USING GIS TO HELP INTEGRATE BIODIVERSITY AND ECOSYTEM SERVICES INTO REDD+ DECISION MAKING



STEP-BY-STEP TUTORIAL: EVALUATING THE IMPORTANCE OF FORESTS FOR SOIL STABILIZATION AND LIMITING SOIL EROSION, A SIMPLE APPROACH using QGIS 2.8





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

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

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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, erosion control and non-timber forest products. Some of the potential benefits from REDD+, such as biodiversity conservation, can be enhanced through identifying areas where REDD+ actions might have the greatest impact using spatial analysis.

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

This tutorial provides a mapping methodology to evaluate the importance of forests for soil stabilization and limiting soil erosion, using a simple quantitative approach. In this example, importance is evaluated as a function of slope, rainfall and the presence of something important downstream that could be adversely affected by soil erosion, such as a dam or water body. For example, forests may play an important role in soil stabilization on steep slopes in areas of high rainfall, with important downstream activities that benefit from clear water such as population centres, hydroelectric plants and navigation routes. Such an analysis can be used to help answer questions such as:

- Where is forest loss likely to result in erosion and consequent sedimentation and where is this important?
- Where might retaining or restoring forests in areas play an important role in retaining soil/reducing sedimentation?

The analysis is undertaken by using an overlay approach, where data on mean precipitation (annual or the average for a subset of particular months if just the wet season is used), slope, and dam catchment are generated and combined with forest data. The process involves generation of single layers with 3 classes (low medium and high) for mean precipitation and for slope. A binary layer is generated for the presence or absence of a dam catchment. These can then be combined additively. Since there are 3 classes for slope (1-3), 3 classes for mean precipitation (1-3) and 2 for the presence or absence of a dam catchment (0-1) the resulting output has a maximum value of 8, and a minimum value of 2, and therefore 7 classes. These classes represent a low – high potential importance of forests for soil stabilization and limiting soil erosion. Highest values represent higher erosion impact in the absence or degradation of forests. No weighting is used in this approach – the relative importance of high precipitation is the same as that for steep slopes. This approach could be further refined for example by adding in additional layers such as soil type.

The analysis runs entirely from within QGIS but many of the processes are using SAGA (System for Automated Geoscientific Analyses) GIS tools. There may be occasions where a tool fails to run on a user's computer so it may be necessary to run the process directly in SAGA. In case of this a quick overview of the SAGA GIS interface is provided in Annex 1.

# 2. The importance of forests for soil stabilization and limiting soil erosion

## 2.1. Data requirements

Download **void-filled** hydroSHEDS DEM data at 3 arc second resolution from: <u>http://hydrosheds.cr.usgs.gov/datadownload.php?reqdata=3demg</u>

The 3 arc second data is served in 1-degree tiles; therefore more than 1 tile will be needed, depending on the size of the required study area.

A void-filled DEM has been modified to fill in areas of no-data (i.e. over large water bodies). The existence of no-data in a DEM causes significant problems for deriving hydrological products, which require continuous flow surfaces. Therefore, a void-filling procedure is applied to provide a continuous DEM for HydroSHEDS. A conditioned DEM has had a number of conditioning procedures applied to it (e.g. sink filling, stream burning, deepening of open water surfaces). The conditioning process alters the original DEM and may render it incorrect for applications other than deriving drainage directions.

# \*\*\*IMPORTANT\*\*\* when using HydroSHEDS data to undertake the analysis described below, a void-filled DEM must be used.

- Download WorldClim precipitation data at 30 arc seconds from: <u>http://www.worldclim.org/current</u> as ESRI grid files. This data is available on large tiles or at global extent. The download for global precipitation data is around 700MB and consists of 12 global monthly data grids.
- Download dams data from: <u>http://sedac.ciesin.columbia.edu/data/set/grand-v1-dams-rev01</u>

The examples above are global data and can easily be substituted if better data are available.

#### 2.2. Prepare raster and vector data layers

#### 2.2.1. Merge DEM tiles into a single raster and clip to area of interest

This first step will be done using the GDAL merge function in QGIS. There are other ways to merge DEM tiles together but avoid using the SAGA merge function as there currently appears to be an error in the 'merge' which means that it does not combine the DEM tiles together properly (leaving a 1 pixel space between the tiles)

Version         Project       Edit       View       Layer       Settings       Plugins       Vector       Raster       I         Image: Settings       Plugins       Vector       Raster       I       Image: Settings       Plugins       Vector       Raster       Image: Settings       Vector       Raster       Image: Settings       Vector       Raster       Image: Settings       Vector       Image: Settings       Image: Settings       Vector       Image: Settings       Image: Setings       Image: Setings	<ul> <li>a. Open QGIS</li> <li>b. Click on the add raster data button</li> <li>c. Navigate to the hydrosheds void filled DEM folder and add the first raster. These data are in ESRI ArcInfo Grid format so in order to load it into QGIS, navigate into the individua grid folder and pick the w001001.adf file (it is the file with the largest size)</li> </ul>
	e030_dem → n00e030_dem - 42 Search n00e030_dem
Organize  New folder	
Image: Sector of the secto	Date modified         Type         Size           18/11/2014 16:13         ADF File         1 KB           18/11/2014 16:13         ADF File         1 KB           18/11/2014 16:13         ADF File         1 KB           18/11/2014 16:13         XML Document         20 KB           18/11/2014 16:13         ADF File         1 KB           18/11/2014 16:13         ADF File         21 KB           18/11/2014 16:13         ADF File         21 KB           18/11/2014 16:13         ADF File         44,673 KB           18/11/2014 16:13         ADF File         Exc. HS
File <u>n</u> ame: w001001.adf	✓ All files (")     ✓     Open    ✓ Cancel

- d. Click Open and the raster will appear in the table of contents
- e. Add the other void-filled DEM raster datasets to QGIS (that cover the area of interest) following steps a to d.



f. Once all the data are added click on the Zoom to full

The map window should now show all the map tiles and look similar to the image below.



