USING InVEST TO MAP THE CONTRIBUTION OF MANGROVES TO REDUCING COASTAL VULNERABILITY

STEP-BY-STEP TUTORIAL V1.0: EVALUATING THE IMPORTANCE OF MANGROVES FOR COASTAL PROTECTION, A SIMPLE APPROACH USING INVEST

Working Document

UN-REDD PROGRAMME

Food and Agriculture Organization of the United Nations

UNDP

UN environment programme

The UN-REDD Programme is the United Nations Collaborative initiative on Reducing Emissions from Deforestation and forest Degradation (REDD) in developing countries. The Programme assists developing countries to 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).

Since its inception in 2008, UN-REDD, the UN interagency flagship programme on forests and climate, has, with support of Norway and other donors, contributed to slowing deforestation, promoted as a guiding principle the informed and meaningful involvement of all stakeholders, including indigenous peoples, local communities and women, established firm social and environmental safeguards, and contributed to the sustainable development of its 65 partner countries.

The United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC) is a global Centre of excellence on biodiversity. The Centre operates as a collaboration between the United Nations Environment Programme and the UK-registered charity WCMC. Together we are confronting the global crisis facing nature.

These training materials have been produced from materials generated for webinars held with partners in Myanmar to aid the production of ecosystem service and biodiversity using open-source GIS software and models, as part of the UN-REDD project 'Integrating mangroves sustainable management, restoration and conservation into REDD+ implementation in Myanmar. This work was funded by the UN REDD Programme and the Norwegian Agency for Development Cooperation (NORAD).

This publication may be reproduced for educational or non-profit purposes without special permission, provided acknowledgement to the source is made. Reuse of any figures is subject to permission from the original rights holders. No use of this publication may be made for resale or any other commercial purpose without permission in writing from the UN Environment Programme. Applications for permission, with a statement of purpose and extent of reproduction, should be sent to the Director, UNEP-WCMC, 219 Huntingdon Road, Cambridge, CB3 0DL, UK.

Disclaimer: The designations and the presentation of the materials used in this publication, including their respective citations, maps and bibliography, do not imply the expression of any opinion whatsoever on the part of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Also, the boundaries and names shown and the designations used in this publication do not imply official endorsement or acceptance by the United Nations.

Acknowledgements: With thanks to Kollie Tokpah and Charlotte Hicks for review.

Suggested citation: Critchley, M. (2023) Using InVEST to map the coastal protection services of mangroves. Step-by-step tutorial v1.0: Evaluating the importance of mangroves for coastal protection, a simple approach using InVEST. Prepared on behalf of the UN-REDD Programme. UNEP World Conservation Monitoring Centre, Cambridge, UK.

UNEP promotes environmentally sound practices globally and in its own activities. Our distribution policy aims to reduce UNEP's carbon footprint.

Contents

1. Introduction

Coastal communities are particularly vulnerable to the impacts of extreme weather, including tropical storms and cyclones. Mangroves, and other ecosystems such as coral reefs, play an important role in protecting coastal communities from coastal inundation, flooding, and erosion. Protecting and restoring mangroves can play an important role in climate change adaptation, particularly where rising sea levels, increasingly intense and frequent storms and heavy rain events are expected.

Modelling allows us to better understand where mangrove ecosystems play the greatest role in reducing vulnerability to coastal inundation, and where these services are particularly important for local communities. In doing so, we can prioritise areas for protection or restoration.

This tutorial will demonstrate how to use the InVEST Coastal Vulnerability model to map the contribution of mangroves to reducing the vulnerability of coastal populations.

InVEST

InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) is a set of free software models used for mapping and valuing environmental goods and services. With InVEST, decision-makers can identify areas where investment in natural capital can improve human development and nature conservation. The application features 18 distinct ecosystem service models designed for terrestrial, freshwater, marine and coastal ecosystems as well as several 'helper tools' to assist with locating and processing input data, generating results and understanding them.

Descriptions of the InVEST models can be found in the online user manual: http://releases.naturalcapitalproject.org/invest-userguide/latest/

The Coastal Vulnerability model

The coastal vulnerability model uses geophysical and natural habitat characteristics of coastal landscapes to compare the exposure of points along the coast to erosion and flooding in severe weather. The model outputs can be used to understand the relative contributions of different natural habitats (e.g. mangroves, coral reefs and seagrass) to reducing coastal vulnerability.

InVEST model description and user manual: http://releases.naturalcapitalproject.org/invest-userguide/latest/coastal_vulnerability.html

2. Software requirements

The InVEST suite of models can be downloaded from https://naturalcapitalproject.stanford.edu/software/invest and a guide to installing the software and sample data on your computer can be found here: http://releases.naturalcapitalproject.org/invest-userguide/latest/getting_started.html#installing-invest-and-sample-data-on-your-windows-computer

This tutorial uses **InVEST version 3.11.0 (Workbench edition)**. Once downloaded, click the settings icon and click 'download sample data'. This contains some of the data we need to input to the model.

3. Data requirements

The model requires data on your area of interest, including geophysical and biophysical data on shorelines, elevation, and natural habitats (including mangroves). Other data includes wave data and population data. Several inputs are optional, therefore if you do not have available data, the model can still run.

Table 1. Data inputs for the InVEST coastal vulnerability model. Including a description of inputs and suggested sources. Information collated from InVEST model user manual

Model input	Type of data	Description	Data source
Area of interest (AOI)	Polygon shapefile	Area of interest for your study. The AOI should extend slightly beyond coastline and habitats of interest. This input must have a projected coordinate system. In this case EPSG:32646 - WGS 84 / UTM zone 46N	Dependant on study context. Can also be drawn in GIS software.
Model resolution	Numeric input	Interval at which to space shore points along the coastline.	Dependant on study context.
Landmasses	Polygon	Map of all landmasses in and around the region of interest. It is not recommended to clip this landmass to the AOI	Provided in the model sample data

Model input	Type of data	Description	Data source
		polygon because some functions in the model require searching for landmasses around shore points up to the distance defined in Maximum Fetch Distance, which likely extends beyond the AOI polygon.	Global land polygons also available (e.g. GADM).
Bathymetry	Raster	Provides the model with water depths used to compute wave power.	GEBCO Bathymetry is globally available and a sufficient resolution for the model. This dataset can be [downloaded here]().
Wave exposure (WAVEWATCHIII)	Point shapefile	Used to estimate the relative exposure of a coastal segment to wave exposure.	WAVEWATCH III data, supplied with model sample data.
Maximum fetch distance	Numeric (metres)	Used by the model to distinguish between sheltered coastal segments (e.g. bays and lagoons) versus exposed coastal segments.	Based on the configuration of the coastline and the distance over the water which wind can blow unobstructed
Habitats Table	The model requires a .csv file with a file path to spatial habitat data (shapefiles) and additional information on each habitat type (id, file path, rank and protection distance)	The model accounts for the role of natural habitats (such as mangroves) in protecting the shoreline, habitats are ranked in the model based on their morphology and ability to protect the shoreline. Greater protection is provided where habitats co-occur.	Natural habitats can be input using maps for the study site, those derived from remote sensing, field data and national land use/land cover maps. Global data is available for the extent of mangroves, coral

