USER MANUAL DEFORESTATION RISK MAP TOOL

Support to the development of an updated Forest Reference Level and develop options to allocate the FRL at multiple spatial scales for REDD+ implementation in Cambodia

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Client: UNDP Cambodia

PROJECT:

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Report:

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CONTENTS:

PACKAGE CONTENTS

The following elements compose the "Deforestation Risk Map Tool" package:

1. Installation Manual: Include the instructions to install the application.

2. User Manual: Include a tutorial explaining, step by step, how to create a Deforestation Risk Map using the Tool.

3. CambodiaApp.7z: Compressed folder which includes the execution files, the tool code and the folders and files that allow the full process. For the correct use of the Tool, It is recommended to do not delete or modify any file or folder included in the CambodiaApp.7z.

4. Layers Cambodia: a set of files in tiff format with the essential information for test and training. These layers were used to develop the Deforestation Risk Map delivered in October 2020.

GENERAL OVERVIEW

The Tool intends to develop a Deforestation Risk Map, using the forest map (land-use), the deforestation maps (land-use change) and distance to some variables like concessions, roads, rivers, etc.

Please follow the instructions as detailed in the User Manual.

The following main principles were considered to develop the Deforestation Risk Map Tool:

- **Future deforestation:** It refers to the deforestation trend that will follow the evaluated period.

    - In the case of Cambodia, deforestation from 2018 ahead will be estimated based on the trend during the period 2014-2018.

- **Two-years period deforestation maps:** It is the biannual deforestation maps available.

    - In the case of Cambodia original layers to be used are FCC Map 2014-2016 and FCC Map 2016-2018, covering the most recent four (4) years.

- Within the study area, both **planned and unplanned deforestation, are relevant**.

    - In the case of Cambodia:

        - **Planned** considered the deforestation happening inside concessions: ELC, SLC, Directive 001, etc.

        - **Unplanned** considered the deforestation happening outside concessions.

DEFORESTATION RISK MAP TOOL:

The Deforestation Risk Map Tool objective is to analyze the deforestation patterns to select the best explanatory variables, generate a multiple regression model and deliver, as the final result, a prediction map of future deforested areas.

The Tool is composed by for modules:

- **Module 1** identifies the planned deforestation trends within the areas identified by the user.
- **Module 2** estimates the deforestation relevance and rate by equal Euclidean distance intervals from the variables introduced by the user, in relation to the most recent available deforestation maps
- **Module 3** allows the user to select the best combination of variables and distance to create a regression model. The selection of variables would be refined by the user consulting the results delivered from the Akaike Information Criteria (AIC) analysis.
- **Module 4** allows the user to apply the multiple regression model and to generate the final prediction deforestation map at different spatial scales.

The Tool has been developed considering the following criteria:

- Deforestation trend in the future will follow the same patterns as deforestation during the last four (4) years.
- Biannual deforestation maps are available for a period of 4 years (i.e. there exist two (2) deforestation maps covering, each one, two (2) years periods):
    - In the case of Cambodia, the layers to be used are Deforestation 2014-16 and Deforestation 2016-18 maps.
    - In the future, the layers would be updated using new maps, for example, Deforestation 2018-2020 and Deforestation 2020-2022 maps.
- Forest area maps for each of the initial and final years of the biannual deforestation maps are required:
    - In the case of Cambodia forest cover maps from 2014, 2016 and 2018 will be required.
    - In the future, the results would be updated using new maps, for example, forest cover maps from 2018, 2020 and 2022.
- In the case of planned deforestation, the assumption used to estimate the future deforested area is that within a specific area (in example, Economic Land Concessions) the existing forest will be converted to other land use at a rate equal to the rate in the last four (4) years.
- In the case of unplanned deforestation:
    - The last updated deforestation map (i.e. 2016-2018) will be used as the ground truth data,
    - The dynamics variables (i.e. deforestation map 2014-2016) and the static variables (i.e. roads, villages, and others) related to the deforestation will be used as the predictor variables to develop a regression model.
    - Once the regression model would be developed, the temporal variables will be updated (i.e. deforestation map 2014-2016 will be replaced by the Deforestation map 2014-2018) to enhance the representativity of data.

During the data preparation, the user should consider three main requirements:

- Only tiff layers are supported by the Tool,
- All variables must have the same spatial resolution (i.e. pixel size),

To reach the final results, the user must follow the module by module flow (i.e. if the user does not run the Module 1 will not be feasible to run the Module 4).

