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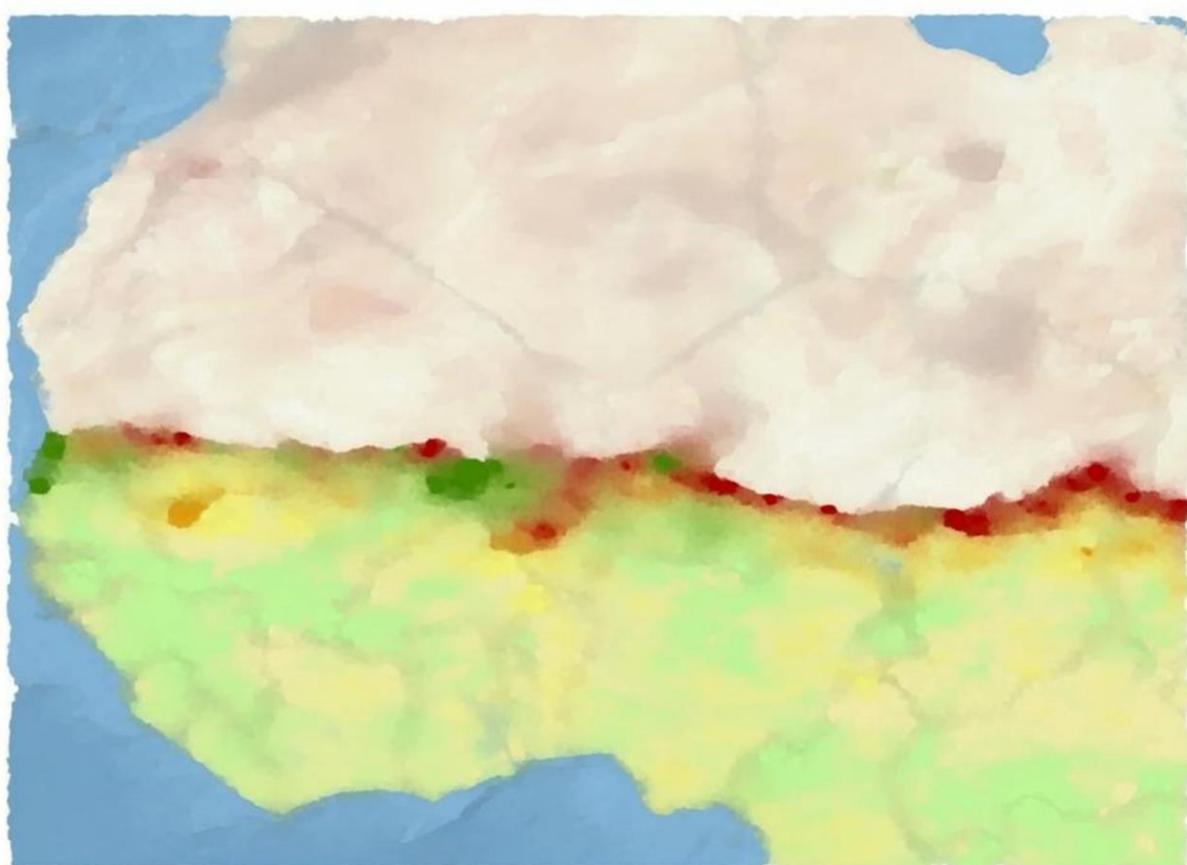
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# **BIOHYDROGENERATOR USER GUIDE**



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## 1 Introduction

BioHydroGenerator is an aggregation of programs developed and used by Action Against Hunger for its early warning system on food crisis in the Sahel. These programs, which generate biomass and water availability maps for pastoralists, are based on satellite remote sensing data.

The biomass and water maps provide access to vulnerability indicators for livestock, particularly for nomadic pastoralists in the Sahel region. This traditional, extensive and nomadic livestock breeding, called pastoralism, is extremely sensitive to climatic conditions and the quality of rain, or West African monsoon.