Model input	Type of data	Description	Data source
			and seagrass: http://data.unep-wcmc.org/
Continental shelf contour	Polyline	This is used by the model to calculate the relative exposure of each shoreline segment to storm surge using distance to the shelf as a proxy for storm surge potential.	A continental shelf polyline comes with the model (sample data).
Digital elevation model (DEM)	Raster	The model requires this to calculate the relief rank, and uses the elevation averaging radius to calculate the average elevation.	A number of DEMs, such as GMTED2010, can be downloaded at several spatial resolutions from NASA Earth Data. A void-filled DEM at 3s (~90m) resolution can be downloaded from HydroSHEDS
Elevation averaging radius	Numeric (metres)	Distance around each shore point which is used to calculate the average elevation.	Depends on the resolution of the DEM. Default value is 5000m.
Geomorphology (optional)	Polyline shapefile with segments which characterise the shoreline geomorphology.	Certain geological features are less prone to erosion (e.g. rocky cliffs) whereas others may be more vulnerable (e.g. muddy deltas).	Check for available datasets.
Human population (optional)	Raster population	The model can account for population exposed and socio-economic metrics e.g. property values and population demographics (e.g. elderly populations).	WorldPop (1km and 100m resolution available). National population data may be available.

Model input	Type of data	Description	Data source
Population search radius	Numeric (metres)	The distance around each shore point which is used to calculate the population density.	Dependant on local context and input data used. Default suggestion is 5000m.
Seal level rise (optional)	Point vector with an attribute table containing a relevant sea level rise metric as an attribute field (rate, net rise, or any other variable that may be relevant to coastal inundation)	If a region of interest is large enough, there may be variations in sea level rise.	Not used in this analysis, review for relevant data is using.

It is important to document the sources of all data, their strengths and limitations. Should new or improved data become available, you can see where there is room for improvement. All spatial data should be in the same projected (not geographic) coordinate system. The chosen coordinate system should be suitable to the region of interest, one commonly used system is UTM. Any data inputs which are not projected, will be reprojected by the model to the same projection as the AOI polygon. For example, in this example we will use EPSG: 32647 - WGS 84 / UTM zone 47N.

4. Data inputs

Biogeographical inputs are ranked to calculate the coastal exposure index, the variables are proxies for various complex shoreline processes that influence exposure to erosion and inundation. Each variable is ranked from 1 to 5, with 1 representing relatively low exposure and 5 representing relatively high exposure.

Table 2. List of bio-geographical variables and a description of their relative ranks used to calculate the coastal exposure index. Adapted from InVEST training tutorial.

Rank	Very Low 1	Low 2	Moderate 3	High 4	Very High 5
Geomorphology	Rocky; high cliffs; fjord; seawalls	Medium cliff; indented coast, bulkheads and small seawalls	Low cliff; glacial drift; alluvial plain; Revetments, rip-rap walls	Cobble beach; estuary; lagoon; bluff	Barrier Beach; sand beach; mud flat; delta
Relief	81 - 100 percentile	61-80 percentile	41-60 percentile	21-40 percentile	0-20 percentile

Natural Habitats	Coral reef; mangrove; coastal forest	High dune; marsh	Low dune	Seagrass; kelp	No habitat
Sea Level Change	0-20 percentile	21-40 percentile	41-60 percentile	61-80 percentile	81-100 percentile
Wave Exposure	0-20 percentile	21-40 percentile	41-60 percentile	61-80 percentile	81-100 percentile
Surge Potential	0-20 percentile	21-40 percentile	41-60 percentile	61-80 percentile	81-100 percentile

In this analysis, we are interested in the role of Mangroves in reducing coastal exposure. Therefore, the natural habitats inputs will only include data on mangroves. Data on protection distances and risk ranks for the selected natural habitats must be included Table 3. The rank and protection distance inputs were taken from Chaplin-Kramer et al. (2019). However, these inputs were used for running the model at a global scale. If data from local, national or regional studies are available, these should be used.

Table 3. Inputs used for the natural habitats .csv file which is input to the model. The data files are located in the same folder. Note, this analysis focuses only on mangroves, other natural habitats can be included.

id	**path**	**rank**	**Protection distance (m)**
Mangrove	tanintharyi_2021_reclass.tif	1	1000

Examples of sources for spatial distribution layers of other relevant natural habitats are shown in Table 4.

Table 4. Example sources of natural habitat extent data.

Natural Habitat	**Source**	**Description**	**Link**
Mangrove	Global Mangrove Watch (Bunting et al. 2018).	Global mangrove distribution 1996-2020.	https://data.unep-wcmc.org/datasets/45
Coral	UNEP-WCMC, WorldFish Centre, WRI, TNC (2021)	Global distribution of coral reefs	https://data.unep-wcmc.org/datasets/1
Seagrass	UNEP-WCMC, Short FT (2021)	Global distribution of seagrasses	https://data.unep-wcmc.org/datasets/7

Natural Habitat	Source	Description	Link
Salt marsh	Mcowen C, Weatherdon LV, Bochove J, Sullivan E, Blyth S, Zockler C, Stanwell-Smith D, Kingston N, Martin CS, Spalding M, Fletcher S (2017)	Global distribution of saltmarshes	https://data.unep-wcmc.org/datasets/43

5. Running the model

The model can be run at any spatial resolution, and the resolution is determined by the distance between shore points as specified by the user. The length of time it takes to run the model is highly dependent on the size of the area of interest, and the model resolution.
When opening the InVEST Workbench app, you need to select the Coastal Vulnerability model from the list of available models (Figure 1).