**g.** Next Add a **vector layer** to the QGIS project for the **area of interest** (e.g. country boundary), make sure it is in geographic projection (i.e. EPSG 4326) as it will be used to clip the DEM raster data which is in geographic.

(This is because QGIS cannot do any analyses with datasets if they are in different projections)



m. The merged grid shows all the tiles together in a mosaic covering the full extent of the study area and is added to the table of contents called **output layer**. Don't worry that QGIS has not shaded it well at present.



- r. Navigate to an output folder and save as a new Output layer eg. Dem\_aoi\_dd.tif in this example.
- s. Click Run
- t. A new Output layer is added to the top of the table of contents. Untick the other layers and see that the new Output layer has been clipped to the area of interest



a. Set Mask layer to the shapefiile of the area of interest e.g. outline\_dd in this example, the country boundary polygon

Parameters Log Help	
Input layer	
Output layer [EPSG:4326]	<ul><li>▼</li></ul>
Mask layer	
outline_dd [EPSG:4326]	<ul> <li>✓</li> <li>…</li> <li>Ø</li> </ul>
Nodata value, leave as none to take the nodata value from input	
none	
Create and output alpha band	
Keep resolution of output raster	
Additional creation parameters [optional]	
Output layer	
C:/forWorkingSession/outputdd/dem_aoi_dd.tif	
X Open output file after running algorithm	

- b. It is not very helpful that QGIS calls the output from the two tools Output layer so right click on 1<sup>st</sup> Output layer>> datasets>> Properties
- c. Change the Layer name from Output layer to the name in the Layer source. E.g. in this example dem\_aoi\_dd
- **d.** Repeat for the 2<sup>nd</sup> Output layer

е.



			7.	497		Renarrie	
🏑 Layer Properties - Out	tput layer   General	-		-	-	-	? ×
General	▼ Layer info						
💓 Style	Layer name	utput layer		displayed as	Output layer		
Style	Layer source C	/forWorkingSession/out	outdd/dem_aoi_dd.t	üf			
Transparency	Columns: 9596 F	Rows: 12108 No-Data Va	lue: n/a				
Pyramids	▼ Coordi ate refi	erence system					
Histogram	EPSG:4326 - W						Specify
() Metadata	▼ □ Scale depe	ndent visibility		<b>,</b>			
The table of cont	ents should no	ow look			<ul> <li>Layers</li> </ul>		<b>B</b> ×
similar to the illu	stration right		j 💿	7 🖬		6	



#### 2.2.2. Add precipitation rasters to area of interest

- a. Click on the Add Raster layer button and add the 12 monthly precipitation rasters to QGIS project
- b. Right click on each of the datasets>>properties and click on the General Tab, change the layer name e.g. prec\_1.

🧭 Layer Properties - w00100	1   General
Ceneral	Layer info Layer name w001001 Layer name c:\Users\corinnar\Downloads\prec_30s_esri\pr Layer source C:\Users\corinnar\pr Layer source C:\Users\corinnar\pr Layer source S:\Users\corinnar\pr Layer source S:\Users\corinnar\pr Layer source S:\Users\corinnar\pr Layer source S:\Users\corinnar\pr Layer source sour
🕮 Pyramids INS Histogram	Coordinate reference system     EPSG:4326 - WGS 84     Specify
	Minimum (exclusive)       I:100,000,000       Maximum (inclusive)       I:0       I:0         current       current       current         Restore Default Style       Save As Default       Load Style       Save Style         OK       Cancel       Apply       Help

ð× c. Do this for each of the Layers Vo 1 🔍 🔻 🖬 🖬 🗔 12 precipitation prec\_12 prec\_11 prec\_10 prec\_9 prec\_8 prec\_7 prec\_6 Q. rasters. (Prec\_1 represent January and Po prec\_12 represents P Q, December) • 318 outli slope -15 9. 15 - 30 V. • oi la 3

#### 2.2.3. Batch clip monthly precipitation rasters

a. Right click click on GDAL Clip raster by mask layer and click 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 rasters

Batch Processing - Clip raster by mask layer							
Parameters	Log Help	1					
Input k	ayer	Mask layer					
		Select from	open layers				
į		Select from	filesystem				



c. Click on the ... 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

🌠 Multiple selection	? <mark>x</mark>
outline_aoi_dd     outline_aoi_la	Select all
water_bodies_la	Clear selection
	Toggle selection
	ОК
	Cancel

