB
et0_04	23/11/2018 03:33	TIF File	101,466 KB
et0_04.tif.aux	23/11/2018 03:34	XML Document	38 KB
et0_04.tif.vat.cpg	23/11/2018 03:33	CPG File	1 KB

4. Once all PET files are open, we need to clip them to the study area border. Open a shapefile of the study area and ensure that it is in the same projection as the PET layers (EPGS 4326). To do that go to **Processing -> Toolbox** and search for **Clip raster by mask layer**. Right click on it and select **Execute as batch process.**

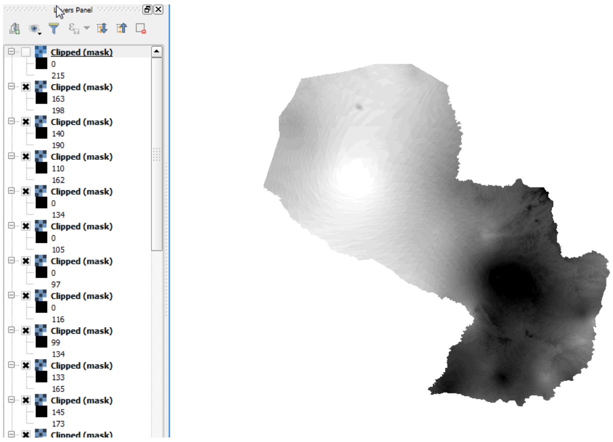


5. In the **Input layer** column, select each of the PET raster layers, in consecutive order. In the **mask layer** column, select the shapefile of your study area. Then, select the folder and name of the 12 clipped layers in the **Clipped (mask)** column. Leave the rest as it is. Once done, click **Run**.



Input layer		Mask layer		Nodata value, leave blank to take the noc
pet_he_1	...	py_border_4326	...	
Pet_he_2	...	py_border_4326	...	
pet_he_3	...	py_border_4326	...	
pet_he_4	...	py_border_4326	...	
pet_he_5	...	py_border_4326	...	
pet_he_6	...	py_border_4326	...	
pet_he_7	...	py_border_4326	...	
pet_he_8	...	py_border_4326	...	
pet_he_9	...	py_border_4326	...	
pet_he_10	...	py_border_4326	...	
pet_he_11	...	py_border_4326	...	
pet_he_12	...	py_border_4326	...	

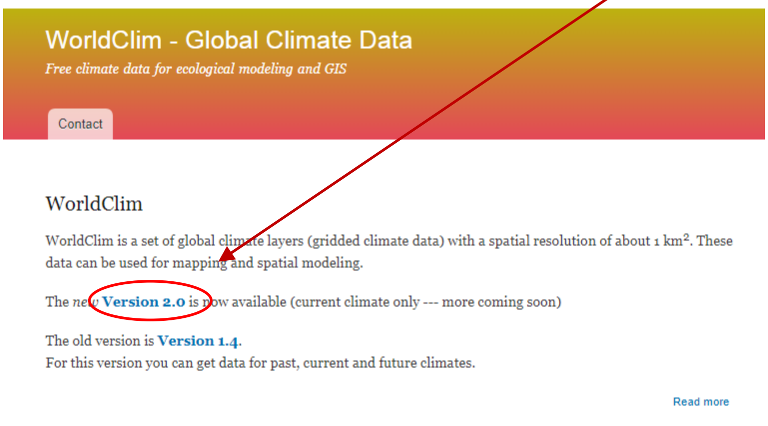
6. QGIS will automatically clip the twelve PET layers to the shape of your study area and save the resulting files in the folder that you specified. The result will be something similar to this:



3.1.3 Extract monthly average precipitation (*Pi*) for your study area

The climate erosivity formula also requires monthly average precipitation (*Pi*) values. If a gridded precipitation layer is not available for your study area, it is possible to extract this data from a global dataset, called WorldClim, following the steps described below:

1. Go to WorldClim (www.worldclim.org), click **Version 2.0.**



2. This will take you to the download page for climate data at different resolutions. Click on the relative link to download raster data for precipitation at the required resolution, in this example, we will select the 30 sec resolution.

variable	10 minutes	5 minutes	2.5 minutes	30 seconds
minimum temperature (°C)	tmin 10m	tmin 5m	tmin 2.5m	tmin 30s
maximum temperature (°C)	tmax 10m	tmax 5m	tmax 2.5m	tmax 30s
average temperature (°C)	tavg 10m	tavg 5m	tavg 2.5m	tavg 30s
precipitation (mm)	prec 10m	prec 5m	prec 2.5m	prec 30s
solar radiation (kJ m^{-2} day^{-1})	srad 10m	srad 5m	srad 2.5m	srad 30s
wind speed (m s^{-1})	wind 10m	wind 5m	wind 2.5m	wind 30s
water vapor pressure (kPa)	vapr 10m	vapr 5m	vapr 2.5m	vapr 30s

The download of a zip file including precipitation layers for each month of the year, numbered 1 to 12, will start.

3. Unzip these files, upload them in QGIS and clip them to the shape of your study area following the same steps described in the previous section.

3.1.4 Use Raster Calculator to compute the climatic 'C' factor layer

Now that we have all the required variables, we can calculate the C factor as per the initial formula using Raster Calculator in QGIS:

$$C = \frac{1}{100} \times \sum_{i=1}^{12} u^3 \left(\frac{PETi - Pi}{PETi}\right) d$$

The 3 sets of monthly layers (windspeed, precipitation and EvapoTranspiration) prepared in the previous steps will be used as input layers in Raster Calculator.
To perform the analysis follow the instructions below:

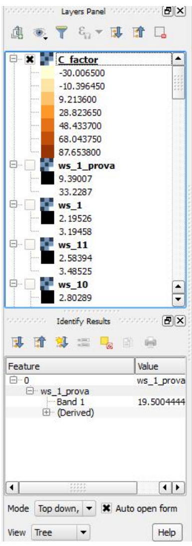
1. Open the 3 set of layers in QGIS. Ensure that they all have the same extent, resolution and are in the same projection.

2. Open the Raster Calculator tool in QGIS, clicking on 'Raster' → 'Raster Calculator'.

3. Write the formula in the raster calculator expression, following the example below. Call the output layer "C_factor" and saved it in your working folder.

```
((("ws_1@1"^3) * (( "pet_1@1" - "prec_1@1") / "pet_1@1")*31) + (("ws_2@1"^3) * (( "pet_2@1" - "prec_2@1") / "pet_2@1")*28) + (("ws_3@1"^3) * (( "pet_3@1" - "prec_3@1") / "pet_3@1")*31) + (("ws_4@1"^3) * (( "pet_4@1" - "prec_4@1") / "pet_4@1")*30) + (("ws_5@1"^3) * (( "pet_5@1" - "prec_5@1") / "pet_5@1")*31) + (("ws_6@1"^3) * (( "pet_6@1" - "prec_6@1") / "pet_6@1")*30) + (("ws_7@1"^3) * (( "pet_7@1" - "prec_7@1") / "pet_7@1")*31) + (("ws_8@1"^3) * (( "pet_8@1" - "prec_8@1") / "pet_8@1")*31) + (("ws_9@1"^3) * (( "pet_9@1" - "prec_9@1") / "pet_9@1")*30) + (("ws_10@1"^3) * (( "pet_10@1" - "prec_10@1") / "pet_10@1")*31) + (("ws_11@1"^3) * (( "pet_11@1" - "prec_11@1") / "pet_11@1")*30) + (("ws_12@1"^3) * (( "pet_12@1" - "prec_12@1") / "pet_12@1")*31)) / 100
```

4. The resulting map will look similar to the one shown on the side. The higher the value is (in dark orange), the higher is expected to be the climatic tendency to produce conditions conducive to wind erosion.