Those programs are grouped into 3 separate and complementary modules:

- DeCompressor (v2.1): this module downloads, prepares and checks the satellite database before use by the other modules.
- BioGenerator (v5.1): this module calculates biomass production and generates maps of annual production anomalies and vulnerability index.
- HydroGenerator (v4.1): this module calculates the water availability index and maps out annual anomalies in water presence.

The main objective of these tools is to show the status of pasture resources for pastoralists at the end of the rainy season, as these are mainly the resources pastoralists have to feed their animals on until the next rainy season.

Water resources provided by real-time sensing of surface water points can be monitored during the dry season.

This user guide first explains the theoretical aspects, and then describes how to use the tools. Some practical examples describe the steps from downloading the data to developing maps and time profiles.

## 2 Satellite Data

The satellite data used are from the VEGETATION sensor embarked on the SPOT-4 (1998-2013), SPOT-5 (2002-2014) and PROBA-V satellites (since 2014).

The outputs from those satellite acquisitions are provided by VITO (Flemish Institute of Technological Research), through the European DevCoCast project (*GEONETCast for and by Developing Countries*) led by the European Commission and JRC (*Joint Research Centre*).

Those satellite outputs are stored in the form of 10-day summaries, and at a spatial resolution of 1x1 km. Outputs are available for download in real time, usually the day following the last day of the 10-day period. There are three 10-day periods for each month: the first 10-day period goes from the 1<sup>st</sup> to the 10<sup>th</sup> day; the second 10-day period from the 11<sup>th</sup> to the 20<sup>th</sup> day; and the third from the 21<sup>st</sup> to the last day of the month. There are 36 10-day periods per year.

### 2.1 Geographic Window

The geographic window covers the entire Sub-Saharan Africa, and Figure 1 shows its stretch. Table 1 gives the geographical coordinates of the spatial window boundaries. That spatial window is called *Sub\_Sahara*.

Window	Top-Left	Lower-Right	Size (pixels×lines)
<b>Sub_Sahara</b>	-18.000°E 27.375°N	52.000°E -5.02678611°N	7841 × 3630

Table 1 – Coordinates of pixels center at the corners of  
the geographical window

All calculations of the different modules are done on that window and at the initial resolution of 1x1 km of satellite products. All image and vector outputs are also obtained from all or part of that window.