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- d. Double click on
   Column heading
   Mask Layer to autopopulate the
   outline\_aoi\_dd
   down the column.
- Click on the ... in the first Output layer and navigate to an output folder and in the Filename type \_aoi.tif
- f. Click Save

🕻 Save file		-			X
🕒 🗢 📕 « forV	Vorkin	gSession 🕨 output_dd	<b>▼</b> 4 <del>9</del>	Search output_dd	٩
Organize 🔻 New	/ folde			:=	. ()
🖳 Recent Places	*	Name	<u>^</u>	Date modified	Туре
C Libraries Documents J Music Pictures Videos	III		No items match yo	our search.	
👰 Computer					
Local Disk (C:)		•			+
	_aoi.tif TIF file				•
) Hide Folders				<u>S</u> ave Car	ncel

- g. Click Fill with parameter values and select Input layer as parameter to use
- h. Set the Input layer to the merged dem created in the previous step i.e. the one labelled Output layer in the table of contents.

Autofill settings									
Autofill mode	Fill with parameter values								
Parameter to use	Input layer 💌								
	OK Cancel								

i. Click OK

Input laye	 Mask lav		ve as none to take the nodata	Searche and autout alaba has	d Keep resolution of output raster	Additional creation parameters	Output la	 Load in QG
	 outline aoi dd	,ei 	none			<ul> <li>vuoruoriai dieauori parameters</li> </ul>	aoiprec 1.tif	 Yes
ec_10	 outline aoi dd		none		1	-	soiprec_10.tif	 Yes
ec 11	 outline_aoi_dd		none				solprec_11.tif	 Yes
ec_12	 outline_aoi_dd		none			-	solprec_12.tif	 Yes
ec_2	 outline_aoi_dd		none		- No	-	_aoiprec_2.tif	 Yes
ec_3	 outline_aoi_dd		none	No	- No	•	_aoiprec_3.tif	 Yes
ec_4	 outline_aoi_dd		none	No	- No	•	_aoiprec_4.tif	 Yes
ec_5	 outline_aoi_dd		none	No	- No	-	_aoiprec_5.tif	 Yes
ec_6	 outline_aoi_dd		none	No	▼ No	-	_aoiprec_6.tif	 Yes
ec_7	 outine_aoi_dd		none	No	▼ No	-	_aoiprec_7.tif	 Yes
ec_8	 outline_aoi_dd		none	No	▼ No	-	_aoiprec_8.tif	 Yes
ec_9	 outline_aoi_dd		none	No	• No	-	_aoiprec_9.tif	 Yes

- **j.** Click **Run** and the tool will run in batch mode.
- k. Click Ok and close once complete

Parameters         Log         Help           Algorithm Clip raster by mask layer correctly executed         Algorithm Clip raster by mask layer correctly executed           Algorithm Clip raster by mask layer correctly executed         Algorithm Clip raster by mask layer correctly executed           Algorithm Clip raster by mask layer correctly executed         Algorithm Clip raster by mask layer correctly executed           Algorithm Clip raster by mask layer correctly executed         Algorithm Clip raster by mask layer correctly executed           Algorithm Clip raster by mask layer correctly executed         Algorithm Clip raster by mask layer correctly executed           Algorithm Clip raster by mask layer correctly executed         Algorithm Clip raster by mask layer correctly executed           Algorithm Clip raster by mask layer correctly executed         Algorithm Clip raster by mask layer correctly executed           Algorithm Clip raster by mask layer correctly executed         Algorithm Clip raster by mask layer correctly executed           Algorithm Clip raster by mask layer correctly executed         Algorithm Clip raster by mask layer correctly executed           Algorithm Clip raster by mask layer correctly executed         Algorithm Clip raster by mask layer correctly executed           Algorithm Clip raster by mask layer correctly executed         Algorithm Clip raster by mask layer correctly executed	Batch processing
---	------------------

 See that there are 12 datasets added to the table of contents all called "Output Layer". Right Click and goto properties on each of the datasets and rename them



#### 2.2.4. Calculate average annual precipitation

- a. From the main menu click Raster>>Raster Calculator
- b. In the expression box add the 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")/ 12
- 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

🌠 Raster calculat	tor	200	R. • 1	-				? ×	
Raster bands -		]	Result lay	er					
slope_aoi_la@ aoiprec_1@:			Output la	yer	/output_	_dd/av_a	an_prec_aoi_o	dd.tif	
_aoiprec_10@ _aoiprec_11@	01"		Current	ayer extent					
"_aoiprec_12@ "_aoiprec_2@ " aoiprec_3@	1"		X min	33.91055	<b></b>	XMax	41.90698	-	
aoiprec_4@: aoiprec_4@:	1"		Y min	-4.67921	<b>*</b>	Y max	5.41091	-	
"_aoiprec_6@3 "_aoiprec_7@3	1" 1"		Columns	960	-	Rows	1211	-	
"_aoiprec_8@: "_aoiprec_9@: "Sum@1"			Output fo	rmat esult to projec	GeoTIFF	:		•	
▼ Operators									
+	*	sqrt s	in	^	acos		(		
-	/	cos a:	sin	tan	atan		)		
<	>	= <	:=	>=	AND		OR		
Raster calculato	r 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" )/ 12 Expression valid									
							ОК	Cancel	