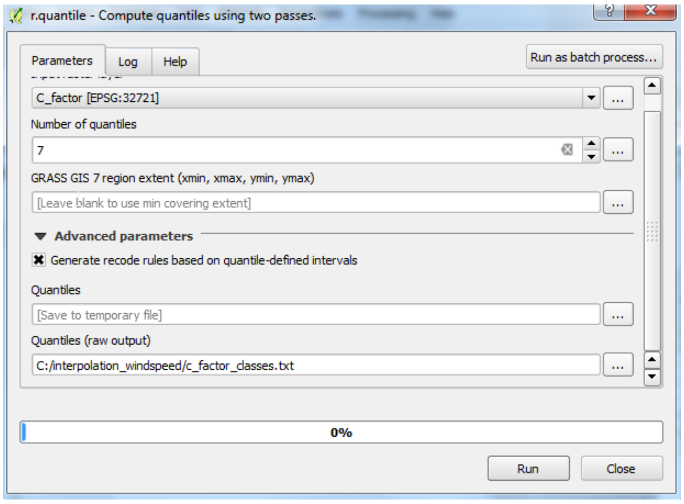


3.1.5 Re-classify the ‘C’ factor layer into classes for analysis

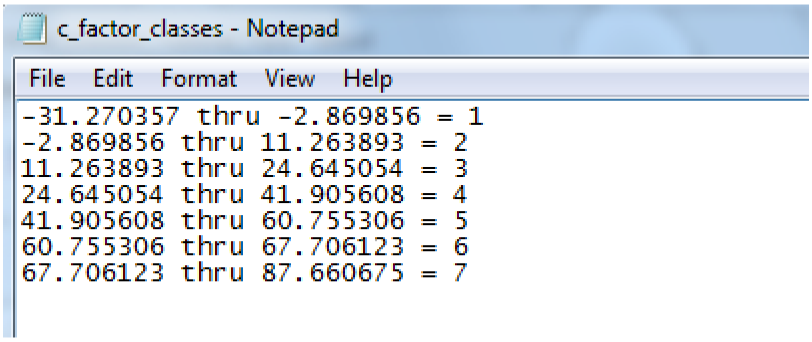
Finally, we need to reclassify the C factor layer into classes, so as to be able to perform the final function which will produce a layer with different classes of wind erosion sensitivity.

First, we will compute the interval classes that will be utilised to reclassify the C factor layer:

1. In the processing toolbox, open the **r.quantile** tool. This tool computes quantiles (intervals that contains equal number of features) in a dataset. In **Input raster layer** select the recently created C_factor layer. In **Number of quantiles**, enter “7”. Thick on Generate recode values based on quantile-defined intervals. Finally in **Quantiles (raw output)** specify the path where to save the output file.



2. There are various reclassification tools in QGIS. We will use the **r.reclass** tool, which requires a text file (.txt) where the user defines the rules for reclassification. To prepare the reclassification rule text file, open the text file created in the previous step and use the intervals to specify the classes, as shown in the image below:


c_factor_classes - Notepad

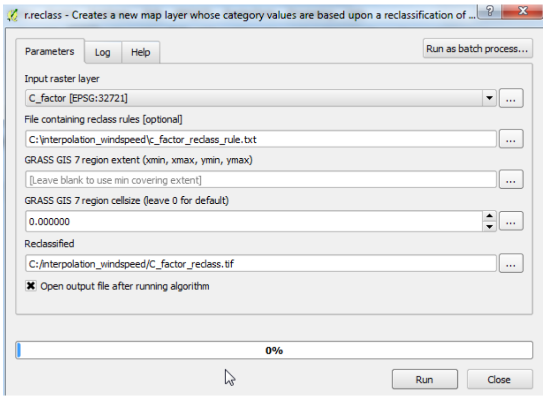
File Edit Format View Help

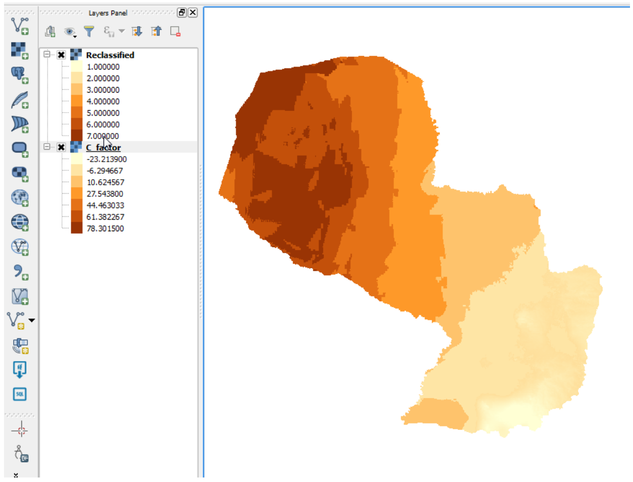
```
-31.270357 thru -2.869856 = 1
-2.869856 thru 11.263893 = 2
11.263893 thru 24.645054 = 3
24.645054 thru 41.905608 = 4
41.905608 thru 60.755306 = 5
60.755306 thru 67.706123 = 6
67.706123 thru 87.660675 = 7
```

* Always ensure to reclassify values in ascending rank, the interval containing the highest values is reclassified to “7”, the second one to “6”, and so on.

When done, save the file as C_factor_reclass_rule.txt

3. Now open the **r.reclass** tool. In **Input Raster** window, enter the C_factor raster file and in **File containing reclass rules**, select the reclass rule text file created in the previous step (C_factor_reclass_rule.txt). Click **Run**. The output file would be similar to the one below.





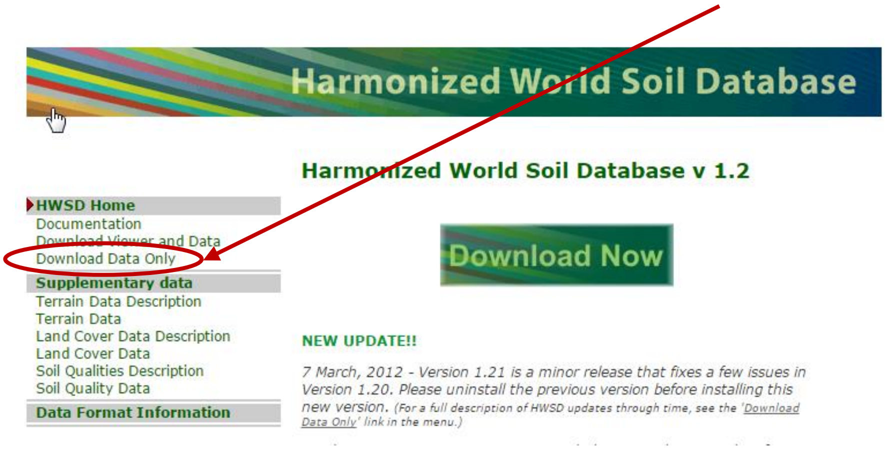
3.2. Create the soil wind erodibility (I') layer

Soil wind erodibility is directly related to the percentage of soil aggregates larger than 0.84 mm in diameter. Based on this indicator, the US Department of Agriculture (USDA), classified the soils into 7 soil wind erodibility classes, based on soil texture and soil carbonate content ($CaCO_3$). The classification goes from 1 (highly susceptible to wind erosion) to 7 (no susceptible to wind erosion).