Together with the User Manual, a set of layers are delivered. These layers are ready to be used as described in the column "Test Layers" in the table:

Module	Header description in the Tool	Details	Pixel deep	Test Layer
Module 1	Deforestation Map in the 4 years period	4-years period deforested area map	Binary 1: Def 0: No Def	Def_14_18.tif
	Forest Map in the initial period	Year 1 forest cover map	Binary 1: Forest 0: No Forest	Forest_boundaries_2014.tif
	Concessions Layers	The area where planned deforestation is assumed	Binary 1: inside limits 0: outside limits	ELC.tif SLC.tif Dir_001.tif
Module 2	Most Recent Period Deforestation Map outside concessions	Period-2 deforested area map (years 3 and 4), excluding deforested area within "Concessions Layers" upload in Module 1.	Binary 1: Def 0: No Def	Def_out_16_18.tif
	Forest Map in the second period outside concessions	Forest cover map for the second period. It should be only the forest outside "Concessions Layers" upload in Module 1.	Binary 1: Forest 0: No Forest	Fores_boundaries_out_16.tif
	Variables to predict Deforestation to be defined by the user	Period-1 deforested area map (years 1 and 2)	Binary 1: Def 0: No Def	Def_14_16.tif
		Year 3 non-forest area map	Binary 1: Non-Forest 0: Forest	Non_forest_16.tif
		Accessibility layers	Binary 1: inside limits 0: outside limits	Roads.tif Villages.tif Water.tif
		Other relevant layers	Binary 1: inside limits 0: outside limits	Concessions.tif

Module	Header description in the Tool	Details	Pixel deep	Test Layer
Module 3	Additional layers	A layer not included in Module 2, such as Population Density.	8-bit Continuous values	Pop_dens.tif
Module 4	Final Year Forest Map	Year 4 forest cover map	Binary 1: Forest 0: No Forest	Forest_boundaries_18.tif
	Final Year Non-Forest Map	Year 4 non-forest area map	Binary 1: Non-Forest 0: Forest	Non_forest_18.tif
	Full Period Deforestation Map	4-years period deforested area map	Binary 1: Def 0: No Def	Def_14_18.tif

In the following sections, the four modules of the Tool will be described:

MODULE 1:

This module computes the Deforestation rate for the total analysis period (4 years) within the areas considered as Planned Deforestation (i.e. Economic Land Concessions, Social Land Concessions and Directive 001).

Planned deforestation is defined as the deforestation on forest lands that are legally authorized and documented to be converted to non-forest land (Infrastructure projects, roads, mining concessions)

This module computes the annual average deforestation rate within the areas considered as "Planned Deforestation".

This information is used to estimate the future planned deforestation over the concession areas

The user must upload the following layers by clicking Browse in each of the sections:

1. *Initial year forest map*: A layer including the forest area at the initial year of the analysis (i.e. 2014) **MANDATORY**
2. *Full period deforestation map*: A layer including the deforested area during the entire analysis period (i.e. 2014-2018) – **MANDATORY**
3. *Concessions layers*: The layers including the area to be considered as "planned deforestation" (i.e., Economic Land Concessions, Directive 001, Social Land Concessions) – **AT LEAST ONE LAYER MUST BE UPLOADED**
4. **OPTIONAL** In the button of the panel, the user is able to upload a specific layer and to establish the annual rate of deforestation estimated within this area:
   - Click the box
   - Type the annual deforestation rate
   - Browse and upload the corresponding layer

Once the layers are uploaded, the user should click on the "Process" button to carry out the analysis.

Initial Year Forest Map

Browse...   forest_boundaries_14.tif   **1**
Upload complete

Full Period Deforestation Map

Browse...   def_14_18.tif   **2**
Upload complete

Add a tiff object with concession area (at least one)

concessions layer 1

Browse...   DIR_001.tif
Upload complete

concessions layer 2

Browse...   ELC.tif   **3**
Upload complete

concessions layer 3

Browse...   SLC.tif
Upload complete

concessions layer 4

Browse...   No files selected

☑ Click to add an additional layer when the deforestation is planned and annual deforestation rate is estimated.

