

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



**ASSESSING THE RELATIVE IMPORTANCE OF FORESTS FOR
LANDSLIDES MITIGATION
QGIS v 2.14**

UN-REDD
PROGRAMME



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Resilient nations.

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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.

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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 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 reduce the risk of landslides is also regarded as a key potential REDD+ benefit. Landslides can be triggered by several factors such as earthquakes, rainfall, deforestation and human induced vibrations; all these factors can interact to initiate the movement, transport and deposit of the material (Michael and Samanta, 2016). Topography characteristics such as slope gradient and curvature are important factors in determining susceptibility to landslides, and vegetation cover can then reduce landslide risk. The complex root systems of trees and shrubs not only stabilize the soil but also help to reduce its water content through transpiration, thus minimizing landslide risk. When landslides happen, forests can also act as a physical barrier against the flow of debris or rocks (Forbes and Broadhead, 2013). Consequently, deforestation can increase both the intensity and frequency of landslides (Forbes and Broadhead, 2013). Landslide vulnerability analyses can help identifying areas more vulnerable to landslides and the potential contribution of forest in reducing the risk of this natural hazard.

Landslide vulnerability maps have traditionally been developed using landslide inventories (old landslide areas are more prone to reactivate) and geotechnical ground survey techniques. Both these techniques can be prohibitive in many countries because of the remoteness of many areas where landslides occur (e.g. in Papua New Guinea records of landslides are not existent for more than 80% of the country, Michael and Samanta, 2016) and because of the lack of resources and expertise. The use of GIS and remote sensing data, often freely available, can help overcoming these issues. The application of GIS and remote sensing methods for the development of landslide vulnerability maps have been tested in Papua New Guinea by Greenbaum et al. (1995) using the Kaiapit landslide (1998) as a case study and have been utilized worldwide to generate landslide susceptibility and other natural hazards maps (Akgün and Bulut, 2007; Yalcin, 2008; Shahabi et al., 2014; Pourghasemi et al., 2014; Samanta and Bunia, 2013).

This tutorial provides a methodology to conduct a preliminary spatial assessment of the relative importance of forest in reducing the risk of landslides by mapping key factors that determine the vulnerability of an area to landslides, using Papua New Guinea (PNG) data as a case study area. The analysis is undertaken by using the weighted linear combination method (WLC), to establish the influence of selected parameters to the occurrence of a landslide by combining weighted averages of

the parameters (Mahini and Gholamalifard, 2006; Ladas et al., 2007; Michael and Samanta, 2016). WLC is a hybrid between a qualitative and quantitative expert-based approach (Shababi and Hashim, 2015; Ayalew et al., 2004) Data on precipitation, distance to roads and rivers, lithology, geomorphology and earthquake hazard data, are generated and combined with forest data.

This method is not designed to predict exact locations of landslide occurrence or making any quantitative estimates– it serves to assess the role of forests to reduce the risk of landslides based on the general sensitivity of the land to this hazard, taking into account some key parameters. The resulting map may be suitable for regional land use management and identify landslide-prone areas, where more detailed quantitative risk mapping may be needed.

The analysis runs entirely in the QGIS version 2.14 (www.qgis.org).

2. Methodology

The Weighted Linear Combination Method (WLC), chosen to conduct this study, usually involves 5 main steps:

1. Choice of the parameters influencing the phenomena under study (in this case, landslides), and their preparation if necessary
2. Standardization of each parameter layer
3. Assignments of weights to each parameter
4. Calculate the equation and produce the final map

The **first step** involves downloading and processing the thematical GIS layers required to estimate the relative importance of forest to mitigate landslides. For this tutorial 9 parameters, known to play an important role in triggering landslides (Michael and Samanta, 2016), are used to generate the final landslide vulnerability map.

Required Thematic layers:

Rainfall

Precipitation is considered the most common triggering agent for a landslide event. Rainfall can load the slope, reduce soil strength, and remove soil particles, thus causing the landslide.

Lithology

Different rock types can be more or less vulnerable to landslides depending on their composition, texture, degree of weathering in relation of slope stability (Kanungo et al., 2009). In general metamorphic rocks are considered the most stable and sedimentary beds the less stable type.

Roads

Road cuts as well as the vibrations induced from moving vehicles along roads can decrease the stability of slopes. The risk decreases as the distance from roads increases (Michael and Samanta, 2016).

Hydrology

Slope stability is reduced by rivers' undercutting. This risk increases in areas of high drainage density and higher altitude and it decreases with the distance from rivers.

Elevation and slopes

There is an increase in landslide incidence at higher altitude, in general landslides are more common at all altitudes above 750 m (Greenbaum, 1995). Slopes between 30° and 45° are more susceptible to landslides, low and near vertical slope angles are less prone (Michael and Samanta, 2016).

Landforms

They are characteristic of geomorphological processes and can be depositional, erosional and volcanic. The different landforms can be more or less prone to landslides; ridges, cliffs, mountains and hills are more susceptible to landslides and volcanic domes less.

Lineaments

They represent faults, shear zones or lines of weakness, along which movement could occur. The lineaments also influence the stability of the slopes, thus increasing their proneness to landslides (Michael and Samanta, 2016; Greenbaum, 1995).

Earthquakes

In PNG, they are the main trigger agents of landslides. Areas characterized by tectonic instability are thus more prone to landslide events.

Forest cover /tree cover

Vegetation acts as a protection layer that can mitigate landslides thanks to the root system which stabilizes the soil layer along slopes (Michael and Samanta, 2016).

In the **second step**, data layers are standardised to a common numerical scale by reclassifying them into classes. The value for each new class is chosen based on its relative influence to landslide occurrence. The rank ranges from 0 (very low influence to landslide occurrence) to 5 (very high influence to landslide occurrence).

In the **third step**, weights are assigned to each parameter according to their degree of influence to landslide risk in relation to the other parameters. These weights are subjective and should be chosen after consultations with experts. In this case the ranks and weights applied are based on Michael and Samanta (2016) and are specific for PNG.

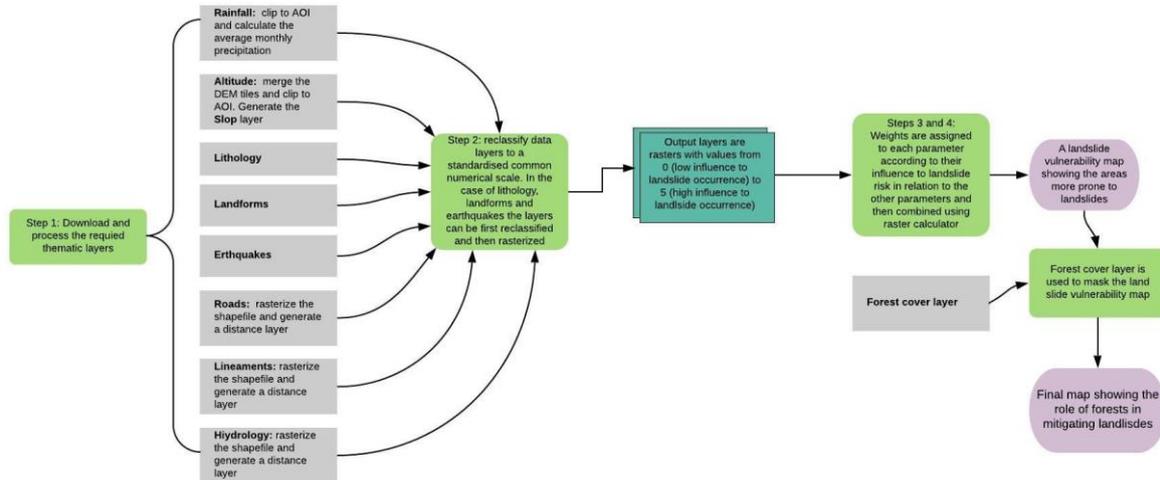
Finally, in the **fourth step**, these layers are combined following the equation below. The output of this operation would be the landslide vulnerability map (LVM):

$$LVM = (Slope *4) + (Rainfall*3) + (Elevation) + (Land formation) + (Geological units) + (Proximity to Roads) + (Proximity to Lineaments) + (Proximity to rivers) + (Earthquake hazard *2)$$

This tutorial will explain in detail how to carry out this analysis in QGIS, using the PNG data as a case study. If, for a particular region of interest, more parameters are known to cause landslides, those layers can be prepared and added to the final equation, following the same steps described here. This method assumes that the user has a forest cover layer available, which will be utilized in the last step

to mask the vulnerability map and thus understand where the forests play an important role in mitigating landslides.

