



Methodological demonstration for **Chapter 19** – [*“Towards Equitable Urban Residential Resettlement in Kigali, Rwanda”*](#) (pp.325-343)







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Disclaimer

This document is an addendum to the chapter mentioned above which is part of the book [*GIS in Sustainable Urban Planning and Management: A Global Perspective*](#). The purpose of this document is to demonstrate the application of the methods described in that chapter using **QGIS 3.4 LTR or higher** along with the data available at [here](#). This document is licensed under a [Creative Commons Attribution-Non Commercial-ShareAlike 4.0 International License](#). Different license terms may apply for the data. If that is the case, a file containing the license terms is included with the data.

How to use this document

Most of the steps described are illustrated with screenshots. Bear in mind that what the screenshot depicts and what you see in our computer might differ slightly depending on the QGIS version you are using and the way your toolbars and add-ons are arranged. Along the text you will see different icons. The key for these icons is as follows:

-  Data or external resource to download;
-  A software action you are supposed to do;
-  Information specific about QGIS.
-  Additional or complementary scientific information;
-  An important concept which we may want keep in mind;
- [1]** An operation that is referenced in the flowchart of operations;
-  A video tutorial explaining software related operations.

Additionally, for the sake of readability, the following style conventions are used:

- A reference to dataset or a layer uses *this style*;
- A QGIS command, or any clickable button is noted using **this style**.
- A QGIS menu or section is highlighted using *this style*.

At the end of the document, a diagram depicting the workflow described in these pages can be seen. It is advisable to look at it first and/or refer to it as we proceed.

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Outline

Using the case of Kigali, Rwanda, an analysis of spatial relocation options of urban households affected by natural disasters-induced displacement is conducted using a GIS-based multi-criteria technique. To that end, accessibility models are developed to assess proximity to a series of urban amenities that are then weighted in order to identify the most suitable areas for resettlement and to predict to what extent of the affected citizens would benefit or not, leading to their impoverishment, in case of resettlement.

Getting started



Download the data; the data consists of the following files:

- `Kigali.qgs` – a QGIS project preloaded with the layers;
- `low_income_residential_area.shp` – Polygon features representing proposed residential areas for low income residents;
- `gasabo.shp` – polygon depicting the Gasabo district;
- `Kigaliboundary.shp` – Polygon features with all the districts occupied by Kigali;
- `Kigali_rivers.shp` – Line features representing the main water courses;
- `Paved_roads.shp` – Line features representing paved roads in Kigali;
- `Unpaved_roads.shp` – Line features representing unpaved roads in Kigali;
- `dem_kigali.tif` – Digital elevation model (25m resolution) for Kigali;
- `Commercial_centres.shp` – Polygon features whose land use is classified as “commercial”
- `Kigali_bus_route.shp` – Line features representing public bus routes;
- `Kigali_bus_stop.shp` – Point features representing public bus stops;
- `Kigali_CBD.shp` – A point representing the center of Kigali;
- `Kigali_ps.shp` – Point features representing primary schools;
- `Kigali_ss.shp` – Point features representing secondary schools;
- `Kigali_universities.shp` – Point features representing universities;
- `Kigali_health.shp` – Point features representing health facilities;
- `Kigali_markets.shp` – Point features representing markets;
- `Origin_settlement.shp` – Polygons representing the informal settlements from where citizens would come in a scenario of relocation;
- `accumulated_cost.model3` – A QGIS model (i.e. workflow);
- `accessibility_model.qml` – A QGIS style file;
- `impoverishment_risk.qml` – A QGIS style file;
- `low_income_residential_areas.qml` – A QGIS style file;
- `pubtra_cost.qml` – A QGIS style file;
- `walk_cost.qml` – A QGIS style file;
- `batch_processing.mp4` – A video tutorial;
- `build_model.qml` – A video tutorial;



Start QGIS and open `Kigali.qgis` (Figure 1).

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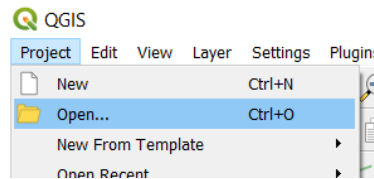


Figure 1 – opening a project

- From the *Layers panel*, **right-click** on a layer and access the attribute table to examine it. Repeat the procedure for the other layers (Figure 2).

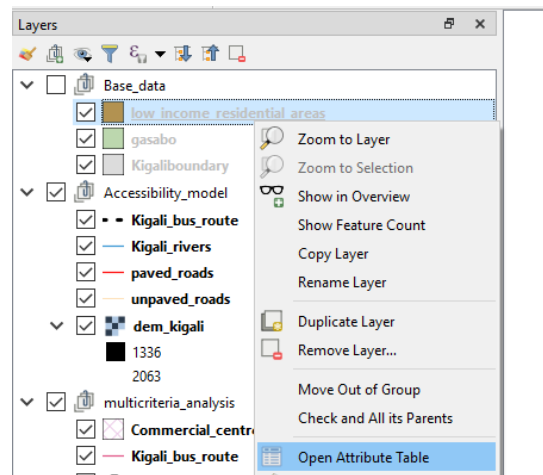


Figure 2 – accessing attribute table

FIRST PART: Accessibility model

We will start by creating two accessibility models. In order to do that we will rasterize the necessary inputs and assign constant pixel values according to table 1. In the end, we combine the layers to obtain a suitability surface that represents our accessibility model.

Surface type	Speed (km/h)	
	Walking	Public transport
Slope	Based on Tobler's hiking equation	
Rivers	0	0
Paved roads	5	5
Unpaved roads	3	3
Public transport network	Not applicable	21

Table 1: Input values for the accessibility models

Rasterize [1]

- From the *Processing toolbox*, filter by “v.to.rast” to find the **v.to.rast** tool. Provide Kigali_river as **Input layer** set the **Source of raster values** to “va”, provide “0” as the **Raster Value** and “25” under **GRASS GIS 7 region cell size** (i.e. the pixel size). Finally provide an output name – we suggest `rivers_raster` and Hit **Run** to execute (Figure 3).

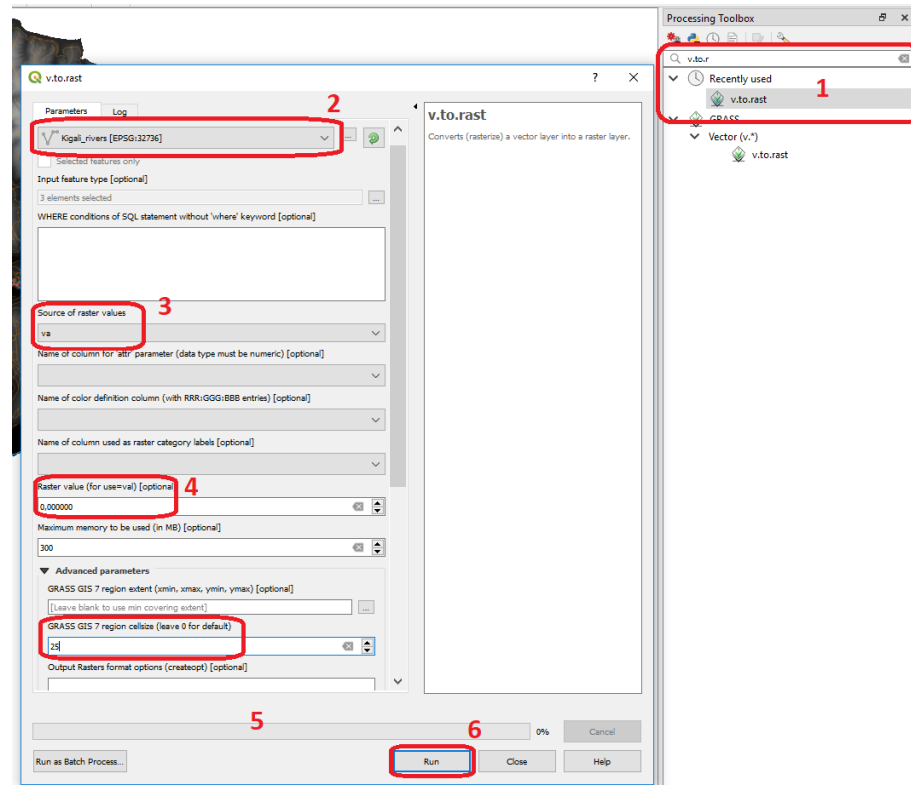





Figure 3 – Using the v.to.rast tool

 The layer we just created may have been added to the Layers Panel with a default name like 'rasterized' or something similar. If that is the case, please rename the layer according with the output name we chose. This will help you to keep track of our project.

