# Seeing the forest for the trees: advances in vegetation monitoring and carbon sequestration modelling using satellite imagery, Google Earth Engine and FullCAM.


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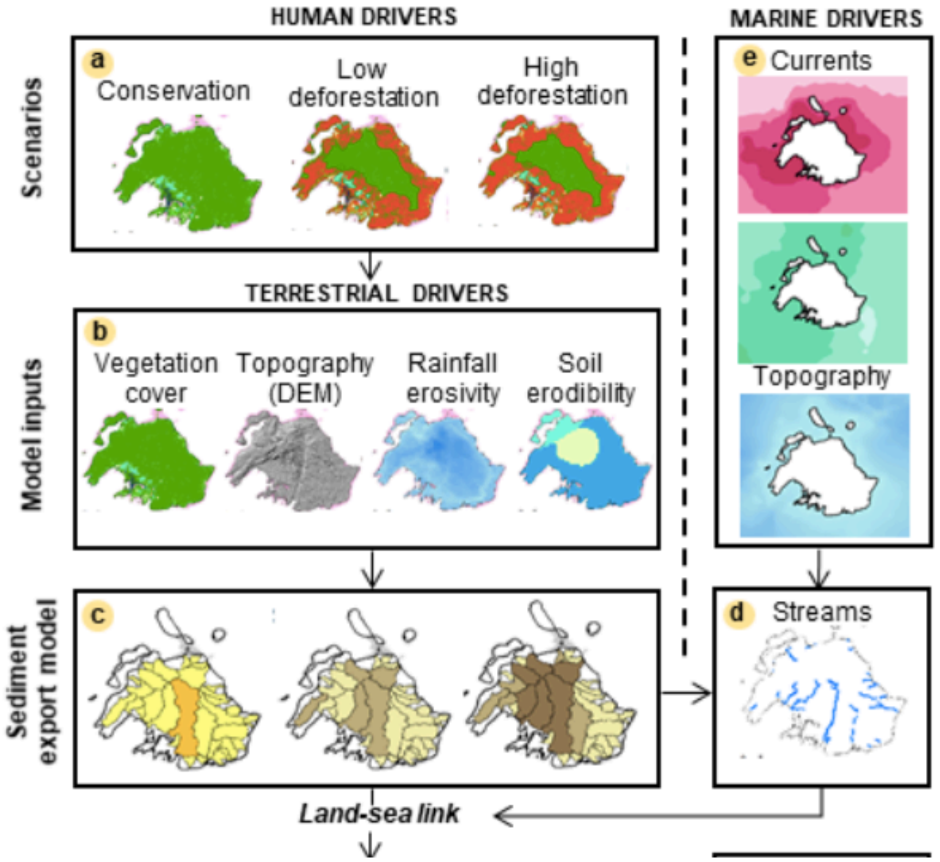




**Key words:** GIS, environmental modelling, forest, water basin, monitoring

# Structure of presentation

1. Background reading - guidelines and past work on spatial prioritization including reports and peer-reviewed literature

2. Methods

a. Steps set out in Vanuatu report

b. Additional steps and troubleshooting

a. Enablers – support

3. Results - in progress

# Literature (guidelines - grey)

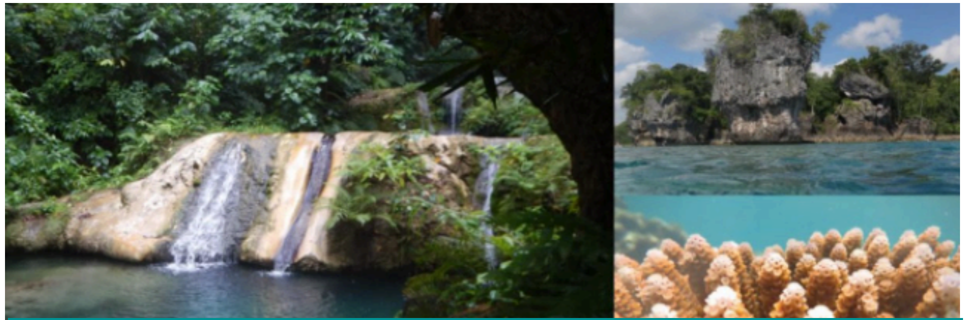
## Main sources and instructions

Delevaux, J.M.S. & Stamoulis, K.A. (2020) Assessment of ridge-to-reef management actions in Tagabe watershed and Mele Bay, Vanuatu. Suva, Fiji SPC, 63 pp.

Assessment of ridge-to-reef management actions in Tagabe watershed and Mele Bay, Vanuatu

**Scenario planning**

Delevaux, J.M.S. & Stamoulis, K.A. (2019) Identification of priority sites for future upscaling ridge-to-reef investments in Vanuatu. Suva, Fiji SPC, 48 pp



**Spatial prioritization**

Identification of priority sites for future upscaling of R2R investments, Vanuatu

Prepared for Ridge-to-reef Programme, GeoScience, Energy & Maritime Division, SPC

by Seascape Solutions, LLC

2

by Seascape Solutions LLC December 2019

InVEST User Guides
Natural Capital Project

**InVEST User Guide**


Public Discussion and Technical Support Forum

**Input datasets for SDR (data sources & pre-processing)**

NatCap Software Support sdr

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Many thanks to the incredibly helpful developers and GIS experts who provide support on these fora…

I have recently completed some of the tutorials for InVEST SDR in both the first module and the data acquisition and processing section in the latter section. The modules allow us to get an understanding of what the input data might look like. I am now in the process of trying to work out how best to generate these data inputs for my own case study area.

The guidelines here are fairly comprehensive too: SDR: Sediment Delivery Ratio — InVEST documentation

I have highlighted the remaining gaps in my knowledge for the SDR model here in yellow:

| MODEL INPUTS | Format | Symbol | Source | Resolution | Link (global dataset) |
|---|---|---|---|---|---|
| Digital Elevation Model | geotiff raster | DEM | Google Earth Engine SRTM | 30m x 30m | 1. https://developers.google.com/earth-engine/datasets/catalog/CGIAR_SRTM90_V4 2. https://asterweb.jpl.nasa.gov/gdem.asp 3. http://dwtkns.com/srtm/ 4. https://search.earthdata.nasa.gov/search/ |
| Rainfall erosivity index | geotiff raster | R | Global Rainfall Erosivity | | 1. https://esdac.jrc.ec.europa.eu/content/global-rainfall-erosivity#tabs-0-description=1 2. https://esdac.jrc.ec.europa.eu/content/global-rainfall-erosivity#tabs-0-description=1&tabs-0-description=2= |
| Soil erodibility | geotiff raster | K | 1. Soil and Terrain Database (SOTER) 2. FAO Dataset | | 1. https://data.isric.org:443/geonetwork/srv/eng/catalog.search 2. https://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/ |
| Land-use / land-use cover | geotiff raster | LULUC | 1. NASA MODIS multiyear dataset 2. ESA dataset (2000, 2005, 2010) | | 1. https://lpdaac.usgs.gov/products/mcd12q1v006/ 2. http://www.esa-landcover-cci.org/ |
| Watersheds | vector | | | | |
| Biophysical table | csv table | | | | |
| Threshold Flow Accumulation | coefficient value | | 1000 | | |
| Drainages | geotiff raster | | | | |
| Borselli K parameter | coefficient value | kb | 2 | | |
| Borselli IC0 parameter | coefficient value | IC0 | 0.5 | | |
| Max SDR Value | coefficient value | | 0.8 | | |

# SPC resources and technical reports

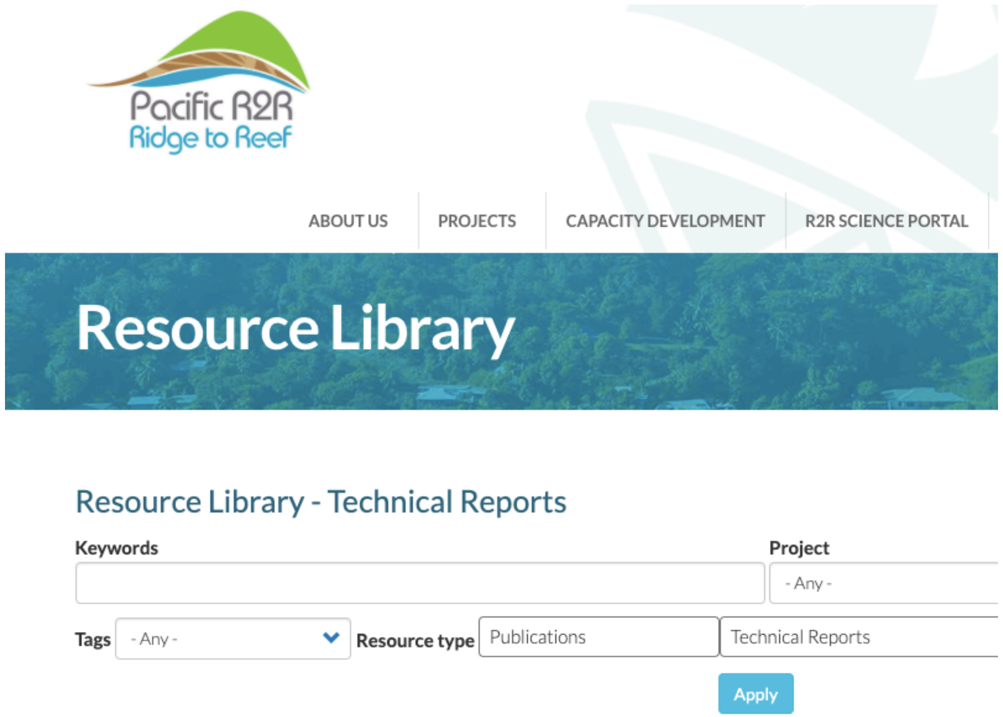
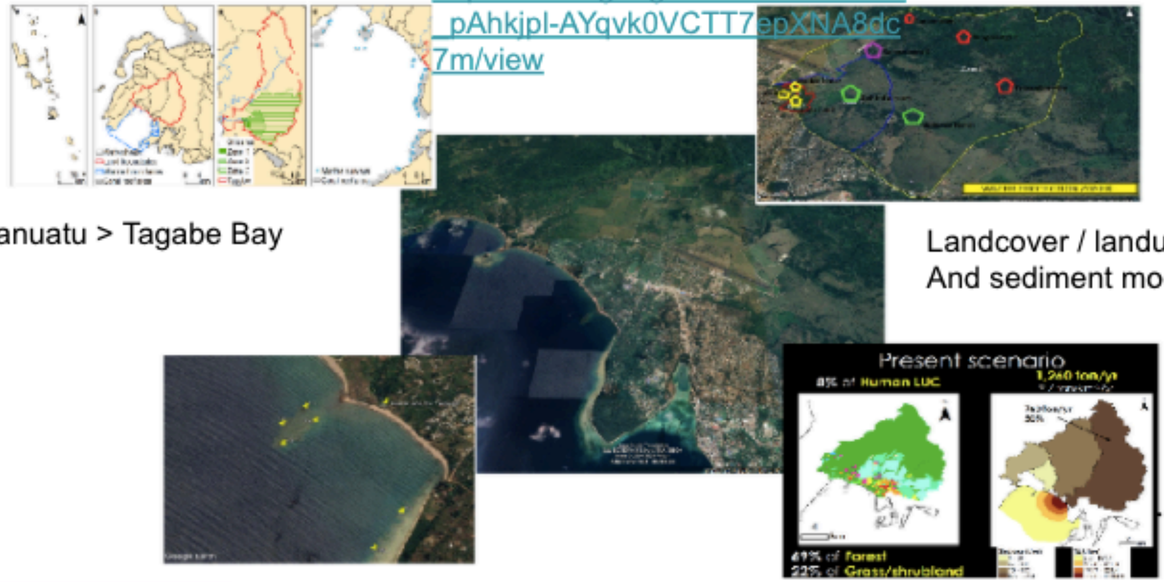