#### e. Click OK



#### 2.2.1. Reclassify mean annual precipitation raster into 3 classes

- a. Right click on the average annual precipitation raster>>Properties
- b. Click on Style

🏑 Layer Properties - av_an_pr	rec_aoi_dd   Style		? <mark>×</mark>
General	Band rendering		<b>A</b>
😻 Style	Render type Singleband pseudocolor 🝷		
Pyramids	Band Band 1 (Gray)   Color interpolation Discrete  Color Interpolation  Value Color Label		□ Invert usses 5 ★ × 218.75
() Metadata	40.00000 100.00000 218.750000 100 - 219	O Min / max	
	Clip		Load
	Restore Default Style Save As Default	Load Style	Save Style
		OK Cance	I Apply Help

- 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 Actual (slower)
- g. Click Load

- **h.** Click Classify and then Manually change the Values and labels to appropriate class breaks for low medium and high precipitation
- i. Click OK. This visualized the class breaks on screen
- j. Now run the Reclassify grid values tool to reclass the values to 1, 2 and 3.

Reclassify grid values		
Parameters Log Help		
Grid		ŀ
av_an_prec_aoi_dd [EPSG:4326]	· · · ·	
Method		
[2] simple table		-
old value (for single value change)		
0.000000		
new value (for single value change)		
1.000000		
operator (for single value change)		
[0] =		-
minimum value (for range)		
0.000000	-	
maximum value (for range)		
1.000000		
new value(for range)		
2.000000		
operator (for range)	k	
[0] <=		-
Lookup Table		
Fixed table 3x3	N .	
operator (for table)		
[0] min <= value < max		<b>-</b>
replace no data values		ĺ
new value for no data values		ſ
0.000000		
replace other values		
new value for other values		
0.00000		
Reclassified Grid		
C:/forPaulus/corrected/av_an_prec_3class.tif		
Copen output file after running algorithm		
0%		
0%		Close

#### 2.2.2. Project raster layers from geographic coordinate system to a projected CRS

It is important to now save the data in a projected coordinate system (such as lambert azimuthal equal area projection (with a Centre latitude and Centre longitude as the centre of the area of interest). The dataset cannot be left in geographic EPSG 4326 as the units of the data for the next processing steps need to be in meters.

	🔏 Custom Coordinate Reference System Definition
The easiest way to	Define
project the data in QGIS	You can define your own custom Coordinate Reference System (CRS) here. The definition must
is to rightclick on each of	conform to the proj4 format for specifying a CRS.
the datasets and save as.	Name Parameters
First you may need to	
create a custom CRS if	
you are using lambert	
azimuthal equal area for	
your area of interest as it	
is not one of the QGIS	
default projections.	
	Add new CRS
a. From the main	Name:
menu click on	
Settings>>	Parameters:
custom CRS	Copy existing CRS
<b>b.</b> Click on <b>Copy</b>	Test
existing CRS	Use the text boxes below to test the CRS definition you are creating. Enter a coordinate where both the lat/long and the transformed result are known (for example by reading off a map). Then press the
	calculate button to see if the CRS definition you are creating is accurate.
	Geographic / WGS84 Destination CRS
	East
	Calculate
	OK Cancel Help
	L

**c.** To create a **custom lambert azimuthal equal area** CRS for example, filter by typing lambert in the filter box. See that there is an existing lambert azimuthal equal area projection for the North Pole that can be modified.

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ilter lam ecently used coordinate reference systems Coordinate Reference System	Autority TD	¢
Coordinate Reference System	Authority TD	
	Authority TD	
	Authority ID	
North Pole Lambert Azimuthal Equal Area	EPSG: 102017	
•		
oordinate reference systems of the world		Hide deprecated CRS
Coordinate Reference System	Authority ID	
·····NAD83(NSRS2007) / Oregon Lambert	EPSG:3643	
MAD83(NSRS2007) / Oregon Lambert (ft)	EPSG:3644	
MAD83(NSRS2007) / Texas Centric Lambert Conformal	EPSG:3666	
···· NAD83(NSRS2007) / Virginia Lambert	EPSG:3970	
···· NEA74 Noumea / Noumea Lambert	EPSG:3165	
···· NEA74 Noumea / Noumea Lambert 2	EPSG:3166	
MTF (Paris) / Lambert Centre France	EPSG:27562	
···· NTF (Paris) / Lambert Corse	EPSG:27564	
MTF (Paris) / Lambert Nord France	EPSG:27561	
···· NTF (Paris) / Lambert Sud France	EPSG:27563	
···· NTF (Paris) / Lambert zone I	EPSG:27571	
···· NTF (Paris) / Lambert zone I	EPSG:5707	
	EDCC-07E70	

- **d.** In the bottom panel you can see the syntax for the projection
- e. Click OK —

- f. Change the name from new CRS e.g. in this example to LAEA\_lon37\_lat0 as the centre lon and lat of the area of interest is 37 and 0
- g. In the Parameters box change the +lat\_0=90 +lon\_0=0 to /lat\_0=0 +lon\_0=37 in this example