Below an image showing the workflow with the steps required to carry out the analysis.



3. Prepare raster layers

3.1. Rainfall

3.1.1. Extract monthly average precipitation for your study area

If a gridded average precipitation layer is not available for your study area, it is possible to extract this data from a global dataset, such as WorldClim (Fickand and Hijmans, 2017), following the steps described below:

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

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

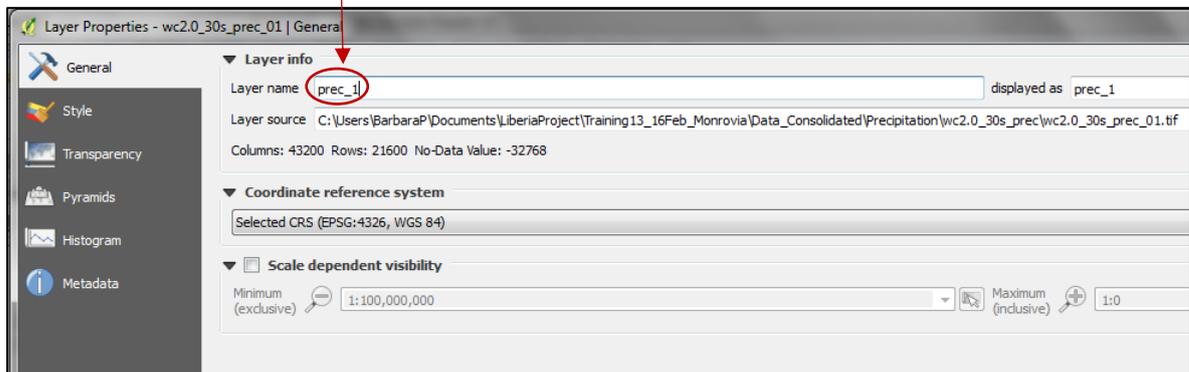
variable	10 minutes	5 minutes	2.5 minutes	30 seconds
minimum temperature (°C)	tmin 10m	tmin 5m	tmin 2.5m	tmin 30s
maximum temperature (°C)	tmax 10m	tmax 5m	tmax 2.5m	tmax 30s
average temperature (°C)	tavg 10m	tavg 5m	tavg 2.5m	tavn 30s
precipitation (mm)	prec 10m	prec 5m	prec 2.5m	prec 30s
solar radiation (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

This will start the download of a zip file containing average precipitation layers for each month of the year, numbered 1 (January) to 12 (December).

- c) Unzip these files, upload them in QGIS and clip them to the shape of your study area following the steps:

3.1.2. Add precipitation raster to the QGIS project

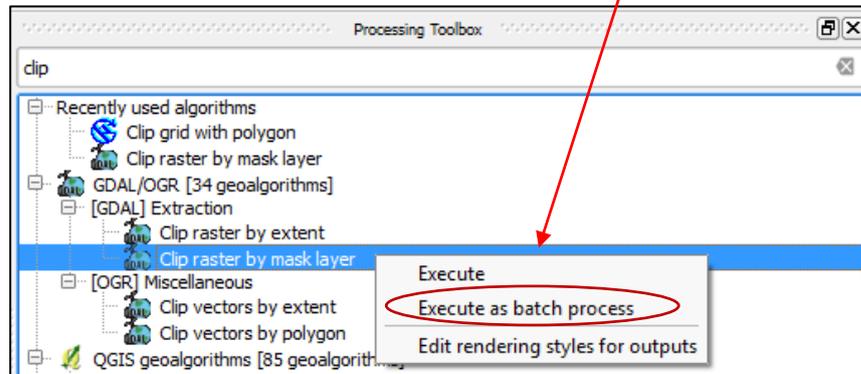
- Click on the “Add Raster layer” button and add all 12 monthly precipitation raster layers to your QGIS project
- Right click on **each of the datasets >> properties** and click on the **General Tab**, change the layer name e.g. **prec_1**.



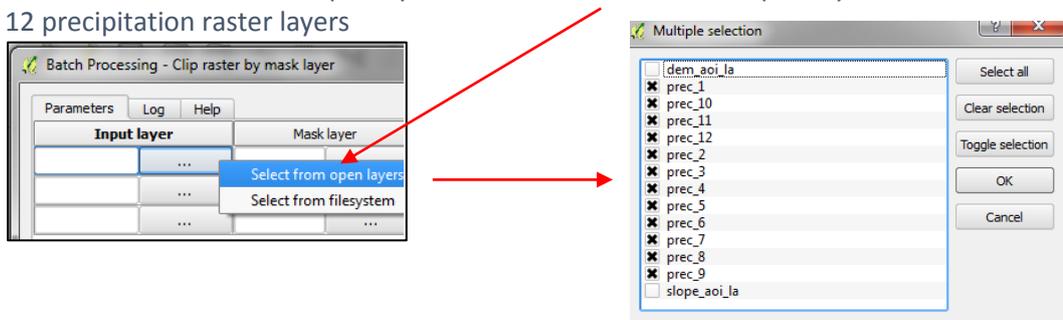
Do this for each of the 12 precipitation raster layers.

3.1.3. Batch clip monthly precipitation raster layers

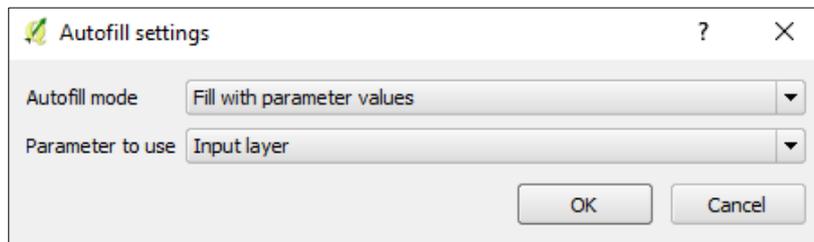
- a. In the search box of the processing toolbox in QGIS, type “clip” and then right click on **GDAL’s clip raster by mask layer** and select **Execute as batch process**.



- b. Click on the ... in the first Input layer and click on “Select from open layers” and select the 12 precipitation raster layers



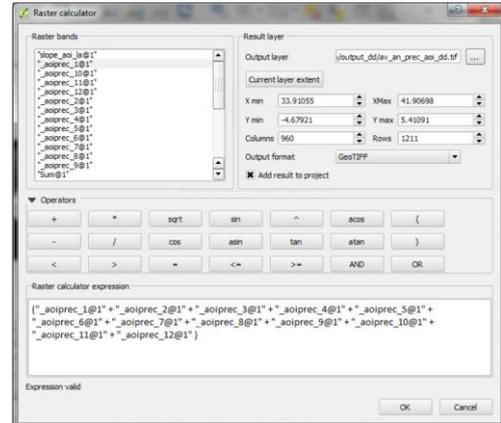
- c. Then, click on the ... button in the first Mask layer and click on “Select from open layers” and Select the AOI shapefile in geographic coordinate system. E.g. in this example outline_aoi_dd. Then double click on the top of the Mask layer column to automatically populate the column fields with the same vector file selected in the first row.
- d. Then go to “Clipped (mask)” column and specify the location to save the clipped raster layers. In the Autofill settings dialog box, specify “Fill with parameter values” and select “Input layer” as the parameter to be used. Then click **Run**.