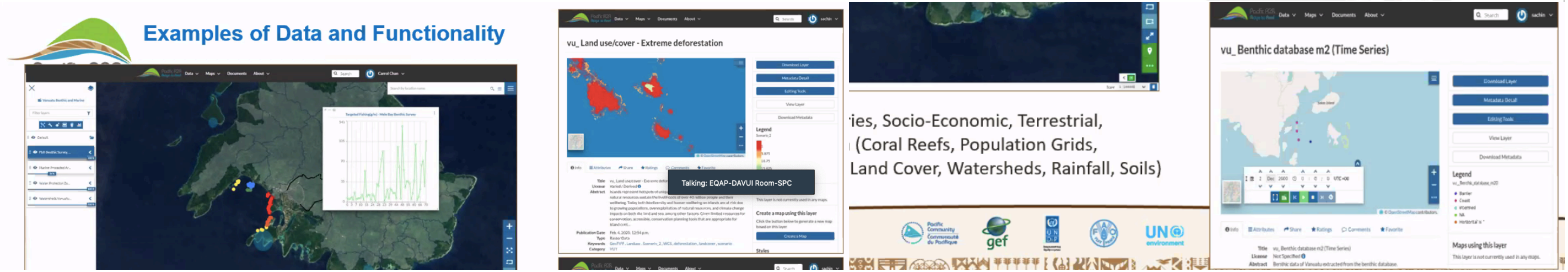

Figure 1 below provides a map showing boundaries, total areas stretching from the upper areas or ridge of the catchment upstream and downstream including adjacent reef systems adjacent to the point of discharge at the mouth of the river catchment.

https://drive.google.com/file/d/1GW_pAhkjpl-AYqvk0VCTT7epXNA8dc7m/view




Vanuatu > Tagabe Bay

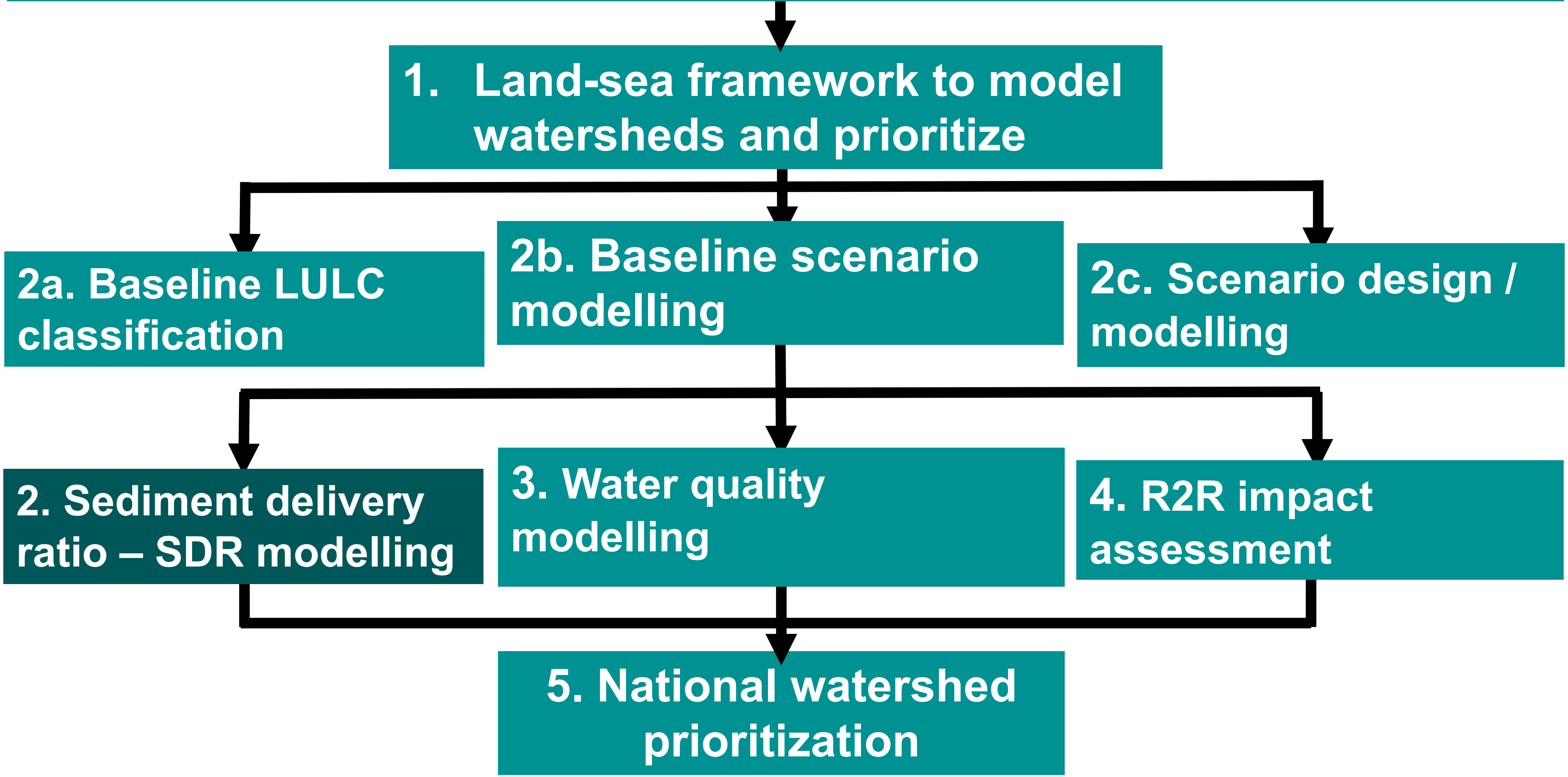
Landcover / landuse change
And sediment modelling



# Literature (peer reviewed)


- Anderson, T. R., Fletcher, C. H., Barbee, M. M., Romine, B. M., Lemmo, S., & Delevaux, J. M. (2018). Modeling multiple sea level rise stresses reveals up to twice the land at risk compared to strictly passive flooding methods. *Scientific reports*, *8*(1), 1-14.
- Ashiagbor, G., Forkuo, E. K., Laari, P., & Aabeyir, R. (2013). Modeling soil erosion using RUSLE and GIS tools. *Int J Remote Sens Geosci*, *2*(4), 1-17.
- Borselli, L., Cassi, P., Torri, D., 2008. Prolegomena to sediment and flow connectivity in the landscape: A GIS and field numerical assessment. Catena 75, 268-277.
- Delevaux, J. M., Whittier, R., Stamoulis, K. A., Bremer, L. L., Jupiter, S., Friedlander, A. M., ... & Ticktin, T. (2018). A linked land-sea modeling framework to inform ridge-to-reef management in high oceanic islands. *PloS one*, *13*(3), e0193230.
- Delevaux, J., Winter, K. B., Jupiter, S. D., Blaich-Vaughan, M., Stamoulis, K. A., Bremer, L. L., ... & Ticktin, T. (2018). Linking land and sea through collaborative research to inform contemporary applications of traditional resource management in Hawai ʻi. *Sustainability*, *10*(9), 3147.
- Dumas, P., & Printemps, J. (2010, April). Assessment of soil erosion using USLE model and GIS for integrated watershed and coastal zone management in the South Pacific Islands. In *Proceedings Interprevent, International Symposium in Pacific Rim, Taipei, Taiwan* (pp. 856-866).
- Ram, A. R., Brook, M. S., & Cronin, S. J. (2019). Engineering geomorphological investigation of the Kasavu landslide, Viti Levu, Fiji. *Landslides*, *16*(7), 1341-1351.
- Ram, A. R., Brook, M. S., & Cronin, S. J. (2018). Geomorphological characteristics of slope failures in northeast Viti Levu island, Fiji, triggered by Tropical Cyclone Winston in February 2016. *New Zealand Geographer*, *74*(2), 64-76.
- Ram, A. R., & Terry, J. P. (2016). Stream turbidity responses to storm events in a pristine rainforest watershed on the Coral Coast of southern Fiji. *International Journal of Sediment Research*, *31*(4), 279-290.
- Ram, A. R., & Terry, J. P. Land use and erosion risk in small forest catchments on the Coral Coast of Fiji: baseline estimates of sediment inputs to coastal lagoons.
- Stamoulis, K. A., & Delevaux, J. M. (2015). Data requirements and tools to operationalize marine spatial planning in the United States. *Ocean & Coastal Management*, *116*, 214-223.
- Stamoulis, K. A., Delevaux, J. M., Williams, I. D., Poti, M., Lecky, J., Costa, B., ... & Friedlander, A. M. (2018). Seascape models reveal places to focus coastal fisheries management. *Ecological Applications*, *28*(4), 910-925.

# Spatial prioritization guidelines - Vanuatu



# InVEST Models

| | |
|---|---|
| Carbon Storage and Sequestration | Habitat Risk Assessment |
| Coastal Blue Carbon | Annual Water Yield |
| Coastal Blue Carbon: Precurssor | NDR: Nutrient Delivery Ratio |
| Coastal Vulnerability | Pollinator Abundance: Crop Pollination |
| Crop production: percentile model | Visitation: Recreation and Tourism |
| Crop production: regression model | RouteDEM |
| **Delineat It** | Scenario Generator: Proximity Based |
| Marine Finfish Agriculture production | Unobstructed Views: Scenic Quality Provision |
| Fisheries | **SDR: Sediment Delivery Ratio** |
| Fisheries: Habitat Scenario Tool | Seasonal Water Yield |
| Forest Carbon Edge Effect | Urban Cooling |
| GLOBIO | Urban Flood Risk Mitigation |
| Habitat Quality | Wave Energy Production |

## Models used in Vanuatu report

**SDR: Sediment Delivery Ratio**

**Delineate It**

## Others – water quality and hydrology

**ArcGIS Hydro Toolbox**

**QGIS Hydrology tools**

**Water quality model > SDR**

# What is InVEST - NatCap

Stanford University

natural capital PROJECT

NATURAL CAPITAL PROJECT

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## InVEST

**InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) is a suite of models used to map and value the goods and services from nature that sustain and fulfill human life. It helps explore how changes in ecosystems can lead to changes in the flows of many different benefits to people.**

### What is InVEST?

InVEST is a suite of free, open-source software models used to map and value the goods and services from nature that sustain and fulfill human life. If properly managed, ecosystems yield a flow of services that are vital to humanity, including the production of goods (e.g., food), life-support processes (e.g., water purification), and life-fulfilling conditions (e.g., beauty, opportunities for recreation), and the conservation of options (e.g., genetic diversity for future use). Despite its importance, this natural capital is poorly understood, scarcely monitored, and, in many cases, undergoing rapid degradation and depletion.