Annual Def. Rate:

10   **4**

def Annual Concession Layer

Browse...   No files selected

Process   **5**

TEST

The following test layers are available for the user:

1. *Initial year forest map*:
    - *forest_boundaries_14.tif*
2. *Full period deforestation map*:
    - *Test Layer: def_14_18.tif*
3. *Concessions layers*:
    - *DIR_001.tif*
    - *ELC.tif*
    - *SLC.tif*

RESULTS

The results delivered by the Tool are displayed in the results panel:

The deforestation rates estimated for the selected variables are the following:

DefRate_DIR_001.tif	DefRate_ELC.tif	DefRate_SLC.tif	**1**
4.53%	3.22%	4.56%	

ForestArea_DIR_001.tif	ForestArea_ELC.tif	ForestArea_SLC.tif	**2**
51521.00 Ha	1089543.00 Ha	23817.00 Ha	

DefRate_Mixed	ForestArea_Mixed	**3**
12.50%	77.00 Ha	

1. *DefRate_Layer*: Annual Deforestation Rate by concession type. The calculation is made dividing the annual deforested area (derived from the layer uploaded in step #2 divided by the number of years of the period – four (4) years) by the forest area (derived from the layer uploaded in step #1) considering each concession boundary (Layers uploaded in step #3)
2. *ForestArea_ Layer*: forest area by concession: the calculation is made summing forest (Layer uploaded in step #1) within the specific boundaries of each concession type (Layers uploaded in step #3).
3. *Def_Rate_Mixed* and *ForestArea_Mixed*: In the case the concessions area layers uploaded in step #3 overlap, the Tool will calculate the annual deforestation rate and forest area over the overlapped areas.

MODULE 2:

This module allows the user to make a preliminary analysis of the variables related to unplanned deforestation trend.

This module creates a distance map of the deforestation from each of the selected variables.

With this information, the Tool calculates the annual deforestation rate and the percentage of annual deforestation by distance interval selected. Then, you can download the CSV file.

In the results area, the module recommends you to use in the model the variables whose distance represent at least a 3% of deforestation rate and 15% of total deforestation.

The user must follow the next steps:

1. **Second recent period Deforestation Map outside concessions**: Upload a layer including the deforested area in the most recent available map (i.e. 2016-2018) excluding deforested area within *"Concessions Layers"* upload in Module 1.– **MANDATORY**
2. **Intermediate Year Forest Map outside concessions**: Upload a layer including the forest area for the initial year of the second period (i.e. 2016). It should be only the forest outside *"Concessions Layers"* upload in Module 1.– **MANDATORY**
3. **Variables to predict Deforestation to be defined by the user**: Upload the layer to be included in the analysis, it is expected that these layers would have a close spatial relationship with the recent deforestation outside concession. **MANDATORY.**
   a. Some common layers to be upload are:
      i. Initial period deforested area map (i.e. 2014-2016); this layer must contain the name "def".
      ii. Intermediate year non-forest map (i.e. 2016): This layer must contain the name 'non_forest'.
      iii. Accessibility layers (Roads, Villages, Water bodies)
      iv. Other relevant data
4. **Select the interval for which the analysis will be performed**: The user must select the distance interval to be applied during the analysis. The distance to be analyzed will be in any case until the 5,000 meters – **MANDATORY**

The Second recent Period variable must contain value 1 in the positions where there is deforestation.

The second recent period Deforestation Map outside concessions

Browse... No files selected   **1**

The Year Forest variable must contain the value 1 in those positions where there is a forest.

Intermediate Year Forest Map outside concessions

Browse... No files selected   **2**

If you want to upload layers in module 4, the following independent variables of this module must be named as follows:

The deforestation variable must contain the name "def".

The forest boundary variable must contain the name 'forest_boundaries'

The non_forest variable must contain the name 'non_forest'

Variables to predict Deforestation ("press shift+click to select multiple layers")

Browse... No files selected   **3**

Select the interval for which the analysis will be performed

500   **4**

Process

Once the layers are uploaded, the user should click on the "Process" button to carry out the analysis.

The following test layers are available for the user:

1. *Second recent period Deforestation Map outside concessions:*
   - ○ *Def_out_16_18.tif*
2. *Intermediate Year Forest Map outside concessions:*
   - ○ *Forest_boundaries_out_18.tif*
3. *Variables to predict Deforestation to be defined by the user:*
   - ○ *Concessions.tif*
   - ○ *Def_14_16.tif*
   - ○ *Non_forest_16.tif*
   - ○ *Roads.tif*
   - ○ *Villages.tif*
   - ○ *Water.tif*

RESULTS

The Tool will recommend an initial set of variables and distance to be applied in the following Modules. The recommended variables are those intervals whose represent at least a 3% of deforestation rate and 15% of total deforestation.

Variable	Distance
M2_concessions	1500
M2_def_1416	2000
M2_non_forest_16	500
M2_Roads	3000
M2_Villages	2500

⬇ Download CSV

Variable X Distance Interval	Deforestation rate	Percentage of total Deforestation
0-500 m	3,5	3%
0-1000 m	3,4	5%
0-1500m	3,3	9%
0-2000m	3,3	12%
Distance selected 0-2500m	3,1	15%
0-3000m	2,7	23%
0-3500m	2,4	27%
0-4000m	1,7	35%
0-4500m	1,5	50%
0-5000m	1,4	54%
>5000m	1,3	100%

Besides, a "CSV" file for each of the variables will be created and must be download by the user.