WEG	Properties of Soil Surface Layer	Dry Soil Aggregates >0.84mm Percent	Wind Erod. Index (I) T/Ac/Yr
1	Very fine sand, fine sand, sand, or coarse sand.	1	310 (a)
		2	250
		3	220
		5	180
		7	160
2	Loamy very fine sand, loamy fine sand, loamy sand, loamy coarse sand, or sapric (1) organic soil materials.	10	134
3	Very fine sandy loam, fine sandy loam, sandy loam, or coarse sandy loamy.	25	86
4	Clay, silty clay, noncalcareous clay loam, or silty clay loam with >35 percent clay content.	25	86
4L	Calcareous (b) loam, silt loam, clay loam, or silty clay loam.	25	86
5	Non calcareous loam and silt loam with <20 percent clay content, or sandy clay loam, sandy clay, and hemic (1) organic soil materials.	40	56
6	Noncalcareous loam and silt loam with >20 percent clay content, or noncalcareous clay loam with <35 percent clay content.	45	48
7	Silt, noncalcareous silty clay loam with >35 percent clay content and fibric (1) organic soil material.	50	38
8	Soils not susceptible to wind erosion due to coarse fragments or wetness	--	0

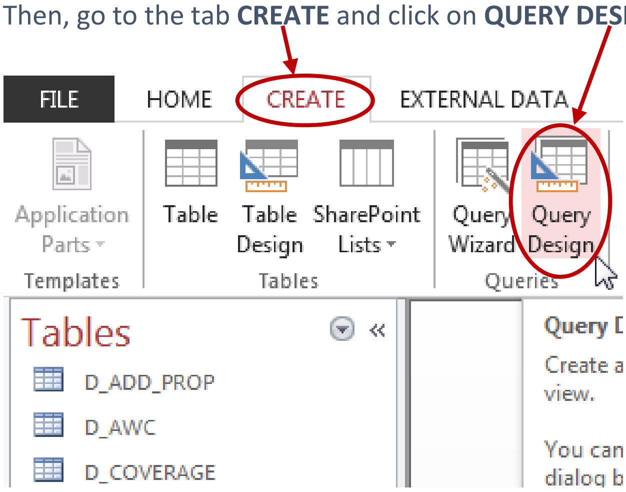
In order to create the soil wind erodibility layer, you would need a soil map for the study area with information on soil texture and carbonate content. This part of the tutorial will show you how to obtain this data from the Harmonized World Soil Database (HWSDA). The HWSD is a 30 arc-second raster database that combines existing regional and national updates of soil information worldwide.

1. Go to http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/index.html?sb=1 and click on Download Data only.



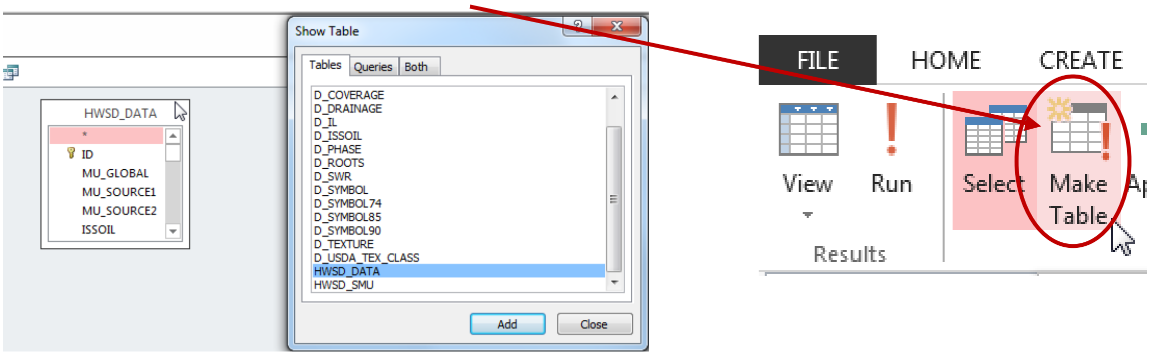
2. The HWSD includes a raster image file and a linked attribute database. In the next window, download the HWSD_RASTER.zip and the HWSD.mbd files.
3. We now need to query the HWSD.mbd database in Microsoft Access to obtain the Soil texture values that will allow to determine to which Wind Erodibility Group they pertain. To do that, open the HWSD.mb in Microsoft Access.

4. Then, go to the tab **CREATE** and click on **QUERY DESIGN**

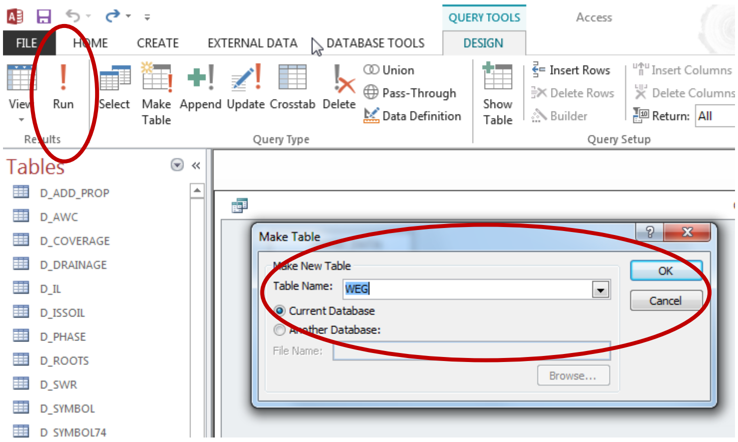


5. A new screen will automatically appear, in the table pick **HWSD_DATA** and click on **Add**

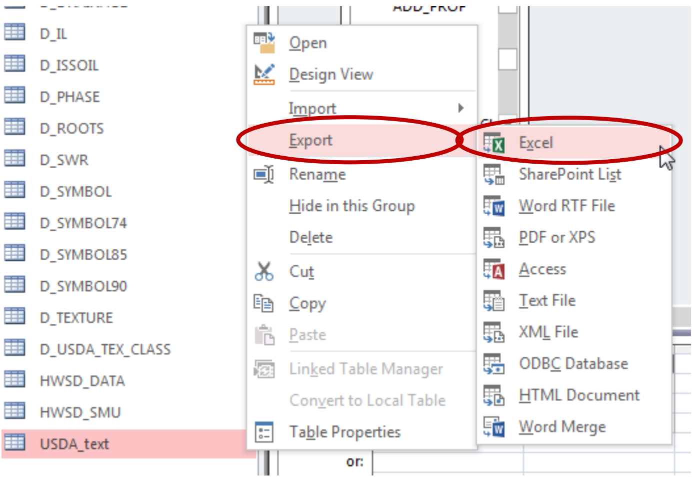
6. The HWSD_DATA table will appear in the workspace. A small panel will appear, double click in this order **MU_GLOBAL**, **T_USDA_TEX_CLASS**, **T_CACO3** and **T_CLAY**. These 4 variables will be added in the table located at the bottom. Now click on the **Make Table** command.



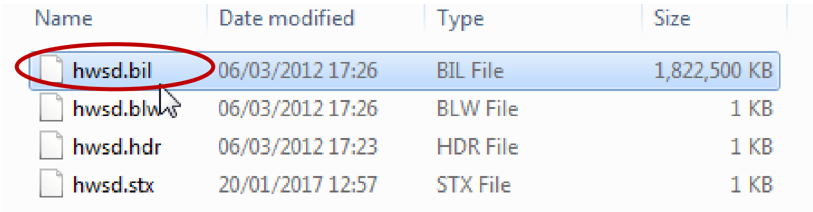
7. Give the table a name (for example WEG) and click OK. Then click on the **Run** button on the top bar.



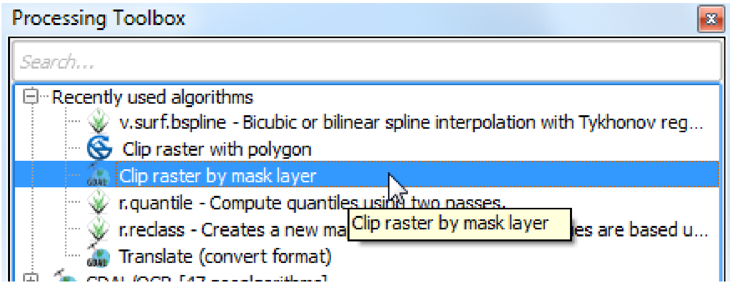
8. The new table will be created and will automatically appear in the table list at the left. Now, right click on it, select **Export** and then **Excel.** Save it in your working folder. When done, open the file in Microsoft Excel and save it in CSV format.