 Repeat the previous operations for the layers `Kigali_bus_route`, `paved_roads` and `unpaved_roads`. To each of them assign the values mentioned in table 1 as the raster value and keep "25" as pixel size. As output name, we suggest `bus_route_raster`, `paved_raster` and `unpaved_raster` respectively.

Slope [2]

Regardless of walking along a road or taking shortcuts, the inclination of the terrain has a huge impact on what speed can people walk. In order calculate that we need a slope map and on top of it we will calculate the walking speed using Tobler's Hiking equation¹

 The Tobler Hiking equation we are using is a simplification of the original one in the sense that it ignores travel direction. Therefore, the slope value is always taken as uphill walking and never as downhill walking.

¹ https://en.wikipedia.org/wiki/Tobler%27s_hiking_function

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- From the *Processing toolbox*, filter by “gradient” to find the **Downslope distance gradient** tool. Provide *dem_kigali* as **Input layer**, “1” under **Vertical Distance** and choose **[2] gradient (degree)**. Finally, provide an output name – we suggest *slope*. Hit **Run** to execute (Figure 4).

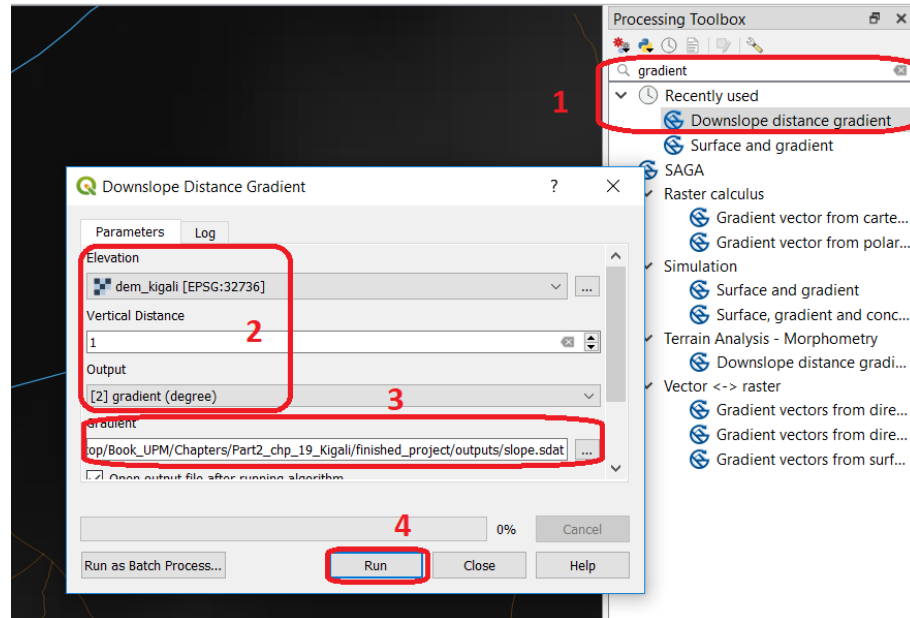


Figure 4 – creating a slope map

- 📌 Tobler's equation for walking speed is as follows:

$$W = 6e^{-3.5 \left| \frac{dh}{dx} + 0.05 \right|}$$

$$\frac{dh}{dx} = S = \tan \theta$$

Where:

W = walking velocity [km/h]

dh = elevation difference

dx = distance

S = slope

θ = angle of slope (inclination).

The tool we used calculates the slope in the form of a gradient, and we will use those values to estimate the walking speeds.

Raster Calculator [3]

- From the Raster menu open the raster calculator and provide the following expression:

```
6*2.71828^(-3.5*( "slope@1"+0.05) )
```

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Save the result of the operation. We suggest you name it `walk_speed` and click on **OK** to execute (Figure 5)

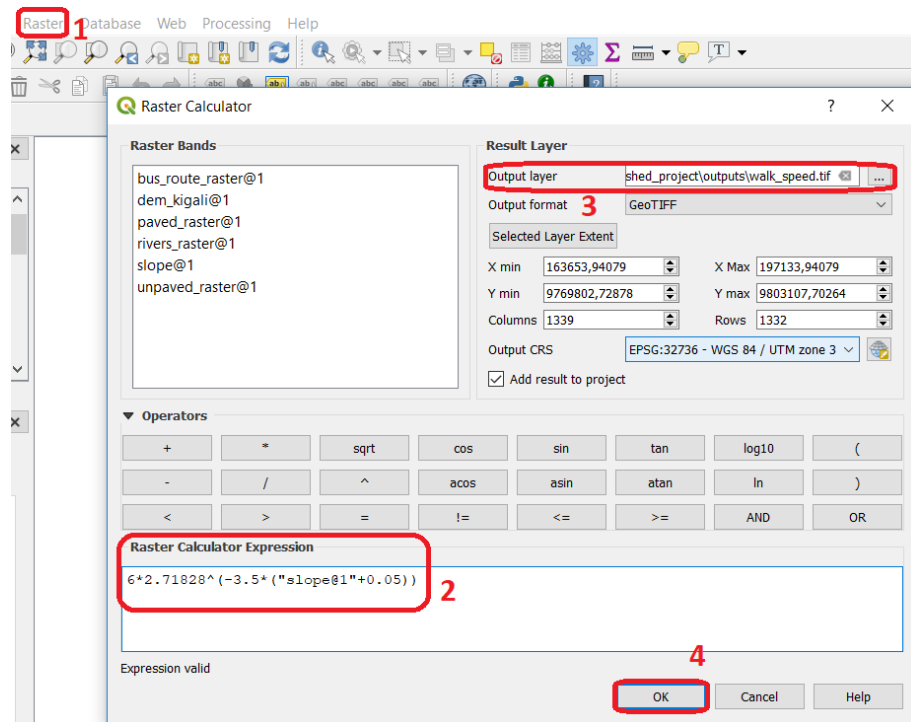


Figure 5 – using the raster calculator

We now have a raster layer whose pixel values represent the walking speed of a person who is traversing the pixel uphill (Figure 6)

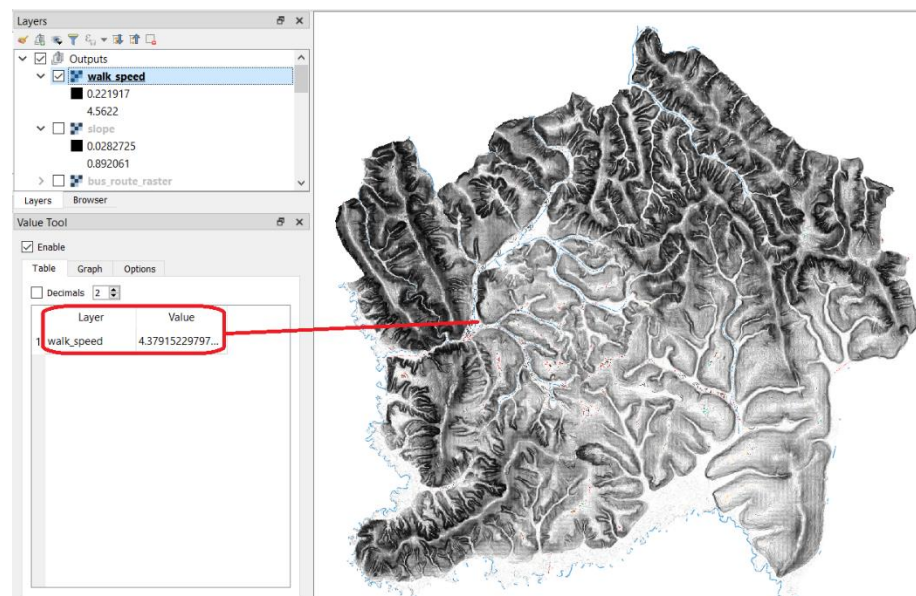


Figure 6 – Walking speed map

🔍 We highly recommend that at this point you install the **Value Tool Plugin**. It allows you to plot the pixel values of all the active rasters of our project at the location of the mouse pointer. Installing plugins in QGIS is trivial, there are many resources explaining how to do it, for example [here](#).

💡 If you use the Value Tool to inspect the `walk_speed` map, you will notice that there are areas of 'no data', meaning no value was calculated for those areas. If you inspect the `dem_kigali` you will notice that those areas correspond to flat areas (Figure 7), in other words, areas of contiguous pixels of the same value. In those areas it is not possible to calculate downslope distances. We will fix this by interpolating `walk_speed` values from the surrounding cells to fill in these 'no data' areas. Interpolating consists of estimating an unknown value based on nearby known values.