Governments, non-profits, international lending institutions, and corporations all manage natural resources for multiple uses and inevitably must evaluate tradeoffs among them. The multi-service, modular design of InVEST provides an effective tool for balancing the environmental and economic goals of these diverse entities.

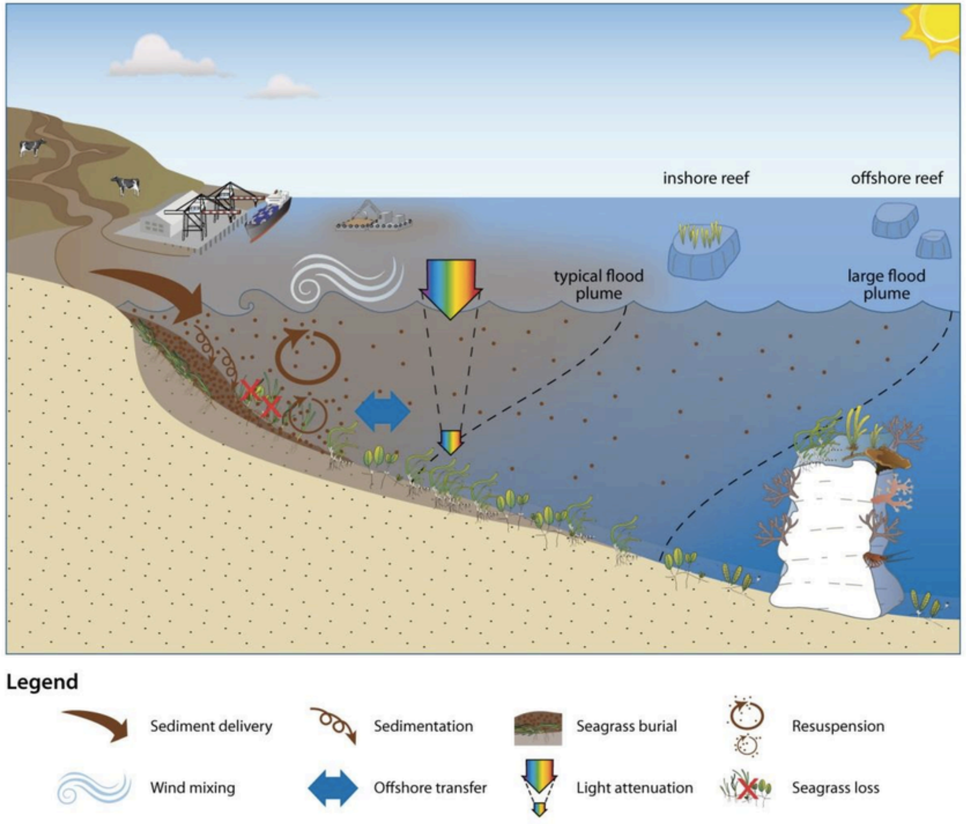
InVEST

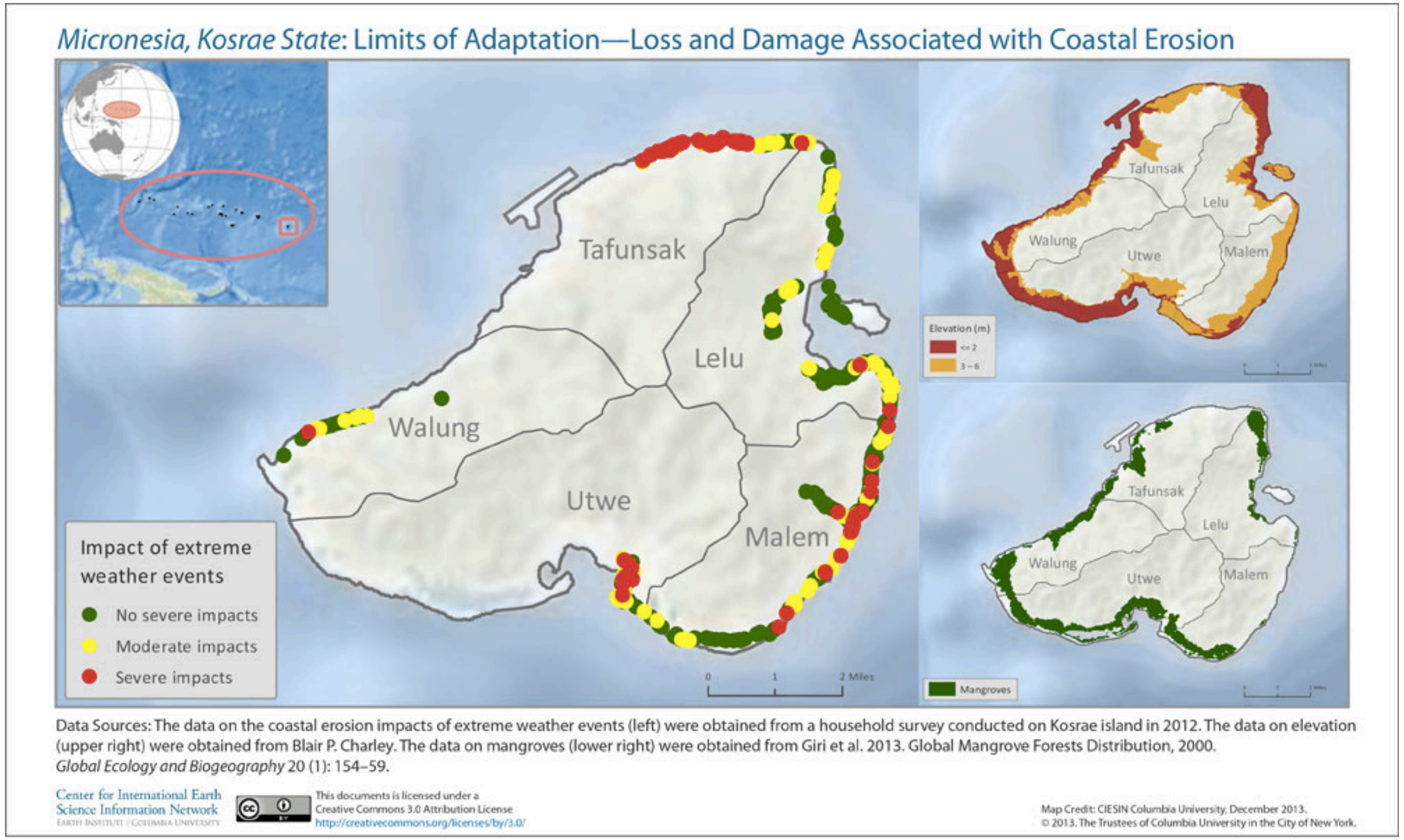
integrated valuation of ecosystem services and tradeoffs

- Download InVEST 3.8.9 (Windows)
- Download InVEST 3.8.9 (Mac)
- InVEST User's Guide (online)
- Older and Development Versions of InVEST

# How the SDR model works:

## Modelling impacts of sediment transport > implications for coastal reef ecosystems



# How the SDR model works:

- **spatially explicit model**
- **uses remote sensing satellite imagery data inputs**
- **computes amount of annual soil loss from each pixel**
- **then computes the ratio of soil loss reaching the stream > transported out of the catchment.**

**The result of soil loss becomes a proxy for catchment vulnerability as the sediment**

## Annual Soil Loss

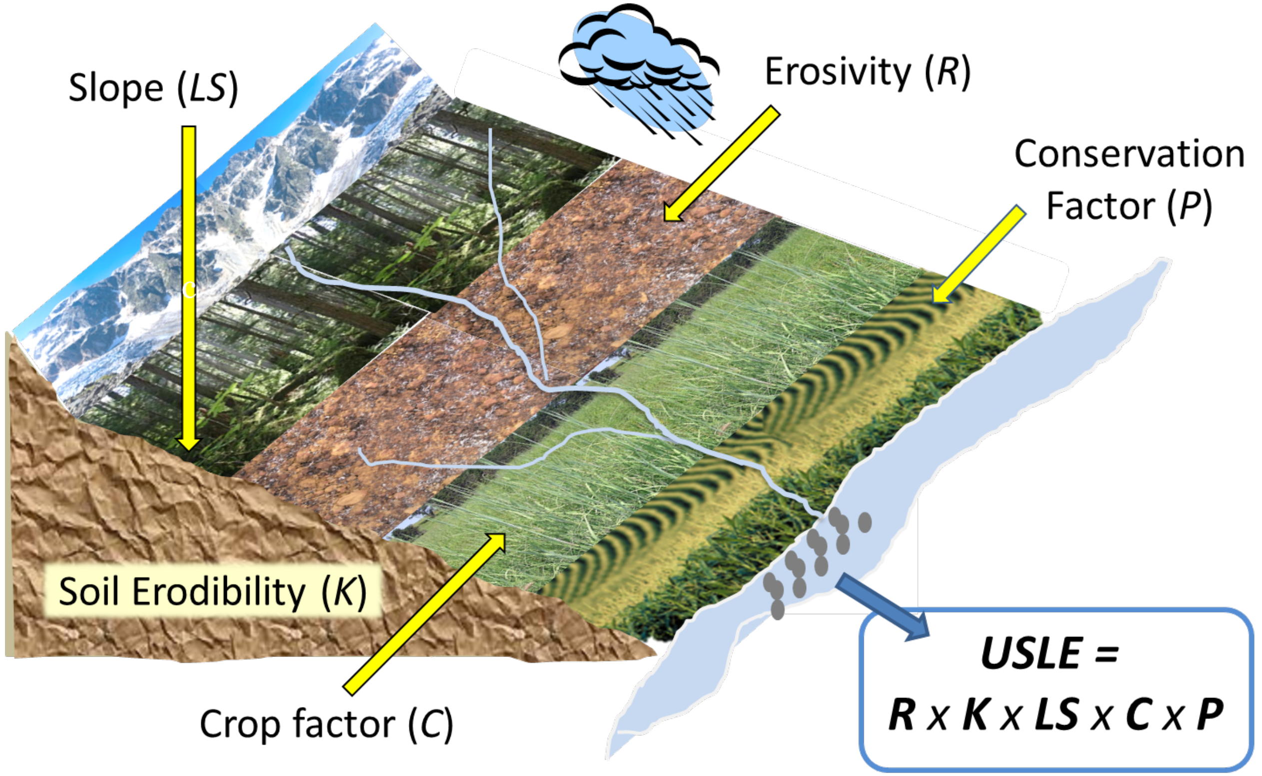
The amount of annual soil loss on pixel $i$, $usle_i$ (units: $tons \cdot ha^{-1} yr^{-1}$), is given by the revised universal soil loss equation (RUSLE1):