3.1.4. Calculate average annual precipitation

- a. From the main menu click **Raster>>Raster Calculator**
- b. In the expression box add the following expression:

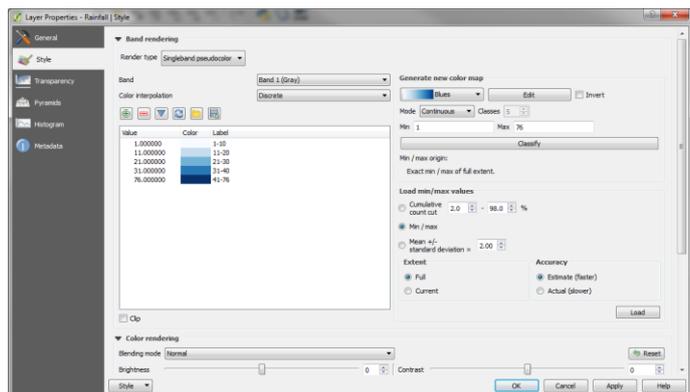
```
("_aoiprec_1@1" + "_aoiprec_2@1" +
 "_aoiprec_3@1" + "_aoiprec_4@1" +
 "_aoiprec_5@1" + "_aoiprec_6@1" +
 "_aoiprec_7@1" + "_aoiprec_8@1" +
 "_aoiprec_9@1" + "_aoiprec_10@1" +
 "_aoiprec_11@1" + "_aoiprec_12@1")
```



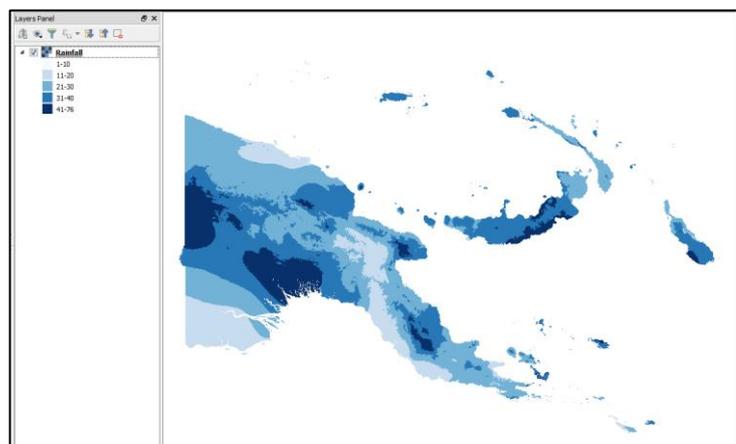
- c. Navigate to an output folder and name the new raster “av_an_prec_aoi_dd.tif”
- d. Click on one of the input precipitation layers and click on the current layer extent to ensure the Raster Calculator is looking at the correct extent.

3.1.5. Reclassify mean annual precipitation in 5 classes

- a. Right click on the average annual precipitation raster -> **Properties**
- b. Click on **Style**
- c. Change **Render type** to **Singleband pseudocolor**
- d. Change **Mode** to **Equal interval**
- e. Change **Color interpolation** to **Discrete**
- f. Change **Load min/max values** to **Min/max** and **Extent** to **Full** and **Accuracy** to **Actual (slower)**
- g. Click **Load**
- h. Click **Classify** and then manually change the values and labels to appropriate class breaks. In this case, we will reclassify precipitation into 5 classes.



- i. Click **OK**. This visualizes the class breaks on the map display area.

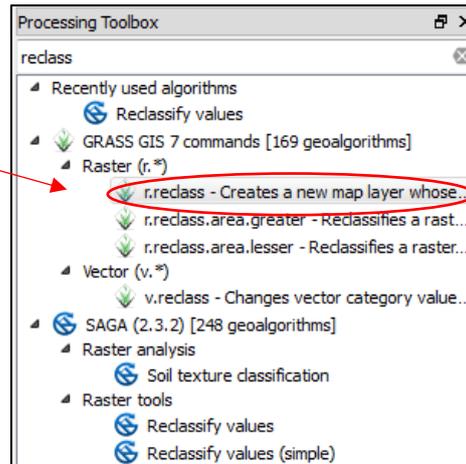


- j. To create a new precipitation raster layer with 5 classes, first create a text document with the classes you have defined as shown in the example, with exactly the same syntax. (The exact minimum and maximum threshold values for each class will depend on your data).

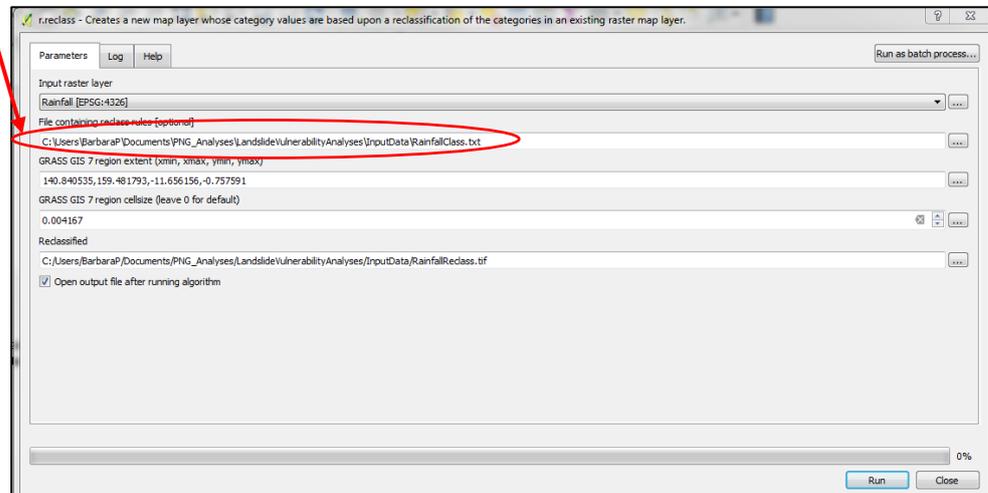
```

1 thru 10 = 1
11 thru 20 = 2
21 thru 30 = 3
31 thru 40 = 4
41 thru 76 = 5
    
```

- k. In QGIS processing toolbox select the tool **r.reclass**.



- l. A new window will appear where the text file where the new classes are defined needs to be uploaded.

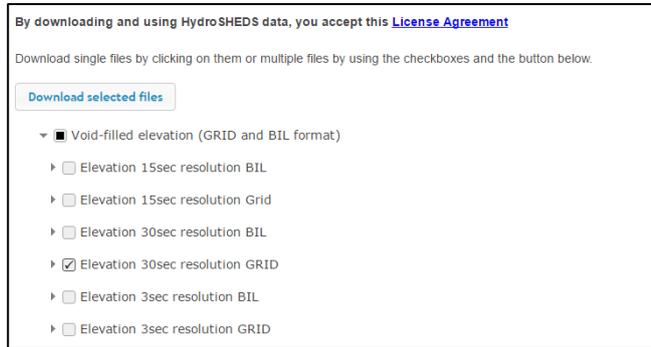


Assign a name to the new raster layer such as “RainfallReclass” and then click **Run**. The new reclassified raster layer for precipitation will appear in the Map display area.

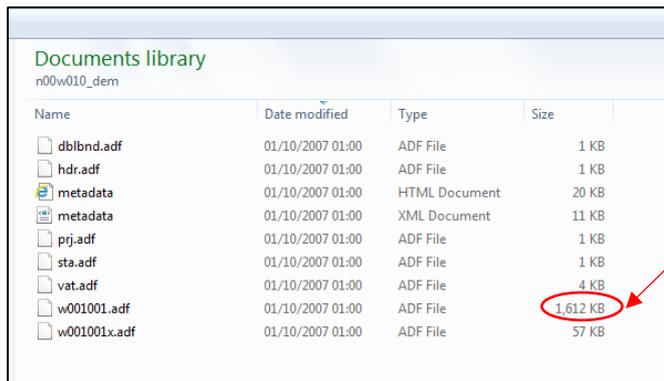
3.2. Altitude and slope

3.2.1. Download and extract an elevation raster layer for your study area

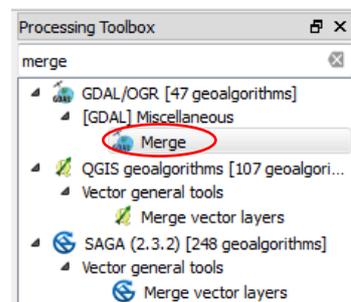
- a. Upload a DEM for your study area. If not available, go to <http://www.hydrosheds.org/> and register as a user. Once registered, go to download, select **Void-filled elevation** and then **Elevation 30 sec resolution GRID**. Then select the one that covers your study area.