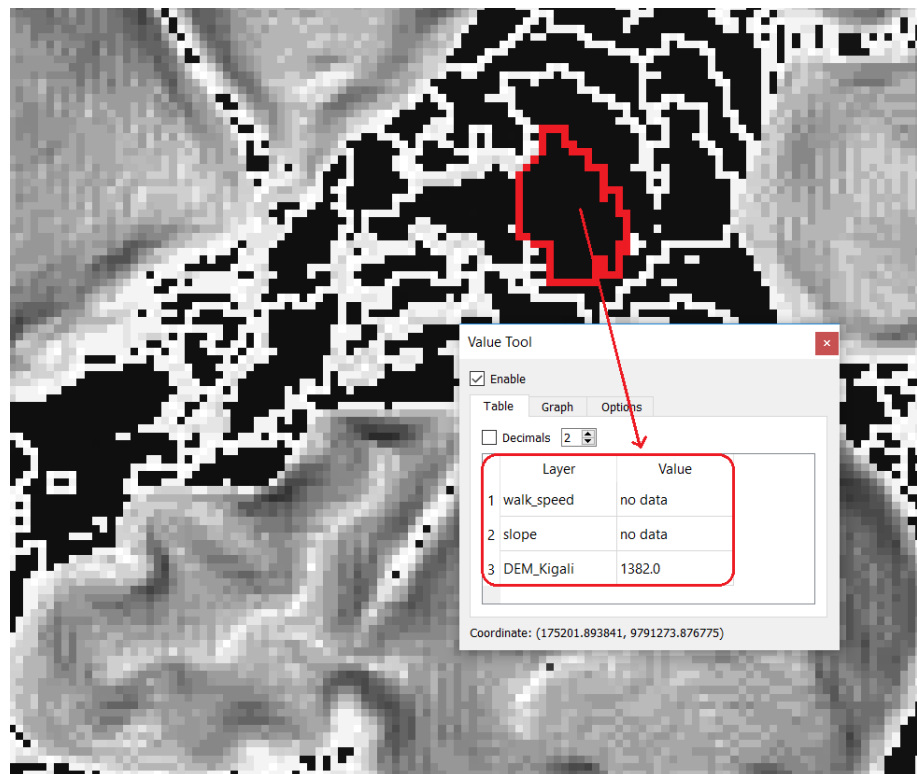


Figure 7 – Relation between flat areas and slope and walk_speed layers

Fill no data values (by interpolation) [4]

- From the *Processing toolbox*, filter by “fill” to find the **Fill nodata** tool. Provide `walk_speed` as **Input layer** and “50” under **Maximum distance (on pixels) to look for values to interpolate**. Provide an output name – we suggest `walking_speed`. Hit **Run** to execute (Figure 8).

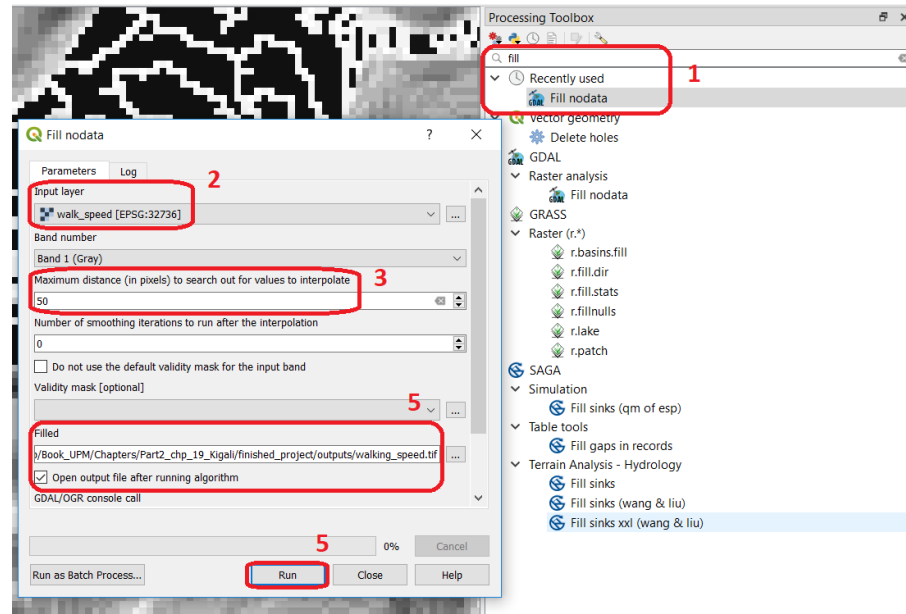


Figure 8 – Filling no data areas by interpolation

- Remove the `walk_speed` layer from the *Layers panel* to avoid confusion with the `walking_speed` layer we just created. We will use this layer from now on.

The next step consists of combining the raster layers we have been generating into one single raster where the pixel value represents the travel speed in km/H. However, we cannot simply sum all the rasters because that would inflate the pixel values to unrealistic values. For example if we sum the off-road walking speed values to the roads walking speed values we will have any value between 3 and 10 km/H of walking speed, which would be unrealistic for the pixels of higher value because humans don't walk at 8,9 10km/H, that is called 'running'. Therefore, we have to combine the raster layers in a way that preserves only one of the values whenever there is an overlap.

- To achieve that we will combine these layers in a way that the pixel values will be derived from only one of the input layers according to the rules described below.

IF for the same location there are two or more pixels covering that area then the output raster will preserve the value of (by order of priority):

- (1) Paved_raster
- (2) Unpaved_raster
- (3) Rivers
- (4) Walking_speed

This concept is illustrated in Figure 8

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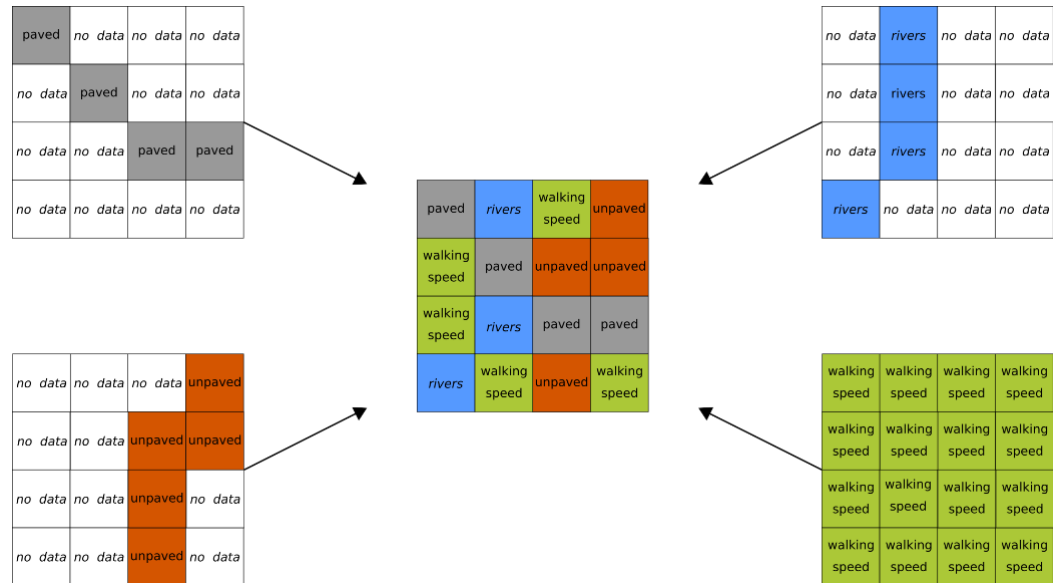


Figure 8 – Combining raster sets

We now will proceed with the combination illustrated above.

Combining rasters [5]

- From the *Processing toolbox*, filter by “mosaic” to find the **Mosaic raster layers** tool. Provide `rivers_raster` and `walk_speed` as **Input Grids**, choose “first” under **Overlapping Areas** and set Cellsize to “25”. Lastly, provide an output name – we suggest `walk_unpaved`. Hit **Run** to execute (Figure 9).