Define		
You can define you conform to the pro	r own custom Coordinate Reference System (C 4 format for specifying a CRS.	RS) here. The definition must
Name	Parameters	
• new CRS	+proj=laea +lat_0=90 +lon_0=0 +x_0=0 ·	+y_u=u +datum=wGs84 +units=
🕀 Add new CR		Remove
Name:	LAEA_lon37_lat0	
Parameters:	+proj=laea +lat 0=0 +lon_0=37 + x_0=0 + +no_defs	y_0=0 +datum=WGS84 +units=m
Copy existing CRS		
est		
the lat/long and th calculate button to	below to test the CRS definition you are creat transformed result are known (for example b see if the CRS definition you are creating is ac	y reading off a map). Then press the curate.
Geographic North	WG584	Destination CRS
East		
	Calculate	
	ОК	Cancel Help

- h. Click OK
- i. Next right click on the DEM that has been clipped to the aoi. i.e. in this example dem\_aoi\_dd
- j. Set Format to GTiff
- k. Click on Browse and chose a folder to save to and save dem\_aoi\_la.tif for example.
- I. For the CRS click on Change and pick the Lamber azimuthal equal area projection you created in the previous step

🎸 Save raster layer as	? ×
Output mode   Raw data   Rendered image	
Format GTiff	Create VRT
Save as C:/forWorkingSession/output_la/dem_aoi_la.tif	Browse
CRS Selected (LAEA_lon37_lat0 , USER:100006)	Change
▼ Extent (current: layer)	
🄏 Coordinate Reference System Selector	
West -343868.90 Define this layer's coordinate refer This layer appears to have no projection specifica project, but you may override this by selecting a d	ation. By default, this layer will now have its projection set to that of the
Filter	
Recently used coordinate reference systems	
Resolution (curre     Coordinate Reference System     North Pole Lambert Azimuthal Equal Area	Authority ID EPSG: 102017
Horizontal     9     Norm Pole Lambert Azimuthal Equal Area     LAEA Ion37 Iat0	USER: 100006
Columns 9	
▼ □ Create Optic	
Profile Default	<b>•</b>
Name	Value + -
	Validate
	OK Cancel

- m. Then click OK and OK to close both windows
- n. The new dataset is not automatically added to the project so click on Add Raster dataset button and add the clipped and projected dem to the project i.e. dem\_aoi\_la.tif
- Repeat steps I n for saving the 3-class average annual precipitation raster in the projected CRS

2

#### 2.2.3. Save vector layers from geographic coordinate system to a projected CRS

- **p.** Next Right click on each vetor layer and save the vector layers from geographic to lambert azimuthal equal area projection.
- q. Save the area of interest vector layer e.g. outline\_dd in this example and save as e.g. outline\_aoi\_la.shp

Save vector layer as...

- r. Save the project. From the main menu Click on File>>Project>>Save project>>
- Navigate to an output folder and save as e.g. soilerosion.ggs
- t. Add lakes and dam points into QGIS and save these also in the same Lambert Azimuthal Equal Area projection. If dam points are in multiple shapefiles use the Merge Vector layers tool in the processing toolbox

Format ESRI Shap	pefile rkingSession/output_la/outl	line ani la chn	▼ Browse
CRS Selected			urowse ▼
LAEA_lon	37_lat0		Change
Encoding		System	•
Save only select			
X Add saved file t	o map		
Symbology export		No symbology	•
Scale		1:50000	×
Extent (cur	rent: layer)		
Datasource Op	tions		
Layer Options			
Custom Option			
		OK Cancel	Help

- Right click on the Dam points >>open attribute table
- v. In the attribute table window click on the editing button
- w. Click on the



- k on the
- calculator button
- x. Create a new field e.g. called ID And in the expression box type \$rownum
- y. Click OK
- z. Repeat steps s-w for the water bodies shapefile

The Geographic layers can now be removed from the QGIS project so that just the \_la ones remain



# 2.2.4. Generate slope from projected DEM

#### Run the GDAL Slope tool

- The output layer that is added to QGIS defaults to the name Output file in the table of contents Right Click on Output file >>Properties
- b. Change the Layer name from Output file to be the same as the Layer source i.e. slope\_aoi\_la

Parameters Log Help	
Input layer	
dem_aoi_la [USER:100006]	· · · · · · · · · · · · · · · · · · ·
Band number	
1	<b>.</b>
Compute edges	
Use ZevenbergenThorne formula (instead of the Horn's one)	
Slope expressed as percent (instead of degrees)	
Scale (ratio of vert. units to horiz.)	
1.000000	÷
Output file	
C:/forWorkingSession/output_la/slope_aoi_la.tif	
X Open output file after running algorithm	
0%	

🌠 Layer Properties - Output f	file   General	? ×
Ceneral Constant Style Constant Styl	<ul> <li>Layer info <ul> <li>Layer name</li> <li>butput file</li> <li>displayed as</li> <li>Output file</li> <li>Layer source</li> <li>C:/forWorkingSession/output_/slope_aoi_la.tif</li> <li>Columns: 9673 Rows: 12135 No-Data Value: -9999</li> </ul> </li> <li>Coordinate reference system</li> <li>USER: 100006 - LAEA_lon37_lat0</li> </ul>	Specify
	Scale dependent visibility       Minimum (exclusive)     1:100,000,000       Image: Current       Current	<b>_</b>