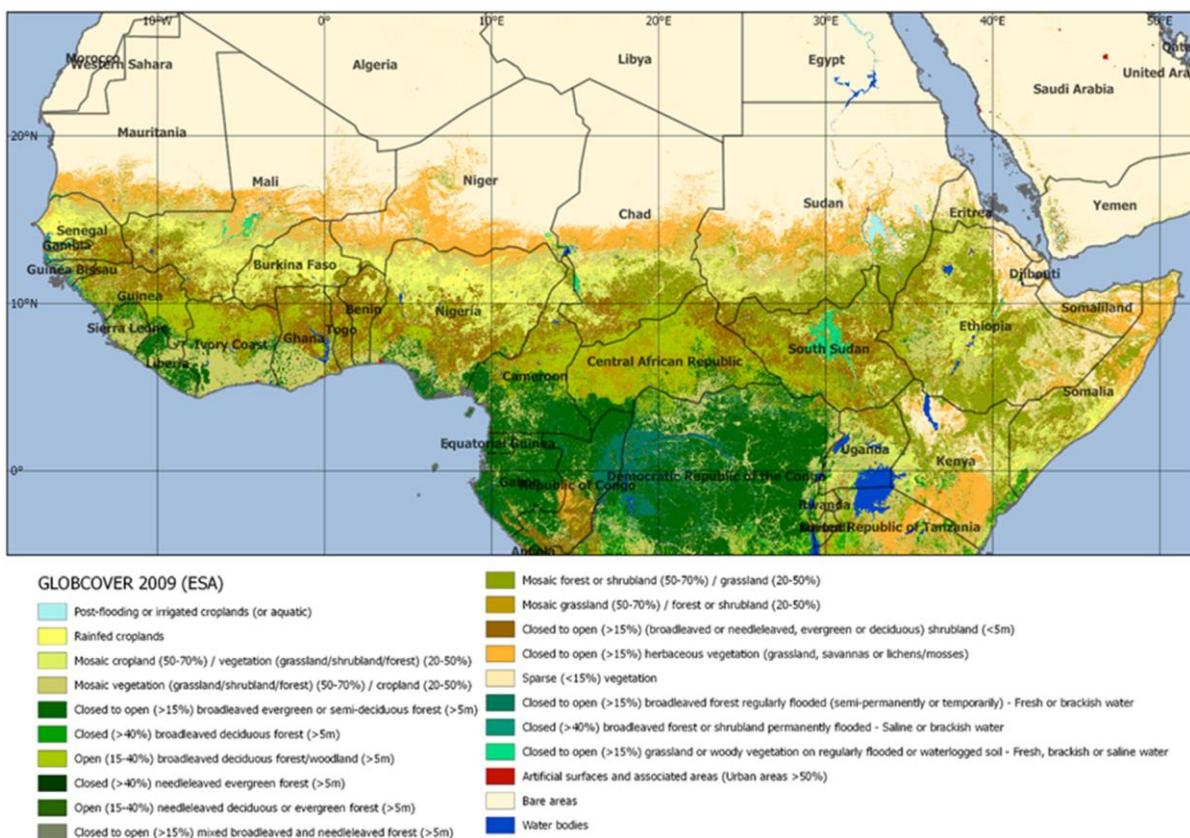


Figure 1 –GLOBCOVER 2009 Classification on  
the *Sub-Sahara* geographical window

## 2.2 NDVI Vegetation index

NDVI – the *Normalized Difference Vegetation Index* – is a dimensionless index that is an indicator of vegetation density and is calculated by comparing the visible red ( $\rho_R$ ) and the near infrared ( $\rho_{NIR}$ ) sunlight reflected by the surface (reflectance) (Baret *et al.*, 2006).

$$\text{NDVI} = \frac{\rho_{NIR} - \rho_R}{\rho_{NIR} + \rho_R} \quad (1)$$

## 2.3 Dry Matter Productivity DMP

The estimate of annual biomass production quantity is calculated as the cumulative total over the growing season of the DMP produced by VITO based on an algorithm developed by JRC.

DMPs are a quantification of instantaneous biomass production expressed in kg of dry matter per hectare per day ( $\text{kg.ha}^{-1}.\text{day}^{-1}$ ). Dry matter production, linked to *net primary production (NPP)* is estimated using Monteith's (1972) model, which is expressed as follows:

$$\text{DMP} = R_G \times s_i \times s_c \times s_b \times 10000 \quad (2)$$

Where:

$R_G$  ( $\text{D.m}^{-2}.\text{day}^{-1}$ ) is the incident solar radiation derived from radiation maps.

$s_i$  is the interception efficiency of the radiation by the vegetation, also called fAPAR (*Fraction of Absorbed Photosynthetically Active Radiation*), and obtained by linear regression of the NDVI according to heuristic calibration (Eerens *et al.*, 2000).

$$s_i = \text{fAPAR} = A + B \times \text{NDVI} \quad (3)$$

$\varepsilon_c$  is the fraction of PAR (*Photosynthetic Active Radiation*) of the incident solar radiation,

$\varepsilon_b$  [ $\text{kgMS.J}_{\text{PAR}}^{-1}$ ] is the conversion efficiency of PAR to dry matter and is a function of air temperature. According to Veroustraete *et al.* (2002),  $\varepsilon_b$  follows a bell-shaped function and reaches a maximum for 22°C, and is close to 0 for temperatures below 0°C and above 40°C. The temperature is obtained by reanalyzing meteorological data.