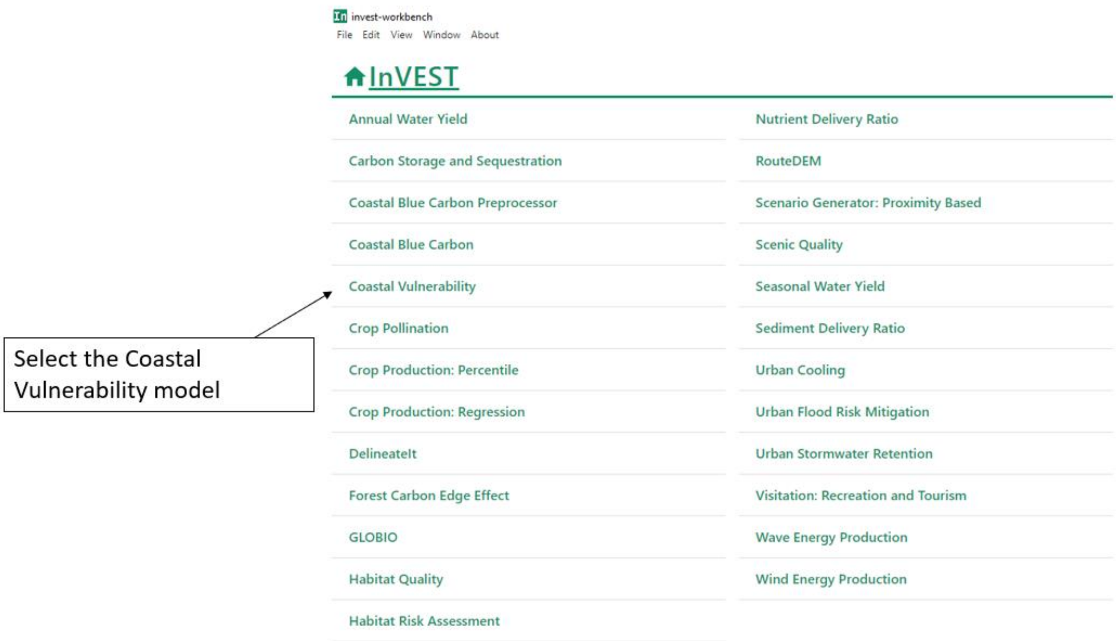

Figure 1. When the InVEST Workbench application is opened, it will list all of the available models. Select the Coastal Vulnerability model for this exercise.

Once the Coastal Vulnerability model has been opened, it will open the model in a new tab (Figure 2).

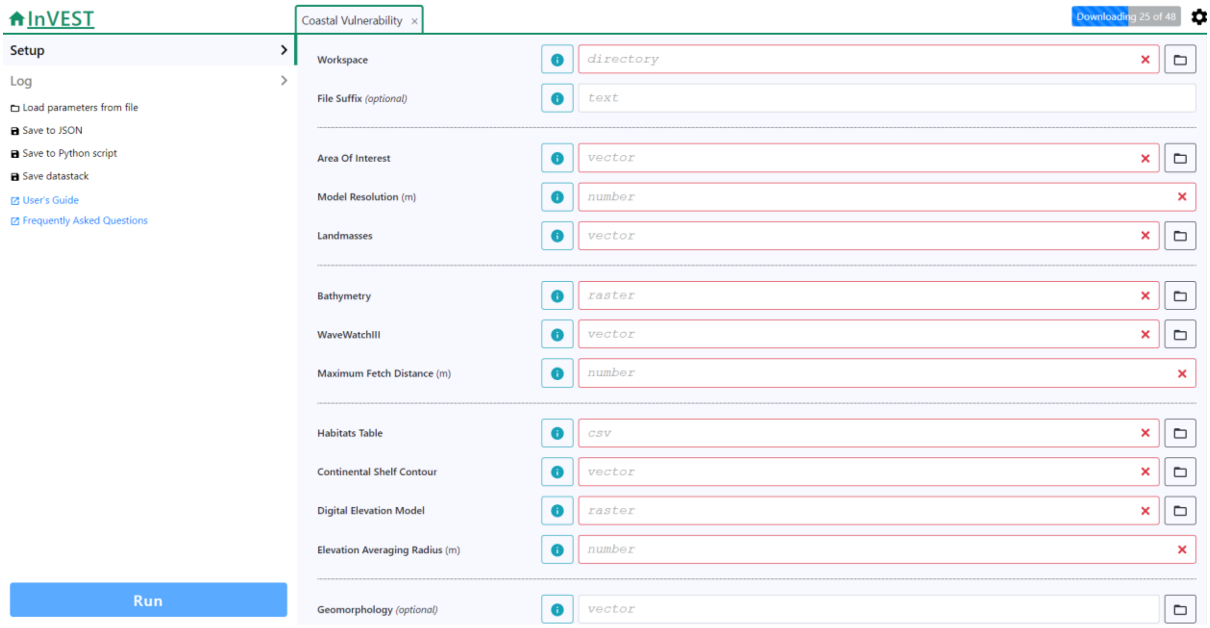

Figure 2. The Coastal Vulnerability model in the InVEST Workbench app. The model details the parameters required, the file paths or numeric values for these parameters need to be specified before the model can run.

The model will ask you to create a workspace (or directory). This is where the model will save outputs. Create a folder somewhere on your desktop called '**InVEST_CoastalV_MMR**'. There is also an option to add a '**File Suffix**', if specified this will allow you to uniquely identify each run of the model and prevent the model from overwriting your work. Type '**run_1**' here.
For each input, the file path to the relevant file should be specified. All input data is included with the data inputs folder.

Table 5. File names for the input datasets.

Input	File name
Area of Interest	MMR_MangroveAOI_UTM47N.shp
Landmass	UN_Boundary_dissolve.shp
Bathymetry	GEBCO_2021_merged_MMR.tif
WaveWatchIII	WaveWatchIII_global.shp
Habitats table	Located in nat_habitats sub folder
Continental Shelf Contour	continental_shelf_polyline_global.shp
Digital Elevation Model	SRTM90_MMR.tif
Human Population	mmr_ppp_2020

The model resolution (m) should be input as '**500**', however, you can choose to run the model at a higher or lower resolution. Higher resolutions will take longer to run.

The '**Maximum Fetch Distance (m)**' should be specified as '**12000**'. This value is based on previous use of the model in Myanmar and a default value suggested for the model. If you can, this value should be refined based on local, national or regional studies.

The ‘**Elevation Averaging Radius (m)**’ and ‘**Population Search Radius (m)**’ should both be entered as ‘**5000**’. Again, if more accurate estimates are available, use these.

In this case, we will not enter any data for the Geomorphology or the Sea Level Rise inputs, as these are optional. However, if data is available, they can be entered.

Once all of the required entries are filled and their boxes have turned green (Figure 3), **click ‘Run’**. Depending on the resolution of the model, it may take a while to run. If it is taking too long, cancel the run and change the resolution. If inputs are not correct, the app will stop running and show an error message. Whilst the model is running you will see the log file being updated with the model’s progress.