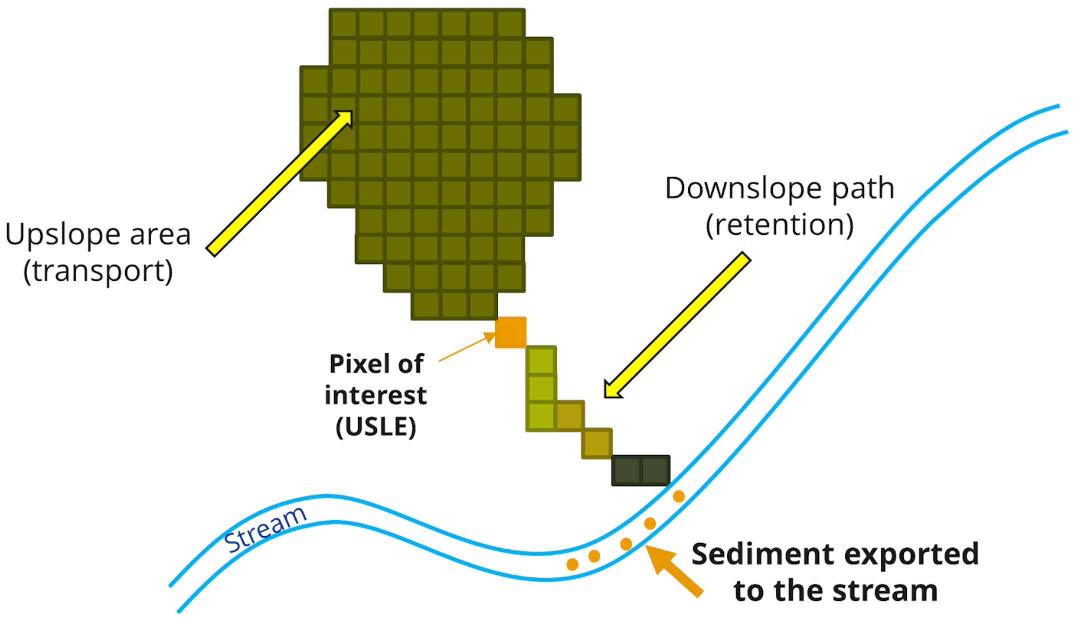
$$usle_i = R_i \cdot K_i \cdot LS_i \cdot C_i \cdot P_i, \quad (44)$$

where

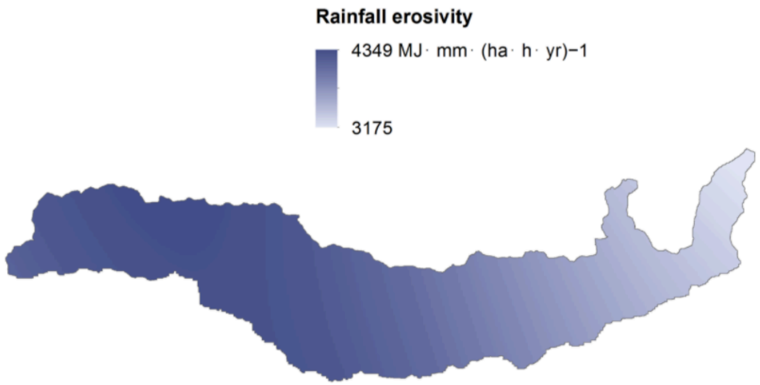
- $R_i$ is rainfall erosivity (units: $MJ \cdot mm(ha \cdot hr)^{-1}$),
- $K_i$ is soil erodibility (units: $ton \cdot ha \cdot hr(MJ \cdot ha \cdot mm)^{-1}$),
- $LS_i$ is a slope length-gradient factor (unitless)
- $C_i$ is a crop-management factor (unitless)
- and $P_i$ is a support practice factor (Renard et al., 1997). (cf. also in (Bhattarai and Dutta, 2006)). (unitless)

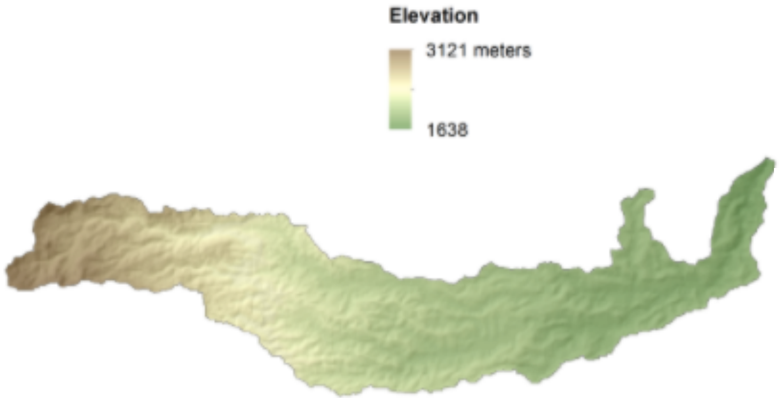
# How the SDR model works:

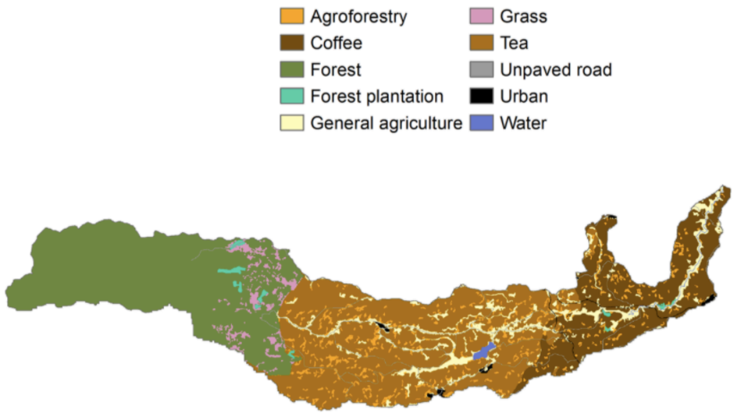


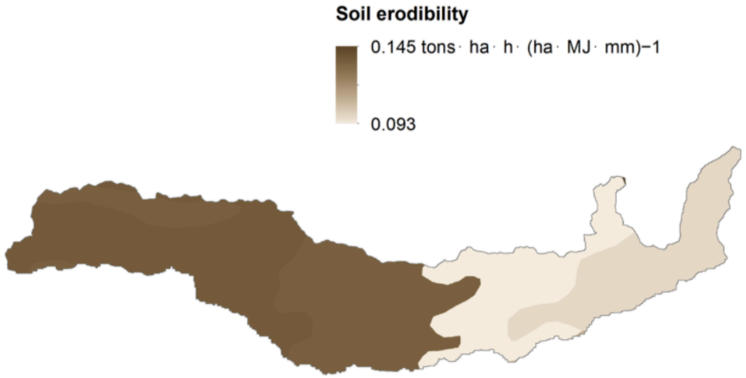



# How the SDR model works:



# How the SDR model works:

## USLE

**USLE:** Soil loss from each pixel, with units of tons/pixel/year.


## Sediment export

**Sediment export:** The amount of eroded soil that actually makes it to the stream, with units of tons/pixel/year.

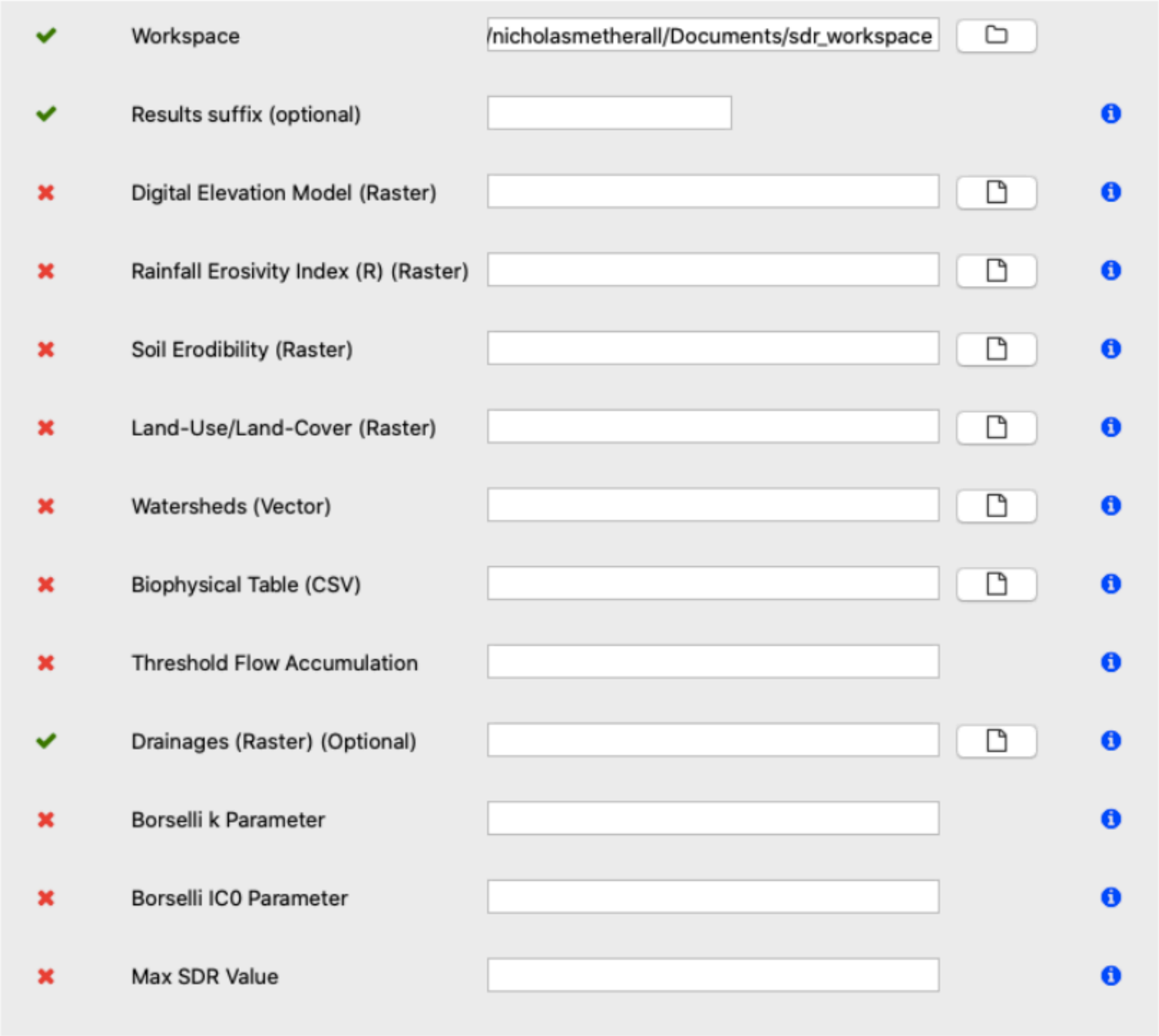

## Sediment deposition

**Sediment deposition:** Amount of eroded soil that is deposited on the landscape, showing where vegetation is helping keep it from entering streams, with units of tons/pixel/year.