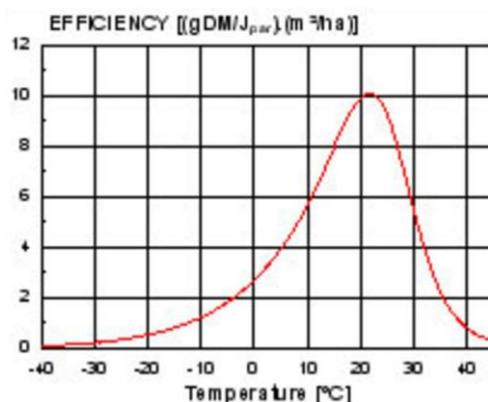


Figure 2 – Conversion efficiency trend as a function of temperature (Baret *et al.*, 2006)

10000 is the conversion factor from  $\text{m}^2$  to hectares.

## 2.4 Small Water Bodies SWB and artificial water points

Small water surfaces are included here within the resolution of the instrument, i.e. surfaces more or less covered with water with a dimension of about 1 km<sup>2</sup>.

The SWB (*Small Water Bodies*) outputs, available in the form of 10-day periods at 1x1 km resolution, provide Boolean information on the presence of surface water. However, the SWBs do not provide information on water depth and quality.

To increase sensitivity, wet vegetation areas and mixed areas detected by SWBs are also considered surface water areas.

To complete the surface water information provided by the SWB, the list of artificial water points and boreholes is entered in the Param/Bores\_List.txt file. For each of the water points, the East longitude, North latitude and a name are given. The list can optimally be included into the biomass weighting calculation accessible by the distance to the water. This list is not exhaustive of all water points, but involves, for the time being, only Northern Mali.

LON	LAT	NAM
-3.855556011	16.319999695	1km North of village
-4.389166832	15.797778130	20m from school
-0.264444441	16.715278625	Next to CS
-2.168888807	15.644721985	To the East
2.414722204	16.593610764	West of school
-0.014166667	16.355833054	Next to Bourem road
...		

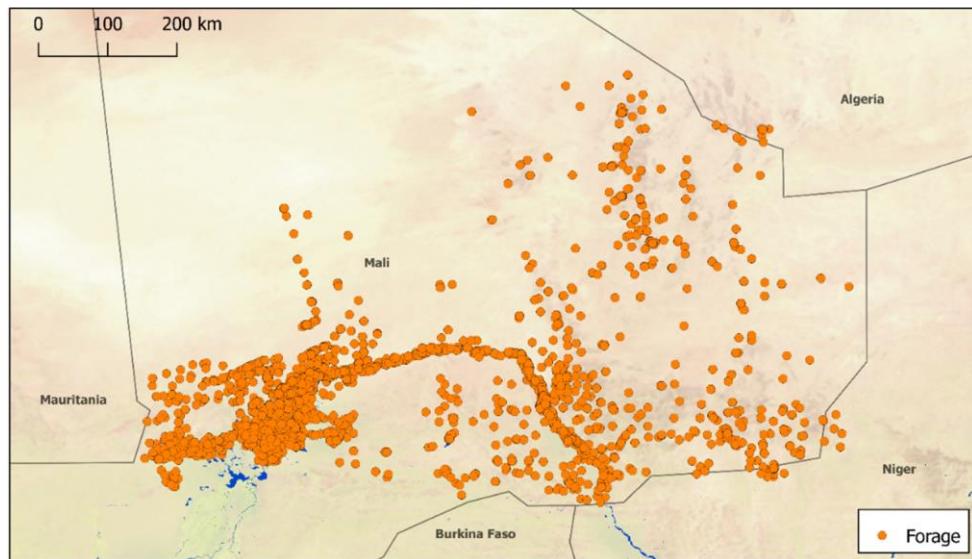


Figure 3 – Positions of artificial water points already included in the list

### 3 DeCompressor

DeCompressor (v2.1) is a program that downloads and prepares data for use by the BioGenerator and HydroGenerator programs.

The functions of DeCompressor are to check the integrity of the satellite database of the three fields – DMP, NDVI, and SWB – to download, decompress the new available 10-day periods, and prepare the vector files for use by the BioGenerator and HydroGenerator programs.