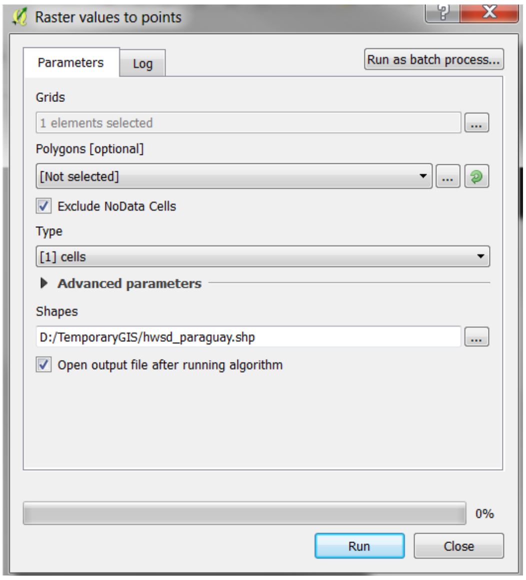
9. Now, unzip HWSD_RASTER.zip and upload hwsd.bil in QGIS. Convert it into Geotiff format by right clicking on the layer and selecting **Save As…**



10. Upload a shapefile of your study area to cut out the hwsd.tiff file created in the previous step to the shape of your study area using GDAL's **Clip Raster by mask layer tool.**

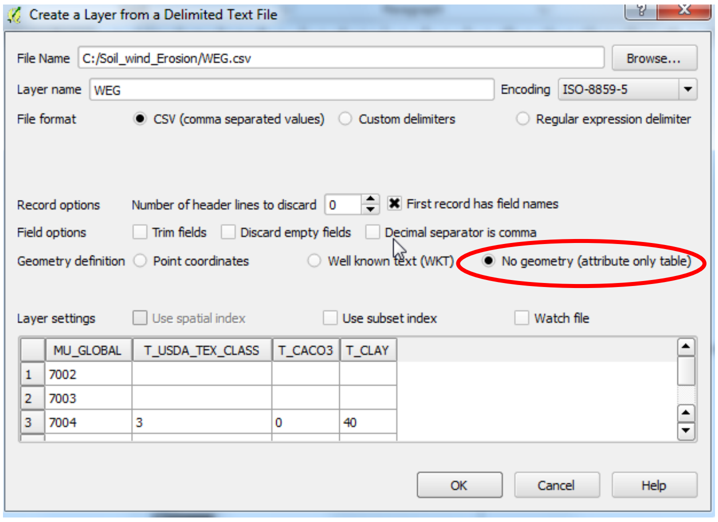


11. Now, we need to convert the output raster file to a point shapefile in order to join it with the excel file created in Access before. To do that, go to the Processing Toolbox window and open the **Raster values to points** tool in Saga. In the **Grids** window, select the raster layer created in the previous step. In Type, select **"cells".** In Shapes, specify the name of the **output** layer and then click **Run**.

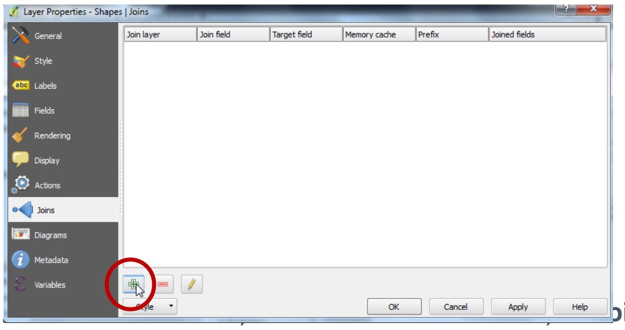


12. When the process is finished, upload the output file in QGIS. Go to the processing toolbox and open the **Refactor fields** tool. This tool is useful to edit the structure attribute table of vector files. Change the name of the variable "clippedmask" to MU_GLOBAL and click on **Run**.

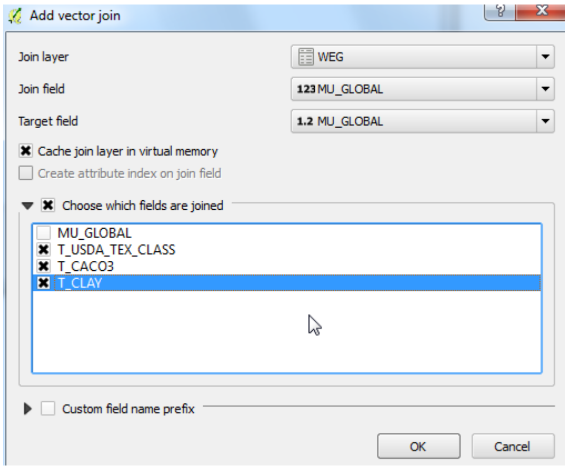
13. Now open the csv file containing the USDA soil texture values (remember to have previously saved the Excel file exported from Access as csv file). To do that, go to **Layer > Add Layer > Add Delimited Text Layer.** In **Geometry Definition**, select **No Geometry (attribute only table).** Then, click OK.



14. Now, right click on the point shapefile created in step 12 and go to **Properties**, and then **Joins.** Then click on the green "**+**" sign button.



15. oin layer. In **Join field** (the common field between both datasets), select MU_GLOBAL, and in **Target field** select MU_GLOBAL again. Then, click **Choose which fields are joined** and select T_USDA_TEXT_CLASS, T_CACO3 and T_CLAY. Save it under a new name and in a projected coordinate system.



16. Now the soil texture and carbonate data will be used to reclassify the map into the Wind Erodibility groups defined by the USDA. To do that you first need to know, how this information is codified in the database. This is explained in the database documentation (available at http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HWSD_Documentation.pdf), and is the following:

T_USDA_TEX_CLASS: The values in this fields contains 13 possible classes of soil texture, which are codified in the following way:

Code	Texture
1	clay (heavy)
2	silty clay
3	clay
4	silty clay loam
5	clay loam
6	silt
7	silt loam
8	sandy clay
9	loam
10	sandy clay loam
11	sandy loam
12	loamy sand
13	sand

T_CACO3: The values in this field represent % of weight. We will use this information to determine if a soil is calcareous or non-calcareous, which is a parameter needed to determine the corresponding wind erodibily group of some soil texture classes. For the purposes of this work, we will assume that all soils with more than 15% of $CaCO_3$ are calcareous, as defined by the FAO (FAO 2016).

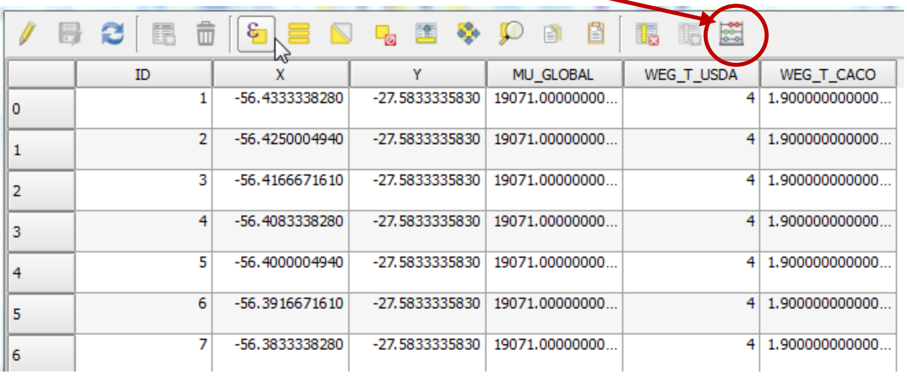
To be consistent in the re-classification process through this methodology, we will consider 7 classes of soil wind erodibiliy in ascending order, from 1 (low susceptibility to wind erosion) to 7 (high susceptibility to wind erosion), as we did in the C factor map; therefore inverting the classes described below (i.e. class 1 'very fine sand, fine sand, sand, or coarse sand' will become class 7 for our analysis, as sandy soils are most sensitive to wind erosion).