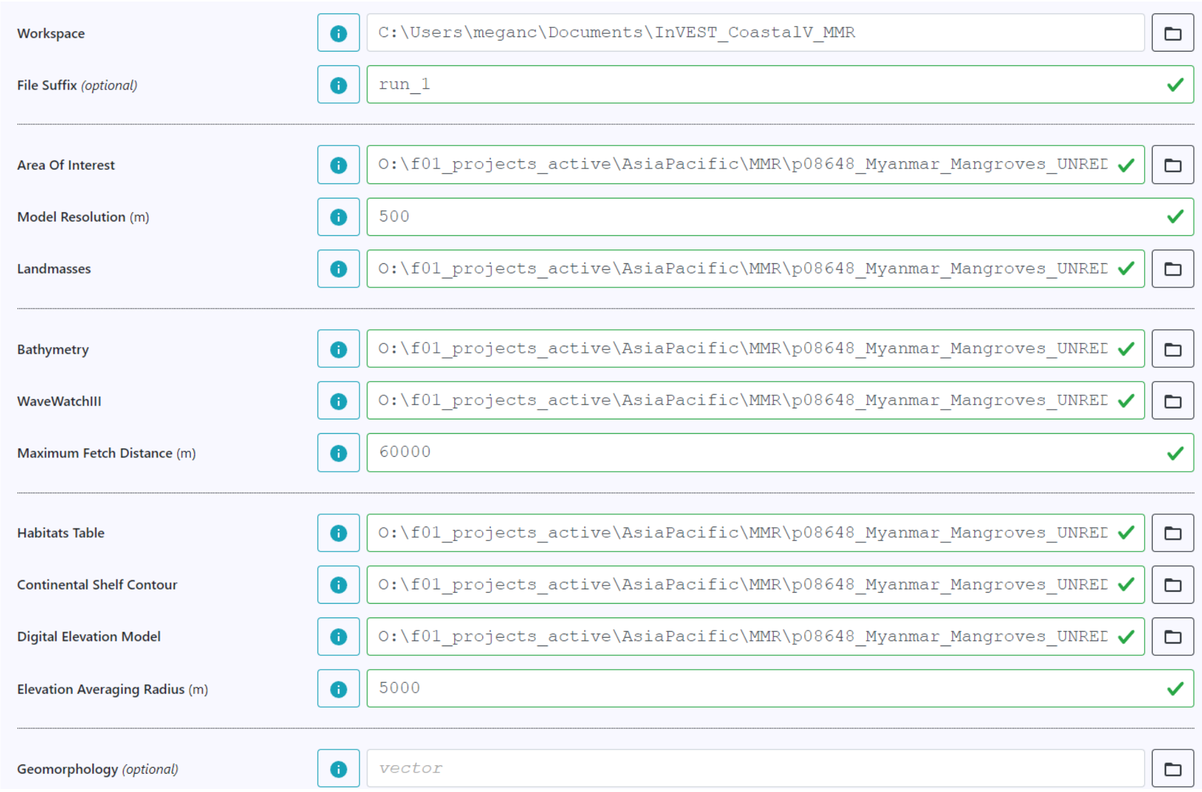

Figure 3. The Coastal Vulnerability model in the InVEST Workbench app with model parameters completed. Model parameters can be improved with local, national or regional data.

6. Model outputs

Once run, the model will output the results into the specified folder. Intermediate results calculated can be found in a sub-folder and are useful for verifying whether the results seem sensible. The final outputs are located in a GeoPackage file (.gpkg). An excel table with all of the points and their corresponding data are also provided.

The model segments the shoreline, and the primary output is the Exposure Index (EI) for each segment, the results are stored as a GeoPackage (.gpkg) and pull in the ‘coastal_exposure_run_1’ excel table.

7. Visualising the results

To visualise the results in QGIS, we need to open the GeoPackage file. To do so click on the Open Data Source Manager (Figure 4).

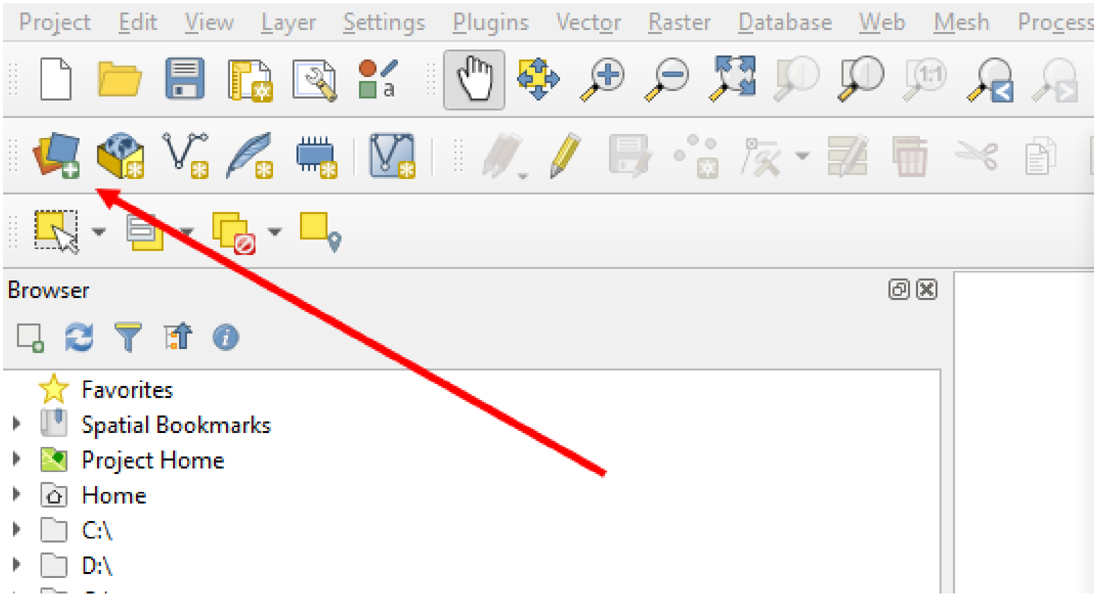

Figure 4. To open a GeoPackage file (.gpkg) click on the Open Data Source Manager in the top left hand corner.

This will bring up a dialogue box, and on the left click on the GeoPackage tab. Then click 'New' and select the GeoPackage file from your model output folder (Figure 5).

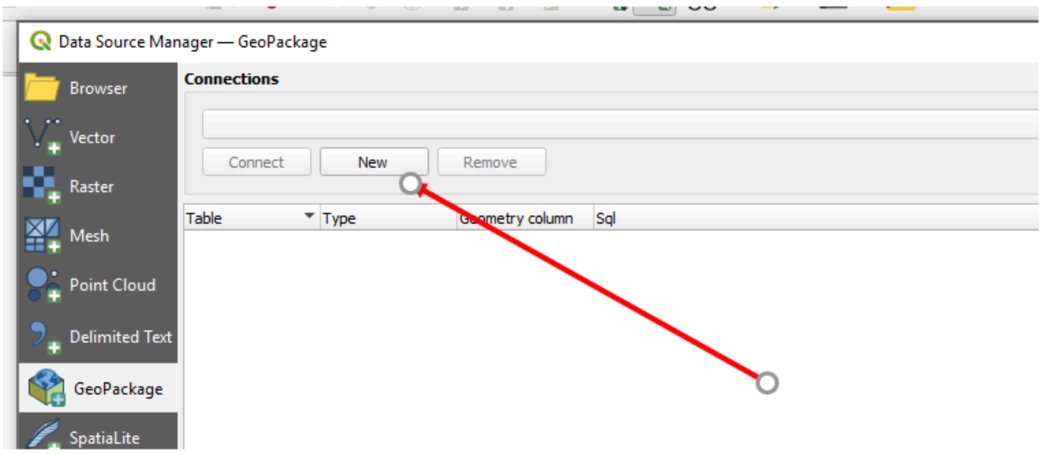

Figure 5. Once the dialogue box is open, select 'GeoPackage', click new and browse to where your output .gpkg file is.