#### c. Click OK

#### 2.2.5. Reclassify slope into 3 classes

- k. Right click on the slope raster>Properties
- I. Click on Style

🏑 Layer Properties - slop	pe_aoi_la   Style	? 🗾	x
General	Band rendering		
	Render type Singleband pseudocolor		
Transparency	Band 1 (Gray)  Generate new color map		
👜 Pyramids	Color interpolation Linear  VIOrBr  Interpolation	ert	
Histogram	🛞 🖃 💙 😂 📄 🔜 Mode Equal interval 🔻 Classes		
Metadata	Value Color Label Min 0 Max 89.7	/125	1
	- 15 0 - 15 Classify		
	89.712500 > 30 Min / max origin:		
	Exact min / max of full extent.		
	⊂Load min/max values		
	Cumulative 2.0 - 98.0	◆ %	
	Min / max		
	○ Mean +/- standard deviation × 2.00 ◆	)	
	Extent Accur	acy	
		stimate (faster)	
	Current • A	ctual (slower)	
		Load	
			-
			(
	Restore Default Style Save As Default Load Style	Save Style	
	OK Cancel	Apply Help	

- m. Change Render Type to Singleband Pseudocolor
- n. Change Mode to Equal Interval
- o. Change color interpolation to Discrete
- p. Change Load min/max values to Min/max and Extent to Full and Actual (slower)
- q. Click Load
- r. Click Classify
- s. Manually change the Values and labels to appropriate class breaks for low medium and high slope
- t. Click OK

Layers         Image: Second	
E □ ■ dem_aoi_la -49.125 2194.46	A CONTRACT OF A

Once you are happy with the class breaks use the Reclassify Grid values tool to create a 3 class slope raster. Chose to reclass by look-up-table

🌠 Reclass	sify grid values			_	×
	<= ıp Table	Help			•
Fixe	🌠 Fixed Table			? ×	
oper [0]	minimum	maximum	new	Add row	
	0	15	1	Remove row	
new	15	30	2		
0.0	20	219	3	ок н	
				Cancel	
new					
	0000			 ₽	
Reda	Reclassified Grid				
C:/f	orPaulus/correcte	d/av_an_prec_3	lass.tif		
	pen output file af			,	
					-
			0%		
				Run Close	



# 2.3. Running hydrological analysis steps

# 2.3.1. Fill the projected DEM and generate hydrological datasets

The next steps generate hydrological datasets from the **dem\_aoi\_la** DEM file.

	Search for Sink Removal in processing toolbox
	Double click on Sink Removal
1	🖉 Sink removal 📃
ې ۲	
	Parameters Log Help
L	DEM
L	dem_gdalmerge_ken.tif
	Sink Route [optional]
L	[Not selected]
L	Method
	[1] Fill Sinks
	Threshold
L	Threshold Height
	Preprocessed DEM
	C:/forPaulus/dem_gdalmerge_ken_preprocess.tif
	Copen output file after running algorithm
l	
L	0%
L	Run Close
	Set the DEM for the merged dem which has been clipped to the area of interest
	dem_gdalmerge_ken.tif in this example
	Leave Sink Route as Not Set
	Set the Preprocessed DEM so that the sink filling does not make changes that will overw
	the original DEM

#### 2.3.1. Generate stream order raster from sink filled DEM

- a. Search for the **Strahler order tool** in the processing toolbox and double click to run the tool
- **b.** Set the Elevation to be the **sink-filled DEM**. The sinkfilled version necessary for correct generation of the stream orders.

🤣 Strahler order	
Parameters Log Help	
Elevation	
dem_gdalmerge_ken_sinkfill_la [USER:100006]	▼
Strahler Order	
C:/forPaulus/dem_gdalmerge_ken_sinkfill_strahler_la.tif	
Open output file after running algorithm	
0%	
	Run Close

You may get an error when running this is run, in which case you will need to split the sink illed DEM into two smaller sections run this step on the two section seperately

 Check it looks correct (it should look similar to the illustration to the right)



#### 2.3.2. Buffer Dam points to overlap with Stream orders and convert to raster

Next the Dam points need to overlap the stream order lines generated from the DEM. The points will be converted to Raster and expanded to ensure they overlap correctly (otherwise the catchments created later on will generate incorrectly)



Illustration of dam points and Stream order lines:-

It is very important that the dams fit the closest stream of the highest order – i.e. in the figure (above), the point when converted to raster should overlap the yellow square, not the green one – or the upstream catchments will not be generated correctly – they will be too small.

- **a.** Zoom in on the Dam points and see how closely they fall on the Stream order raster. Decide on how much to buffer the point by. E.g. as the DEM cells are 92m suggest to try 200m The points need to fall exactly on the nearest high order stream (as in the diagram above).
- b. From the main menu click Vector>>GeoprocessingTools>>Buffer(s)

		🌠 Buffer(s)	? 🔀
		Input vector layer dams_hydro_la	
		Use only selected features	
		Segments to approximate	5
		Buffer distance	200
c.	Set the shapes to the projected dam points	O Buffer distance field	
d.	Select Buffer distance	NAME	<b>•</b>
e.	Set Buffer Distance to	Dissolve buffer results	
	fixed value e.g. 200	Output shapefile	
f.	Set an output shapefile.	C:/forPaulus/corrected/dams_hydro	_la_buf.shp Browse
g.	Click Okay to run	Add result to canvas	OK Close