The file reports the results of the percentage of deforestation explained and the deforestation rate by variable for all the distance intervals selected.

MODULE 3:

This module allows the user to create a Multiple Regression Model to predict future deforestation.

In the panel of the right, the user can enable/disable the variables and distance used to compute the regression model. Together with the regression model, the Tool presents the AIC results to identify the statistically best combination of variables.

 The user can repeat the process as many times as needed until the regression model is robust enough.

Each time there is a modification in the selected variables, the regression model must be recalculated by clicking the "Process" button. The user must follow the next steps:

1. **Enter the Population density layer**: The module allows the user to **include additional variables** do not consider in Module 1, such as Population Density. The variable could be enabled or disabled by click on the "Reset" button.
2. **Select the variables and distance** to be included in the regression model:
   a. By default, the module automatically selects the variables and distance that represent at least a 15% of deforestation and at least a 3% of deforestation rate. This information is delivered previously in Module 2.
   b. However, the module allows the user to enable or disable layers and to select the distance to be considered for each variable manually.
   c. The Tool allows the user to use two different distance for the same variable – example: deforestation 14-16 500 m; deforestation 14-16 2500 m.

Once the criteria are defined, the user could run the module clicking the "Process" button.

The following test layer is available for the user:

1. **Population density layer:**
   - ***Pop_dens.tif***

RESULTS

The result delivered is a multiple regression model, including all variables selected by the user; the model will be applied in module 4 to create the final map. In the results panel, the user can find:

1. **Summary of statistical for the model**, including:
   a. Residuals
   b. Coefficients, standard error, t value, and P-value
   c. Residual standard error
   d. R-Squared and Adjusted R-squared
   e. F-statistic
2. **Results of the AIC analysis**, to be download:
   a. The "CSV" files to be download provides the results of the AIC analysis for all the possible combination of variables selected by the user.

```
Call:
lm(formula = deforestationSurface ~ . + 0, data = mod3Results$regressionModel)

Residuals:
    Min      1Q  Median      3Q     Max
-372.88  -10.81    0.00    1.98  791.99

Coefficients:
                        Estimate Std. Error t value Pr(>|t|)
rg_M2_def_14_16_2_2000  0.080745   0.006234  12.953   <2e-16 ***
rg_M2_Roads_2_3000     -0.003884   0.026953  -0.144    0.886
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 135.8 on 195 degrees of freedom
Multiple R-squared:  0.6734,    Adjusted R-squared:  0.67
F-statistic:   201 on 2 and 195 DF,  p-value: < 2.2e-16
```

1

⬇ Download AIC   **2**

The user can repeat the process as many times as needed until the regression model is robust enough. If a variable is enabled/disabled, and/or a distance is modified, the regression model must be recalculated by clicking the "Process" button.

RECOMMENDATION:

It is highly recommended to follow a robust statistical procedure to select the best model to be applied. Akaike information criterion (AIC) (Akaike, 1974) is a fined technique based on in-sample fit to estimate the likelihood of a model to predict/calculate the future values. A good model is the one that has minimum AIC among all the other models.[1]

The AIC results allow the user to select the best combination of independent variables to explain the dependent variable. The proposed approach to choose the best combination of variables is the Forward approach.

In the first step, the user should review the AIC results for the single variables. The lower AIC value is the best explanatory variable, and therefore, this variable should be selected.

In the following step, the user should review the combination of the variable selected in the previous step with the rest of the variables and determine the lower AIC value. The variables combination will be chosen if the AIC is lower than the one obtained previously.

The process iteratively including a higher number of variables until the selection of the best combination.

Once the best combination of variables is identified, the regression model should be recalculated. Some statistical from the regression model should be reviewed to determine if the model is robust enough:

- Coefficients: should be positive if the expected correlation between the dependent and independent variable is positive.

- Confidence Interval at 95%: range should not encompass negative and positive values.

Example:

Variable	Coefficient	Confidence Interval (95%)	Select/Discard
Deforestation 14/16	+ 0.045	+0.020 ; +0.070	SELECT
Forest Edge 16	+ 0.023	-0.04 ; +0.077	DISCARD
Main Roads	- 0.012	-0.016; -0.08	DISCARD
Villages	+ 0.011	+0.001 ; +0.021	SELECT

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[1] https://www.sciencedirect.com/science/article/pii/B9780128025086000326

MODULE 4:

Module 4 allows the user to define the spatial resolution and the units (ha or %), and to generate the "Deforestation risk map.