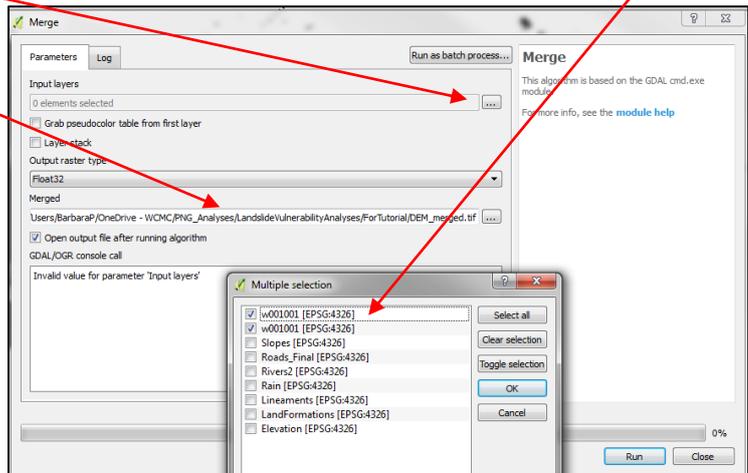
- b. This will download a zip file. You must store the file and extract all data (right click, then select **Extract All...**) in order to open the DEM data in QGIS.
- c. Open QGIS and add the DEM data as a 'raster layer'. To do this, click on **Layer** in the tools bar at the top of the document, then click **Add Layer** and select **Add Raster Layer...** from the drop-down menu.
- d. These data are in ESRI ArcInfo Grid format so in order to load it into QGIS, navigate into the individual grid folder and pick the w001001.adf file, which is the file with the largest size.



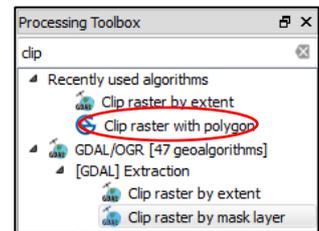
- e. Click **Open** and the raster will appear in the table of contents in QGIS. For PNG two DEM raster layers have to be added, one for Asian and one for Australian regions.
- f. Then, add the area of interest boundary vector layer to the QGIS project, in this case PNG country boundary. Make sure this layer is in geographic projection (i.e. EPSG 4326) as it will be used to clip the DEM raster data that is in geographic coordinates.
- g. Search for Merge in the processing toolbox window and select the GDAL Merge tool.



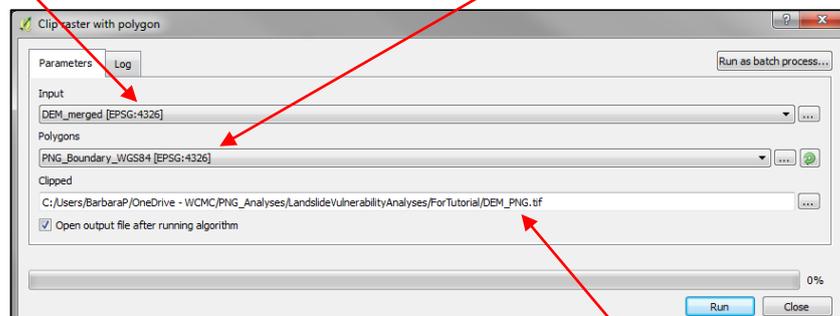
- h. Click on the ... next to input layers and tick all the DEM tiles to merge. In this case, two tiles.
- i. Navigate to an output folder and save as a new output layer e.g. DEM_merged
- j. Click **Run**.



- k. In the processing toolbox, search for clip tools and select the **SAGA's Clip raster by polygon tool**.



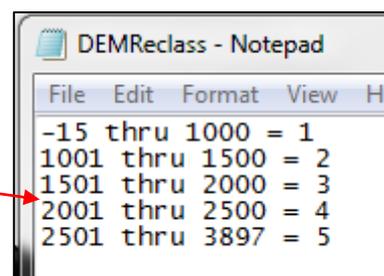
- l. Set your recently created merged DEM file as **Input**. In **Polygons**, select the vector file of the area of interest



- m. Navigate to an output folder and save as a new output layer, e.g. **DEM_PNG**
- n. Click **Run**.

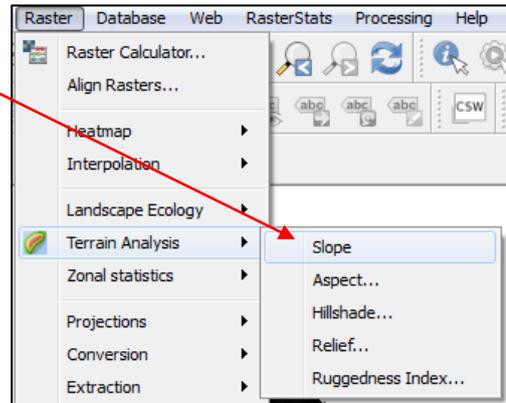
3.2.2. Reclassify the DEM file in 5 classes

The DEM has to be reclassified in 5 classes. Using the DEM_PNG layer, the steps described in section 3.1.5 have to be carried out. For PNG, the classes to be used are shown here:

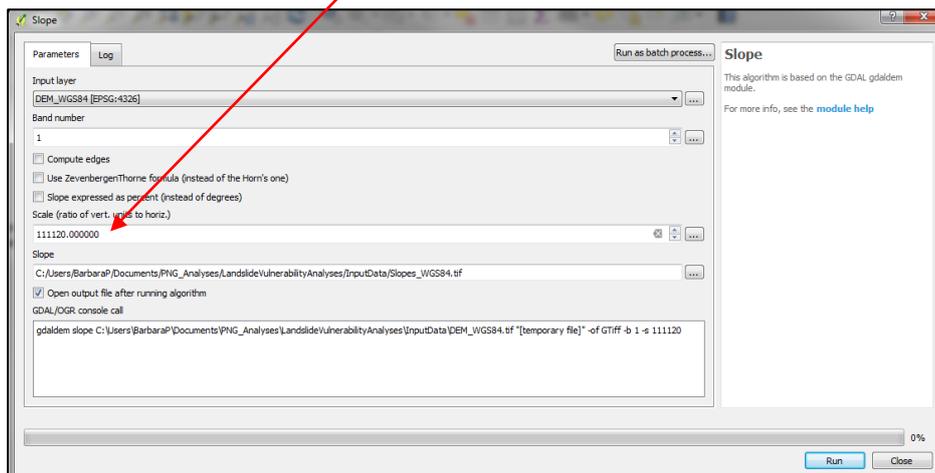


3.2.3. Generation of the slope raster layer

- a. In this section, the DEM_PNG layer generated in Step 3.2.1 is now used to create the slope layer. To do this, open the **Raster** menu in the main toolbar, and then select **Terrain analysis**. Double click on **Slope**.



- b. In the new dialog window, select the merged DEM as **Input layer** (in this case, "DEM_PNG"). If the DEM is in geographic coordinates, we need to set the **Scale** (ratio of vertical units in meters to horizontal units in degrees) to generate the slope layer. In this case, the scale to be used is 111120.