 Right click on the Buffers and add to the Strahler orders map. Check to see if the buffer size is appropriate



- i. Next search for the Shapes to Grid tool or GDAL rasterize (vector to raster) to and and use it to convert the dams buffers shapefile to a raster
- j. Set Shapes to The buffered dams
- k. Set Attribute to ID
- I. Set Preferred Target Grid Type to Integer (4 Byte)

🏑 Shapes to grid 🧮	x
Parameters Log Help	
Shapes dams_hydro_la_buf [USER: 100006]	
Attribute	
Method for Multiple Values [0] first	
Method for Lines	
Preferred Target Grid Type [2] Integer (4 byte)	
Output extent (xmin, xmax, ymin, ymax)	
-343921.18486,545929.369737,-531027.992853,598986.330365	
0%	
Run Close	

- m. Set the output extent to the same as the sink filled DEM i.e. dem\_ken\_sinkfilled\_la
- n. Set the Cellsize to 92 (make sure this is the exact cellsize used for the sinkfilled dem)

#### Using open-source GIS to support REDD+ planning

- Navigate to the output folder and the the new output grid a name e.g. dambufgrid.tif
- p. Click Run
- q. The output added to the display is called 'Grid' rename it to damsbufgrid\_la.tif
- Repeat steps i to 0 to convert the water bodies shapefile to Raster

Shapes to grid
Parameters Log Help
Shapes
water_bodies_la [USER: 100007]
Attribute
ID dI
Method for Multiple Values
[0] first
Method for Lines
[0] thin 💌
Preferred Target Grid Type
[0] Integer (1 byte)
Output extent (xmin, xmax, ymin, ymax)
-343921.18486,545929.369737,-531027.992853,598986.330365
Cellsize
92.000000
Grid
waterbodies_la_grid
Open output file after running algorithm
<u>.</u>
0%
Run Close

#### 2.3.3. Merge Dam and water bodies rasters into a single raster

а.	Search for Merge	🔏 Merge
	in the processing	
	toolbox and	Parameters Log Help
	Double click on	Input layers
	the GDAL: Merge	2 elements selected
	Use it to mosaic	Layer stack
	the Dam and	Output raster type Int16
	water bodies into	Output layer
	a single raster.	C:/forPaulus/corrected/damsbufgrid_waterbodies_la.tif
		Open output file after running algorithm
		0%
b.	Select the <b>Input</b>	Run Close

- layers i.e. Dams
  - and water bodies rasters
- c. Set the raster output type to int16
- **d.** Give the dataset a new name
- e. Click RUN
- f. Rename the Merged Grid to damsbufgrid\_waterbodies\_la

#### 2.3.4. Generate upstream catchments of dams and water bodies

The next step will generates upstream catchments of dams and/or water bodies by determining the contributing area above a set of dam and water body cells (i.e. the upstream catchment of dams and lakes)

- **a.** Search for upslope in the geoprocessing toolbox.
- b. Double click on Upslope Area located in the Terrain Analysis – Hydrology tools

Processing Toolbox	ana ana ang ang ang ang ang ang ang ang
upslope	⊗
GRASS commands [168 Graster (r.*) SAGA [227 geoalgorithr Ferrain Analysis - Hydro Upslope Area	ction of slope cur ms]

Target Area [optional]	
damsbufgridwaterbodies_la [USER:100006]	▼
Target X coordinate	
0.000000	<b>↓</b>
Target Y coordinate	
0.000000	<b>↓</b>
Elevation	
dem_ken_sinksfilled_la [USER:100006]	<ul> <li>✓</li> </ul>
Sink Routes [optional]	
[Not selected]	<ul> <li>▼</li> </ul>
Method	
[0] Deterministic 8	▼
Convergence	
1.100000	
Upslope Area	
C:/forPaulus/corrected/upslope_dam_waterbodies_la.tif	
Copen output file after running algorithm	

- c. Set the Target Area to be the Merged Dams and water bodies raster
- d. Set the Elevation to be the Sink filled DEM
- e. Navigate to an output folder and save the Upslope Area raster to a new name

If you get the following message you need to change the grid extent of the Merged water bodies and dam



f.	<b>Right click on</b>	the Sink filled	<b>DEM</b> and click	on the <b>Metadata tab</b> .
----	-----------------------	-----------------	----------------------	------------------------------

🌠 Layer Properties - dem_k	ten_sinksfilled_la   Metadata
General	Description
🟹 Style	Title
Transparency	Abstract
👜 Pyramids	Keyword list
Histogram	Data Url Format
🚺 Metadata	Attribution
	MetadataUrl
	LegendUrl
	Properties
	92.1934,-92.1934
	No Data Value
	-99999
	Data Type
	Float32 - Thirty two bit floating point
	Pyramid overviews
	Layer Spatial Reference System
	+proj=laea +lat_0=0 +lon_0=37 +x_0=0 +y_0=0 +datum=WGS84 +units=m +no_defs
	Layer Extent (layer original source projection)
	-343921.1848604931146838,-531027.9928526221774518:545929.3697368563152850,598986.3303653337061405
	Restore Default Style         Save As Default         Load Style
	OK Cancel Apply Help