New classes	WEG	Properties of Soil Surface Layer	Dry Soil Aggregates >0.84mm Percent	Wind Erod. Index (I) T/Ac/Yr
7	1	Very fine sand, fine sand, sand, or coarse sand.	1 2 3 5 7	310 (a) 250 220 180 160
6	2	Loamy very fine sand, loamy fine sand, loamy sand, loamy coarse sand, or sapric (1) organic soil materials.	10	134
5	3	Very fine sandy loam, fine sandy loam, sandy loam, or coarse sandy loamy.	25	86
4	4	Clay, silty clay, noncalcareous clay loam, or silty clay loam with >35 percent clay content.	25	86
4	4L	Calcareous (b) loam, silt loam, clay loam, or silty clay loam.	25	86
3	5	Non calcareous loam and silt loam with <20 percent clay content, or sandy clay loam, sandy clay, and hemic (1) organic soil materials.	40	56
2	6	Noncalcareous loam and silt loam with >20 percent clay content, or noncalcareous clay loam with <35 percent clay content.	45	48
1	7	Silt, noncalcareous silty clay loam with >35 percent clay content and fibric (1) organic soil material.	50	38
NA	8	Soils not susceptible to wind erosion due to coarse fragments or wetness	--	0

Groups 4 and 4L will be combined into one, group 4.

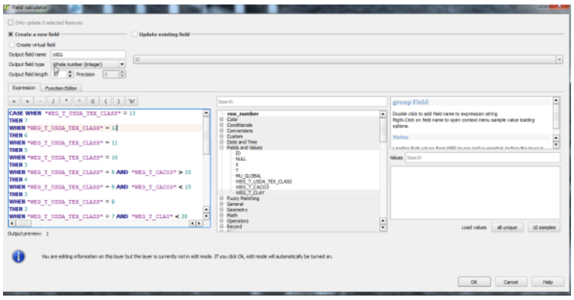
Group 8 is not relevant to this analysis and we will therefore not consider it

To do that, open the attribute table of the point shapefile created in the step 15 and click on **field calculator**. This tool allows to perform calculations on the basis of existing attributes values or functions.



	ID	X	Y	MU_GLOBAL	WEG_T_USDA	WEG_T_CACO
0	1	-56.4333338280	-27.5833335830	19071.00000000...	4	1.900000000000...
1	2	-56.4250004940	-27.5833335830	19071.00000000...	4	1.900000000000...
2	3	-56.4166671610	-27.5833335830	19071.00000000...	4	1.900000000000...
3	4	-56.4083338280	-27.5833335830	19071.00000000...	4	1.900000000000...
4	5	-56.4000004940	-27.5833335830	19071.00000000...	4	1.900000000000...
5	6	-56.3916671610	-27.5833335830	19071.00000000...	4	1.900000000000...
6	7	-56.3833338280	-27.5833335830	19071.00000000...	4	1.900000000000...

17. In the next window, click on **Create new field**. In the **Output field name** insert WEG.



18. In the Expression window, insert the text below. This function will automatically compute the corresponding WEG value based on the values of USDA texture classes, $CaCO_3$ and Clay content, as defined in the WEG table included in the previous page.

```
CASE WHEN "WEG_T_USDA_TEX_CLASS" = 13
THEN 7
WHEN "WEG_T_USDA_TEX_CLASS" = 12
THEN 6
WHEN "WEG_T_USDA_TEX_CLASS" = 11
THEN 5
WHEN "WEG_T_USDA_TEX_CLASS" = 10
THEN 3
WHEN "WEG_T_USDA_TEX_CLASS" = 9 AND "WEG_T_CACO3" > 15
THEN 4
WHEN "WEG_T_USDA_TEX_CLASS" = 9 AND "WEG_T_CACO3" < 15
THEN 3
WHEN "WEG_T_USDA_TEX_CLASS" = 8
THEN 3
WHEN "WEG_T_USDA_TEX_CLASS" = 7 AND "WEG_T_CLAY" < 20
THEN 3
WHEN "WEG_T_USDA_TEX_CLASS" = 7 AND "WEG_T_CLAY" > 20
THEN 2
WHEN "WEG_T_USDA_TEX_CLASS" = 6
THEN 1
WHEN "WEG_T_USDA_TEX_CLASS" = 5
THEN 4
WHEN "WEG_T_USDA_TEX_CLASS" = 4 AND "WEG_T_CLAY" > 35 AND "WEG_T_CACO3" < 15
THEN 1
WHEN "WEG_T_USDA_TEX_CLASS" = 4 AND "WEG_T_CLAY" > 35 AND "WEG_T_CACO3" > 15
THEN 4
WHEN "WEG_T_USDA_TEX_CLASS" = 4 AND "WEG_T_CLAY" < 35
THEN 4
WHEN "WEG_T_USDA_TEX_CLASS" = 3
THEN 4
```

This part of the code, says: When the USDA Texture class is 13 (sand), insert “7” (Highly susceptible to wind erosion) in the WEG column.

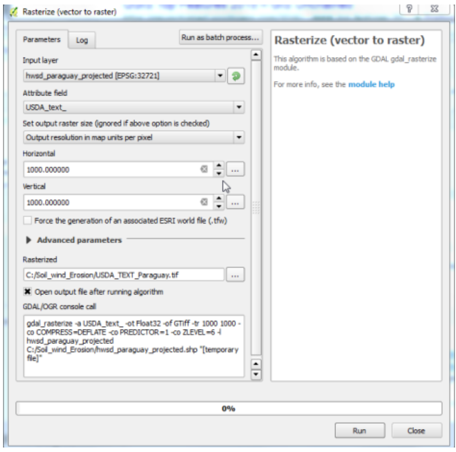
This part of the code, says: When the USDA Texture class is 9 (loam), and $CaCO_3$ is higher than 15% (calcareous) insert “4”. If USDA Texture class is 9 (loam), and $CaCO_3$ is smaller than 15% (non-calcareous) then insert 3.

```
WHEN "WEG_T_USDA_TEX_CLASS" = 2
THEN 4
WHEN "WEG_T_USDA_TEX_CLASS" = 1
THEN 4
END
```

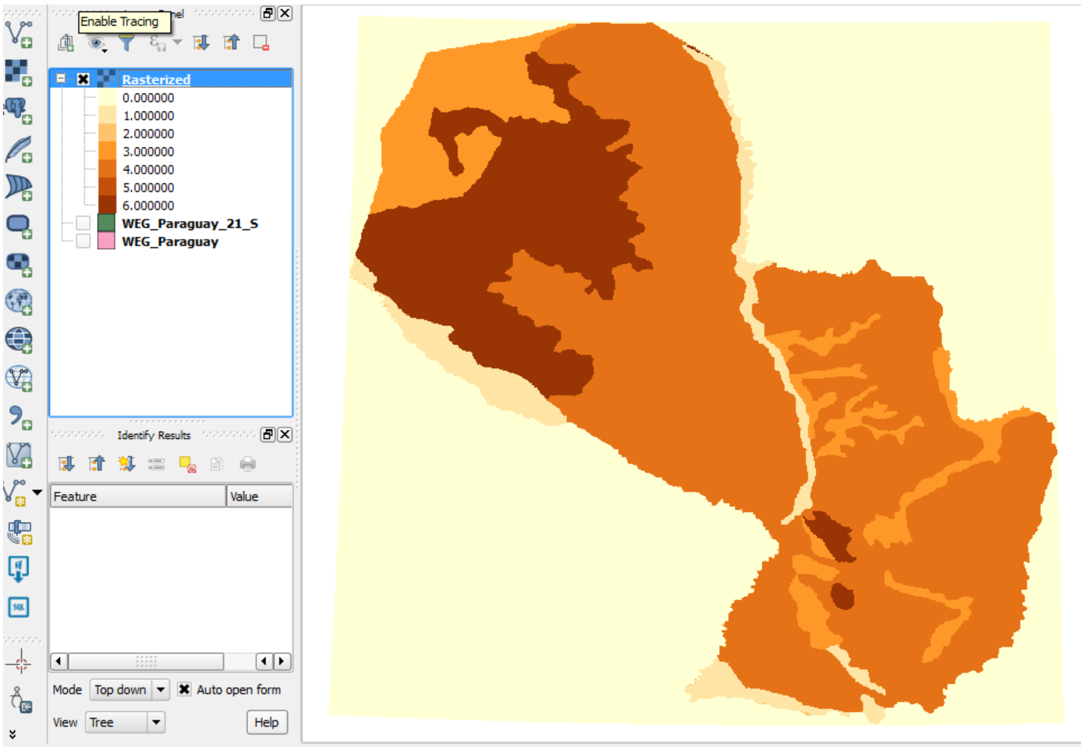
This will classify all points for which USDA texture class is 1 (clay) as 4 in the WEG column and then close the function.