- c. Select the output folder and the name of the output layer, e.g. Slopes_WGS84.tif
 d. Click **Run**

3.2.4. Reclassify the slope layer in 5 classes

The slope layer generated in the prior step now has to be reclassified in 5 classes, following the steps described in Section 3.1.5. In this example, the following classes are used to reclassify the slope layer:

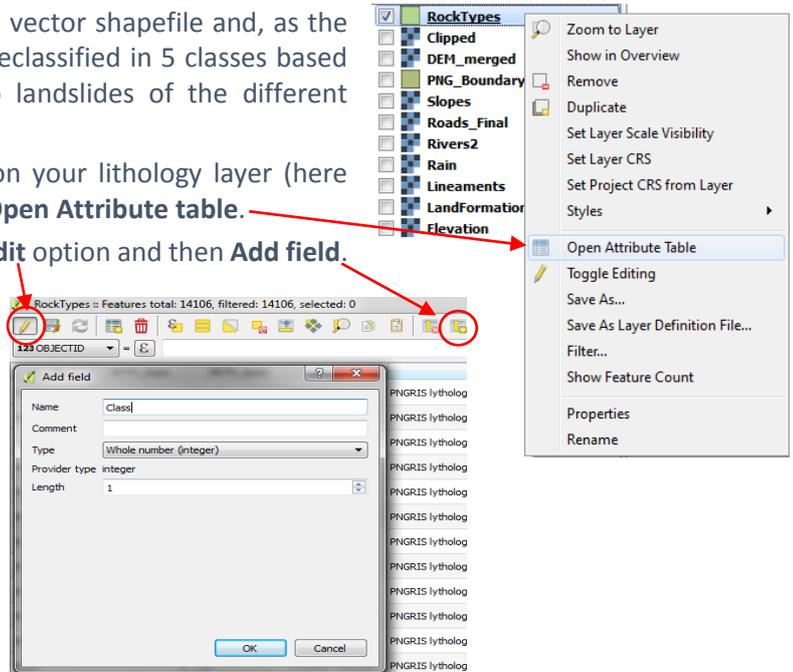
0 thru 10 = 1
 11 thru 20 = 2
 21 thru 30 = 3
 31 thru 40 = 4
 41 thru 47 = 5

3.3. Lithology

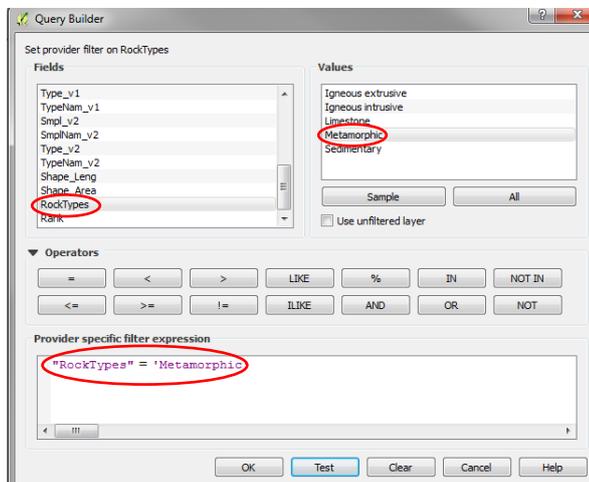
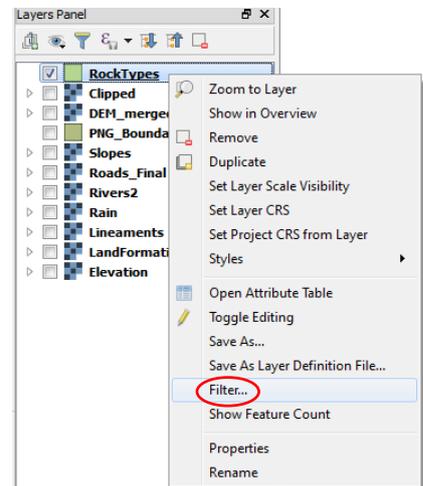
3.3.1. Download and process lithological data

If a lithological layer is not available for the study area it might be available from the ArcGis website <http://www.arcgis.com/home/index.html> or from the FAO Geonetwork website <http://www.fao.org/geonetwork/srv/en/main.home>.

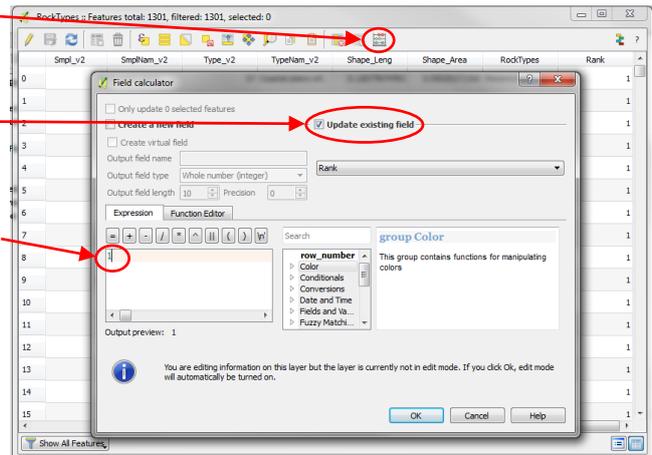
- The lithological layer is usually a vector shapefile and, as the previous layers, it needs to be reclassified in 5 classes based on the relative vulnerability to landslides of the different lithological categories.
- In the layers panel, right click on your lithology layer (here called "Rock types") and select **Open Attribute table**.
- In the Attribute table, click the **Edit** option and then **Add field**. Call the new field "Class" or "Rank".



- In the layers panel right click again on the "RockTypes" layer and select **Filter**.
- In the filter window select in **Fields** the field where the rock type names are stored in your shapefile. In the **Values** box, select the option **All** to visualize all the values included in the field, after having added the equal symbol in the filter expression double click on the value to be filtered, in this case Metamorphic, then click **OK**.

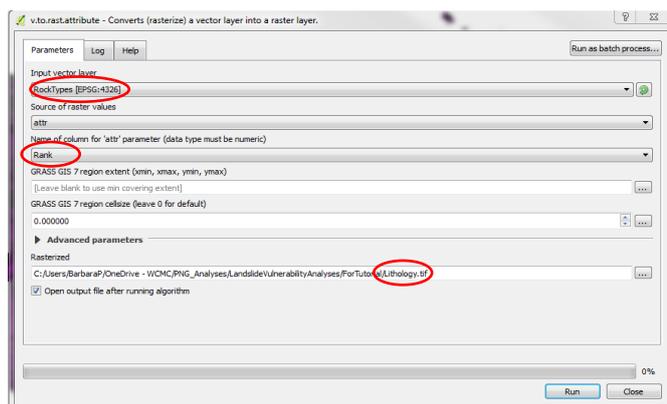
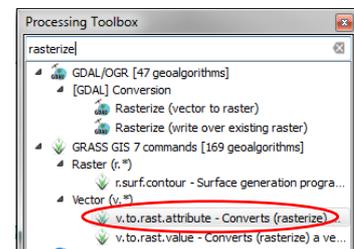


- f. In the layers panel, right click the RockTypes layer and open its **Attribute table**. Check that the table now contains information just for the value filtered, in this case “Metamorphic”.
- g. Click on **Edit** and then **Field calculator**.
- h. In the Field calculator window, tick the option **Update existing field** and select the field created in step c, called Rank or Class. In the **Expression** box, type the value to be assigned to the type of rock. For metamorphic rock the value is 1 and then click OK.
- i. In the Attribute table, click the Edit option again and then **Save**.
- j. For each rock type in the study area repeat the steps from d to i, but first select the option **Clear** in the filter window to select the new rock type.
- k. In this example, the values to be used for the other Rock types are:
 - o Igneous extrusive: 3
 - o Igneous intrusive: 2
 - o Limestone: 4
 - o Sedimentary: 5

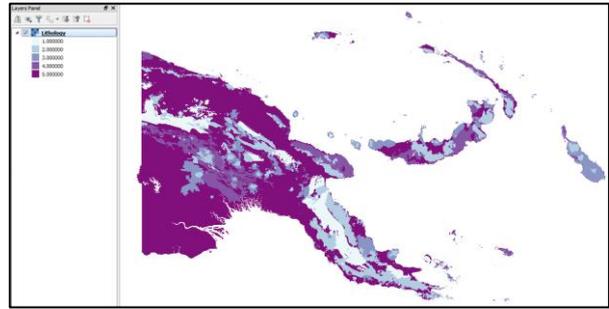


3.3.2. Rasterize lithology layer

- a. To generate a raster from the lithology shapefile, search in the processing toolbox “Rasterize” and then Select the tool **v.to.rast.attribute**
- b. As **Input vector layer** select “RockTypes”, as **Name of column for “attr” parameter (data type must be numeric)** select the column with the new classes, in this case “Rank”.
- c. Select an output folder and the output name of the new raster file, e.g. Lithology.tif
- d. Click **Run**



- e. The new raster layer will be added in the Map display area.



