Land Use Planning for Enhanced Resilience of Landscapes Program (LAUREL)

Land Degradation Baseline
Approach Paper

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Executive summary

Land degradation in Mozambique can jeopardize the country's agricultural productivity and economic development. Indeed, an assessment by the European Space Agency (ESA) found that ca. 42% of the lands in Mozambique are degraded and ca. 19% of land is now experiencing active degradation.

The *Land Use Planning for Enhanced Resilience of Landscapes (LAUREL)* program led by the World Bank aims to support integrated decision making for landscape management in Mozambique, through improved spatial data on land degradation, and through the development of prototype platform (LandSIM-P) for simulating, evaluating, and re-orienting as appropriate, land use and land use change processes.

The former objective is to develop a sound, consistent and up-to-date baseline and locally relevant estimates of land degradation in Mozambique, following the latest guidance of international UN conventions and institutions and state-of-art earth observation technology (e.g. remote sensing times series analysis, Google Earth Engine). The **end product will be a nationally consistent database of land degradation maps** and sound information of the underlying causes of the degradation indicators observed in Mozambique.

The methodology relies on compiling and verifying available global and national datasets, developing dedicated geospatial analysis for the key indicators mentioned above, validating the land degradation outputs by comparing with national databases coupled with ground control surveys and finally, publishing the results on webGIS portal. We will use open source software and scripts, which will facilitate technology transfer and capacity building for national organizations and individuals. This work will be realized in partnership with local institutions or projects that conduct land degradation measuring and monitoring activities (FNDS/MRV Unit, UEM, SECOSUD, etc.)

We will express degradation as both the status and trend of three primary degradation indicators that require in-depth calculation and validation: i) land cover and land cover change, derived using Landsat images archive, and cloud-free image processing chain; ii) land productivity trend using MODIS times series and ancillary data analysis; and iii) soil erosion and retention using the Universal Soil Loss equation adapted to Mozambique; and secondary degradation indicators, such as biodiversity indicators and soil and biomass carbon stocks, which are a combination of information from ancillary providers.

The analysis will be conducted for the period 2000 to 2016, and at 30 to 250 m ground resolution.

The outcomes of this degradation baseline is to help decision-makers identify the constraints and opportunities for the conservation, restoration and the sustainable management of land resources.

Overall Approach

Context

In the last five years, a number of global and regional targets and commitments have been agreed to by national governments to halt and reverse land degradation and restore degraded land. These include the United Nations Convention for the Biodiversity (UNCBD), Aichi Targets, the United Nations Convention to Combat Climate Change (UNFCC), REDD+ (Reducing Emissions from Deforestation and forest Degradation) mechanism, and the United Nation Convention to combat desertification (UNCCD), Land degradation neutrality (LDN) initiative, the Bonn challenge and the Sustainable Development Goals (SDG), in particular SDG target 15.3 dedicated to the restauration of degraded land and soil and achieving LDN. Each of these initiatives have set up ambitious target to reduce poverty, increase food security and nutrition and reduce land degradation for the next decades.

Despite the numerous initiatives, there is still a lack of clear and agreed quantified measurement of land degradation. In addition, many countries currently do not have the capacity to monitor and report on land degradation.

The UNCCD defines land degradation as the:

"*Reduction or loss of the biological or economic productivity and complexity of rainfed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as soil erosion caused by wind and/or water, deterioration of the physical, chemical and biological or economic properties of soil, and long-term loss of natural vegetation*."[1]

[1] http://www.unccd.int/Lists/SiteDocumentLibrary/conventionText/conv-eng.pdf

Objectives

Our aim is to develop sound, consistent and up-to-date baseline and locally relevant estimates of land degradation in Mozambique, by following the latest guidance of international UN conventions and state-of-art Earth observation technology. The end products will be a national database of spatial dataset available on-line, derived land degradation maps and sound information on the "dark spot" and "bright spots" of Mozambique.

The outcomes of this degradation baseline is to 1) help decision-makers identify the constraints and opportunities for the conservation, restoration and the sustainable management of land resources, and to 2) input that information in the Land use change simulation platform prototype (LandSIM).

Scope

The latest report of UNCDD on land degradation provides some methodological guidance on the choice of land degradation indicators and how to measure and monitor. It suggests expressing land degradation as the status of three main indicators: (i) land cover and land cover change, (ii) land productivity, and (iii) carbon stocks above and below ground. These main indicators are justified due to the fact that they can be quantified in a spatially explicit manner using Earth observations and/or ancillary data from national to sub-national databases, and thus provide a practical approach to monitoring and reporting progress. Countries are invited to develop their one other secondary or user-defined land degradation indicators as well.

In this project, we will base our analysis on this framework and adjust indicators set and methodology for national circumstances. We will express degradation as both the **status and trend of selected primary degradation indicators** with a focus on land cover change, land productivity, and soil erosion and retention estimates, over a selected historical period that range from 2000 to 2016.

This approach was preferred to an approach based on the distance from a reference condition of non-degradation, because it is very difficult to find non-degraded conditions representative of each agro-climatic zone. Also, the trend approach was considered better than a "degradation risk" approach (based on the calculation of a risk using environmental variables such as topography, soil, climate, land use, etc.) that relies on a subjective weighing of the factors, and which result is very sensitive to the scale and accuracy of the input layers.

The 2000-2016 period covers a significant historical period time frame (16 years), corresponding the period that is expected to be simulate in the future with the LandSIM simulation plateforme (ranging from 10 to 20 years in the future from 2017). Also last date analyzed (2016) allow to produce a recent baseline. Finally it corresponds to data availability constraints (Modis images) available since 2000. This historical period is also the one used in the national REDD+ strategy which further enable comparison and quality control.