Once selected, click 'Connect'. In the central part of the window you should now see a list of all the layers contained in the GeoPackage file. Select the 'coastal_exposure_run_1 file and then click on the 'Add' button at the bottom of the dialogue box (Figure 6).

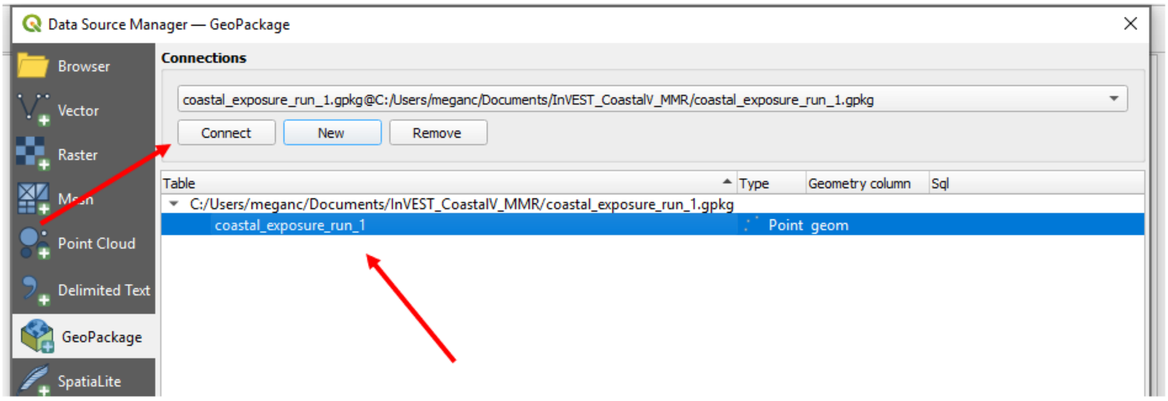

Figure 6. Once you have selected your file, press connect and the layers should appear in the table below. Select the 'coastal_exposure_run_1' layer and then 'Add' at the bottom of the dialogue box.

Your layer should now be displaying on your map.
On the main map screen we can alter the way in which the data is visualised to produce a useable map.

The attribute table for the data contains variables which can be used to break down results and map variables of interest:

Shore_id: a unique ID for each shore point
R_hab, **R_wind**, **R_wave**, **R_surge**, **R_relief**, and **R_geomorph** are the ranks for each variable for each shoreline point.
Population: summarises the average population density (people per square kilometre) within a user defined search radius around each point.
Exposure: the coastal exposure index
Exposure_no_habitats: the exposure, but calculated assuming R_hab is always 5 (i.e. provides no protection)
Habitat_role: is the relative contribution of habitat at each shore point. It is calculated by taking the difference between *exposure_no_habitats* and exposure.

It is important to examine the individual variables that fed into the coastal exposure index. Doing so helps you understand the exposure results and what is driving the exposure in your area of interest, and to feel confident that the model has worked correctly. If some results do not make sense to you, you may need to go back to the model inputs and tweak until you are confident with results. For example, if there is high wave activity in sheltered coves, you may need to adjust the fetch length. If elevation ranks look choppy and uneven, you may wish to adjust the averaging window.

Habitat role in reducing vulnerability of local coastal populations

The data from the model includes the populations within a 5km radius of each point, as well as an index of the role of natural habitats in reducing coastal exposure. We can combine these two attributes to show the relative amount of protection service provided by habitats to those populations.

Open the attribute table and add a new field by clicking the ‘Toggle editing mode’ in the left hand corned (yellow pencil icon) and then the New Field button (Figure 7).

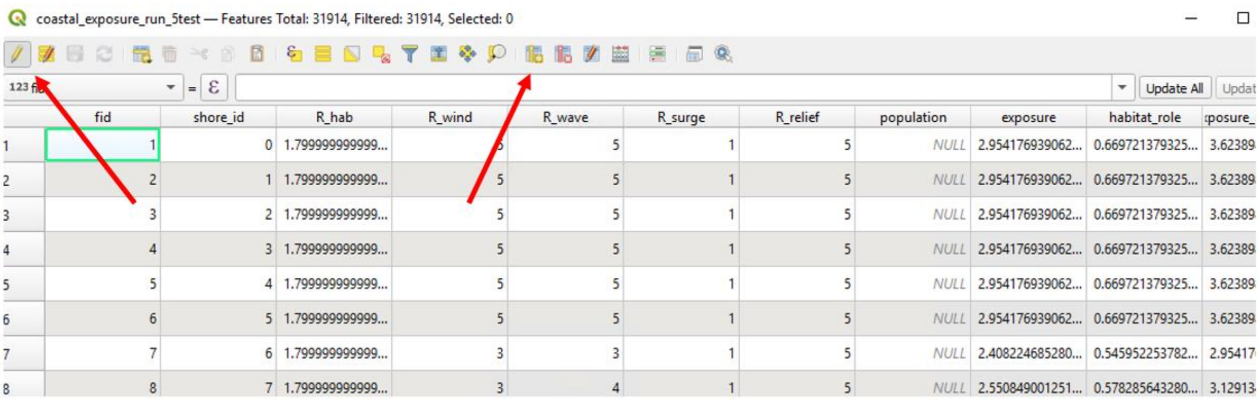

Figure 7. To add a new field to the attribute table, click the toggle editing button (far left) and then the new field button.

When you click ‘**New Field**’, the add field box will come up, name this ‘**PopxHabRol**’ and in the Type drop down box, select ‘Decimal number (real)’. This will add a new column called PopxHabRol to the far right side of your attribute table, all the values will be ‘NULL’.

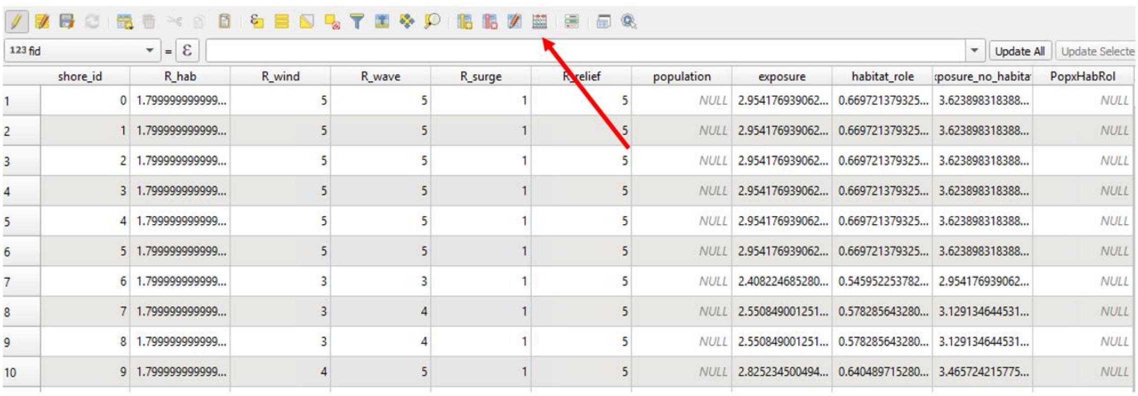

Figure 8. Click Open Field Calculator to populate your new attribute.