# Sediment Delivery Ratio (SDR) Model

INVEST SDR - data input requirements:

1. DEM (raster)
2. Rainfall erositivity index (raster)
3. Soil erodibility (raster)
4. Land-use / land-cover (raster)
5. Watersheds (vector)
6. Biophysical table (CSV)
7. Threshold Flow Accumulation
8. Drainages (raster - optional)
9. Borselli K parameter
10. Borselli IC0 parameter
11. Max SDR Value



# Model - data inputs

**SDR guidelines:** http://releases.naturalcapitalproject.org/invest-userguide/latest/sdr.html

**MODEL INPUTS**

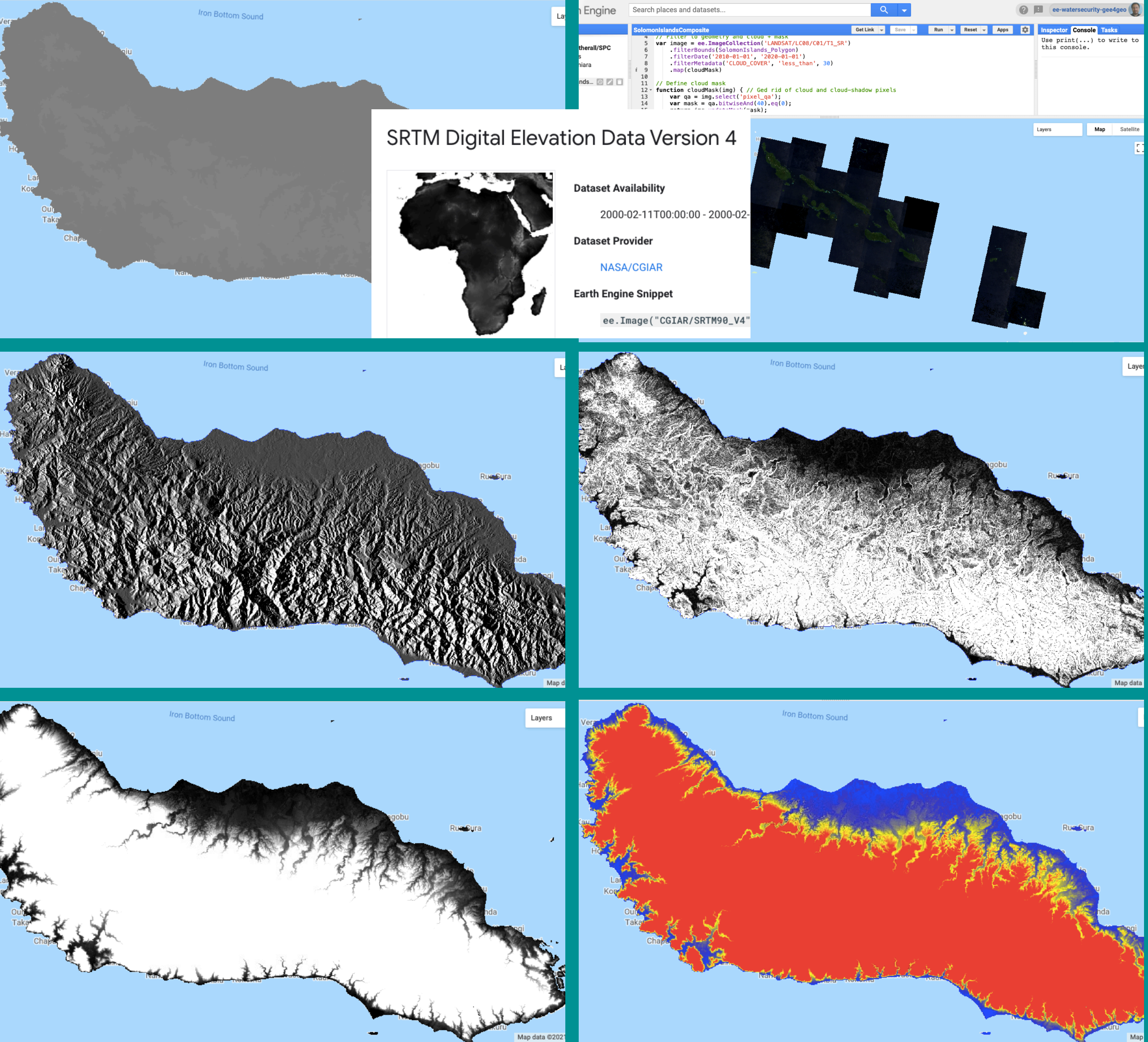
**Slides:** https://docs.google.com/presentation/d/1alZm7C7mAeCwfzShkJzB67UzZCfJHGwlrNuknWXv6Ss/edit#slide=id.gae1f0f23af_0_22

$$usle_i = R_i \cdot K_i \cdot LS_i \cdot C_i \cdot P_i,$$

| Symbol | Parameter | Unit measurement | Sources |
|---|---|---|---|
| Ri | rainfall erosivity | (units: MJ·mm(ha·hr)−1) | |
| Ki | soil erodibility | (units: ton·ha·hr(MJ·ha·mm)−1), | |
| LSi | slope length-gradient factor | (unitless) | |
| Ci | crop-management factor | (unitless) | |
| Pi | support practice factor | (unitless) | (Renard et al., 1997). (cf. also in (Bhattarai and Dutta, 2006)). |

# Model - data inputs

| $usle_i = R_i \cdot K_i \cdot LS_i \cdot C_i \cdot P_i,$ | Format | Symbol | Source | Resolution | Link (global dataset) |
|---|---|---|---|---|---|
| **Digital Elevation Model** | geotiff raster | DEM | Google Earth Engine SRTM | 30m x 30m | 1. https://developers.google.com/earth-engine/datase<br>2. https://asterweb.jpl.nasa.gov/gdem.asp<br>3. http://dwtkns.com/srtm/<br>4. https://search.earthdata.nasa.gov/search/ |
| **Rainfall erositivity index** | geotiff raster | R | Global Rainfall Erosivity | | 1. https://esdac.jrc.ec.europa.eu/content/global-rainfa<br>2. https://esdac.jrc.ec.europa.eu/content/global-rainfa |
| **Soil erodibility** | geotiff raster | K | 1. Soil and Terrain Database (SOTER)<br>2. FAO Dataset | | 1. https://data.isric.org:443/geonetwork/srv/eng/catalo<br>2. https://webarchive.iiasa.ac.at/Research/LUC/Exter |
| **Land-use / land-use cover** | geotiff raster | LULUC | 1. NASA MODIS multiyear dataset<br>2. ESA dataset (2000, 2005, 2010) | | 1. https://lpdaac.usgs.gov/products/mcd12q1v006/<br>2. http://www.esa-landcover-cci.org/<br>3. https://lpdaacsvc.cr.usgs.gov/appeears/task/area |
| **Watersheds** | vector | | 1. ArcHydro<br>2. QGIS Hydro tools<br>3. InVEST - DelineatIt | | |
| **Biophysical table** | csv table | | | | |
| **Threshold Flow Accumulation** | coefficient value | | 1000 | | |
| **Drainages** | geotiff raster | | | | |
| **Borselli K parameter** | coefficient value | $kb$ | 2 | | |
| **Borselli IC0 parameter** | coefficient value | $IC0$ | 0.5 | | |
| **Max SDR Value** | coefficient value | | 0.8 | | |




# Remote sensing data inputs (DEM)

- Solomon Islands - Guadalcanal
- Landsat satellite imagery Java scripting in Earth Engine
- Land mask
- DEM – SRTM dataset (30m x 30m)
- Slope, Hill shade, Colour gradient
- Geotiff raster format
- GDEM available from NASA

# Remote sensing data inputs - erosivity

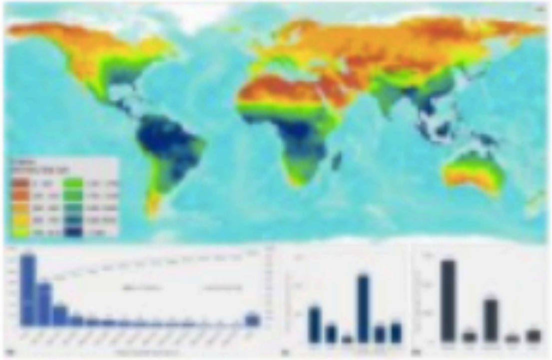
## Global Erosivity

https://esdac.jrc.ec.europa.eu/themes/global-rainfall-erosivity

https://esdac.jrc.ec.europa.eu/content/global-rainfall-erosivity#tabs-0-description=0