The final output of this assessment will be a spatial database on land degradation at 30 to 500 m resolution and national scale, which will be made available for other national initiatives such as REDD+ (Reducing Emissions from Deforestation and Forest Degradation) or LDN (Land Degradation Neutrality).
The overall approach proposed herein is guided by three main principles: i) cost-effectiveness; ii) adoption and replication by local partners; and iii) value to other national and sub-national initiatives. Therefore, we propose to make use of free global and national datasets, which will enable us to develop and use free and open-source data processing tools that can be easily adopted by local counterparts and installed on a personal computer or launched on-line. These tools will be accompanied by training sessions to facilitate the process.

Methodology

The general approach to the project workflow is presented in Figure 1, and comprises **4 main steps (data collection and preparation; calculating primary and secondary indicators; ground control & validation; and publication)**.

1. Data collection

   Identify and download global and national datasets. Build a consistent national database on climate, land use, soil, infrastructure, and socio-economics. Evaluate the quality of the datasets considering our objectives. Select the best available Earth Observation (EO) and ancillary dataset. The data collection process is a joint effort linked with the development of the land use simulation platform that will be developed within LAUREL.

2. Calculation of primary and secondary indicators

   Primary indicators include: land cover change; land productivity trends; & soil erosion and retention. Secondary indicators include, but are not limited to: carbon emissions from deforestation; trends of the annual crops and woody vegetation layers; and overall status and trends in land degradation in Mozambique.

3. Ground control & validation

The land degradation maps will be evaluated using experts opinions and ground observations/ surveys conducted on hot-spots, either dark-spots (degradation) or bright-spots (improvement), in different agro-climatic regions.

4. <u>Publication</u>

The degradation maps (primary and secondary indicators) as well as the complete dataset collection will be published and made available on a web portal, and disseminated through scientific publications in partnership with local institutions.

These analyses will be applied at the national scale, over the 2000-2016 period, with a spatial resolution between 30 m and 1-km.

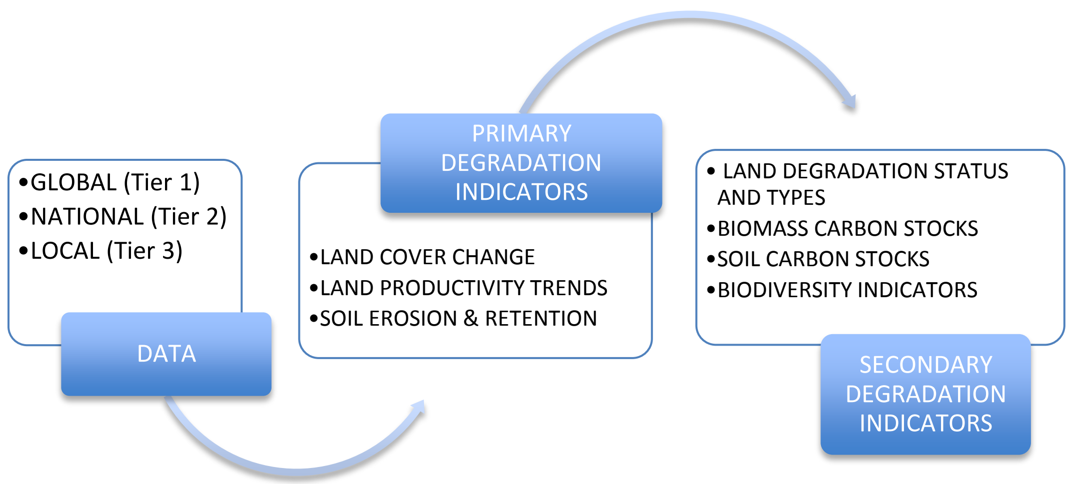

Figure 1: Illustration of the general approach proposed in this study to map land degradation at the national scale.

Land Cover Change Analysis

We will download existing Global Land Cover datasets and adapt them to the national level. These datasets are of great value for broad-scale applications, but may lack accuracy at national or landscape scale, especially when adjusting for local land cover and land cover change definitions. Therefore, the first step in the project is to explore and analyze the global datasets for their relevance and consistency for Mozambique.

This dataset collection includes the European Space Agency Global Land Cover ("GLC30" product), which has produced maps at 30 m resolution for 2000 and 2010, and the Global Forest Watch dataset, produced by Hansen et al (2013)[2], which focuses on forest loss and forest gain dynamics at 30 m resolution on a yearly basis for the 2000-2015 period. Furthermore, a recent global land cover dataset called "Climate Change Initiative Land Cover" (CCI-LC) has been made available to the public in April 2017[3], and comprises a 300m annual global land cover time series from 1992 to 2015 (24 maps), with 28 natural vegetation classes and 3 crop classes and 6 non-vegetation classes. However the resolution of those products is too coarse to detect small land cover change and they were not calibrated nor validated for Mozambique.

In this project, we will develop and apply a national land cover change (LCC) analysis, focusing on forest cover and forest cover change. The classification method follows a direct change detection approach, which is a supervised classification scheme using both stable land cover and land cover change training plots. This method detects changes using all time-series data in a row, which reduces the likelihood of false change detection often found in a combination of forest maps over different time periods. A second positive feature of this method is the use of the *RandomForest* classifier, which is a powerful tool to identify reliable land cover change patterns in multi-season and multi-scene remote sensing frameworks. Finally, this method requires a large quantity of photo-interpreted plots that guarantee the correct identification of land cover.

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[2] Hansen M.C. et al. 2013. High-Resolution Global Maps of 21st-Century Forest Cover Change. *Science*, 342 (6160): 850-853

[3] http://cci.esa.int/content/land-cover-annual-global-land-cover-maps-v207-dataset-release

The proposed methodology has been fully described in previous peer-reviewed scientific papers by team members[4,5], and an example of the type of results can be seen in *Figure 2*. Indeed, our team has successfully applied this methodology at a national scale in Madagascar, as well as more recently as part of the Zambezia Integrated Landscape Management Program (ZILMP), over 9 districts in the Zambezia province for the 1990 to 2015 period (5 reference years) -- see Mercier et al., 2016[6].