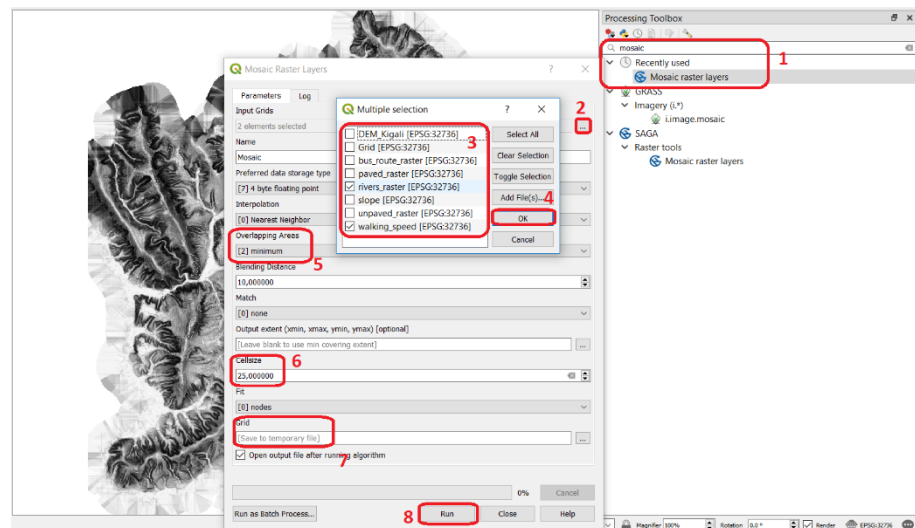


Figure 9 – Combining raster sets using SAGA’s Mosaic raster layers

- We will need two more iterations to obtain our final input. Repeat the previous operation according to the parameters listed in table 2.

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Input 1	Input 2	Overlapping areas	Cellsize	Output
walk_rivers	unpaved_raster	first or last ²	25	walk_rivers_unpaved
walk_unpaved	Paved_raster	maximum	25	walking_accessibility

Table 2: Raster combination steps to generate a pedonal travel mode raster

At the end of the steps listed above we will have a raster layer with values between 0 and 5 representing the estimated walking speed, in km/H, which one would walk while traversing them. This is our accessibility model for pedonal travel mode.

We also need an accessibility model for public travel mode. This consists of simply considering the public transport (bus) routes on top of our pedonal travel mode model.

- Repeat the previous operation following the parameters listed in table 3 to generate a raster representing the model for public travel mode.

Input 1	Input 2	Overlapping areas	Cellsize	Output
walking_accessibiity	Bus_raster	maximum	25	pubtransp_accessibility

Table 3: Raster combination to generate a public travel mode raster

Clip accessibility model [6]

The interpolation used to fill the *nodata* values went beyond the study area, creating extra cells that add nothing to our analysis. As a result, when combining all the layers we inherited that. We will clip the accessibility models according with the actual extent of the study area.

- From the *Processing toolbox*, filter by “clip” to find the **Clip raster by mask layer** tool. Provide `pubtransp_accessibility` and `kigaliboundary` as **Input Grids** and check the option **Keep resolution of output raster**. Lastly, provide an output name – we suggest `pubtra_accessibility`. Hit **Run** to execute (Figure 10).
- Repeat the previous operation having `walking_accessibility` and `kigaliboundary` as **Input Grids**. For output name – we suggest `walk_accessibility`.

² The order of the layers matters! The option between “first” or “last” depends on what order are the layers listed in the **Grids** menu of the **Mosaic raster layers** tool. We do want to preserve the values of `unpaved_raster`, so it is up to weto assess if that layer is listed above or below the `walk_rivers` layer and set the **Overlapping areas** parameter accordingly.

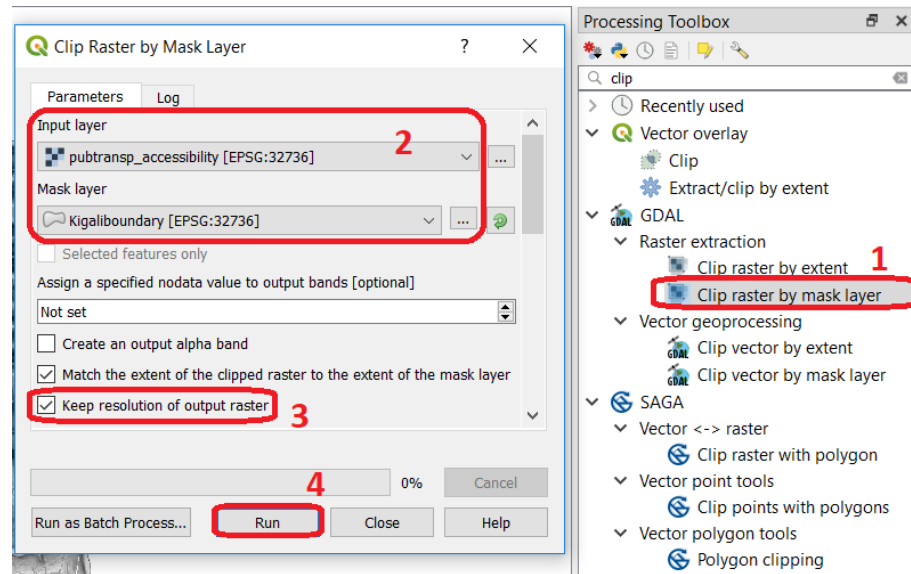


Figure 10 – Clipping rasters by mask extent

Styling rasters (optional)

To have a better visual insight of the accessibility models you may want to style them using the style template we provided along with the data.

- From the *Layers panel*, **right-click** on the `Walk_accessibility` layer and access that layer's **Properties**. At any tab in the *Layer Properties* dialog click on the **Style** button, choose **Load Style** and point to the style file (`accessibility_model.qml`). Finish by clicking on **Apply** (Figure 10)

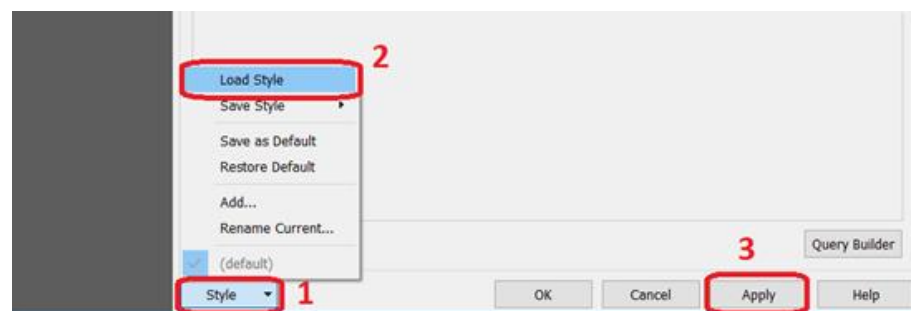


Figure 11 – Applying a style file

- Repeat the previous operation for layer `pubtra_accessibility`

If you applied the styles, the rasters representing the accessibility models should now look like this (Figure 11)

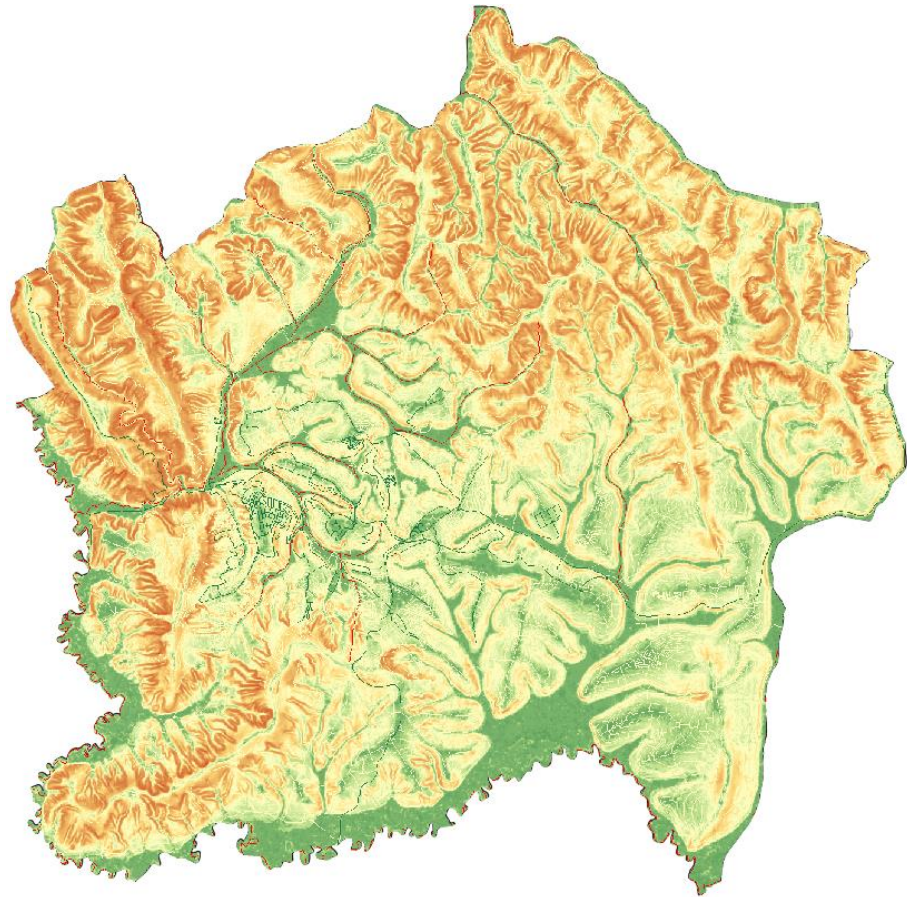


Figure 12 – Aspect of walk_accessibility layer after applying the style file.