Click ‘**Open Field Calculator**’ (Figure 8) and select the option ‘**Update existing Field**’ and then choose the PopxHabRol column from the drop down. In the Expression box multiply the habitat_rol and population attributes and press okay (Figure 9). Once you are done, deselect the toggle editing button.

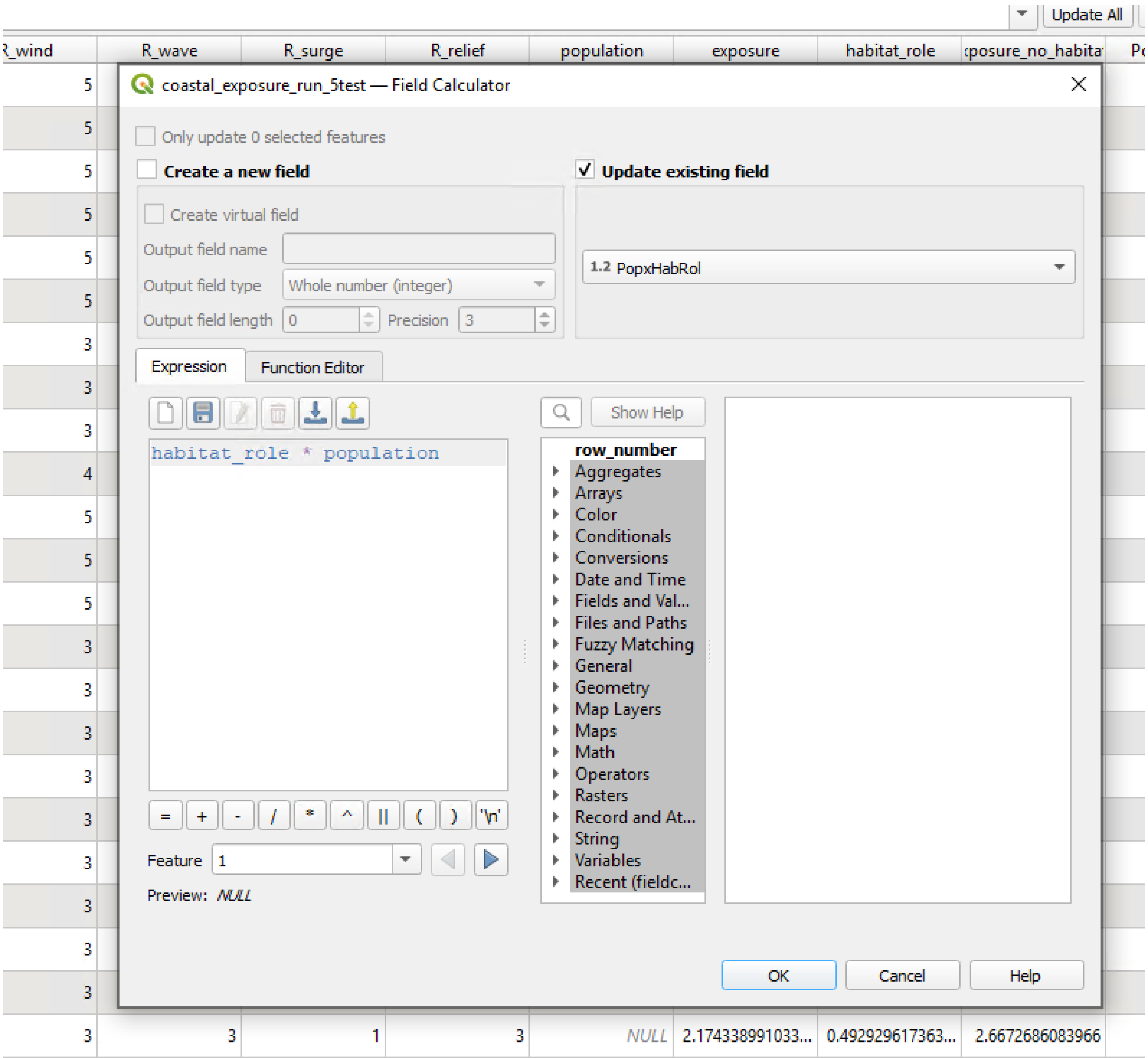

Figure 9. Assign the expression for the PopxHabRol field.

As we are interested in the role of mangroves in reducing the vulnerability of local people, we can use this output in the attribute table to demonstrate where this service may be highest. The result of multiplying people by the service provides only a relative ranking (there are no units). These outputs can help with identifying areas which are crucial to protect, as they provide important services to local people.

Filtering the dataset

This dataset has points extending along the coast of Myanmar. For this analysis we only want to focus on points where mangroves play a role in reducing coastal exposure. Therefore, we need to filter the dataset to where the value for the column ‘habitat_role’ is greater than 0.

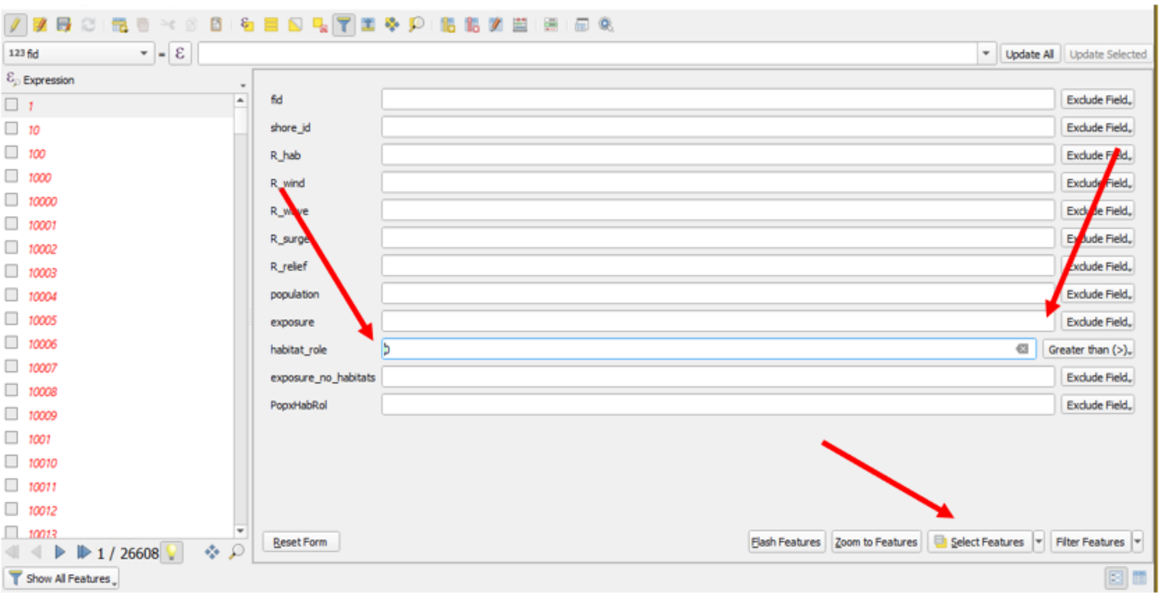

Figure 10. To filter for points where mangroves play a role, select points which have a 'habitat_role' value greater than 0 and press 'Select Features'.