3.4. Landforms

If a landform layer is not available for the study area it might be available from the ArcGis website <http://www.arcgis.com/home/index.html> or from the FAO Geonetwork website <http://www.fao.org/geonetwork/srv/en/main.home>

To prepare the landform layer, which is usually a vector shapefile, follow the steps described in Section 3.3.

- a. The classes to be used in subsection 3.3.1 (a – k) are:
 - Alluvial plains: 3
 - Volcanic footslopes: 2
 - Volcanic domes: 1
 - Mountains and hills: 4
 - Ridges and cliffs: 5
- b. Once the vector shapefile is reclassified, rasterize it following the steps described in subsection 3.3.2.

3.5. Earthquakes

The earthquake hazard map used in this example was downloaded from the Pacific Risk Information System website (<http://pcrafi.spc.int/>). The layer provides, at any location, the value of a ground motion intensity measure that is expected to be exceeded at least once in 100 year mean return period (Spectral = 0.3 second spectral acceleration).

This earthquake hazard layer is a vector shapefile, therefore has to be first reclassified and then rasterized following the same steps described in Section 3.3

- a. The classes used to reclassify this shapefile are:
 - 0.048448-0.277644 = 1
 - 0.277644-0.506843 = 2
 - 0.506843-0.737047 = 3
 - 0.737047-0.965240 = 4
 - 0.965240-1.94430 = 5
- b. Once the shapefile has been reclassified, it has to be rasterized following the steps in subsection 3.3.2

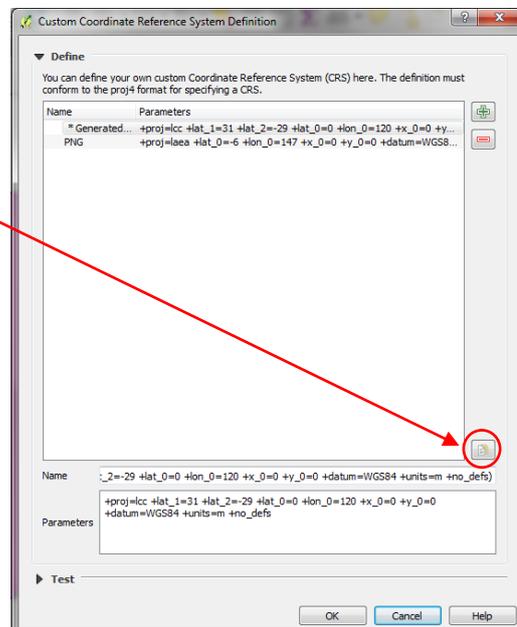
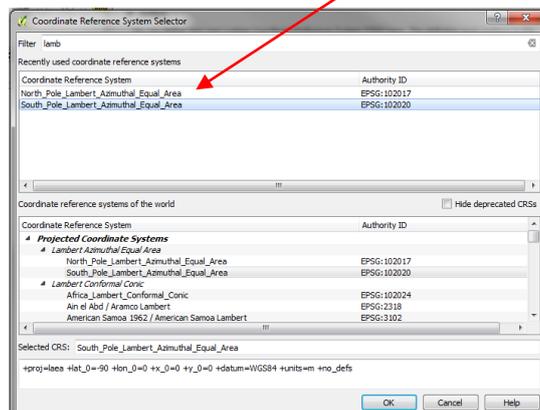
All the layers to this point are in geographic coordinates (WGS84), but the layers to be processed in the following sections (Roads, Rivers and Lineaments) needs to be in projected coordinates, as the units of the data for the next processing steps need to be meters.

3.6. Project layers from geographic coordinate to a projected CRS

The easiest way to project the data in QGIS is to right click on each layer and then click **Save as**. In the new window, select the projected coordinate system you want to project your data into. In this example, we will use the Universal Transverse Mercator (UTM) coordinate system. This system divides the globe into 60 north and south zones, each spanning 6° of longitude. Areas are referenced by quoting the longitudinal zone number, followed by the latitudinal zone letter. For example, the southern end of South America is 19F. Given that PNG crosses more than one UTM zone, it is necessary to create a custom CRS.

The Lambert Azimuthal Equal Area projection is one option for creating a custom projection.

- From the main menu click on **Settings** -> **Custom CRS**
- Click on **Copy existing CRS**
- To create a **custom lambert azimuthal equal area** CRS filter by typing **lambert** in the filter box to check if there is already a lambert azimuthal equal area projection for the South Pole that can be modified.



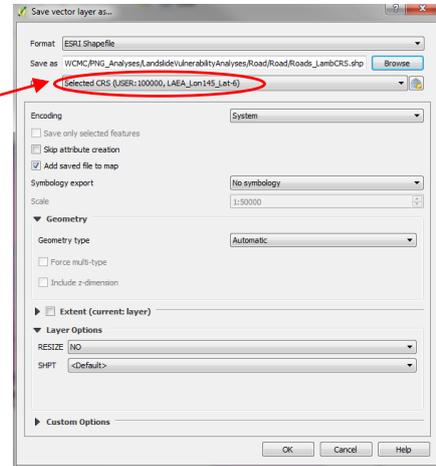
- Since this projection is available in QGIS, select the **South_Pole_Lambert_Azimuthal_Equal_Area** and click **OK**
- The name can be changed to **LAEA_lon145_lat-6**, as the centre Lon and Lat for PNG is 145 and -6
- Click **OK**. A new projected CRS was created and added to the QGIS list.

3.7. Roads

3.7.1. Project the shapefile to the new CRS

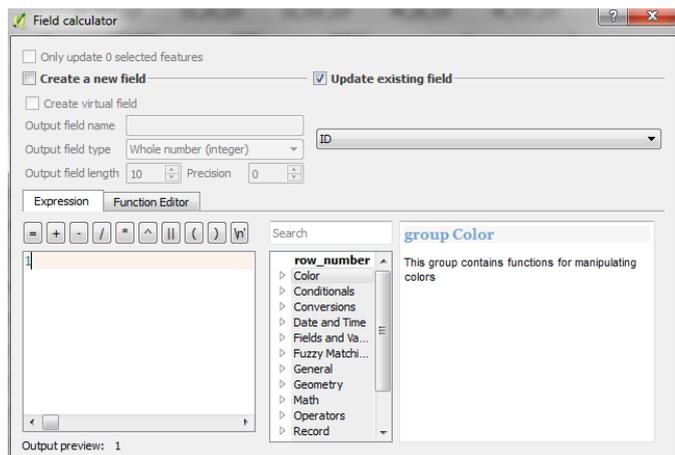
The roads data for PNG are in geographic coordinate system and they have to be projected in the new created Lambert Azimuthal CRS system. To do that, follow these steps:

- Right click on the roads layer and click **Save as**
- Select an output folder and a name for the layer, e.g. Roads_LambCRS.shp
- Choose the CRS: LAEA_Lon145_Lat-6
- Click **OK**

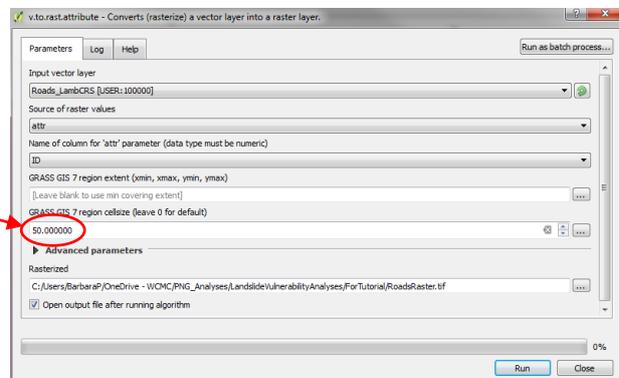


3.7.2. Rasterize the vector shapefile

- Create a new field in the attribute table called ID as described in Subsection 3.3.1, steps a-c.
- Update the new ID field using the **Field calculator** and insert the value "1" in the **expression box**.
- Save the changes.