SECOND PART: Multicriteria analysis

Let us keep in mind that the final goal of this methodology is to assess resettlement sites that would minimize the risk of impoverishment of households in a scenario of relocation triggered by natural disaster.

💡 It is important to understand that poverty does not concern only income. When assessing poverty, other factors just have to be considered, namely proximity to certain kind of amenities that have the potential to provide employment opportunities, access to education and health care, as well as the proximity to previous social networks – an especially important factor when considering the cases of relocation – among other factors that are further described in the article.

The indicators used to assess suitability of potential resettlement sites, their weights and the datasets from where they will be calculated can be seen in table 4.

Subset	Indicator	weight	dataset
Site location preferences	Distance to city centre	0.33	Kigali_CBD
	Distance to commercial centres	0.22	Commercial_centres
	Distance to original settlement	0.11	Origin_settlement
Social and public services	Distance to markets	0.11	Kigali_markets
	Distance to Primary Schools	0.045	Kigali_ps
	Distance to Secondary schools	0.029	Kigali_ss
	Distance to Universities	0.015	Kigali_universities
	Distance to health facilities	0.067	Kigali_healthcare
	Distance to bus route	0.044	Kigali_bus_route
	Distance to bus stop	0.022	Kigali_bus_stop

Table 4: Multicriteria analysis indicators

💡 As shown in the table, all the indicators will be assessed based on distance criteria. The distance however is not a simple euclidian distance but distance measured as a function of travel speed, a more realistic approach. This travel speed distance is taken from the accessibility model developed in the previous section. Because not all indicators have the same weight, these travel speed measurements have to be normalized in order to allow the final combination of the indicators into one final suitability map.

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- 🖨 To calculate the indicators described above It is important to understand that the accessibility map that will be on the basis of the travel speed distance we are interested represents *suitability* but we need to generate a *cost* surface in order to rank locations in respect to distance in travel time to certain features.

Raster calculator [7]

- From the *Raster menu*, open the **Raster calculator** . Use the expression:

$25 / ("walk_accessibility@1" * 1000 / 3600)$

Provide an output name - we suggest you name your output `walk_cost`. In **Raster Bands** select the `Walk_accessibility@1` and then click on **Selected Layer extend**. Click **Ok** to finalize (Figure 13)

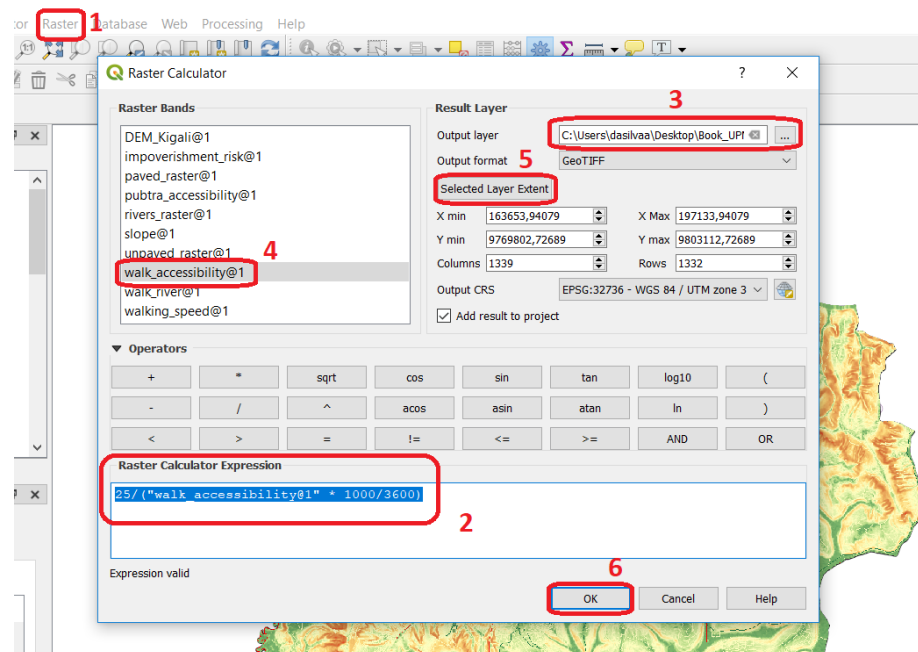


Figure 13: Generating a cost surface

- Repeat the previous procedure but for the `pubtra_accessibility`. For output name we suggest `pubtra_cost`.

Styling rasters (optional)

To have a better visual insight of the cost surfaces we may want to style them using the style template we provided along with the data.

- From the *Layers panel*, **right-click** on the `Walk_cost` layer and access that layer's **Properties**. At any tab in the *Layer Properties* dialog click on the **Style** button, choose **Load Style** and point to the style file (`walk_cost.qml`). Finish by clicking on **Apply** (Figure 14)

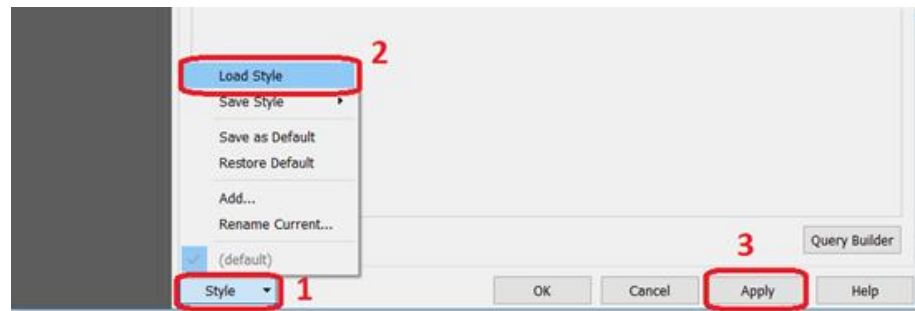


Figure 14 – Applying a style file

- Repeat the previous procedure for the `pubtra_cost` layer.

If you applied the styles, the cost surfaces should now look like this (Figure 15)

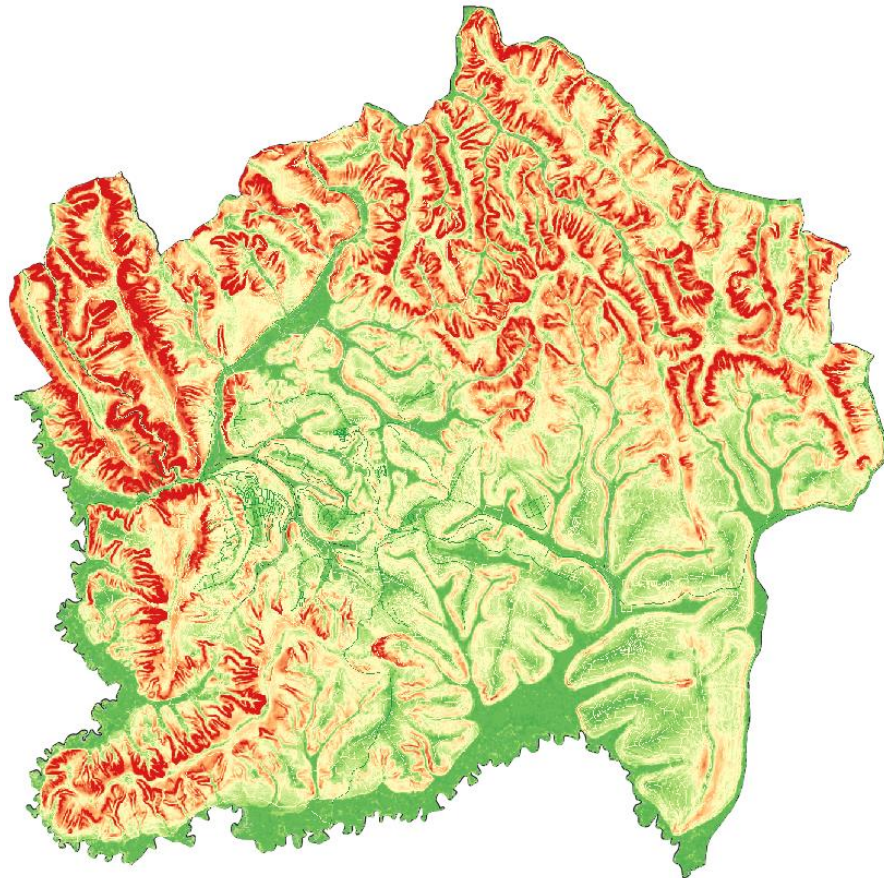


Figure 12 – Aspect of `walk_cost` layer after applying the style file.