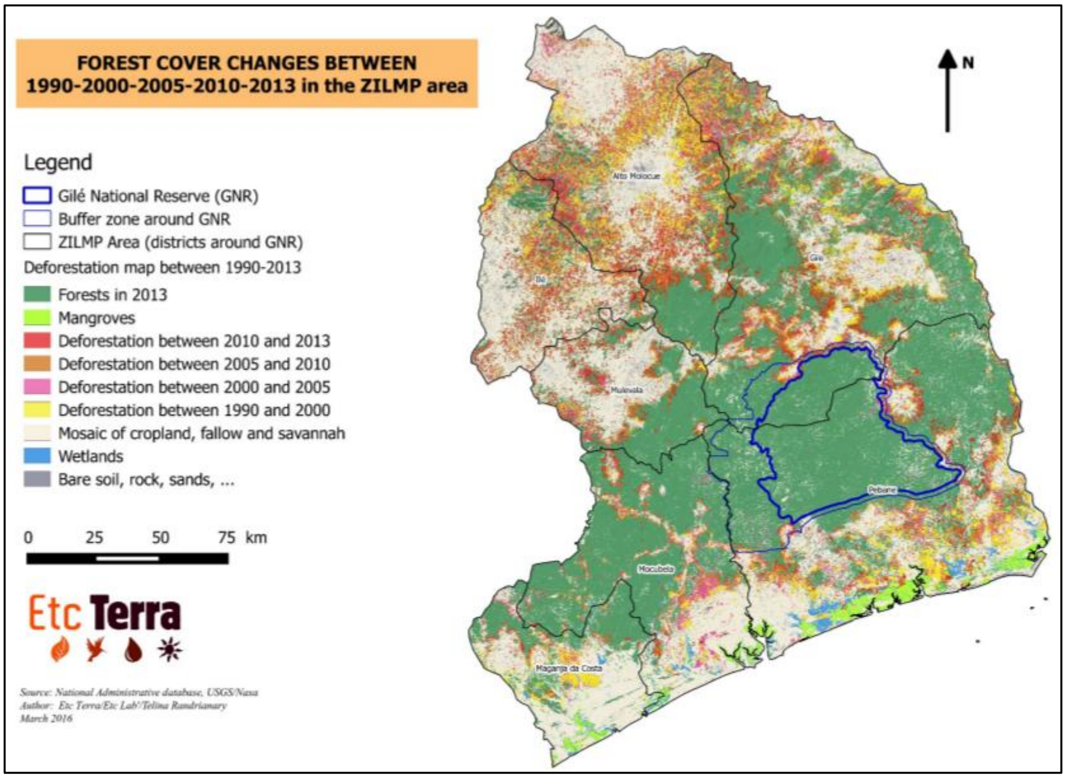

Figure 2: Illustration of a forest cover and forest cover change product over the Zambesi region (Graphic by ETC Terra -- Mercier et al., 2016)

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4 Grinand C, Rakotomalala F, Gond V, Vaudry R, Bernoux M, Vieilledent G. 2013. Estimating deforestation in tropical humid and dry forests in Madagascar from 2000 to 2010 using multi-date Landsat satellite images and the random forests classifier. *Remote Sens Environ*, 139:68–80.

5 Rakotomalala F.A, Rabenandrasana J.C., Andriambahiny J. E., Rajaonson R., Andriamalala F., Burren C., Rakotoarijaona J.R., Parany L., Vaudry R., Rakotoniaina S., Grinand C., 2015. Estimation de la déforestation des forêts humides à Madagascar entre 2005, 2010 et 2013. *Revue Française de Télédétection et Photogrammétrie*, 211-212, 11-23

6 Mercier C., Grinand C., Randrianary T., Nourtier M. and Rabany C. 2016. *Background study for the preparation of the Zambézia Integrated Landscapes Management Program*. Report for the Government of Mozambique and FCPF. Etc Terra.

The forest cover and forest cover change analysis relies on 4 key steps (depicted below in Figure 3):

1. Preparation of the reference Landsat satellite images database

   Landsat images (NASA/USGS) span more than 25 years of archives and are widely used for land cover change assessment worldwide. A key drawback of such optical imagery is that they are greatly impacted by cloud cover. Recent advances in remote sensing technology, however, allow us to process large-scale time series images to produce reference “cloud-free” image over a selected time period. Here, we will use *Google Earth Engine* and develop a dedicated code to **process Landsat “cloud free” images at 30 m resolution over Mozambique for the reference years of 2000, 2005, 2010 and 2016**. These four national Landsat Mosaic will be made available publicly and will serve as useful input to other research and land use planning.

2. Preparation of training plots geographical database

   Training plots are used to calibrate the spatial model that will then be used for the supervised classification. These are delineated using visual inspection of the Landsat time series images, and controlled by observations of very high spatial resolution images available in Google Earth to ascertain forest definition. We then delineate a cluster of plots at landscape scale representing the various observed land cover and land cover change. A team of photo-interpreters will be trained and responsible to create the training plot database.

   Current ongoing REDD+ preparation activities at national scale are using a regular sampling scheme of one point every 4 kilometers to assess current and past Land Cover Change using photo-interpretation.
   Beside,a similar task is near completion within the SECOSUD project. Both initiatives use the FAO Open Foris Collect Earth tool and methodology. This technique produces high quality point information on Land Use and Land Cover Change (LULCC). Those dataset provide point observations of 0,5 to 1 ha every 4 or 5 kilometers. This is extremely valuable information but cannot be used to assess and report small land cover change exhaustively nor input as a the required base map layer into the LandSIM plateforme. We will however set up collaboration with MRV Unit and Secosud project to make use of this point sampling database as a mean to calibrate or validate the land cover change map

The methodology proposed herein – combining large point sampling dataset with cloud free Landsat mosaic in a wall-to-wall mapping objective – is innovative and will overcome the limitations of both methods.