The user is also allowed to update the layers related to the land use and deforested area, aiming to include the most representative information.

The user can modify the resolution and units, and to recalculate the map as many times as needed.

The following steps must be followed:

1. **Final year forest map**: Update the forest layer, using the most recent forest cover data (i.e. Forest 2018) – **MANDATORY.**
2. **Final year Non-forest map**: Update the non-forest layer, using the most recent non-forest cover data (i.e. Non-Forest 2018) – **MANDATORY.**
3. **Full Period Deforestation map:** Update the historical deforestation layer. In this case, the layer to be upload should be the deforested area during the total analysis period (i.e. Deforestation 2014-2018) – **MANDATORY.**
4. **Select the resolution of the generated risk map (meters):** The user must select the spatial resolution of the final risk map, the higher resolution is the same as the layers and the lower is 6,000 meters – **MANDATORY.**
5. **Select the format in which the values will be represented in the risk map:** The user must select the parameter to be reported in the results, the possibilities are:
   a. **"Ha"**: predicted deforestation in hectares by year per pixel.
   b. **"Rate"**: predicted deforested area divided by forest area by year per pixel.

Final year forest map

Browse...   No file selected   **1**

Final year Non-forest map

Browse...   No file selected   **2**

Full Period Deforestation map

Browse...   No file selected   **3**

Select the resolution of the generated risk map (metres):

100   **4** 00

30   630   1,230   1,830   2,430   3,030   3,630   4,230   4,830   5,430   6,000

Select the format in which the values will be represented in the risk map:

Ha   **5**

Process

Once the user clicks on the "Process" button, the Tool will compute the final results.

TEST

The following test layers are available for the user:

1. ***Final year forest map:***
   - ***Forest_boundaries_18.tif***
2. ***Final year Non-forest map:***
   - ***Non_forest_18.tif***
3. ***Full Period Deforestation map:***
   - ***Def_14_18.tif***

RESULTS

The user must download the "Deforestation Map" and the detailed results by clicking the corresponding buttons.

📥 Download Deforestation Map   📥 Download results of module 4

The resulting Deforestation Risk Map is a tiff layer that can be open in a geographic information system software. Each cell of the layer represents the prediction of how much forest (in hectares will be deforested annually:
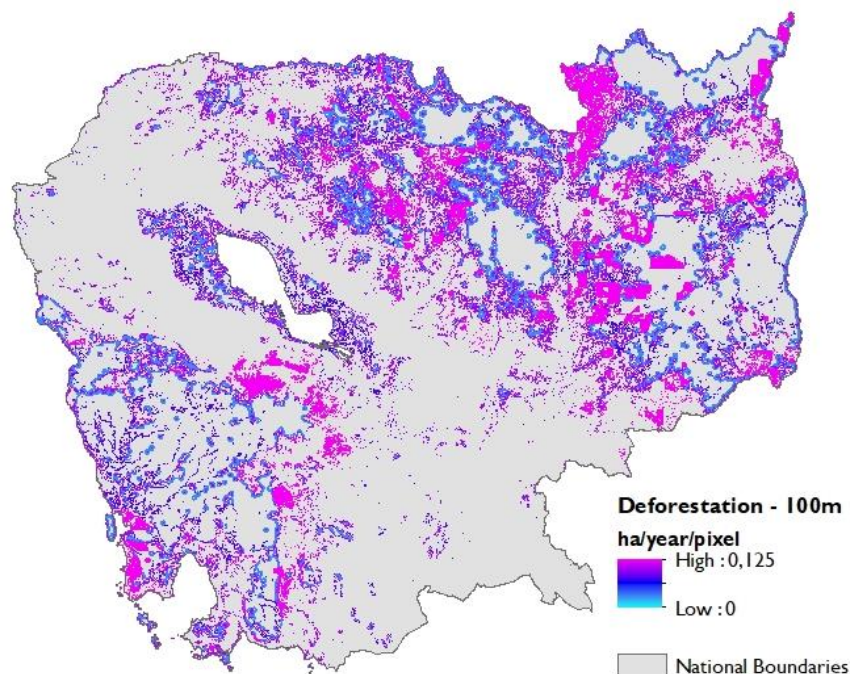
USER MANUAL –

DEFORESTATION RISK MAP TOOL

Support to the development of an updated Forest Reference Level and develop options to allocate the FRL at multiple spatial scales for REDD+ implementation in Cambodia.

31 OCTOBER 2020

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