The two new layers produced by the **Raster calculator** tool now have pixel values that represent an estimation of how many seconds are required to transverse the pixel. Note that no direction, slope or other constraints are being taken into account, so essentially, what we calculated is, given the speed of the traveler, the amount of seconds necessary to cover 25m.

Rasterization, Accumulated cost and Normalization [8]³

Now we have the cost surface we need to calculate the indicators described in table 4. Figure 12 shows the procedure needed to calculate the indicators. We have to run that procedure once for every indicator. Luckily, QGIS allows the automation of workflows and its execution as a batch process as we will see.

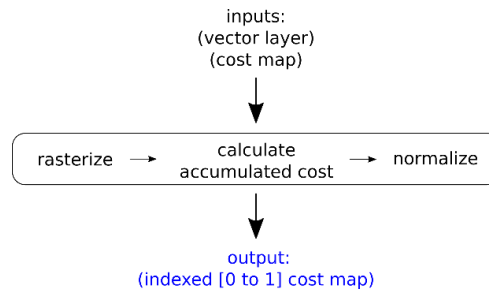


Figure 14 – Workflow for calculating the indicators needed for the multicriteria analysis

The workflow execution is detailed in figure 14.

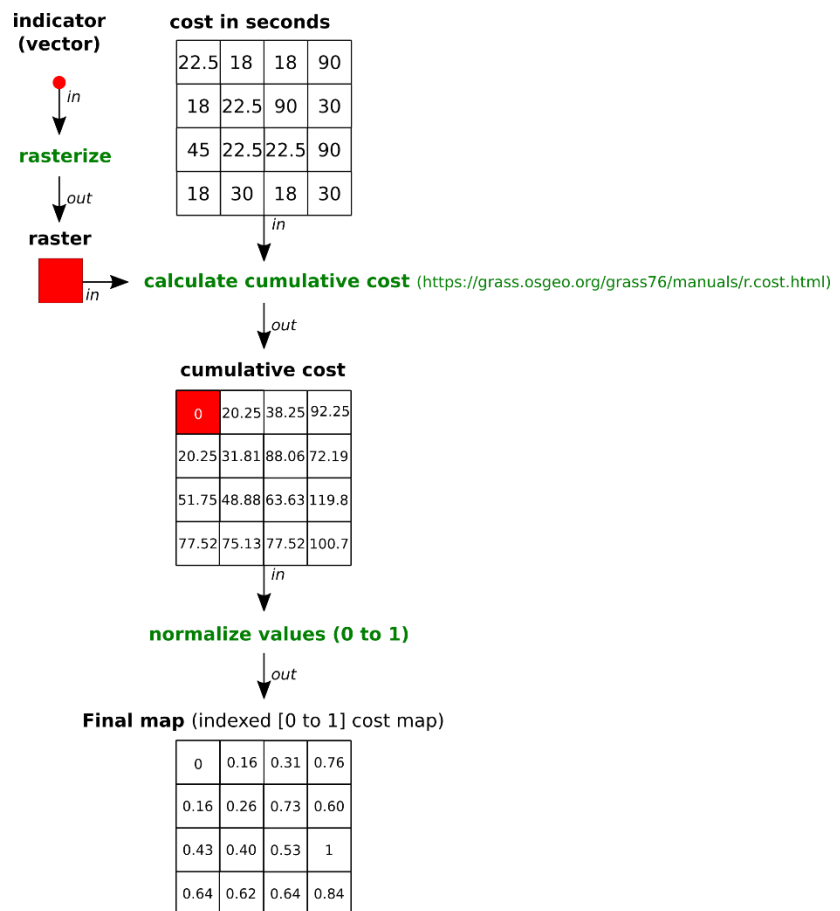


Figure 14 – Detailed depiction of the workflow

³ The procedure in this section takes as input the walking cost surface. All the procedures from here onwards would be the same for the public transport cost surface.

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- ▶ To implement the workflow described in the previous page, watch the video “build_model” to see how to build the workflow depicted in figure 14;

-OR-

- ▶ From the *Processing toolbox*, click on **Models** and then on **Open Existing Model...** and open `accumulated_cost.mpd13` which is included in the ‘Models’ folder. (Figure 15)

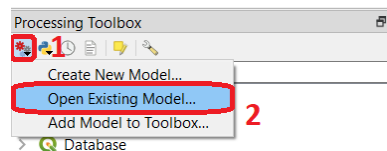


Figure 14 – Opening a pre-existing model

Once the model is imported, you can simply run it from the Processing Toolbox like any other tool. We will have to repeat this proceeding for every indicator listed in table 4. Every time we run it remember change the **Features** parameter (Figure 14)

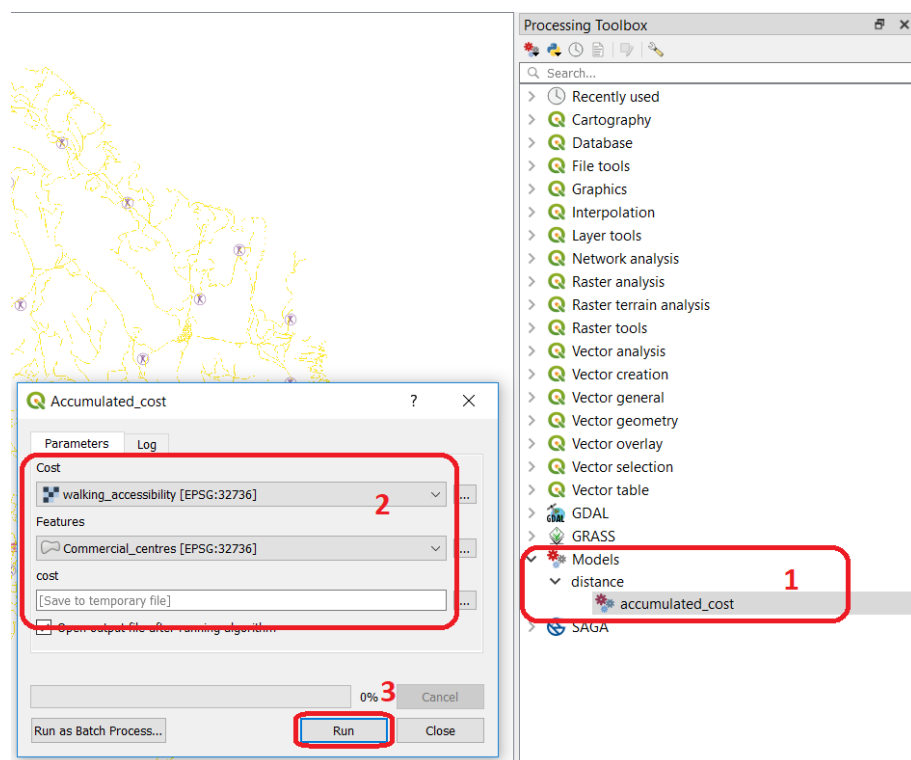


Figure 15 – Running a model

- ▶ Check the video “batch_processing” to see how you can run the **accumulated_cost** tool as a batch process (i.e. in one execution) for all the input layers instead of having to repeat the process 10 times – one for each indicator.

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Raster calculator [9]

We now have the ten indicators we need; we can proceed to obtain the final output of the suitability analysis – a map showing potential resettlement sites and their suitability levels in terms of minimizing the impoverishment risk. To do that we need to perform a weighted average according to the weights specified in table 4.