First, open the attribute table, and press the filter icon. In the habitat role row, select the ‘Greater than (>)’ option and enter ‘0’ into the text box. To apply this filter press the ‘Select Features’ button (Figure 10).

When you go back to the main QGIS window, you will see that all points with a habitat role values greater than zero have been selected (they will show in yellow). We want to save a version of the dataset with just these points. Right click on the dataset and select ‘Export’>’Save Selected Features As…’ (Figure 11). Save the new dataset with an appropriate location and name.

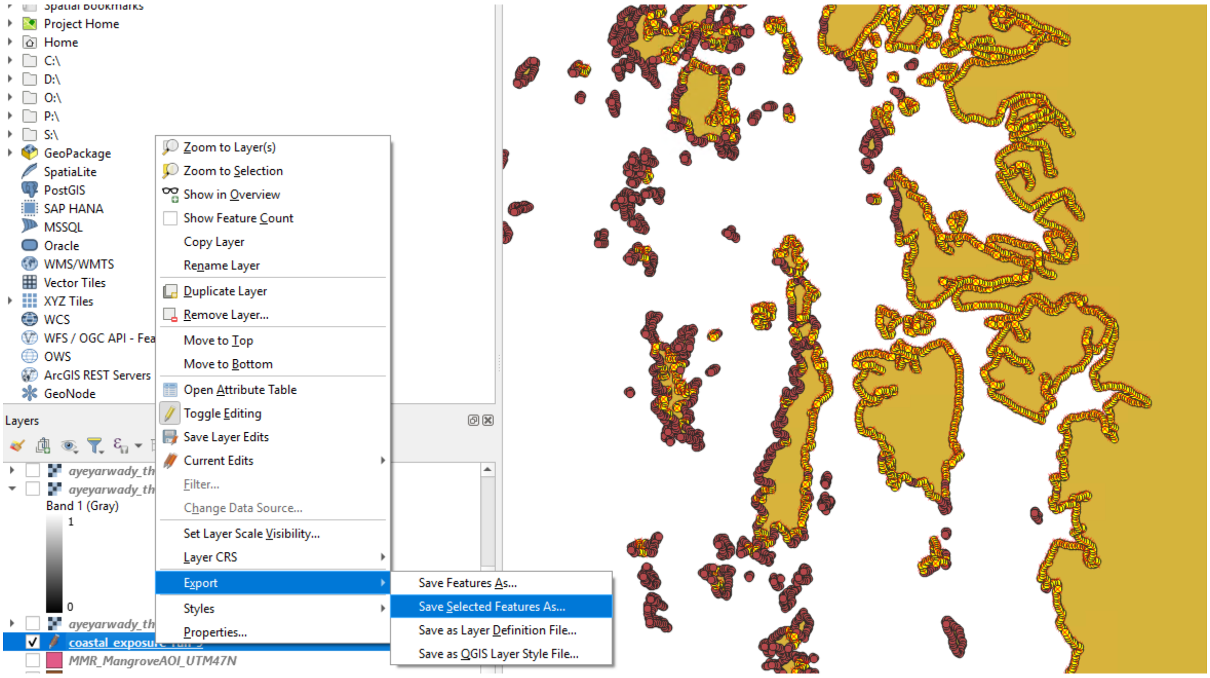

Figure 11. Once points are selected they will turn yellow on the QGIS window. Right click on the layer, select 'Export' and then 'Save Selected Features As...'

Now, the new filtered dataset should show in your QGIS window. Remove the old layer as this is no longer needed.

8. Creating maps

The output point data files can be overlayed with features such as land mass, administrative boundaries and protected areas or KBAs.

When creating maps, you need to select an attribute to display. In QGIS right click on your output point data file and then click '**Symbology**' on the left-hand side. At the top of the dialogue box there is a drop-down menu with options for displaying results. From here choose the '**Graduated**' option.

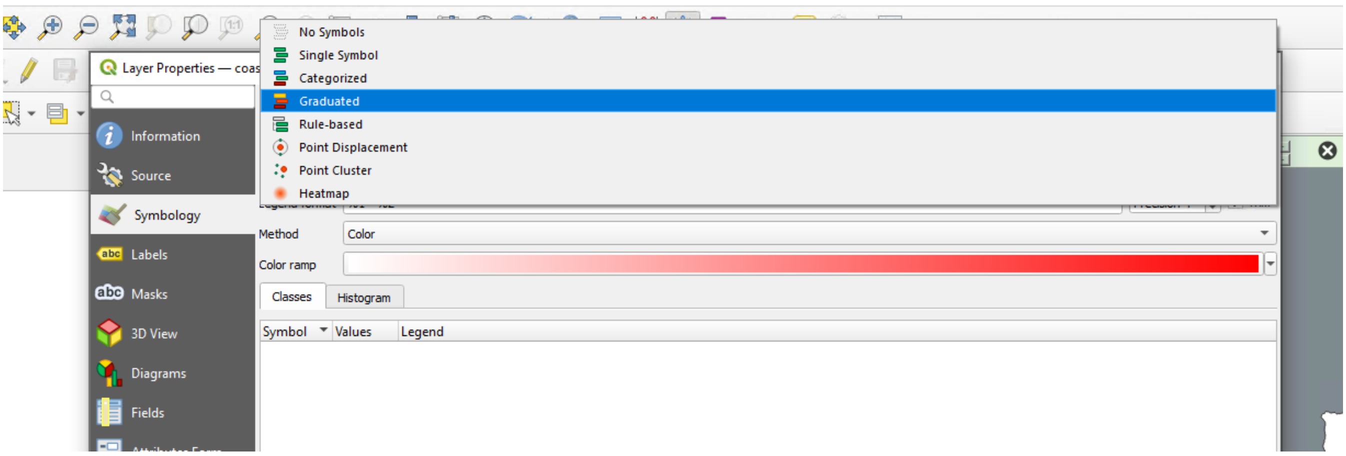

Figure 12. To visualise the data, go to the Symbology tab within the layer properties dialogue box. To show areas of high/low importance chose the 'Graduated' option.

Once the graduated option has been selected, choose a value to be displayed. In this case we will select the new variable we created **PopxHabRol**. Select an appropriate colour ramp and press the '**Classify**' button near the bottom of the box. You may wish to try selecting different modes and visualising them until you get an output you are happy with. You may also wish to change the number of classes shown, for example three classes could show low, medium and high (Figure 13).