Then click **OK.** QGIS will create a column named "WEG" and automatically populate it following the criteria established in the code. This may take a few minutes. Then click **Save**.

19. Once the previous step is completed, we need to convert the point shapefile layer into a raster file again. The **Rasterize (vector to raster)** tool can be used to perform this step. In **Input layer**, select the projected point shapefile created in the previous step. In **Attribute field**, select the soil texture variable (WEG), then select an appropriate raster resolution for your study area. In our case, we will set it to 1000 x 1000 meters. Give the output file a name and click **Run.**



You have just created a soil texture map for your study area, as it is shown in the image below.

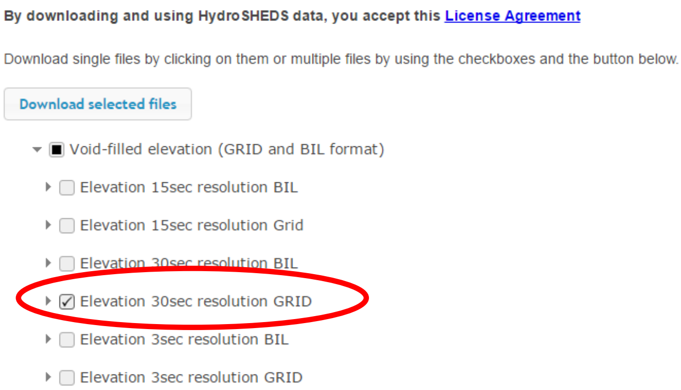


Note, in this analysis, there are only 6 classes because those are the soil types present in our study area, Paraguay.

3.3. Create the Topography (K') layer

The more "rough" the surface is, the lower is the wind speed, hence the wind erodibility will decrease. To estimate surface roughness, a DEM dataset can be used to compute the Terrain Ruggedness Index (TRI) developed by Riley *et al.* (1999). This index computes the difference between the value of each cell and the mean of an 8-cell neighbourhood of surrounding cells and classifies its values in seven classes (from "level" to "extremely rugged"). To create a Terrain Ruggedness Index map for your study area, follow the steps described below:

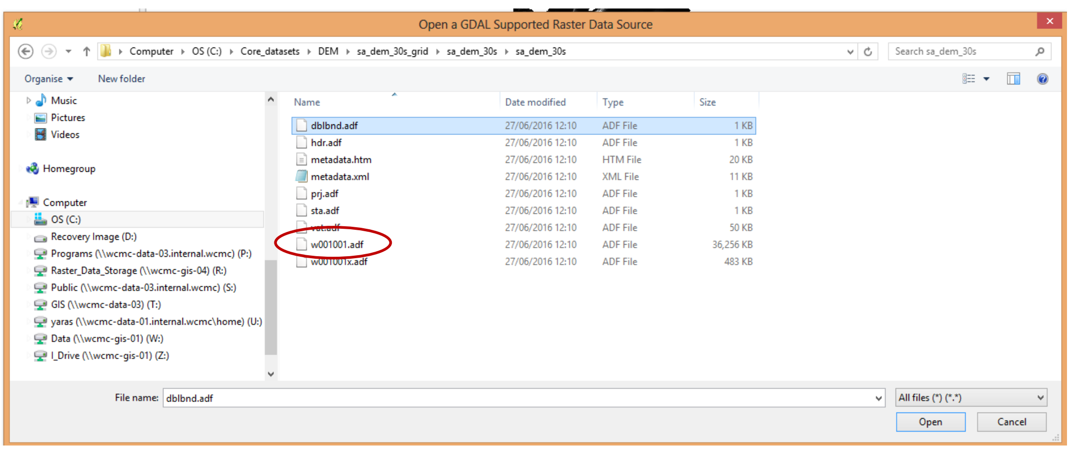
1. Upload a DEM for your study area. If not available, go to http://www.hydrosheds.org/download select **Void-filled elevation** and then **Elevation 30 sec resolution GRID.** Then select the one that covers your study area (in the case of Paraguay, we will choose **sa_dem_30s_grip.zip**



2. This will download a zip file. You must store the file and extract all data (right click, then select **Extract All**...) in order to open the DEM data in QGIS.

3. Open QGIS and add the DEM data as a 'raster layer'. To do this, click on **Layer** in the tools bar at the top of the document, then click **Add Layer** and select **Add Raster Layer...** from the drop-down menu.

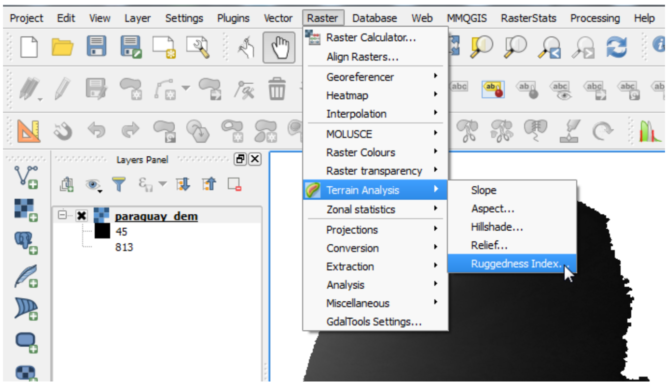
4. You can then browse to the folder location where the DEM is saved. The DEM raster is located within the sa_dem_30s sub-folder. Within that folder, click on any of the files, and click **Open**.



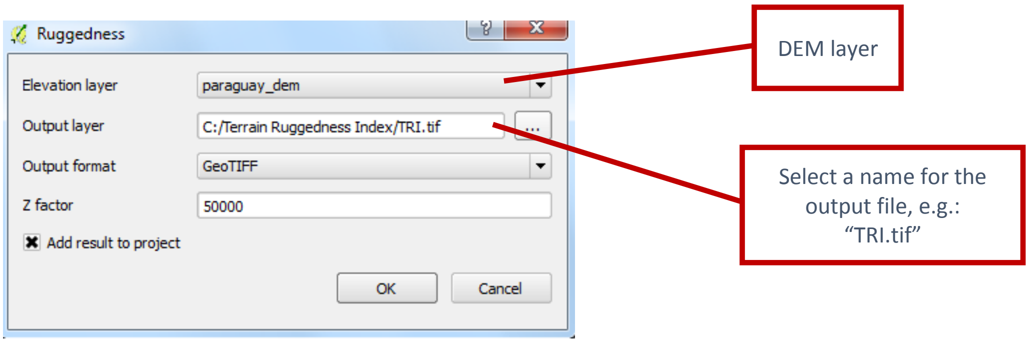
You will now have the DEM layer in your QGIS.

5. Clip the DEM to the shape of your study area, using GDAL's **Clip Raster by mask layer** tool as done in previous steps.