The running of the DeCompressor prior to the use of the BioGenerator and HydroGenerator modules is necessary in three cases:

- For downloading new DMP, NDVI or SWB 10-day periods and updating the database
- In case of doubt about the integrity of the database
- After editing the ADM\_n.shp or GEO\_n.shp and WATER.shp vector division files
- After editing the MASK.shp raster file of the area of interest.

#### 3.1 Directory Structure

It is essential to follow the structure and hierarchy of directories and files. The programs of the DeCompressor, BioGenerator and HydroGenerator modules must be placed at the root of the working directory or root directory. Since programs operate in relative position, the entire root directory can be moved freely.

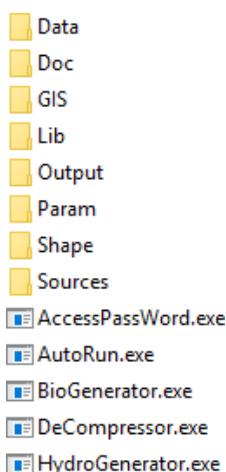


Figure 4 – Root Directory Structure

## 3.2 Definition of download sites and identifiers

NDVI and DMP data are downloaded from VITO FTP site, and SWB data from DataPool Copernicus. The addresses of the FTP and DataPool sites as well as Log-in identifiers and password are previously entered in the DeCompressor module. It is still possible to edit FTP and DataPool site addresses and identifiers using the AccessPassWord program (see section 3.2.3).

### 3.2.1 NDVI and DMP data

VITO provides Action Against Hunger-Spain (ACF-Spain) with a specific version of the DMP and NDVI 10-day period outputs. Those data, present in the form of 10-day periods, are made available for download on the VITO website. The access credentials to this FTP website are confidential to ACF-Spain, but previously registered in the DeCompressor program (Table 2).

### 3.2.2 SWB Data

VITO, through the European DevCoCast project, provides SWB 10-day periods downloadable from the *Copernicus Global Service* website at: land.copernicus.vgt.vito.be. A log-in and password request can be made through the website address. A valid login and password are already registered in the DeCompressor program (Table 2).

### 3.2.3 AccessPassWord

The AccessPassWord program, accessible in the Lib/User/ directory, allows editing the addresses of the FTP and DataPool websites as well as identifiers and passwords. The saved passwords are encrypted. Caution should be exercised when using AccessPassWord and changing connection information as those changes are irreversible.

Data	Address	Type	Login	Password
DMP NDVI	cvbftp.vgt.vito.be	FTP	meteo	*****
SWB	http://land.copernicus.vgt.vito.be/PDF/	DataPool	ACF_User	*****

Table 2 – Initial addresses and identifiers for downloads

### 3.3 Cartographic boundaries

Six cartographic boundaries shapefiles are used by the BioGenerator and HydroGenerator programs. Those files are in the form of *Shapefile* (.shp) and are initially placed in the Shape/ directory.

The first three files named ADM\_0, ADM\_1 and ADM\_2 correspond respectively to the administrative divisions at country, regional and departmental levels. The three following GEO\_3, GEO\_4 and GEO\_5 are free to be edited by the user.

To edit a file, simply save the new *shapefile* under the target name GEO\_3.shp, GEO\_4.shp or GEO\_5.shp by replacing the previous file. It should be noted that ADM\_n.shp files can be edited in the same way, but it is advisable to keep the existing administrative boundaries.

The vector file WATER.shp is used exclusively by HydroGenerator and sets the polygons for monitoring the temporal progression of the water points filling rates at the 10-day period time step.

The MASK.shp vector file sets out the cutting and masking of the *geotiff* raster files produced by BioGenerator and HydroGenerator. This MASK.shp file defines the area of interest. When the mask option is enabled, the output raster files of BioGenerator and HydroGenerator are cut and hidden. The cutting out is done according to the spatial extension of the polygon(s) of the MASK file, within the limit of the maximum extension of the Sub-Sahara window. A special mask value is applied to pixels that are outside the areas covered by a polygon in the MASK file (see sections 4.3 and 5.3).