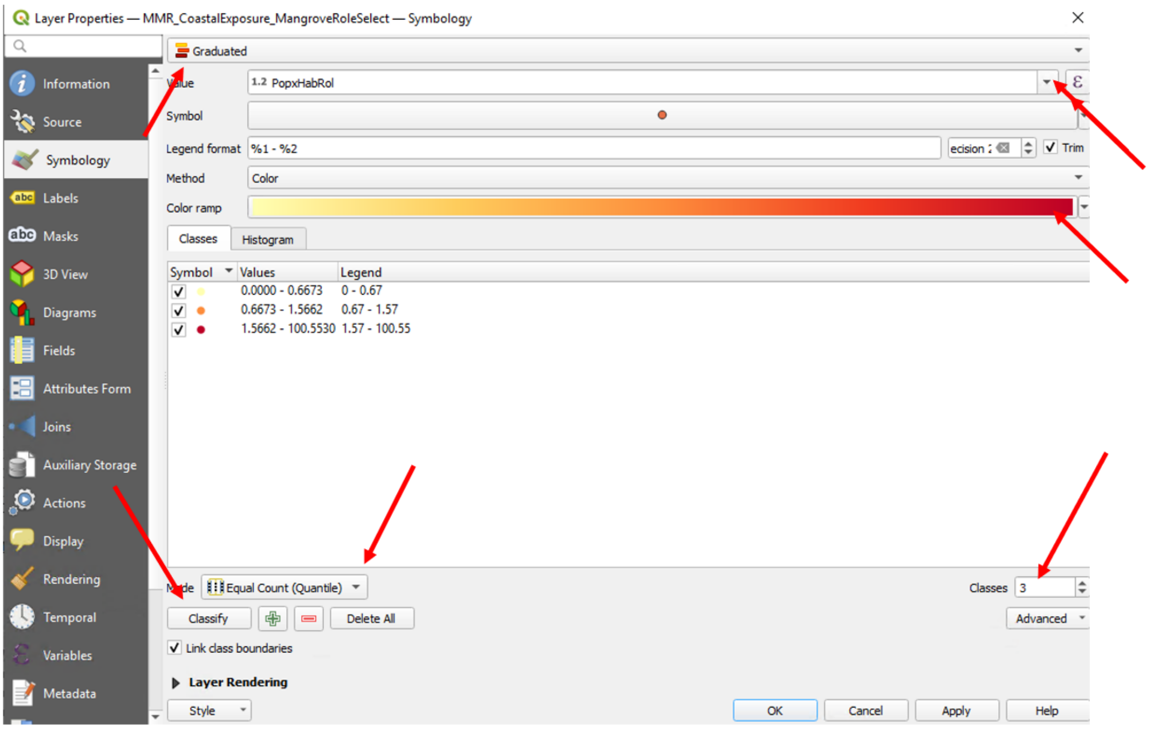

Figure 13. Options to alter when preparing the symbology for the data, you may wish to try several options and then choose the one which makes most sense.

We can also overlay other data, such as protected areas and KBAs (Figure 14), to understand whether any areas of high importance currently fall outside these (e.g. using the WDPA). Furthermore, outputs can be combined with other ecosystem services provided by mangroves (such as habitat for biodiversity, fisheries and wood fuel production) to indicate where there are hotspots of services.

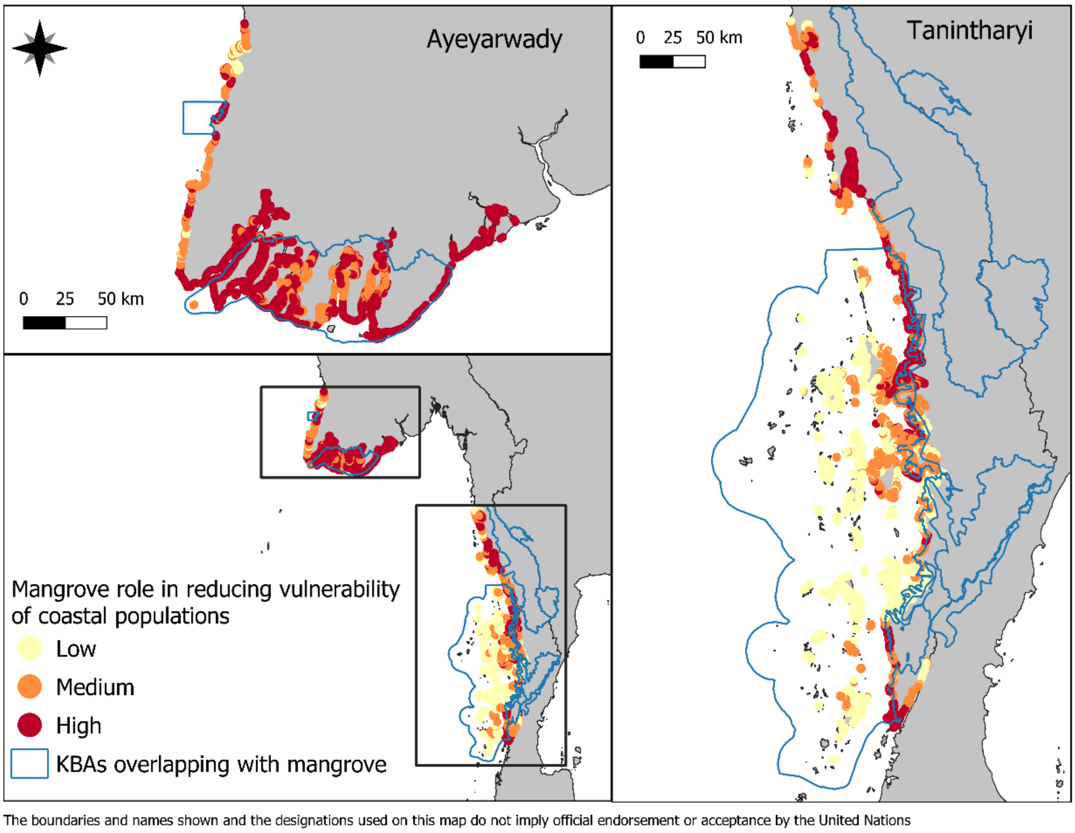

Figure 14. Example visualisation of the model analysis. The figure demonstrates where mangroves play a role in reducing the vulnerability of coastal populations, and the level of this role. The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations

You can also choose to produce maps of the other variables. For example, you may wish to produce a map with three panels, showing the habitat role, the populations, and then habitat role in reducing vulnerability of coastal population.

9. Model limitations

The model does not take the amount of quality of mangroves (or other included habitats) into account. Therefore, it is not possible to distinguish intact vs degraded mangroves in the model and understand the impacts of restoring or degrading existing mangroves on coastal vulnerability. The model does not quantify the role of habitats in reducing coastal hazards, the output is the relative contribution of the habitats to reducing exposure at each shore point.

The scoring of the model is the same throughout the region of interest and does not take interactions between the different variables into consideration. For example, the relative wave and wind exposure will have the same weight whether a shore point is a sandy beach or a rocky cliff.

The default data which comes with the tool, WAVEWATCH III, has been simplified to allow its use globally. As a result, it does not fully represent the impacts of extreme events.