3. Calibration and validation of the spatial model

We then separate the visually delineated plots in two sets: one used for calibration (70%) and the other for validation (30%); the latter being used to produce a confusion matrix. We refer to this as internal validation. It is used to refine the forest cover change map, by focusing on misclassified categories and adding or modifying training plots. The model will be calibrated using the *RandomForest* classifier in *R* statistical analysis software, and also in *Google Earth Engine*. The process of delineation of training plot and production of LCC maps is iterative and performed until satisfactory results are obtained based on the internal confusion matrix. External validation is carried out after the release of the final product by using external datasets such as LULCC Collect Earth information or SECOSUD products.

4. Post-processing

Once satisfactory results are obtained through the internal validation, all the plots are then used to produce the Raw Deforestation Map. The raw deforestation map for 2000-2005-2010-2016 will be then filtered to meet the minimum mapping units (MMU). This task includes spatial filtering using majority and sieving filters that retain dominant class within a specified radius of the floating window. For this we will use the national REDD+ forest definition, which requires greater than 1 ha of forest, with trees above 5 meters and whose canopy covers more than 30% of the area.

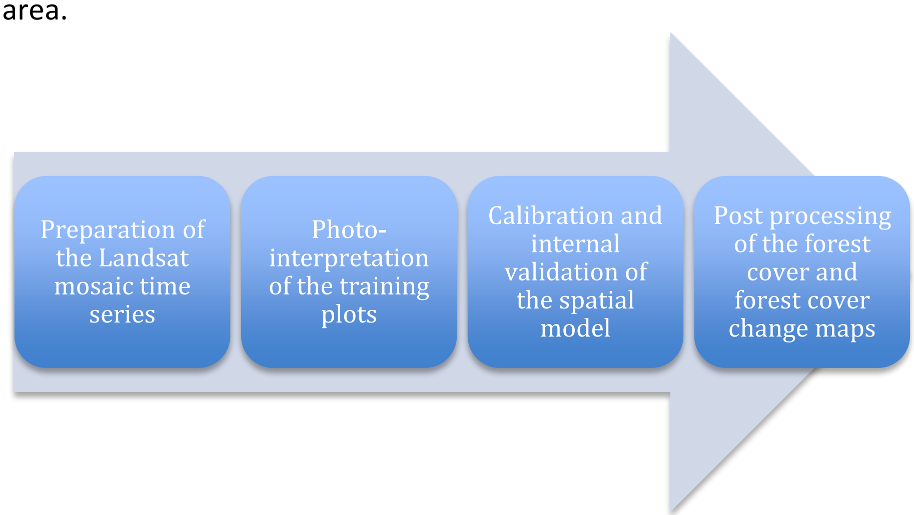

Figure 3: Forest cover and forest cover change analysis workflow

As mentioned in Step 3 above, we will use external point database on LCC to produce indicators of goodness of fit based on a confusion matrix. Depending on the plot database used for training the classifier, the remaining and not-used plot database will be used for comparison with the LCC map.

To account for land cover change outside the intact forest area, we propose to combine the LCC maps with the maps produced by the Global Forest Watch (GFW, Hansen et al. 2013) on tree cover loss. Any tree cover loss detected by GFW outside the initial forest area, mapped using the methodology described above, indicates a removal of trees in non-intact areas, which can then be considered as an additional indicator of land degradation. This task will complement and provide a source of validation for the land productivity analysis described in the next section.

Key Results from the Land Cover Change Analysis

1. **Land cover maps:**

   Four intact forest maps representing the intact forest (mostly *Miombo* forest but also gallery forest and semi-evergreen forest) at a national scale for the periods: 2000, 2005, 2010, & 2016.

2. **Land cover change maps:**

   Three deforestation maps representing conversion from forest to non-forest land during the periods 2000-2005, 2005-2010, & 2010-2016.

Land Productivity Trend Analysis

Normalized Difference Vegetation Index (NDVI) derived from remote sensing images has been used for decades in the assessment of land degradation at different scales and for a range of applications, including the resilience of agro-ecosystems[7]. Because NDVI has shown consistent correlation with vegetation biomass and dynamics in various ecosystems worldwide (e.g. Myneni et al. 1995[8]), NDVI trends integrated over a time period can be used as a proxy to monitor changes in land and vegetation productivity.

To date, the most frequently utilized NDVI dataset is the Advanced Very High Resolution Radiometer (AVHRR) dataset from the National Oceanic and Atmospheric Administration (NOAA) satellite due to its high temporal resolution and its availability since the early 1980s. This technology has enabled the monitoring of vegetation trends over nearly thirty-five years at a spatial resolution of 8 km (e.g., Dardel et al., 2014[9]; Herrmann et al., 2005[10]). However, recent studies based on Moderate Resolution Imagery Spectroradiometer (MODIS) data, which have supported vegetation monitoring at a 250m spatial resolution since 2000, have highlighted the spatial heterogeneity of these trends (including in research by LAUREL team members, Leroux et al., 2017[11]).

Our team has been at the forefront of the updated NDVI application in studies for the Sahel region in West Africa (Leroux et al., 2017). The proposed methodology will be adapted to account for Mozambican vegetation status (mainly semi-deciduous *Miombo* forest) and dynamics. This includes **the development of NDVI trend series analysis according to the vegetation phenological stages**. This will enable us to have a finer understanding of land

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[7] Yengoh G.T., Dent D., Olsson L., Tengberg A.E., Tucker C.J. Use of the Normalized
Diff erence Vegetation Index (NDVI) to Assess Land Degradation at Multiple Scales
Current Status, Future Trends, and Practical Considerations. Springer Briefs in Environmenal Science, London, UK, DOI 10.1007/978-3-319-24112-8, 124 pages

[8] Myneni RB, Hall FG, Sellers PJ, Marshak AL (1995) The interpretation of spectral vegetation indexes. IEEE *Trans Geoscience Remote Sens*, 33: 481– 486

[9] Dardel, C., Kergoat, L., Hiernaux, P., Mougin, E., Grippa, M., & Tucker, C. J. (2014). Re-greening Sahel: 30 years of remote sensing data and field observations (Mali, Niger). *Remote Sens. Environ*., 140, 350–364.