New *shapefiles* must only contain polygons with an attribute table. In the attribute table, if a NAME table exists, then its values will be included in the tables and attribute tables under the BioGenerator and HydroGenerator programs outputs, otherwise, a NAME column is created with an incremental index for each of the polygons in the file.

Description	Name	Directory	File
Admin Level 0	ADM_0	Shape/	ADM_0.shp
Admin Level 1	ADM_1		ADM_1.shp
Admin Level 2	ADM_2		ADM_2.shp
User Cutting 1	GEO_3		GEO_3.shp
User Cutting 2	GEO_4		GEO_4.shp
User Cutting 3	GEO_5		GEO_5.shp
Water Surfaces	WATER		WATER.shp
Output mask	MASK		MASK.shp

Table 3 – Vector cutting files

### 3.4 Parameter setting

Parameters of the DeCompressor module are accessible and can be edited via the Param/DeCompressor\_Param.txt. file.

```
DeCompressor Parameters
 0  Forced download (Default: 0)
```

#### Forcing download (0: Off, 1: On)

This setting enables or disables forcing download. If forcing is enabled, then all the data available on the FTP and DataPool sites are downloaded and replace the data already present locally. This option is useful to force the database to download completely, for example in the case of a new version of the products.

### 3.5 Program runtime

Installing MATLAB Compiler Runtime 2016a is required before running the program. If necessary, it is required to set up the Libs/Utils/MCR\_R2016a\_win64\_installer.exe should be run program.

The DeCompressor program is launched simply by double-clicking on the file DeCompressor.exe.

The runtime window shows the program progress level for each step. At the end of the setup, the number of converted vector files (Table 3) and the number of 10-day periods downloaded and decompressed for each DMP, NDVI and SWB fields is recorded.

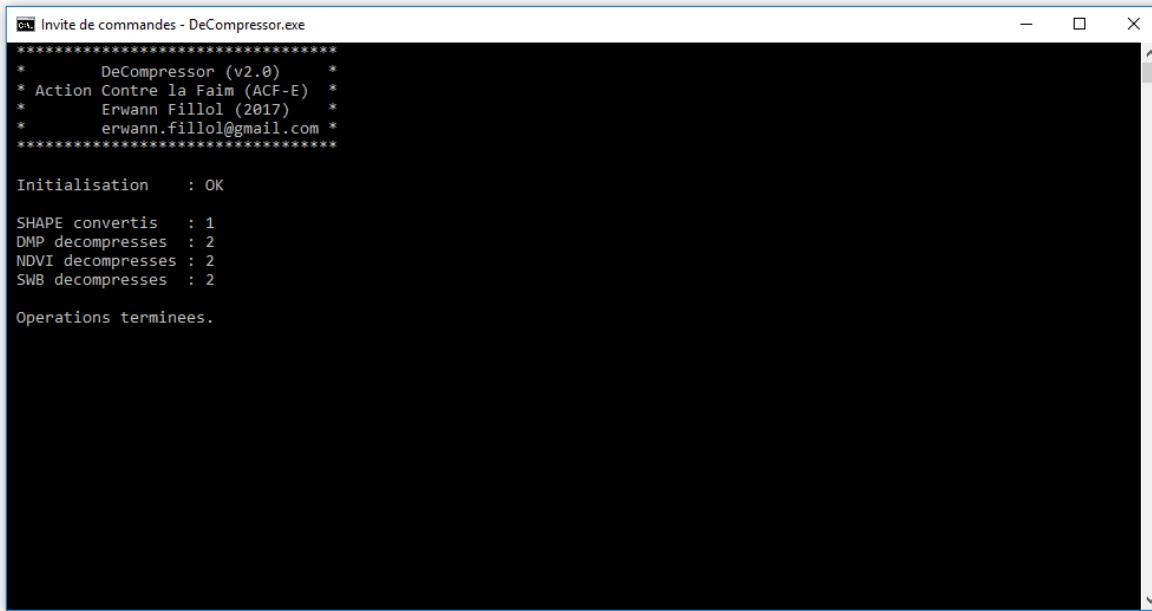


Figure 5 – DeCompressor setup window

## 3.6 Events log file

Following the execution of the DeCompressor program, all events concerning the detection and decompression of the DMP, NDVI and SWB 10-day periods are recorded in the Log/DataLog.txt text file.