6. To calculate the terrain ruggedness index, go to **Raster > Terrain Analysis > Ruggedness Index.**



Load the Raster Terrain Analysis plugin in the Plugin Manager. Go to **Raster > Terrain Analysis > Ruggedness Index**. Fill in the tool dialogue box as shown below and click OK:



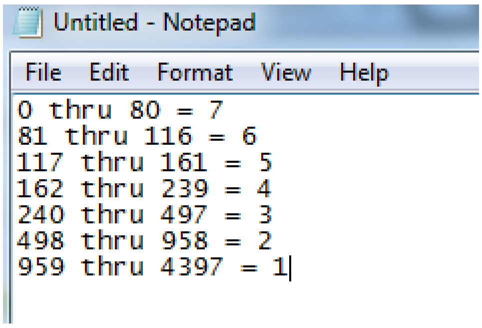
You should now have a new raster layer with values within the index. In our case, the values range from 0 to 572.228

7. We now need to reclassify the final layer into 7 classes. We will use the classification suggested by Riley et al. (the authors of this index) and re-classify the layer into 7 classes, where 7 indicates low ruggedness index values, meaning a higher sensitivity to wind erosion.

Ruggedness Classification	Ruggedness Index Value
Level	0 – 80m
Nearly Level	81 – 116m
Slightly Rugged	117 – 161m
Intermediately Rugged	162 – 239m
Moderately Rugged	240 – 497m
Highly Rugged	498 – 958m
Extremely Rugged	959 – 4397m

(Source: https://planet.qgis.org/planet/tag/terrain%20analysis/)

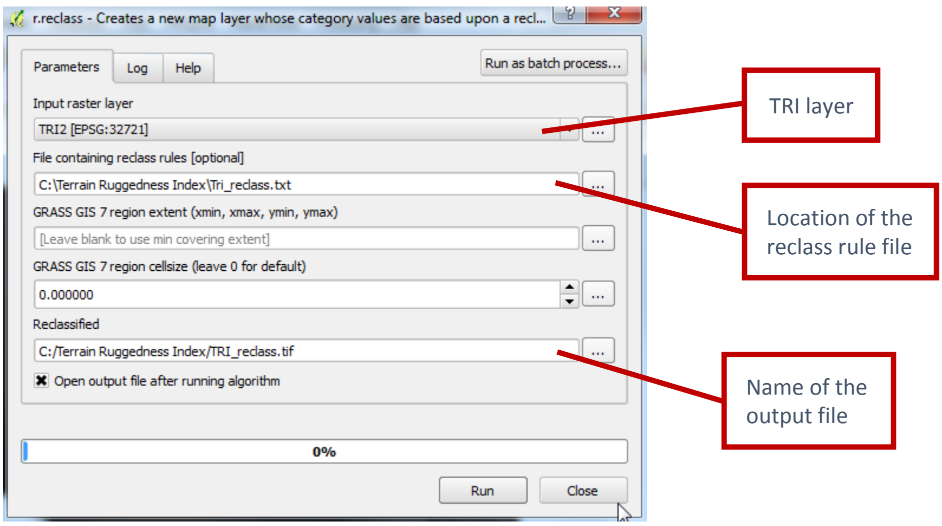
To reclassify the layer, open a text editor and create a reclass rule text file, using the as shown below:


Untitled - Notepad
File Edit Format View Help

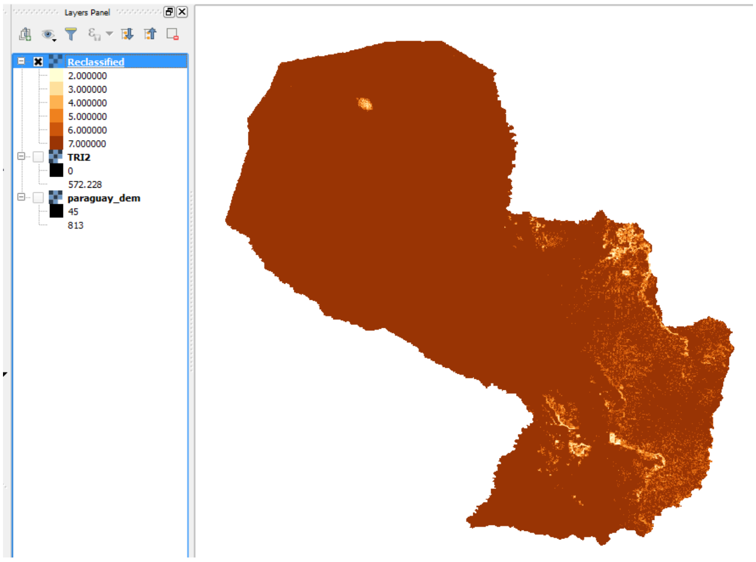
```
0 thru 80 = 7
81 thru 116 = 6
117 thru 161 = 5
162 thru 239 = 4
240 thru 497 = 3
498 thru 958 = 2
959 thru 4397 = 1
```

Then save the file with the name TRI-reclass.txt

8. Open the **r.reclass** tool to reclassify the Terrain Ruggedness Index into 7 classes.



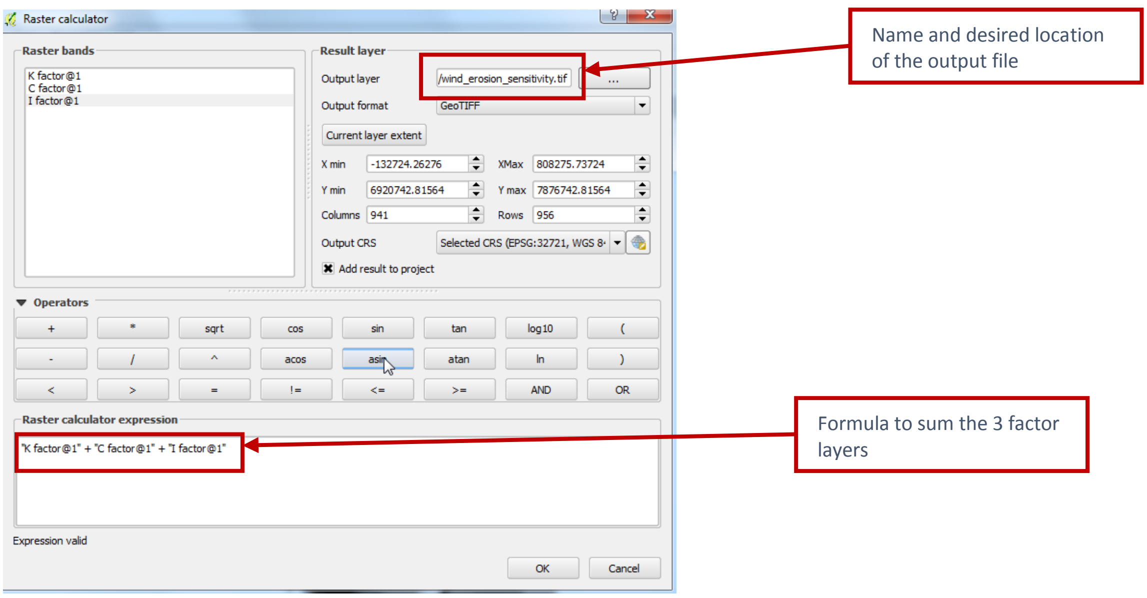
You will obtain something similar to the image below:



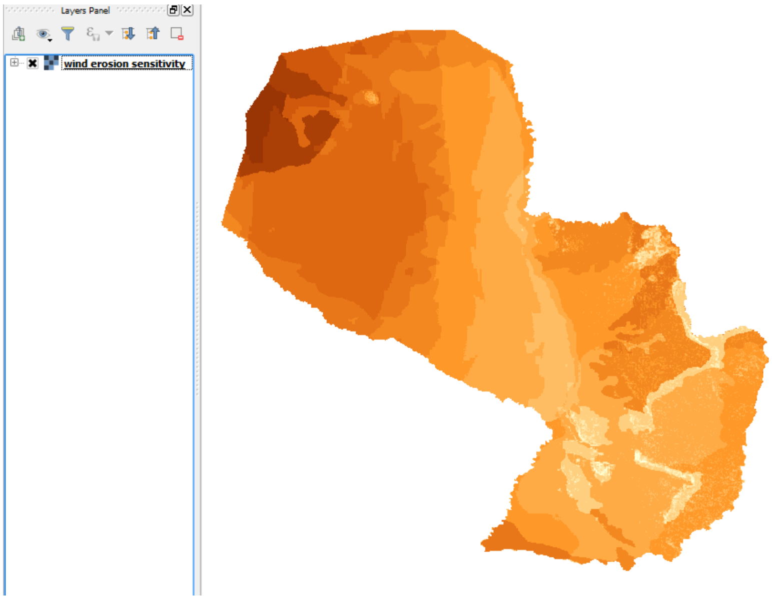
3.4. Combine layers to produce wind erosion sensitivity map

Now that we have all the layers we can perform the final analysis as per the original formula. We will sum the C’ (climate), I’ (soil erodibility) and K’ (soil roughness factor) factors using the **Raster Calculator** tool to create a wind erosion sensitivity map.