[10] Herrmann, S. M., Anyamba, A., & Tucker, C. J. (2005). Recent trends in vegetation dynamics in the African Sahel and their relationship to climate. *Global Environ. Change*, 15:394–404.

[11] Leroux L., Bégué A., Lo Seen D., Jolivot A. and F. Kayitakire, 2017. Driving forces of recent vegetation changes in the Sahel: Lessons learned from regional and local level analyses. *Remote Sens. Environ*., 191: 38-54.

productivity change differentiated between annual vegetation (including crops) and woody vegetation. The trends (neg.=degradation & pos.=improvement) will be then de-correlated from climate change influence, which results in a change in precipitation regime during the reference period, to account for human-induced change (e.g. deforestation, land management practices). Finally, the land productivity trend results will be analyzed using multifactorial statistical regression to provide sound explanations on the causes and drivers of the observed trends.

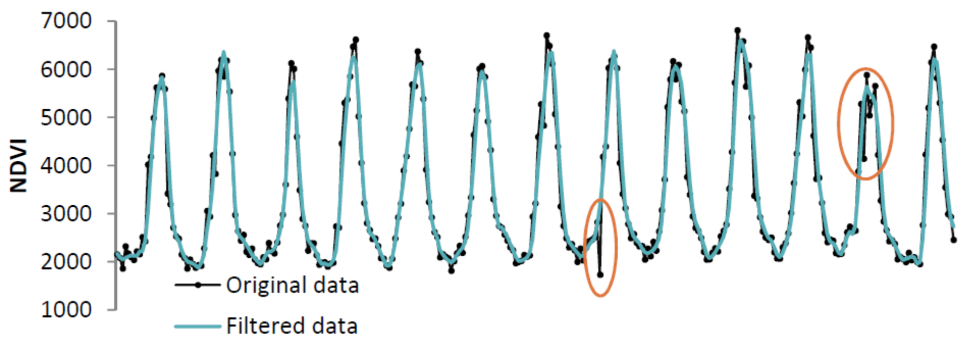

Figure 4: Illustration of a NDVI trend times series indicating the raw biophysical information (black line and points) measured by MODIS satellite and pre-processed times series using Savitzky-Golay filter (blue line). (Leroux, 2015][12].

The 4 key steps to develop and quantify the land productivity indicators are presented below:

1. Collect and pre-process the NDVI time series

   The first step is to build a harmonized database of NDVI time series. After downloading the NDVI time series (MOD13 collection 6) for the entire country, we will pre-process these images using a Savitzky-Golay filter to reduce the residual noise in the NDVI time series, which can be present despite the atmospheric corrections (Figure 4).

2. NDVI trend analysis

   Then, the NDVI image database will be further processed to obtain NDVI trends. We will detect vegetation productivity changes using a statistical trend analysis over a 16-year period (2000-2016), based on the MODIS NDVI time series. To identify changes in woody vegetation productivity

[12] Leroux, L., 2015. Suivi et Caractérisation des Dynamiques de la Production Agricole en Afrique de l'Ouest par Télédétection à Moyenne Résolution Spatiale. Thèse de doctorat de l'Université de Montpellier, CIRAD.

from changes in crop vegetation productivity, NDVI will be integrated over the dry season for woody cover trends (Brandt et al., 2016[13]) and over the rainy season (or growing season) for annual vegetation layers trends (see Leroux et al., 2017). The phenological stage and climate season will be identified using climate datasets analysis and local knowledge on vegetation dynamics.

3. Analysis of climate variability effect on NDVI trend

   The purpose of this next step is to analyze and remove the climate change effect, namely the change in air temperature and precipitation regime over the reference period, which could highly influence the NDVI trend pattern. We will use a robust and widely accepted residual analysis method called RESTREND (developed by Wessels et al., 2007[14]). This method is based on a trend analysis of the residuals between the observed NDVI and the climate-normalized NDVI. Since rainfall and air temperatures are the main limiting factors of vegetation growth, the RESTREND analysis will be conducted for both drivers.

4. Analysis of the main drivers of the Land Productivity change

   Once climate variability effect is removed from the NDVI trend results, we can then analyze the causes and factors that may be responsible for the change patterns observed.

   Potential factors influencing land productivity – including, but not limited to environmental (topography, soil), humans (demography, physical accessibility), and land cover change – will be analyzed using a multi-factorial regression analysis using various statistical tools including a data mining algorithm. We will first derive and compile all the potential factors maps and then intersect with the land productivity change results.

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[13] Brandt, M., Hiernaux, P., Rasmussen, K., Mbow, C., Kergoat, L., Tagesson, T., Fensholt, R. (2016). Assessing woody vegetation trends in Sahelian drylands using MODIS based seasonal metrics. *Remote Sens. Environ.*, 183, 215–225. http://doi.org/10.1016/j.rse.2016.05.027

[14] Wessels, K., Prince, S. D., Malherbe, J., Small, J., Frost, P., & VanZyl, D. (2007). Can human-induced land degradation be distinguished from the effects of rainfall variability? A case study in South Africa. *J. Arid Environ.*, 68, 271–297. http://doi.org/10.1016/j.jaridenv.2006.05.015