► From the *Raster menu*, open the **Raster calculator** . Use the expression:

```
"cost_Kigali_CBD@1" * 0.33 + "cost_Commercial_centres@1" * 0.22 +  
"cost_Origin_settlement@1" * 0.11 + "cost_Kigali_Markets@1" *  
0.11 + "cost_Kigali_ps@1" * 0.045 + "cost_Kigali_ss@1" * 0.029 +  
"cost_Kigali_universities@1" * 0.015 + "cost_Kigali_Healthcare@1"  
* 0.067 + "cost_Kigali_bus_route@1" * 0.044 +  
"cost_Kigali_bus_stop@1" * 0.022
```

Provide an output name - we suggest the name `impoverishment_risk`. Click **Ok** to finalize (Figure 15)

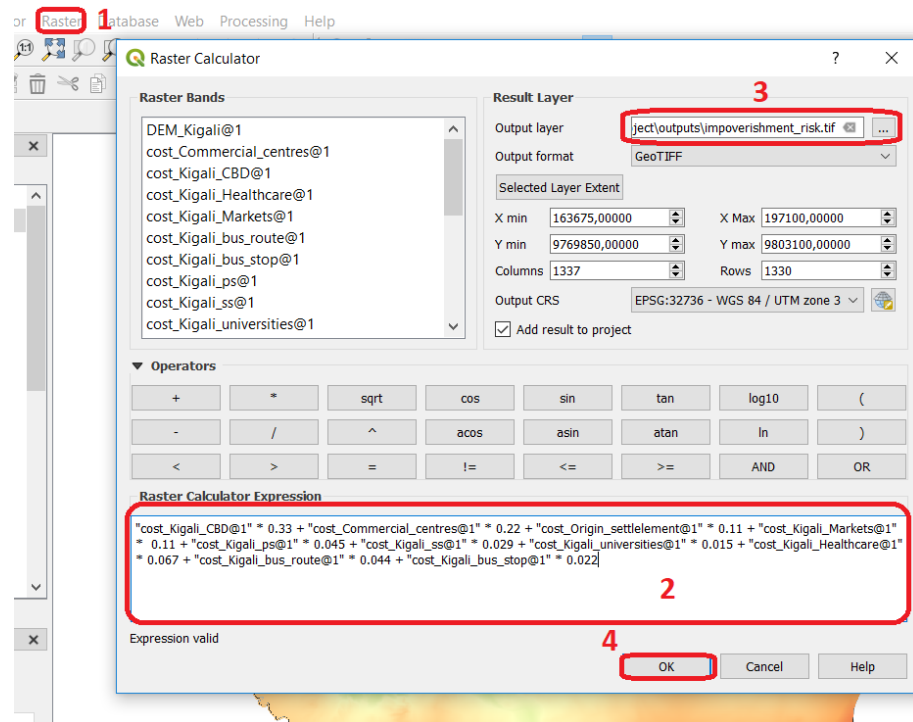


Figure 15: Generating a the impoverishment_risk map

Styling rasters (optional)

To have a better visual insight of the cost surfaces you may want to style them using the style template we provided along with the data.

► From the *Layers panel*, **right-click** on the `impoverishment_risk` layer and access that layer's **Properties**. At any tab In the *Layer Properties* dialog click on the

Style button, choose **Load Style** and point to the style file (walk_cost.qml). Finish by clicking on **Apply** (Figure 16)

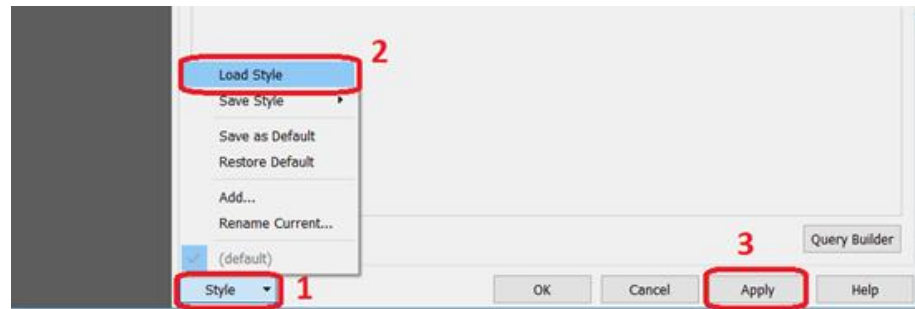


Figure 16 – Applying a style file

If you applied the styles, the impoverishment map will look like this (Figure 17)

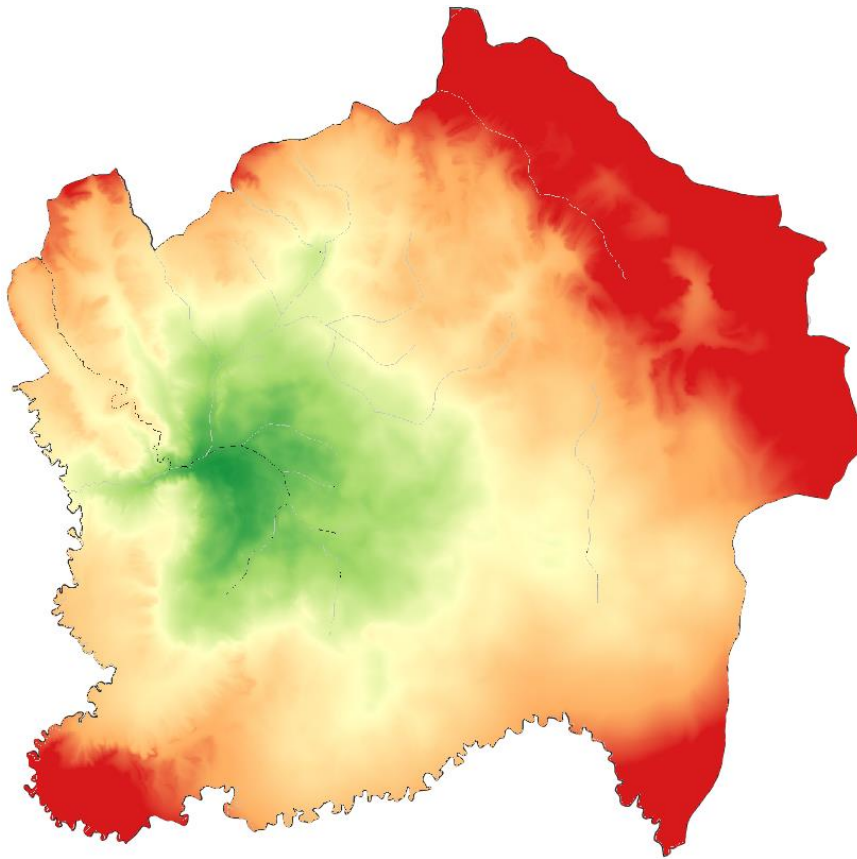


Figure 17 – Aspect of impoverishment_risk layer after applying the style file.

With the data on impoverishment risk we can now evaluate what would be the best options to resettle those citizens within a set of candidate locations in case of a forced community displacement motivated by a natural disaster event. The best options are those whose impoverishment risk is lower than what it was in the original settlement.

The original location is the Gatsabo sector within the Gasabo district. This location is represented by the layer `origin_settlement`. On the other hand, the set of

candidate locations for resettlement consists of several low-income residential areas spread all over the Gasabo district. These areas are provided by the layer `low_income_residential_areas` (Figure 18).

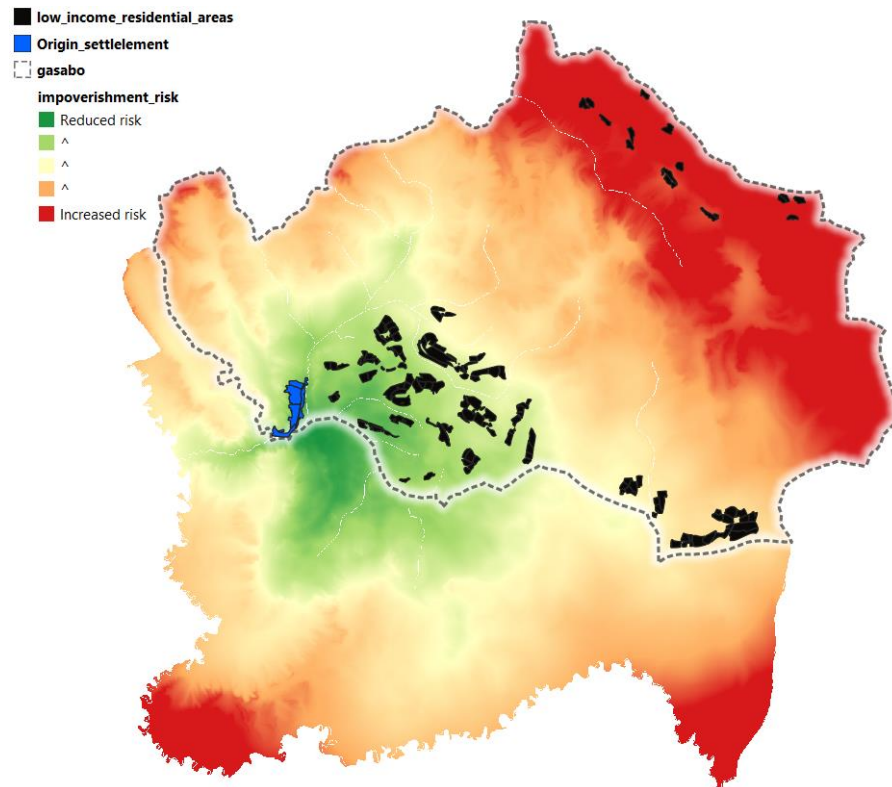


Figure 18 – Gasabo district settlements

Zonal statistics [10]

- From the *Processing toolbox*, filter by “zone” to find the **Zonal statistics** tool. Provide `impoverishment_risk` and `origin_settlement` as **Input layer** and **Vector layer containing zones** and chose “mean” as the **Statistics do calculate**. Hit **Run** to execute (Figure 19).