First, ensure that the layers have all the same cell size, geographic projection and layer extent. Go to Raster calculator and fill in the parameters as shown in the image below.



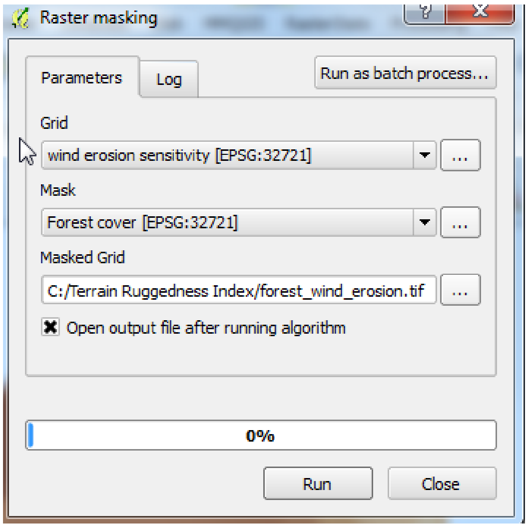
The final map should look similar to the one below.



3.5. Mask the wind erosion sensitivity map using the forest cover layer

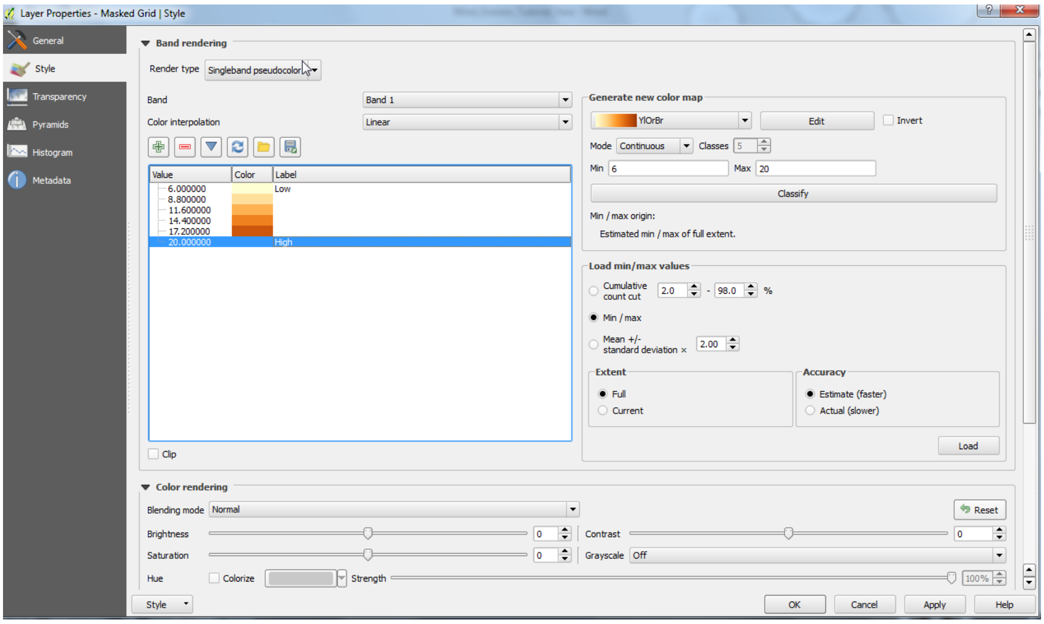
The forest cover layer will now be used to mask the previously created wind erosion sensitivity map to understand where the forests play an important role in controlling wind erosion. To do that, load the forest cover layer in QGIS, and use the **Raster masking** tool to cut the wind erosion sensitivity map to only show areas with forest cover.

1. Search **Raster masking** in the Processing toolbox, and open it. In **Grid**, enter the wind erosion sensitivity layer, in **Mask**, enter the forest cover layer and in **Masked Grid** enter the name and desired location of the output file. Then click **Run**.

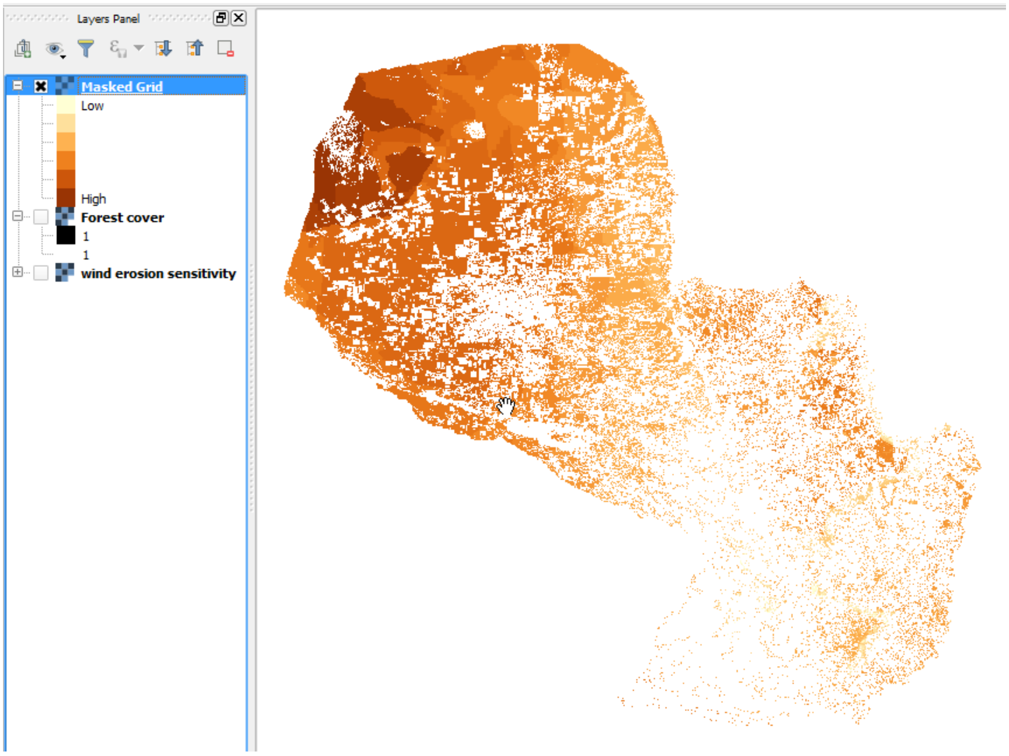


We have now created the final map, a layer that indicates the relative importance of forests to control wind erosion from 21 (maximum importance) to 3 (minimum importance).

2. Now, right click on the layer and choose **Properties**. Then go to **Style. In Render Type,** select "Singleband pseudocolor", select a color ramp that you like, in **Mode** select "Equal Interval", in **classes** select "6" and then click **Apply**.



The resulting file indicates the relative importance of forest to control wind soil erosion in 6 classes, from Low to High.



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