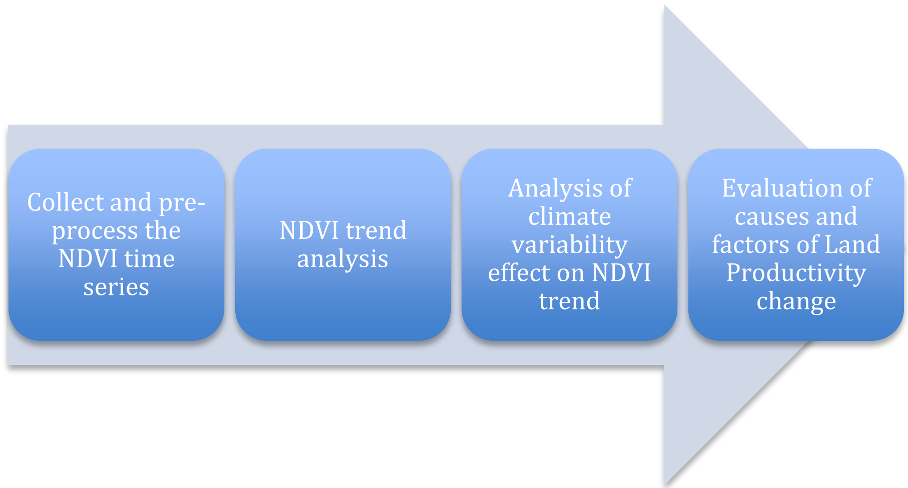

Figure 4: Land productivity analysis workflow

Key Results from the Land Productivity Trend Analysis

1. **Maps of Land Productivity Trends.**

   These maps will identify and locate the positive and negative productivity trends categorized according to the level of significance (p-value). We will use 5 to 7 categories, from highly decreasing trend (increasing productivity loss) to highly increasing trend (increasing improvement), according to selected p-value threshold.

2. **Map of the main drivers of the Land productivity trend**

   This map will display the dominant cause of the land productivity trends observed according to the factor analysis results. The legend will explain changes in land productivity that can be attributed to precipitation change, land change conditions, or human factors (e.g. demography or urban proximity factors).

Soil Erosion and Retention Analysis

Soils provide numerous ecosystem services that may be affected by land degradation. Those services include climate change mitigation by storing the carbon within the organic matter that is decomposed from the vegetation, food production by nutrient retention, erosion control and water flow regulation, among others. In particular, soil erosion and retention are important given the impact of these services on water access and quality (turbidity & pathogen transport).

In the LAUREL project, we will adapt an established methodology (the Revised Universal Soil Loss Equation - RUSLE) to analyze and forecast potential soil erosion and nutrient retention changes in Mozambique. This is a simple and well-established method for estimating the amount of soil that is eroded from the landscape, and the amount that reaches the streams, as well as locating the areas that provide the service of retaining sediment.

Our proposed methodology has been effectively used in other ecosystem services analyses and has been applied regionally in Mozambique,[15] where it is referred as the Sediment Delivery Ratio (SDR) Model. Since the methodology relies on standard geospatial dataset and equations we can easily calculate the land degradation indicators on any GIS software, and redo the calculation whenever updated datasets are made available.

Once developed and tested, we will integrate this model into DINAMICA for ease of replication. It could then be used as a sub-module of the LANDSIM prototype.

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[15] http://data.naturalcapitalproject.org/nightly-build/invest-users-guide/html/sdr.html. Also see Mandle L, Wolny S., Hamel P. 2016. *A preliminary natural capital assessment for Mozambique to identify key ecosystem service provision areas*. Natural Capital Project, 9 pages. And Hamel, P., Chaplin-Kramer, R., Sim, S., Mueller, C., 2015. *A new approach to modelling the sediment retention service* (InVEST 3.0): Case study of the Cape Fear catchment, North Carolina, Science of the Total Environment 524-525

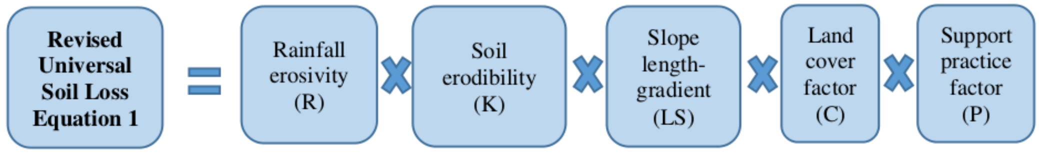

Figure 5: The 5 factors that composed the Universal Soil Loss Equation. The individual maps are bio-physical and quantitative information that are multiplied to obtain soil loss in tons per ha. Recent improvements to this technique allow us to quantify the amount of sediment that either enters a stream or is "trapped" within the landscape.

The 4 key steps to develop and quantify the soil erosion and retention indicators are presented below and in Figure 5:

1. <u>Collect and prepare the RUSLE input factor maps</u>

   To be as precise as possible, we will work on the latest LULC map produced by the national MRV Unit for 2016 using Sentinel 2 images, and which is expected to be available by November 2017. Then we will derive topographical factors using the highest resolution and freely available DEM available (30 meters). Rainfall erosivity will be obtained through global Wordclim database. A soil erodibility map will be adjusted for national conditions using the national soil map and available reference values from ISRIC, the World Soil Information research center. Finally, the USLE "C" crop factor values will be based on Africa literature review, for instance Breetzke et al. (2007)[16], and applied to the LULC map. The p factor will be set to 1 for each LULC category except urban areas.

2. <u>Process the soil loss map</u>

   We will then apply the Revised Universal Soil Loss Equation (RUSLE), which is a linear equation combining the five factors listed above. To account for model parameters and map uncertainties we will test several input data sources (DEM, LULC, erosivity and erodibility maps) and crop parameters. The soil loss map, however, expressed in tons per hectare, represents the gross loss and does not account for deposition processes and is therefore difficult to ground-truth.

3. <u>Process the sediment export map</u>

[16] Breetzke G.D., Koomen E., Critchley W.R.S 2007. GIS-Assisted Modeling of Soil Erosion in a South African Catchment : Evaluating the USLE and SLEMSA Approach.

This index accounts for the sediment volume that is effectively conveyed to a stream. We will compute the connectivity index (IC), which represents the degree of connectivity of a pixel to a stream, based on the upslope contribution area and flow path to the stream. Then we will derive the Soil Delivery Ratio (SDR) factor, which is expressed as an exponential relationship with the connectivity index. The final sediment export map is then calculated by multiplying the soil loss map with SDR map.

The sediment export map, expressed in tons by hectare, will be calculated for all Mozambican watersheds by summing the pixel values that fall within each watershed. Those values will then be compared with existing national or globally available statistics such as FAO Aquastat database [17] for accuracy assessment.