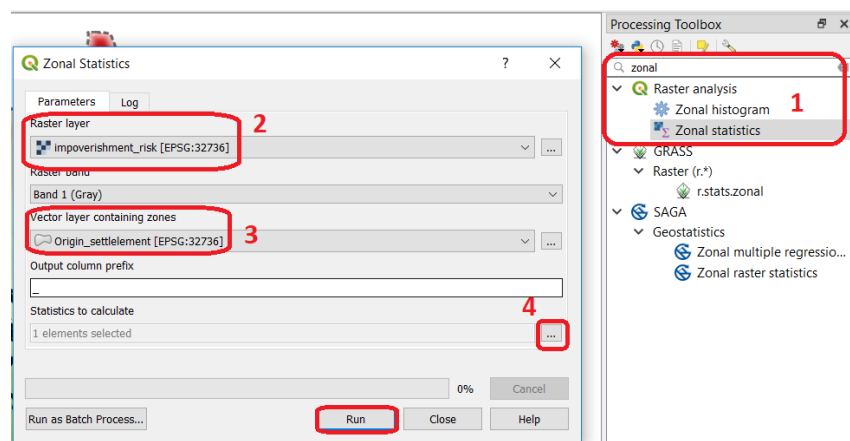


Figure 19 – Using Zonal statistics

- ▶ Repeat the procedure for the `low_income_residential_areas` layer.
- 💡 What we just did was to calculate the average impoverishment risk for all the areas covered by the `origin_settlement` and the `low_income_residential_areas`. This will allow us to evaluate and rank how the resettlement areas (i.e. `low_income_residential_areas`) compare to the origin settlement to assess if they represent an increased risk of impoverishment should citizens be moved to one of those areas. The average impoverishment risk for the `origin_settlement` is 0,067147441862501. We will use this as a threshold for the last steps of the analysis.

Field calculator [11]

- ▶ From the *Layers panel*, **right-click** on layer `low_income_residential_areas` and choose the option **Properties**. From the **Source Fields** tab start editing mode by clicking on the **Toggle editing mode** button and then on the **Field Calculator** icon. In the *Field Calculator* window choose **Create a new field**, provide “`risk_dif`” as the **Output field name** and *Decimal number (real)* as the **Output field type** and enter the following expression:

`"lu_type_en" - 0.067147441862501`

Press **OK** to dismiss the *Field Calculator* dialog and click on **Toggle editing mode** to make the newly created field permanent (Figure 20).

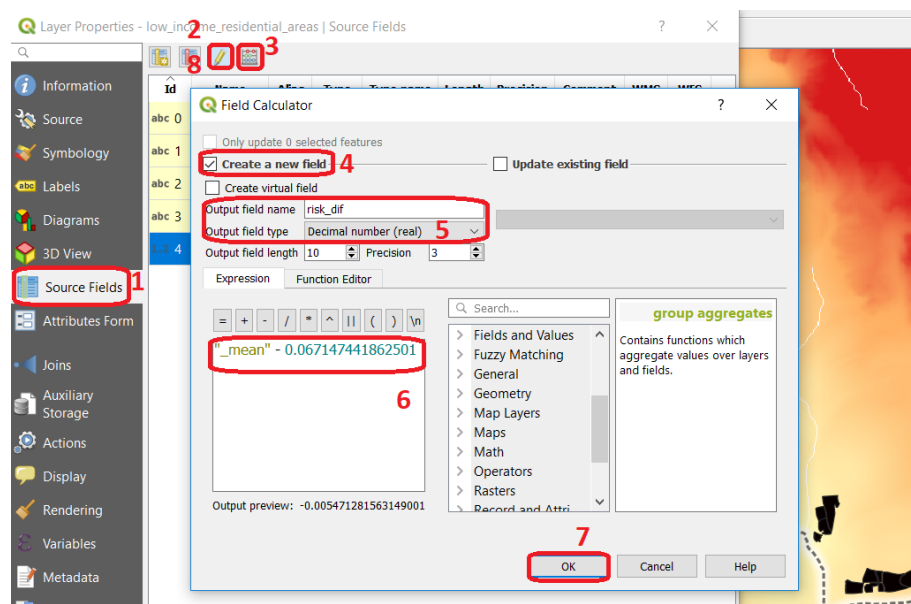



Figure 20 – Using The Field calculator

-  The “risk_dif” field is a simple difference measurement: if the obtained value is positive it means the location represents a risk increase in comparison with the original settlement. On the other hand, if the value is negative it means the new location will actually decrease the impoverishment risk.

Styling [12]

As a last step of this demonstration we will style the layer `low_income_residential_areas` in a way that that shows clearly how the potential resettlement location rank in respect to reducing or increasing the impoverishment risk when compared to the original location.

- From the *Layers panel*, **right-click** on the `low_income_residential_areas` layer and access that layer’s **Properties**. At any tab In the *Layer Properties* dialog click on the **Style** button, choose **Load Style** and point to the style file (`low_income_residential_areas.qml`). Finish by clicking on **Apply** (Figure 21)

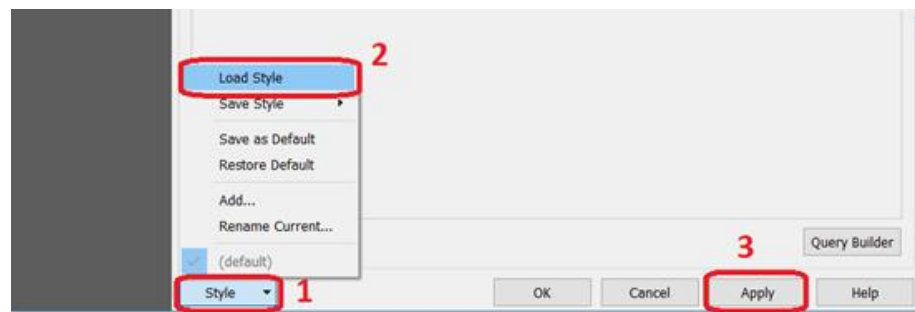


Figure 21 – Applying a style file

The final result of the whole analysis process can be seen below (Figure 22).

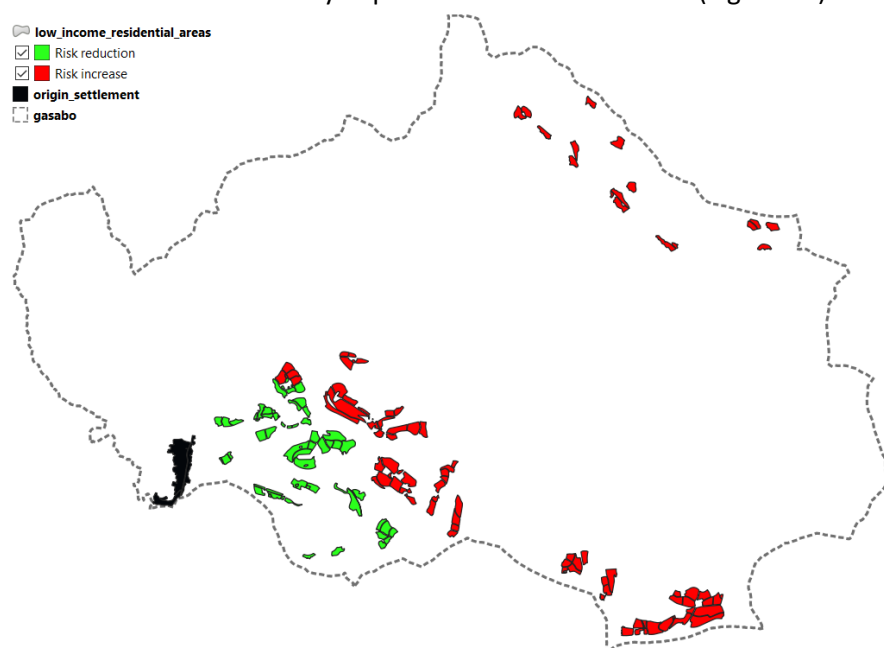


Figure 22 – Map of impoverishment risk in case of resettlement

Flowchart of operations

FIRST PART - accessibility model