- **g.** Check the cellsize and extent and copy them into a notepad. Do the same for the combined waterbodies and dams raster
- h. Notice in this example there are some differences in cellsize and extent



- i. Right click on the dams and waterbodies raster and click save as
- j. For the extent change it so it mataches itentically with the sinkfilled dem
- k. Change the Cellsize so it matches identically with the sinkfilled dem

🌠 Save raster lay	er as	2 Mar	? ×
Output mode 💿	Raw data 🛛 Rendered ima	ge	
Format GTiff			▼ Create VRT
Save as C:/forPa	aulus/corrected/combinedwate	r_dambuf_la_extentfixed.t	f Browse
CRS Layer (LAEA	A_lon37_lat0 , USER:100006)		▼ Change
Extent (curren	nt: user defined)		
	North 5989	986.3303653337061405	
West -343921	. 1848604931146838	East	545929.3697368563152850
	South -531	027.9928526221774518	
	Layer extent	Map view	extent
Resolution (a	urrent: user defined)		
Horizontal	92.1934	Vertical 92.1934	Layer resolution
O Columns	9652	Rows 12257	Layer size
▼ □ Create Op			
	Name		Value + -
	Name		Value Validate
			OK Cancel

- I. Click OK
- m. Add the new raster (combinedwater\_dambuf\_la\_extentfixed) to the QGIS session
- n. Now return to step a try and run the analysis using this file. This time it should work

#### 2.4. Combine outputs to create importance of forests for limiting soil erosion layer

#### 2.4.1. Sum the slope and precipitation raster and clip to forest extent

- **a.** From the Raster menu >> Raster calculator
- b. Add an expression to Sum the 3class slope and 3 class precipitation rasters
- c. "slope\_3class\_la@1" + "slp3\_plus\_prec3\_la@1"

Raster calculato	r						6	? ×
Raster bands		Result layer						
"slope_3class_la "av_an_prec_3c		Output layer		rWorkingSession/output_dd/slp3_plus_prec3_la				
"dem_aoi_la@1"		Current lay	ver extent					
		X min	343869.3996	L 🔶		XMax	546067.74704	-
		Y min	517741.7078	· +		Y max	598323.76614	-
		Columns 8	90	<b>*</b>		Rows	1116	-
		Output form	nat	GeoTIFF			•	
		X Add res	ult to project					
<ul> <li>Operators</li> </ul>								
+	*	sqrt	sin	^	acos		(	
•	1	cos	asin	tan	atan		)	
<	>	=	<=	>=	AND		OR	
Raster calculator	expression							
"slope_3class_la@	01" + "av_an_pre	c_3dass_la@1"						
	01" + "av_an_pre	c_3dass_la@1"						

d. Clip the result of the above sum of the slope and precipitation to forest extent

🔏 Clip grid with polygon	×
Parameters Log Help	
Input	
slp3_plus_prec3_la [USER:100006]	<b>▼</b>
Polygons	
ke_forests_la [USER:100007]	▼ … ②
Output	
C:/forPaulus/corrected/slp3_plus_prec3_clip_for_la.tif	
X Open output file after running algorithm	
0%	
	Run Close





#### 2.4.2. Combined Slope and Precipitation rasters with upstream catchments

The next step will be to clip combined slope and precipitation layer with the upslope catchment area. You can then display this subset in the same values (2 - 6) but using a different colour ramp.

In discussion you may chose to combine the data together in different ways. You may also want to use other water related point or polygon data in addition to the dam/hydro points and water bodies



# Map 12: Importance of forests for limiting soil erosion

This map shows areas where forests are particularly important for limiting soil erosion that might cause sedimentation problems for dams in Tanzania.

**Example map for Tanzania** 

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Slope: generated from Lehner, B., Verdin, K., Jarvis, A. 2008: New global hydrography derived from spaceborne elevation data. Eos, Transactions American Geophysical Union, 89 (10) (2008) 93-94. Precipitation: Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. 2005. Jarvis. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25

Dams: Dr. Mark Mulligan, Department of Geography, Kings College, London.

(2005): 1965-1978. Journal Article.

Journal Article.

#### **Annex 1: Introduction to SAGA**

SAGA (System for Automated Geoscientific Analyses) is an open source GIS software that runs under Windows and Linux operating systems. One of Its strengths is that it has a wealth of easy to use spatial algorithms which run quickly and efficiently. SAGA algorithms can be accessed through the SEXTANTE plugin in QGIS 1.8, however at the time of writing this tutorial some of the tools failed to run in QGIS.

Many of SAGA's tools can run from within QGIS but there may be occasions where a tool fails to run or there are additional tools that can only be run from within SAGA. The screen grabs below provide a quick overview of the SAGA interface to help new users to SAGA orientate themselves with the layout.

On opening SAGA the user is presented with the Graphical User Interface below. On the Left there are 3 tabs (Modules, Data and Maps) and on the right **Object Properties**. In the middle is the area where graphits will be displayed (e.g. a map or chart).



The two bottom sections show error messages and the progress of an algorithm when it is running.



**a.** Click on **Modules** to display the list of the algorithms. The algorithms are grouped and can be expanded by clicking the '+'

b. Click on Data Tab to see the data
 that has been added into the current
 SAGA project





# c. Click on the Maps tab to see the map displays that have been created