4. Process the sediment retention map

This index is a relative value that represents the avoided soil loss by the current land use compared to bare soil, weighted by the SDR factor. In other words, it represents the amount of soil retained by vegetation cover based on its location on the landscape. We will compute this index and it will enable hot spot identification on ongoing retention areas that may benefit from infrastructure and agriculture investments. It will be validated through ground-truth field visits.

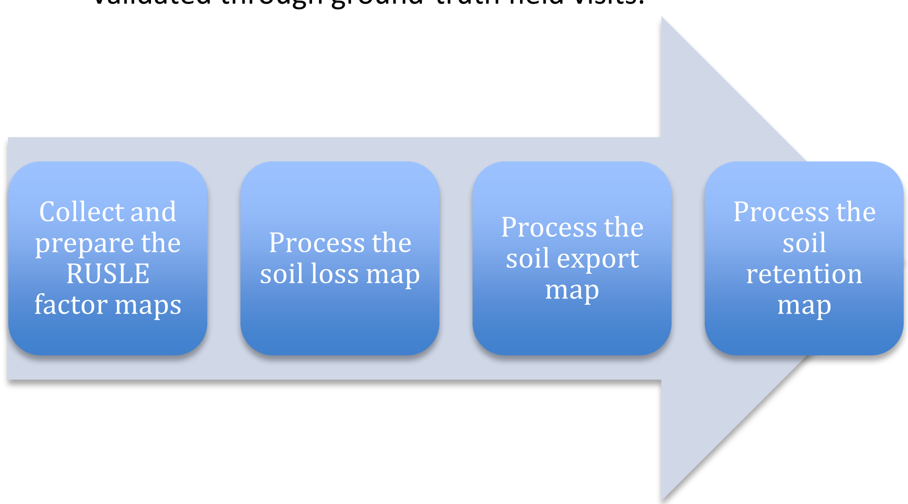

Figure 5: Land productivity analysis workflow

[17] http://www.fao.org/nr/water/aquastat/dams/index.stm

Key Outputs for the Soil Erosion Component

1. **A national map of soil loss**

   This map will show soil loss (tons per ha by pixel and by year) at a national scale.

2. **A national map of soil run-off into streams**

   This map will depict the quantity of soil that actually reach the bodies of water.

3. **A national map of soil retention**

   This map is a relative measurement of the quantity of soil that is retained due to vegetation and topography.

Secondary Land Degradation Indicators

To complement our primary land degradation indicators, we will compile and calculate a set of secondary land degradation indicators, presented below, that arise from a combination of spatial datasets. This is not an exhaustive list, and new land degradation indicators may appear relevant and be added during the LAUREL program implementation.

1. National land degradation status and types

   The primary land degradation indicators can be combined to produce a preliminary national land degradation map that depicts the spatial extent of degraded lands and the type of degradation. This map can be disaggregated by land cover type and/or other policy relevant units, such as agro-ecological, bio-cultural or administrative units. This could serve as an example of spatially explicit reporting system for Land Degradation or Sustainable Goals national engagements.

2. Carbon emission from Above Ground Biomass (ABG) carbon pool removal

   A global ABG map has recently been produced within the GOFC-GOLD program (Avitabile et al., 2016[18]). This map represents the average Carbon Stock in native vegetation at 1 km resolution for 2000-2010 period (average). We will combine this map with the Land Cover Change map in order to estimate carbon emissions (annual tCO_2eq released to the atmosphere) at national scale. This can then be compared to and integrated into ongoing REDD+ activities that aim to establish the Reference Emission Level.

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[18] Avitabile, V., Herold, M., Heuvelink, G. B. M., Lewis, S. L., Phillips, O. L., Asner, G. P., Armston, J., Ashton, P. S., Banin, L., Bayol, N., Berry, N. J., Boeckx, P., de Jong, B. H. J., DeVries, B., Girardin, C. A. J., Kearsley, E., Lindsell, J. A., Lopez-Gonzalez, G., Lucas, R., Malhi, Y., Morel, A., Mitchard, E. T. A., Nagy, L., Qie, L., Quinones, M. J., Ryan, C. M., Ferry, S. J. W., Sunderland, T., Laurin, G. V., Gatti, R. C., Valentini, R., Verbeeck, H., Wijaya, A. and Willcock, S. (2016), An integrated pan-tropical biomass map using multiple reference datasets. Glob Change Biol, 22: 1406–1420. doi:10.1111/gcb.13139

3. Soil organic carbon estimation

   Digital Soil Mapping techniques that use state-of-the-art statistical tools, Earth Observation data combined with soil field survey now allow us to produce consistent and fine-resolution soil properties map throughout the world. Here we propose to use the recent globally available soil properties dataset available in the SoilGrid database[19] which gather various soil properties maps at 90 m and for various soil layers (up to 1 meter). In particular, we will use organic carbon content, soil bulk density and gravel content in order to compute the Soil Organic Carbon (SOC) stocks at 30 cm and 100 cm soil layers. This will be a new product for Mozambique, since to our knowledge there are no available soil carbon maps.

4. Biodiversity indicators
   The baseline information on biodiversity are important, yet difficult to assess directly since ground survey or field observation of fauna and flora are scarce and expensive to collect. In this project we will collaborate with national scale SECOSUD project that aim to develop and nationally sound and consistent biodiversity database over a 4 years project. Using the available biodiversity dataset, the Secosud team will produced biodiversity maps (alpha or beta biodiversity) using ecological statistical models. Those biodiversity maps will then be able to be used directly as a mean to develop conservation strategy at national scale and input into LandSIM platform as a mean to assess the impact of land use change.

[19] https://soilgrids.org

Accuracy Assessment and Quality Control

Accuracy assessment will be performed during the processing stage using standard and best practices accuracy measurement techniques. Quality control (QC) will be prioritized during all the steps of the current analyses. This includes appropriate model validation and documentation using standard statistical goodness of fit indicators (coefficient of determination R2, and Root Mean Square Error, RMSE). Specific metrics such as a confusion matrix using independent and external dataset will be performed during the workflow (see land cover change validation description above).