## Global Rainfall Erosivi

*Rainfall erosivity dataset (2017) is one of the input layers w*



**Data - Maps**

The data are also accessible in: Global R-factor

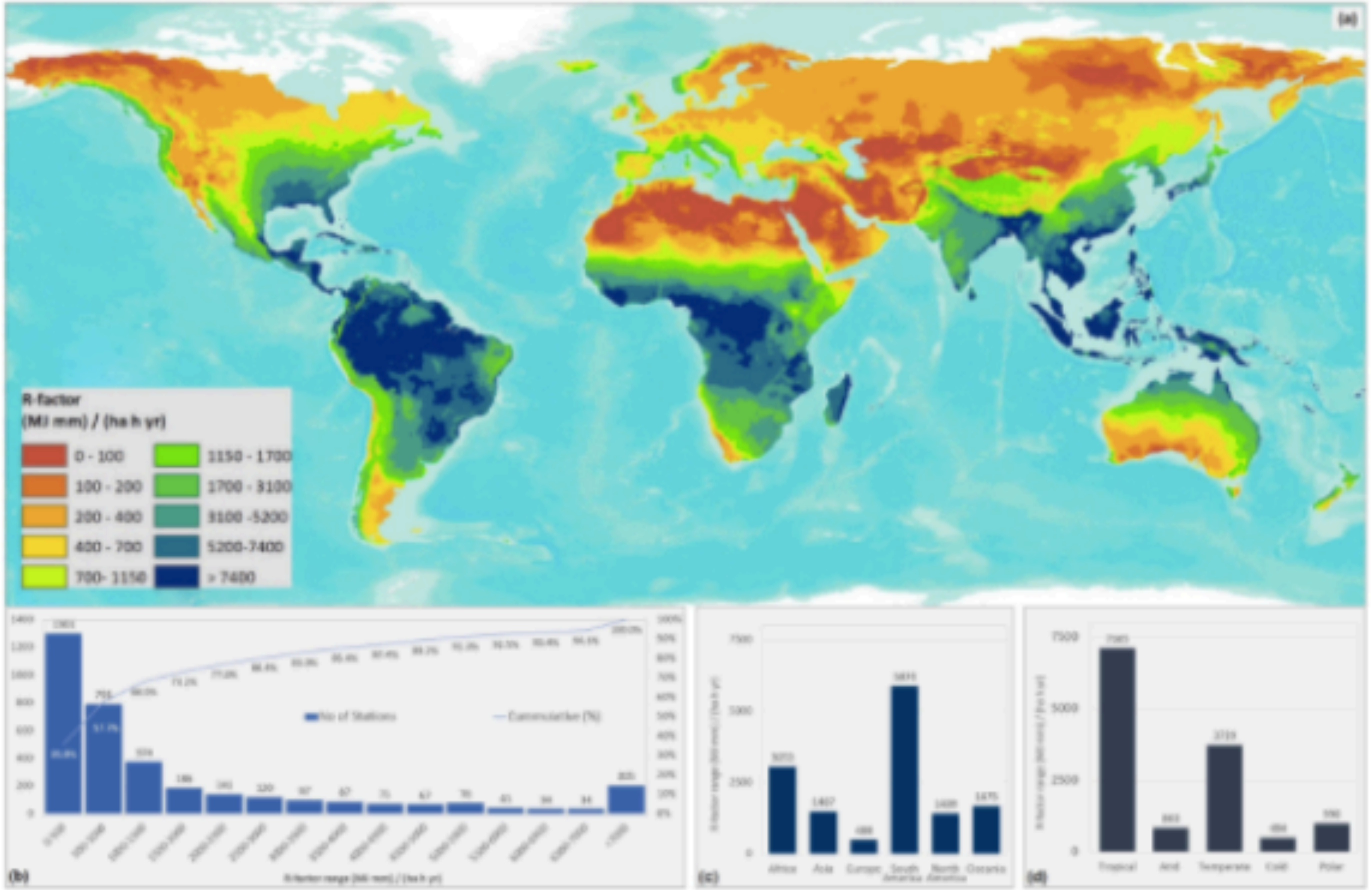
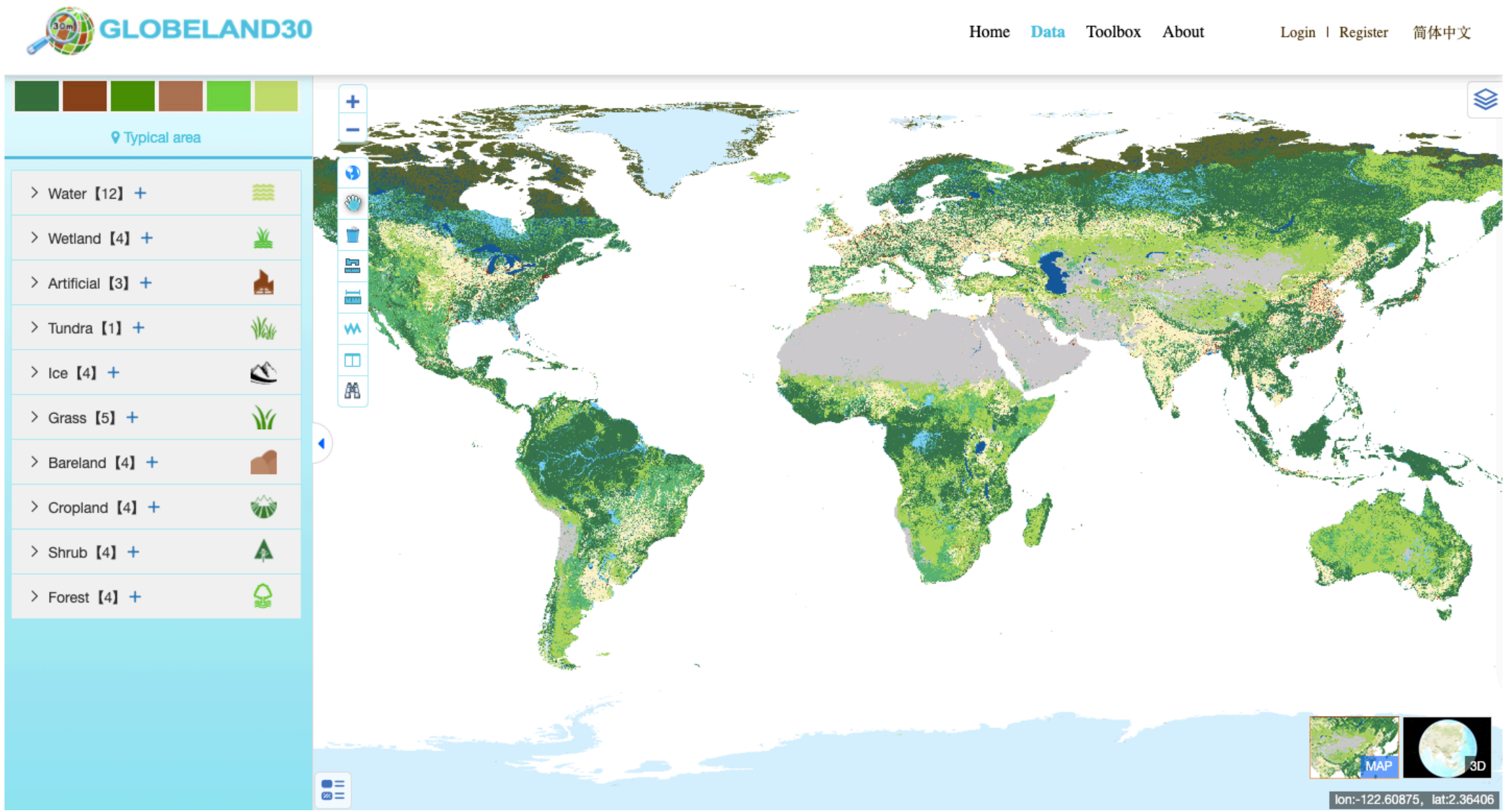
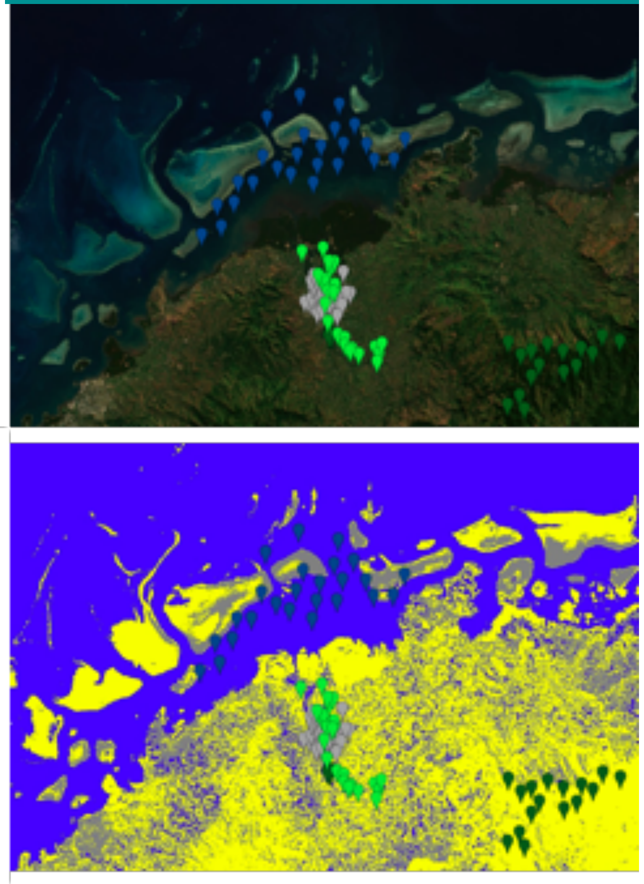



Fig 1: (a) Global Rainfall Erosivity map (spatial resolution of 30 arc-seconds). Erosivity classes correspond to quantiles:

# Land use and landcover (LULC)

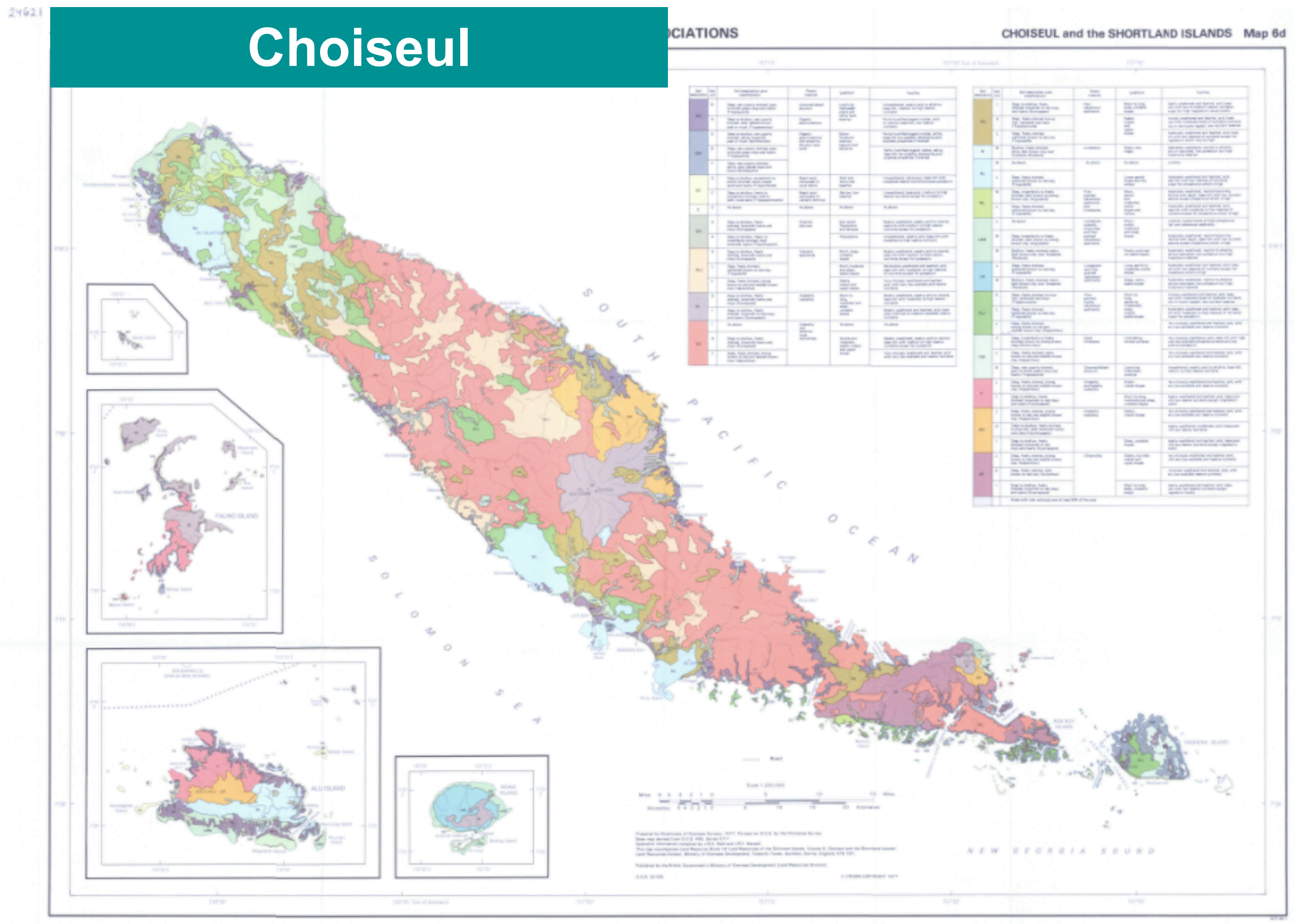



## LULC classification (supervised)



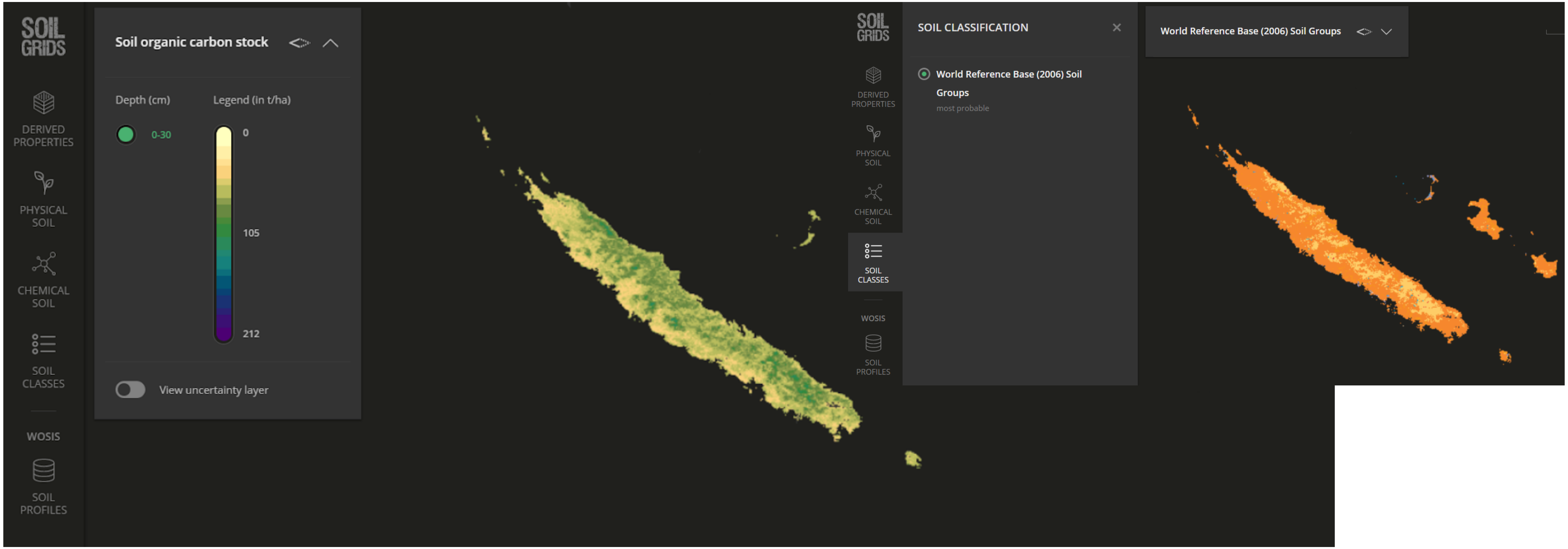
# Model - data inputs - erodibility

## Choiseul




- Incomplete datasets do not cover all areas in Solomon Islands
- In image format rather than in shapefile raster / vector format
- Requires many hours to digitize
- Then additional work to pre-process and group soil classes data

# Alternative source – soil grids dataset

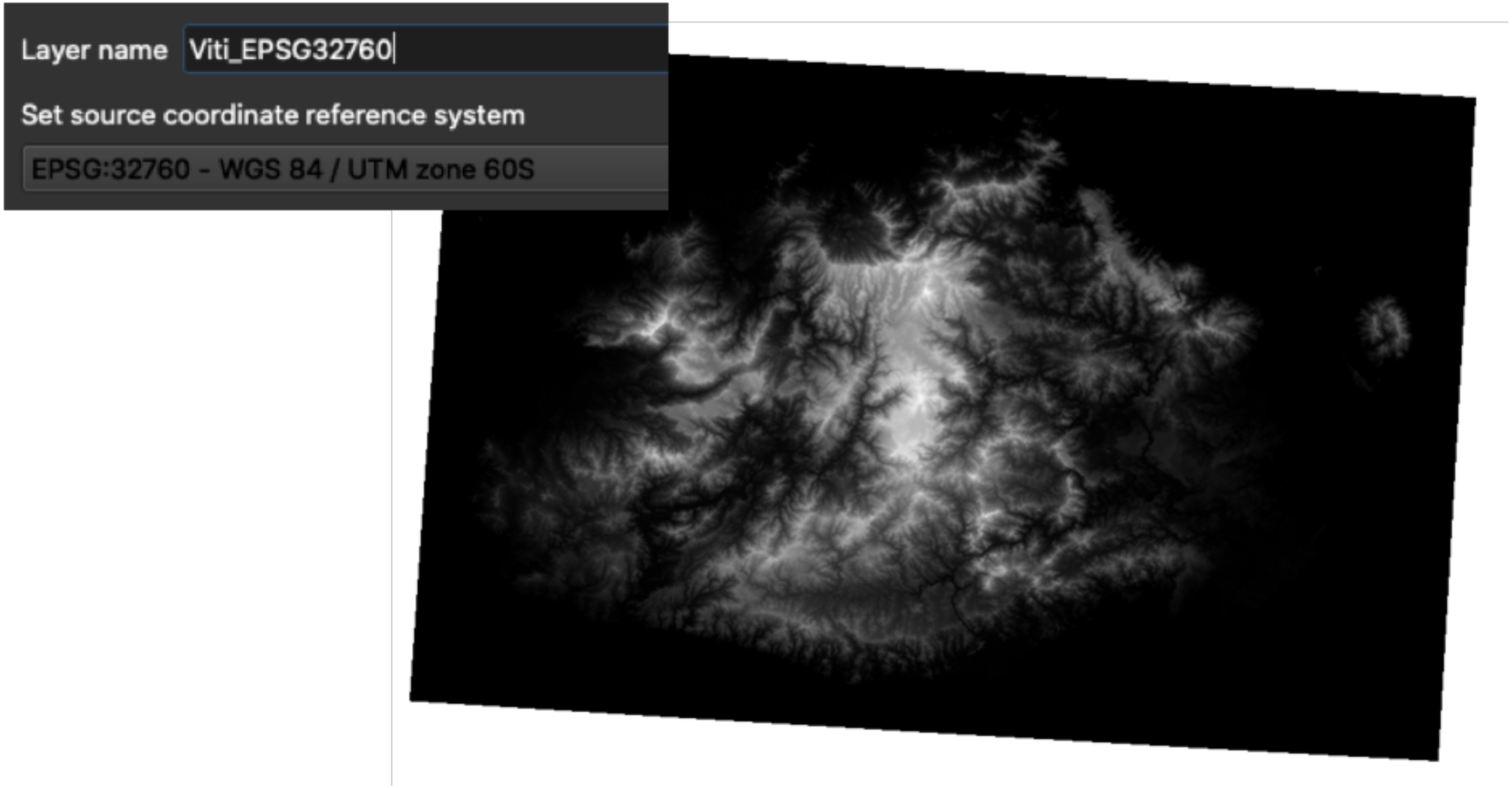



**Released in May 2020 – relatively new dataset**

**Still requires additional processing / grouping work**

# Working with existing dataset (QGIS)

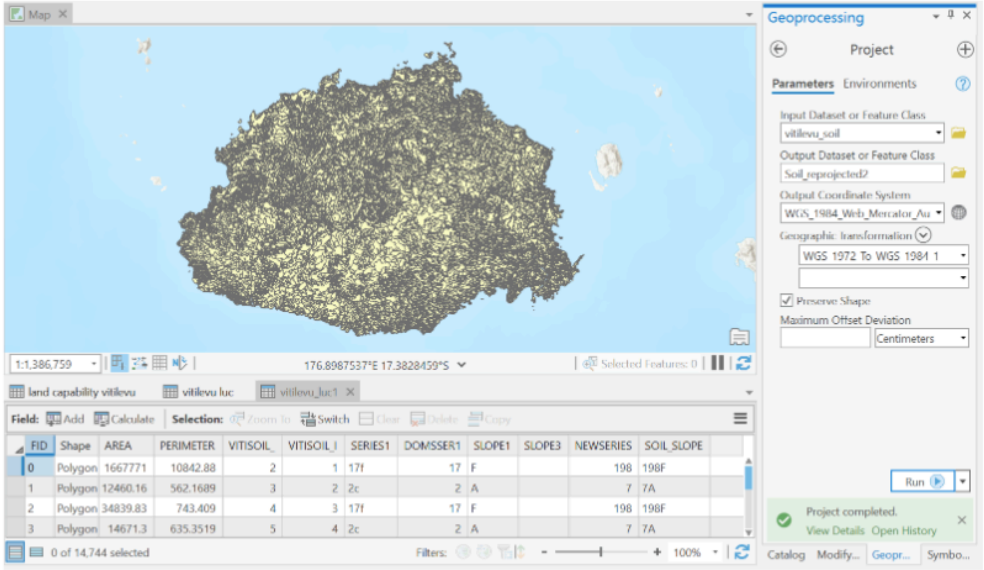
Reprojection (warp) from EPSG: 4326 to EPSG: 32670 – WGS 84 / UTM zone 60S



# Working with existing dataset (QGIS)

## Contacted Ministry of Lands to seek soil and land use data

Reprojecting soil files - don't use QGIS - use ArcGIS




WGS 1094 web mercator

14,473 vector shapefile features - each with data:

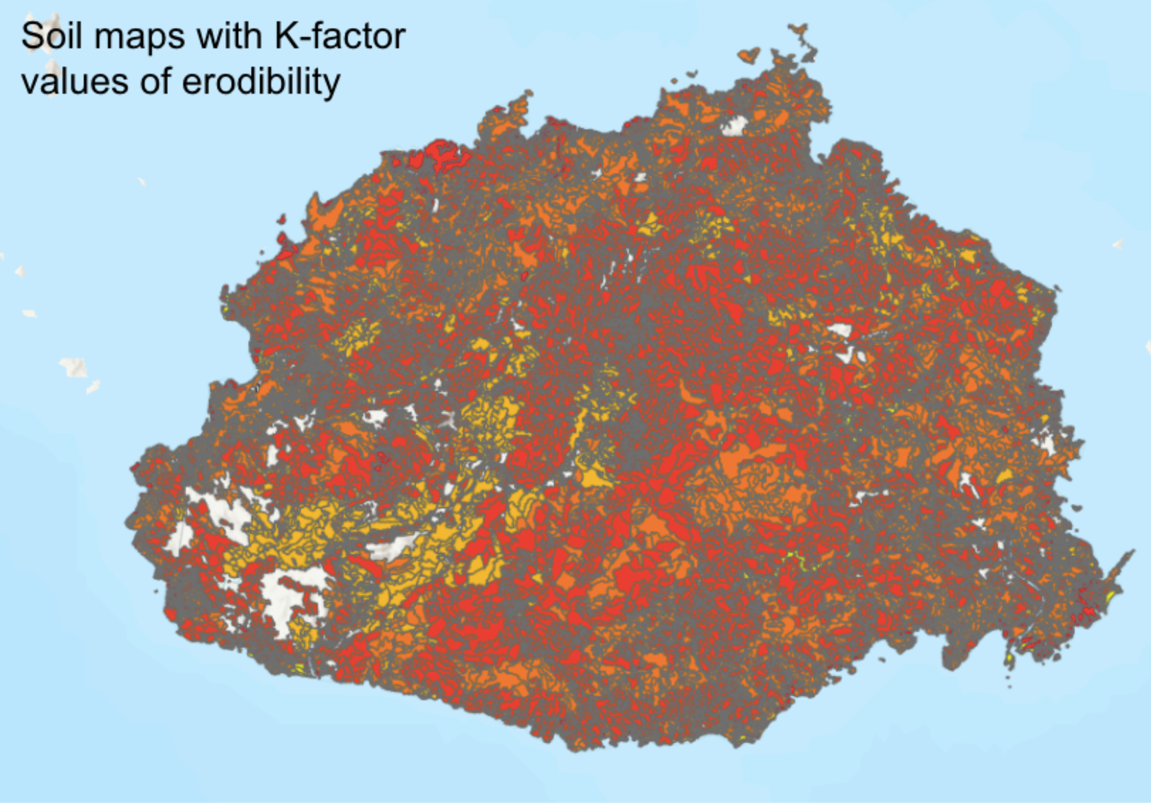
- Area
- Perimeter
- Soil-type
- Texture
- Aeration
- Drainage
- pH
- Slope
- Soil group name