The date and time are shown in the first line, and then all the events that occurred for the DMP data processing, followed by NDVI and finally SWB. If an archive is corrupt and its decompression is not possible, this will be reported in the event log file.

It should be noted that this file is never deleted, and that each time DeCompressor is run again, an entry is added.

Example of entry in the Log/DataLog.txt event log file after converting an ADM\_0 *shapefile*, and detecting, downloading and decompressing two new DMP, NDVI and SWB 10-day periods:

```
15/11/2017 17:44:24
*****
Shapefile Start
Shape converted: ADM_0
Shapefile End
*****
DMP Start
DMP_20171021 successful download attempt 1
DMP_20171021successful decompression attempt 1
DMP_20171101 successful download attempt 1
DMP_20171101successful decompression attempt 1
DMP End
```

```
*****
NDVI Start
NDVI_20171021 successful download attempt 1
NDVI_20171021 successful download attempt 1
NDVI_20171101 successful download attempt 1
NDVI_20171101 successful download attempt 1
NDVI End
*****
SWB Start
SWB_20171021 download attempt 1
SWB_20171021 successful decompression attempt 1
SWB_20171101 download attempt 1 SWB_20171101
successful decompression attempt 1 SWB End
*****
LOG End
*****
```

## 3.7 Examples of uses

This section presents two examples of how to use the DeCompressor program. The first example concerns the addition of new 10-day periods to the database. The second example shows the inclusion of a new vector polygon as a reference.

### 3.7.1 Addition of new NDVI, DMP and SWB 10-day periods

The NDVI, DMP and SWB 10-day periods are generally available for download within 24 hours of the end of the 10-day period.

1. Running the DeCompressor program: The program is executed as described in section 3.5. The display shows the number of 10-day periods detected, downloaded and properly decompressed. The log file (section 3.6) informs the user of any errors that may have occurred.

### 3.7.2 Editing a cartographic boundary

The use of a new vector cutting by the BioGenerator and HydroGenerator modules is possible. The first 3 ADM\_0, ADM\_1 and ADM\_2 divisions correspond to the administrative boundaries, the next three - GEO\_3, GEO\_4 and GEO\_5 – are free.

1. Saving a new polygon: The new vector file must be saved as GEO\_n.shp (n = 3, 4 or 5) in the directory described in section 3.3. The vector file must be *shapefile*, containing only polygons and using the reference ellipsoid WGS-84. If in the attribute table the NAME column exists, then it is included in the program output fields, otherwise, an incremental index will be assigned. Only the polygons now inside the geographic window (Figure 1) are taken into account.

2. Running the DeCompressor program: The program is run as described in section 3.5. The display shows the number of new vector files discovered and properly integrated.

## 4 BioGenerator

BioGenerator 2 is a tool capable of generating annual maps of biomass production quantity and biomass production quantity anomalies from data obtained from the acquisitions of the VEGETATION sensor onboard the SPOT satellite series follow by the PROBA-V satellite.

In its V5.1 version, the BioGenerator keeps the same algorithm based on the year-to-date aggregation of DMP (*Dry Matter Production*), and the calculation of the anomaly against the average year or typical year. The document “Mesure de la quantité de biomasse sur la zone Sahélienne Mali-Niger par télédétection” (Fillol, 2007) explains in detail the methodology used for biomass estimate.

The spatial extension of BioGenerator covers the whole of Sub-Saharan Africa according to the spatial window given in Figure 1.

This chapter explains the implementation and use of the BioGenerator, compares it with field measurements for the validation of biomass quantities, and concludes with some examples of use.