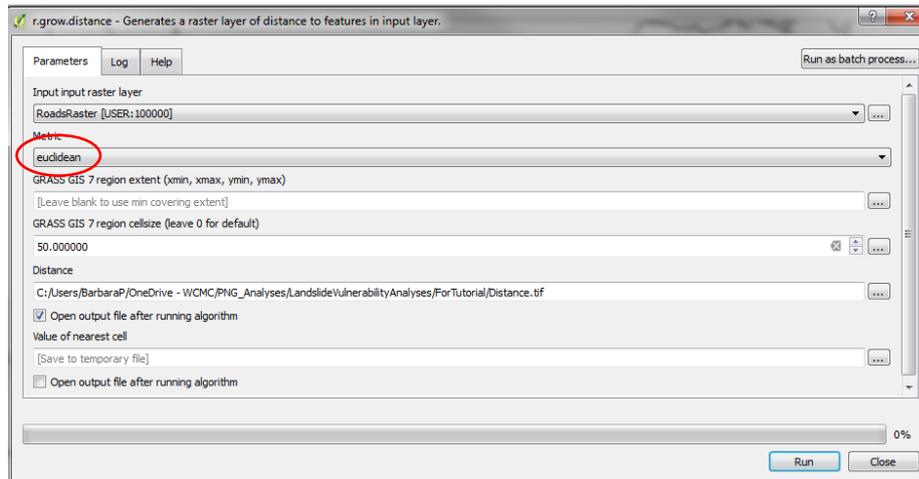
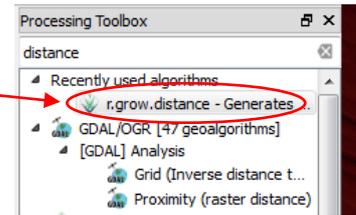


- Open the v.to.rast.attribute tool from the processing toolbox and rasterize the shapefile.
- In the **Cell size** option type 50, this will create a raster with cells of 50x50m. In **Name of column for 'attr' parameter**, select "ID"



3.7.3. Generate a distance layer

- In the processing toolbox search for distance and then select **r.grow.distance**
- In the tool window, select the roads shapefile and as **metric Euclidean**. Type the cell size as 50m
- Choose an output folder and a name for the layer
- Click **Run**. If the area is large this processing step might take 10 min or more.



If the area to be processed is too large consider to split the layer in 2 or 3 different parts and run the analyses for each zone individually. Once the distance layers are created can be merged together and reclassified as described below.

3.7.4. Reclassify the distance raster layer

- To reclassify the raster layer follow the steps described in 3.1.5, steps j-l.
- The new classes for the Distance raster layers, based on the assumption that with the increase in distance the vulnerability to landslides decrease, are:
 - 0 thru 50 = 5
 - 51 thru 100 = 4
 - 101 thru 150 = 3
 - 151 thru 200 = 2
 - 201 thru Max value of your data = 1

3.8. Lineaments and Hydrology

Lineaments and hydrology data are also usually stored as vector files. To process both layers, the same steps described in section 3.7 for roads have to be followed. In the last subsection 3.7.4 the same classes shown are used for both lineaments and hydrology.

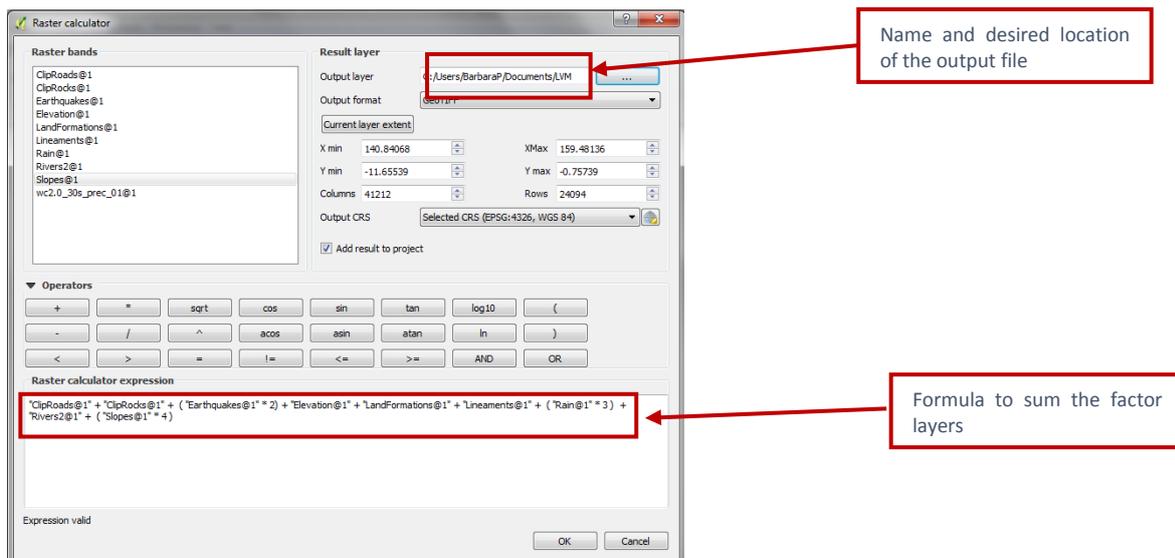
*The final raster layers generated for roads, lineaments and hydrology can now be saved in the geographic coordinate system WGS84, by right clicking each individual layer and selecting **Save as**. In the CRS box select WGS84, choose an output folder and a new layer name and then click Save.*

4. Combine layers to produce the landslide vulnerability map

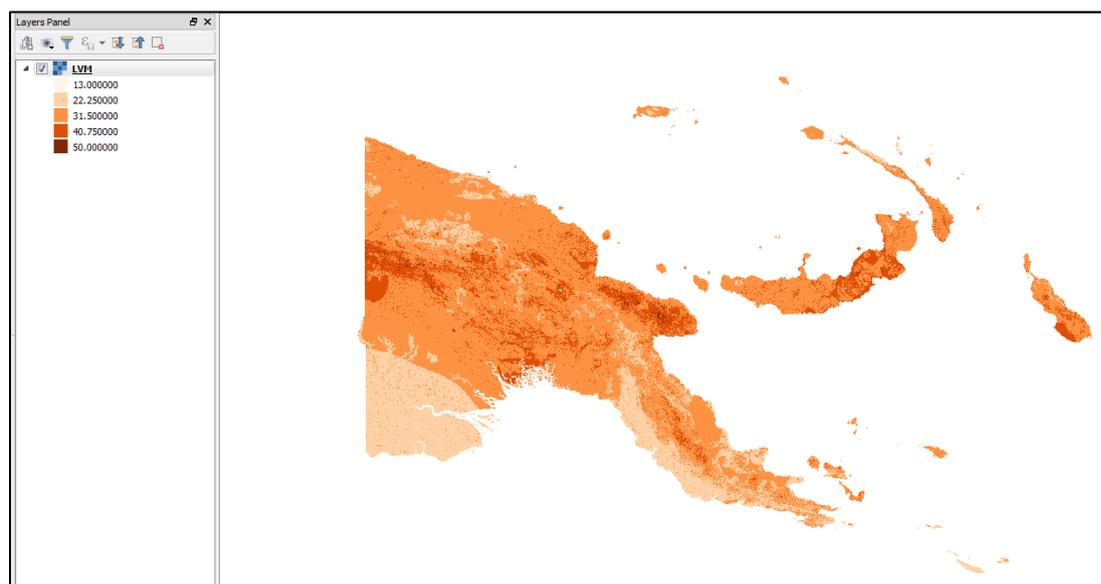
The layers developed through the previous steps can now be combined using **Raster calculator** as per the equation below:

$$LVM = (Slope *4) + (Rainfall*3) + (Elevation) + (Land\ formation) + (Geological\ units) + (Proximity\ to\ Roads) + (Proximity\ to\ Lineaments) + (Proximity\ to\ rivers) + (Earthquake\ hazard *2)$$

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 resulting map should look like the one below:

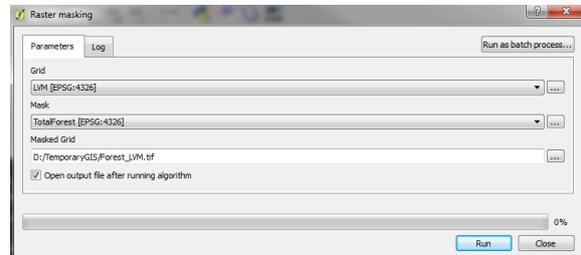


The final map, is a layer that indicates the relative importance of forests to mitigate landslides from 13 (minimum importance) to 50 (maximum importance).