GIS attribute table

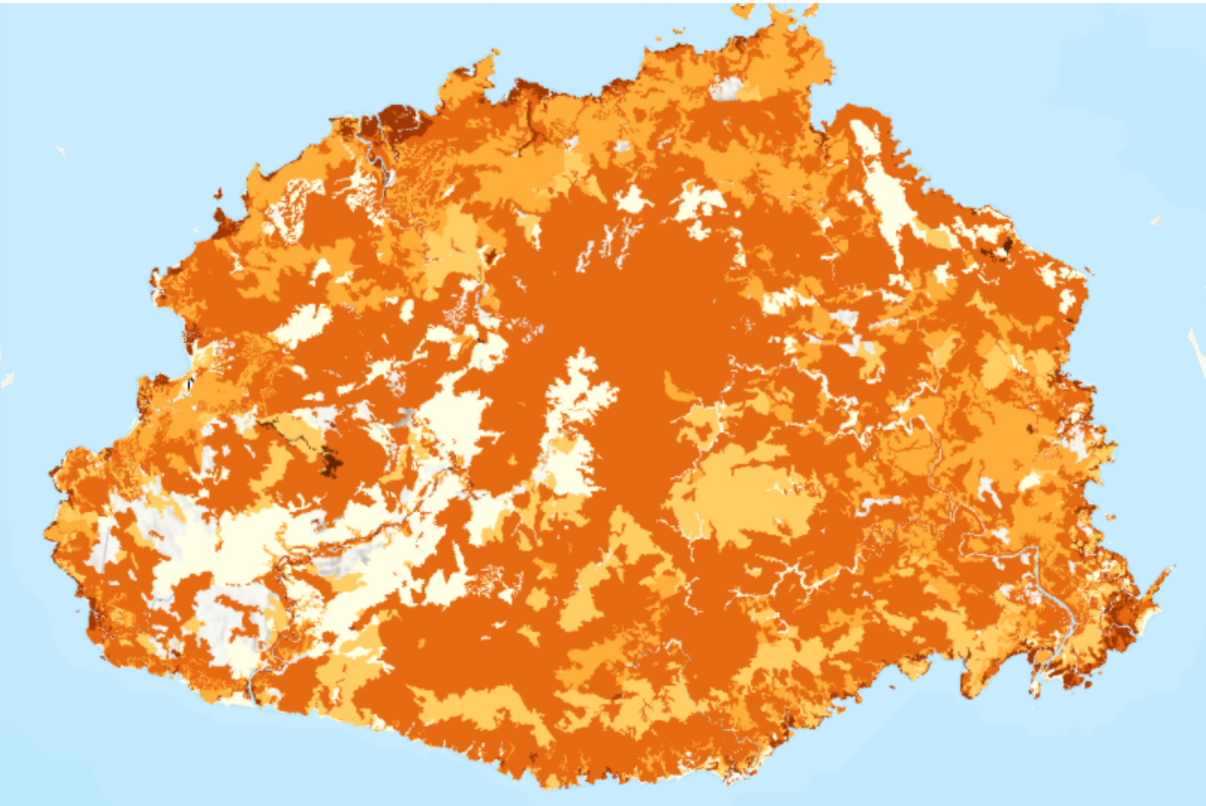
| FI | Shape | AREA | PERIMETER | VITISOIL_ | VITISOIL_I | SERIES1 | DOMSSER1 | SLOPE1 | NEWSERIES | Vitiid_2 | OID |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 14743 | Polygon | 23578.77 | 816.6111 | 14745 | 15109 | 39b | 39 | A | 9 | 14744 | 8 |
| 14742 | Polygon | 30578.64 | 923.4788 | 14744 | 15108 | 39b | 39 | A | 9 | 14743 | 8 |
| 14741 | Polygon | 27234.17 | 864.9823 | 14743 | 15107 | 39b | 39 | A | 9 | 14742 | 8 |
| 14740 | Polygon | 27582.61 | 683.6816 | 14742 | 15106 | 39b | 39 | A | 9 | 14741 | 8 |
| 14739 | Polygon | 326232.3 | 2673.489 | 14741 | 15105 | 60b | 60 | F | 160 | 14740 | 159 |
| 14738 | Polygon | 423306.9 | 2852.427 | 14740 | 15104 | 60b | 60 | G | 160 | 14739 | 159 |
| 14737 | Polygon | 451323.4 | 4023.558 | 14739 | 15103 | 54h | 54 | G | 128 | 14738 | 127 |
| 14736 | Polygon | 83277.53 | 1236.763 | 14738 | 15102 | 71e | 71 | A | 5 | 14737 | 4 |
| 14735 | Polygon | 39329.27 | 1169.398 | 14737 | 15100 | 65a | 65 | A | 30 | 14736 | 29 |
| 14734 | Polygon | 170457.3 | 4515.554 | 14736 | 15098 | 71b | 71 | A | 2 | 14735 | 1 |
| 14733 | Polygon | 33211.53 | 738.3934 | 14735 | 15096 | 71d | 71 | A | 4 | 14734 | 3 |
| 14732 | Polygon | 65938.86 | 1262.463 | 14734 | 15095 | 39b | 39 | A | 9 | 14733 | 8 |
| 14731 | Polygon | 23477.58 | 693.4404 | 14733 | 15099 | 68a | 68 | A | 13 | 14732 | 12 |
| 14730 | Polygon | 30205.39 | 680.1248 | 14732 | 15097 | 68a | 68 | A | 13 | 14731 | 12 |
| 14729 | Polygon | 32785.13 | 853.5484 | 14731 | 15093 | 71d | 71 | A | 4 | 14730 | 3 |
| 14728 | Polygon | 79440.75 | 2104.309 | 14730 | 15101 | 71c | 71 | A | 3 | 14729 | 2 |
| 14727 | Polygon | 46089.16 | 1083.28 | 14729 | 15091 | 71e | 71 | A | 5 | 14728 | 4 |
| 14726 | Polygon | 237052.1 | 3122.174 | 14728 | 15092 | 71d | 71 | A | 4 | 14727 | 3 |
| 14725 | Polygon | 22918.95 | 662.8014 | 14727 | 15090 | 65a | 65 | A | 30 | 14726 | 29 |

# Working with existing dataset (QGIS)

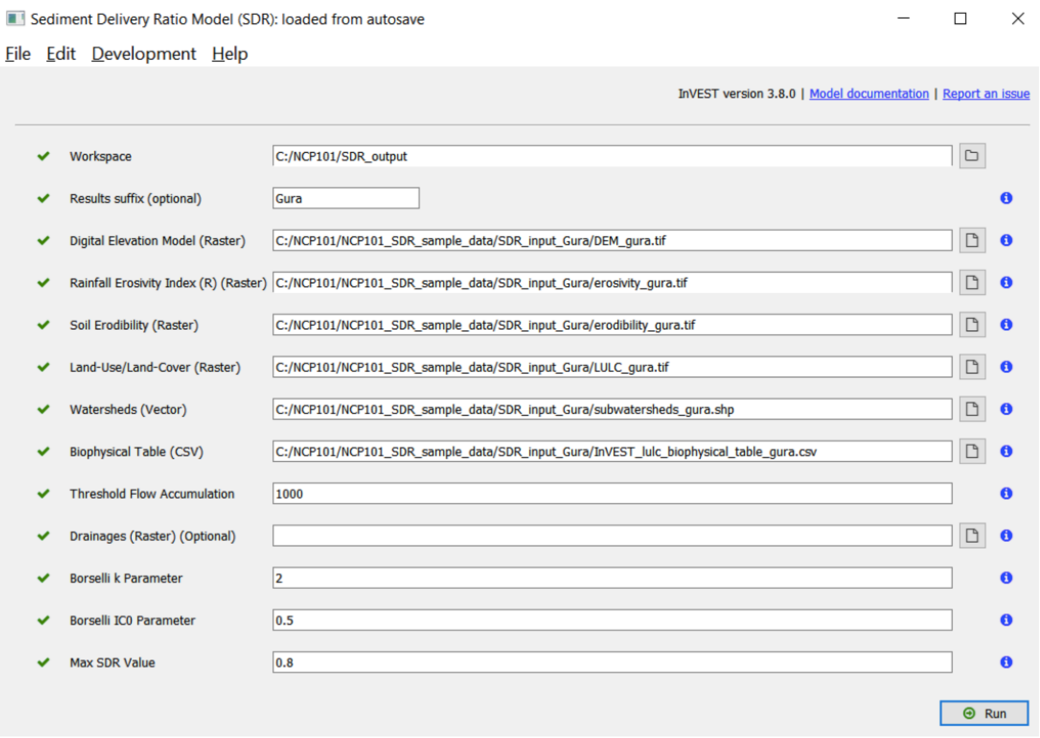
## Polygon vector



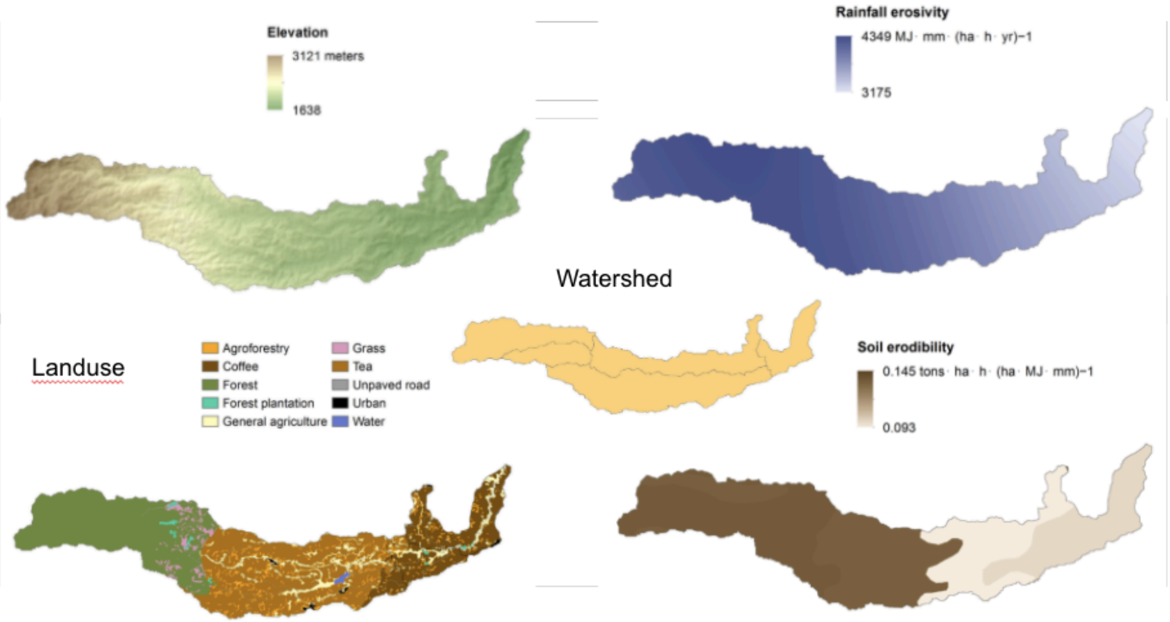

## Raster



# Example inputs




# Example outputs



# Workflow (time – resourcing)

1. Background reading (10%)
2. Collating model input datasets – researching different databases, Earth Engine scripting (30%)
3. Processing datasets / digitizing / joining attribute tables / reprojecting converting to rasters (30%)
4. Trialing + troubleshooting, seeking feedback and revising (20%)
5. Report write-up (5%)
6. Presentations (5%)

# VINAKA