One key element of the QC framework is that our work is based on open source software or tools and the processing chains will be scripted in command line format. This choice allows us to quickly check the various steps, dataset used and results, and also to redo the calculation with an improved and updated dataset. This facilitates quality control, technology transfer and provides support for training sessions.

In addition, we will perform two levels of validation: comparing our results with national and external database or project results; and carrying out ground control surveys.

1. <u>Comparison with national and external database</u>

   There are a number of databases that can be used to assess the quality of our land degradation indicators. For land cover change, two main projects are bringing new insight on these topics: i) the Reference Emission Level point sampling database and ii) the SECOSUD project. Both projects use the FAO Collect Earth tool to fully describe the land cover status and evolution for thousands of location throughout the country. Those observations are of great value and will be used to produce a comparison matrix with the LCC.

2. <u>Ground control surveys</u>

   Local knowledge is critical for the validation of the degradation maps and understanding of the underlying causes. Ground control surveys will be organized targeting degradation (dark-spots) and restoration hot spots (bright-spots), situated in selected agro-ecological (AEZs) or livelihood zones

(FEWS-Net[20]). Local workshops will also be organized in 2 or 3 locations. This will involves presenting the degradation estimates (maps) to village focus group and discussing the actual and past degradation areas and causes.

Data Sharing and Visualization Tool

We will install and configure a dedicated geospatial server for the degradation baseline inputs and outputs dataset. The webmapping application relies on open source technologies and is fully compatible with QGis, an open source Geographical Information System (GIS). A similar portal was built by the team during the Regional REDD+ program in Madagascar, and was transferred to national authorities, the National Environment Agency (*Office National de l'Environnement*; ONE), which is now currently hosting and managing the portal (http://www.perr-fh-mada.net/). A similar webportal is currently under development for the MozBio projet (www.mozbio-gile.org).

The platform will be installed on a dedicated cloud server with FTP secured assess. This will enable fast data transfer and visualization capacity thanks to enhanced bandwidth. The data transfer protocol is a simple FTP secured access that enables us to customize user access and rights. We will install a free and open source webmapping engine called LizMap. LizMap uses QGis server capacity and provide GIS services, such a Web Mapping Service (WMS) or Web Feature Service (WFS). The spatial datasets and webmapping engine will be stored within a docker container, which can easily be shared or transferred to any server.

We will provide the basic web interface with the baseline degradation datasets to the host organization(s). It could be refined – for instance by adding specific functionality in the type of query or report – according to the interim discussion along LAUREL implementation. Dedicated training on the installation and use of the platform will be provided for the host organization and other interested partners. This webmapping interface is different compared to the LANDSIM webmapping interface (See LANDSIM approach paper) since it only provides a

[20] https://www.fews.net/

static representation of land degradation indicators with visualization and downloading capacities.

Training & Capacity Building

To transfer technology and build capacity we will deliver training sessions once we will have sufficient feedback on the research methodology and reach final production steps. During the assignment of Laurel, various technical papers will be produced to relate the progress made on producing the land degradation baseline maps. This material will be discussed with World Bank and Institutions during workshop. Once satisfactory results will be achieved and validated by local institutions, the training material and session will start, approximately around May 2018.

Three training sessions will be conducted, each for 2 or 3 days. By the end of the training session the participants will be familiar with the national development context and will be proficient in the practice of creating the land degradation maps, using open source software, compiling datasets and programming scripts. The participants can be university researchers, students, or engineers working in administration or current land use and land use change related programs (e.g., MRV Unit). Communication will be performed to collect candidacy for those training sessions. A maximum of 20 participants is expected by session in order to keep the session efficient and logistically doable (computers, internet, data sharing, etc.). Additional sessions can be provided if necessary.

Specific objectives of the training are:

Session 1: Land Cover Change

- ✓ Produce large scale Landsat Mosaic using Google Earth engine;

- ✓ Perform supervised classification of land cover change using Random Forest classifier within stand-alone statistical software (R Studio) or Google Earth Engine; and

- ✓ Interpret the results and evaluate the quality of the map using REDD+ best practices.

Session 2: Land Productivity Trends

- ✓ Understand the underlying physical and biological processes of the NDVI trends analysis;

- ✓ Calculate of the NDVI trends (to update the results as satellite data are acquired); and

- ✓ Interpret the trends in terms of land degradation/restoration.

Session 3: Soil Erosion and Retention

- ✓ Derive the Universal Soil Loss Equations and understand the assumptions behind the model;

- ✓ Apply Sediment Delivery Ratio models, produce sediment export and retention maps; and

- ✓ Interpret the results and evaluate the quality of the various erosion and retention maps

Timetables & Deliverables

In the table below, we summarize the activities and deliverable for the land degradation baseline (we highlight in gray background the deliverables proposed for November 2017).

Activities	Timetable	Deliverable	Deadline
Land cover change *First set of results*	*Aug. to Oct. 2017*	*Raw land cover change map*	*Nov. 2017*
Final set of results	Dec. to Apr. 2018	Final land cover change map	May 2018
Land productivity change *First set of results*	*Aug. to Oct. 2017*	*NDVI trend map*	*Nov. 2017*
Final set of results	Dec. to Apr. 2018	Final Land Productivity results	May 2018
Soil erosion and retention First set of results Final set of results	Dec. to Feb. 2018 Feb. to Mar. 2018	Initial Soil erosion and retention results Final Soil erosion and retention results	Feb. 2017 May 2018
Initial field visit	Sep. 2017		
Field ground control visit	March. 2018		
Training sessions			May 2018
First technical report on Land Degradation		*First technical report*	*Nov. 2017 (instead of august 2017 in TORs)*
Final technical report on Land Degradation		Final technical report	May 2018 *(instead of march 2018 in TORs)*
Land degradation scientific and stakeholder workshop in Maputo			May 2018