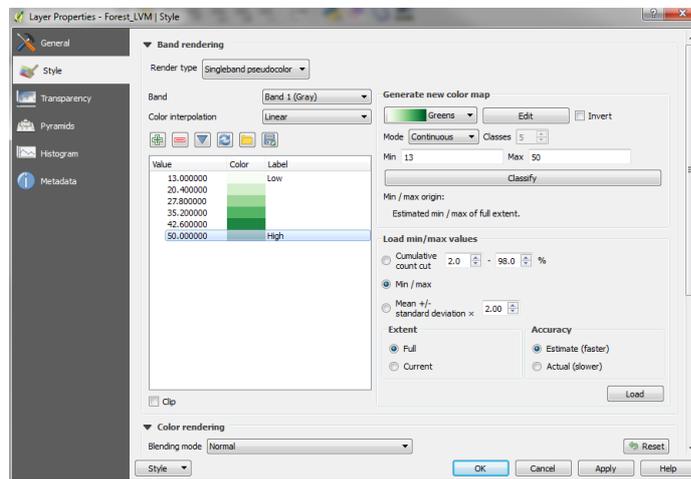
4.1.1. Mask the landslide vulnerability map using the forest cover layer

- a. The forest cover layer will now be used to mask the previously created landslide vulnerability map to assess the relative role of forests in mitigating landslides. To do that, the forest cover layer has to be loaded in QGIS, and the **Raster masking** tool is used to clip the landslide vulnerability map to only show areas with forest cover.

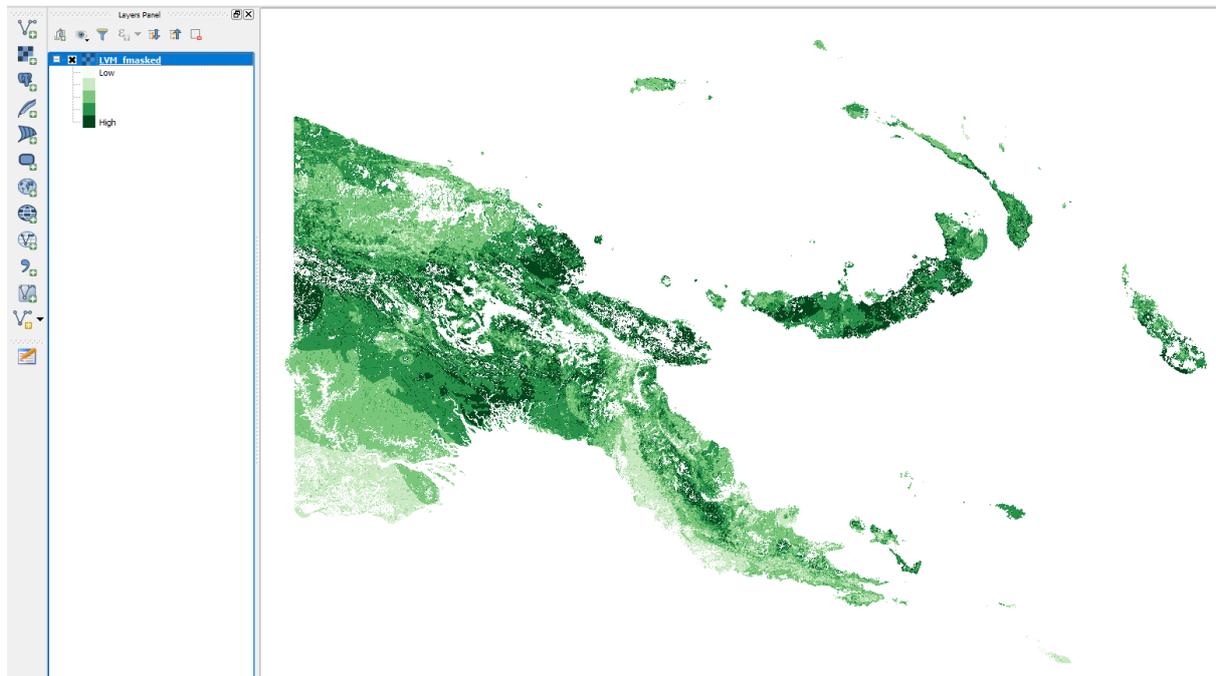
- b. Search **Raster masking** in the Processing toolbox, and double click on it. In **Grid**, enter the landslide vulnerability layer. In **Mask**, enter the forest cover layer and in **Masked Grid**, enter the name and desired location of the output file. Then click **Run**.



- c. 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**.



- d. The resulting file indicates the relative importance of forest to mitigate landslides in 6 classes, from Low to High.



5. REFERENCES

- Akgün, A. and Bulut, F. (2007) GIS-based landslide susceptibility for Arsin-Yomra (Trabzon, north Turkey) region. *Environmental Geology* 51, 1377–1387
- Ayalew, L., Yamagishi, H. and Ugawa, N. (2004) Landslide susceptibility mapping using GIS-based weighted linear combination, the case in tsugawa area of Agano river, Niigata prefecture, Japan. *Landslides* 1, 73-81
- Fick, S.E. and R.J. Hijmans (2017). Worldclim 2: New 1-km spatial resolution climate surfaces for global land areas. *International Journal of Climatology*, 37(12): 4302–4315.
- Forbes, K., and Broadhead, J. (2013). *Forests and landslides: The role of trees and forests in the prevention of landslides and rehabilitation of landslide-affected areas in Asia*. Food and Agriculture Organization of the United Nations. Regional Office for the Asia and the Pacific, Bangkok.
- Greenbaum, D. et al (1995) *Rapid methods of landslide hazard mapping: Papua New Guinea case study: British Geological Survey Technical Report—WC/95/27*
- Kanungo, DP., Arora, MK., Sarkar, S. and Gupta, RP. (2009) Landslide susceptibility zonation (LSZ) mapping – a review. *International Journal of Applied Earth Observation and Geoinformation* 2(1):81-105
- Ladas, I., Fountoulis, I. and Mariolakos, I. (2007) Using GIS and Multicriteria decision analyses in landslide susceptibility mapping – a case study in Messinia prefecture area (SW Peloponnesus, Greece). *Bulletin of the Geological Society of Greece* 40(4):1973-1985
- Michael, EA. and Samanta, S. (2016) Landslide vulnerability mapping (LVM) using weighted linear combination (WLC) model through remote sensing and GIS techniques. *Modeling Earth Systems and Environment* 2: 88, 1-15
- Pourghasemi, H., Moradi, H., Aghda, S. F., Gokceoglu, C. and Pradhan, B. (2014) GIS based landslide susceptibility mapping with probabilistic likelihood ratio and spatial multi-criteria evaluation models (North of Tehran, Iran). *Arabian Journal of Geosciences* 7, 1857–1878
- Samanta, S. and Bhunia, G. (2013) Landslide susceptibility zone identification of Markham Watershed, PNG—a study based on remote sensing and GIS technology. *International Journal of Physical and Social Sciences* 3(1):307–322
- Shahabi, H. and Hashim, M. (2015) Landslide susceptibility mapping using GIS-based statistical models and remote sensing data in tropical environment. *Scientific Reports* 5:9899.
- Shahabi, H., Khezri, S., Ahmad, B. B. and Hashim, M. (2014) Landslide susceptibility mapping at central Zab basin, Iran: A comparison between analytical hierarchy process, frequency ratio and logistic regression models. *Catena* 115, 55–70
- Yalcin, A. (2008) GIS-based landslide susceptibility mapping using analytical hierarchy process and bivariate statistics in ardesen (Turkey): Comparisons of results and confirmations. *Catena* 72, 1–12