The significant improvements of this fifth version of the BioGenerator include:

- The possibility of taking into account the accessibility of biomass by distance to surface water points detected through remote sensing, and to artificial water points of known positions
- The possibility of taking into account the usability of biomass
- Calculation of statistical analysis charts (trend, standard deviation)
- Calculation of a configurable vulnerability index based on the situation of recent past years
- Adoption of the *geotiff* 32-bit real output format with compression capacity
- The addition of a configurable spatial filter for all output maps
- Calculation of total biomass production quantities, for each year, according to administrative boundaries from level 0 to 2, and user-defined polygons

- Outputs in geographic vector format *shapefile*
- The polygon according to the mask of the area of interest of the raster file outputs.

As for the previous versions, the user is given the possibility to manage the inclusion of period by defining the 10-day periods from the beginning to the end of the growing period (rainy season). This is particularly useful in the case of East Africa where there are two distinct annual rainy seasons.

## 4.1 Operating Principles

This chapter describes the methodology used to estimate the amount of biomass produced annually from satellite remote sensing data, as well as the weighting for usability and water accessibility.

### 4.1.1 Estimating the amount of biomass produced

The annual quantity of dry matter produced is calculated by cumulating the daily productivity values given by the 10-day period DMP. The result obtained is the total production over the year, or yield per hectare, and expressed in kg of dry matter per hectare ( $\text{kg.ha}^{-1}$ ).

$$\text{Total Biomass}_{\text{Year}}(i,j) = \frac{365.25}{36} \times \sum_{\text{10-day-period(Year)}} \text{DMP}_{10\text{-yr-per}}(i,j) \quad (4)$$

It is important to note that the system provides an estimate of biomass production over the integration period. This production value should not be confused with the amount of biomass actually present.

#### 4.1.2 Biomass Usability

Only a fraction of the total biomass produced can be used for livestock farming, due to the edible nature of plant species and the part lost through decomposition, trampling, fire, etc.

The portion of biomass actually usable for animal husbandry is given by a factor called conversion factor (5).

$$\text{UsableBiomass}_{\text{Year}}(i,j) = \text{TotalBiomass}_{\text{Year}}(i,j) \times \text{ConversionFactor}(i,j) \quad (5)$$

Literature gives a conversion factor ranging from 30% in Sudanese climate (South isohyet 600 mm) to 50% in Sahelian climate (North isohyet 400 mm) (Toutain and Lhoste, 1978).

The conversion factor is calculated based on the rainfall map produced by WorldClim - Global Climate Data ([www.worldclim.org](http://www.worldclim.org)).

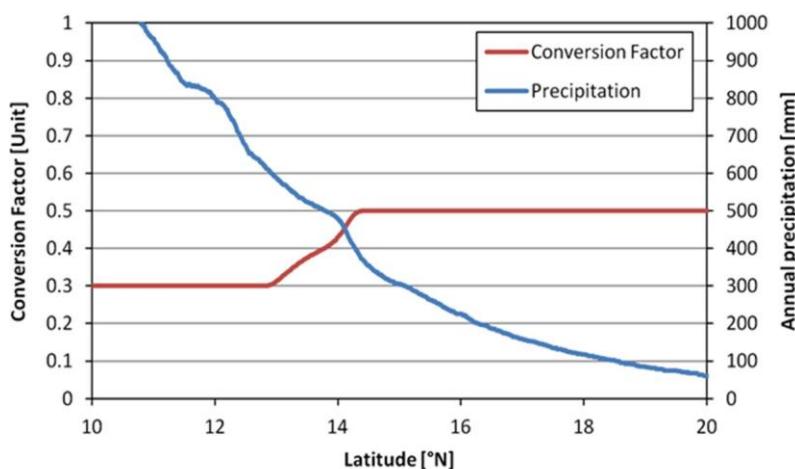


Figure 6 – Trends of usability conversion factor as a function of rainfall.

Example for a South-North transect at 0° of longitude.

BioGenerator allows setting the conversion factor values initially at 30% in Sudanese climate and 50% in Sahelian climate.

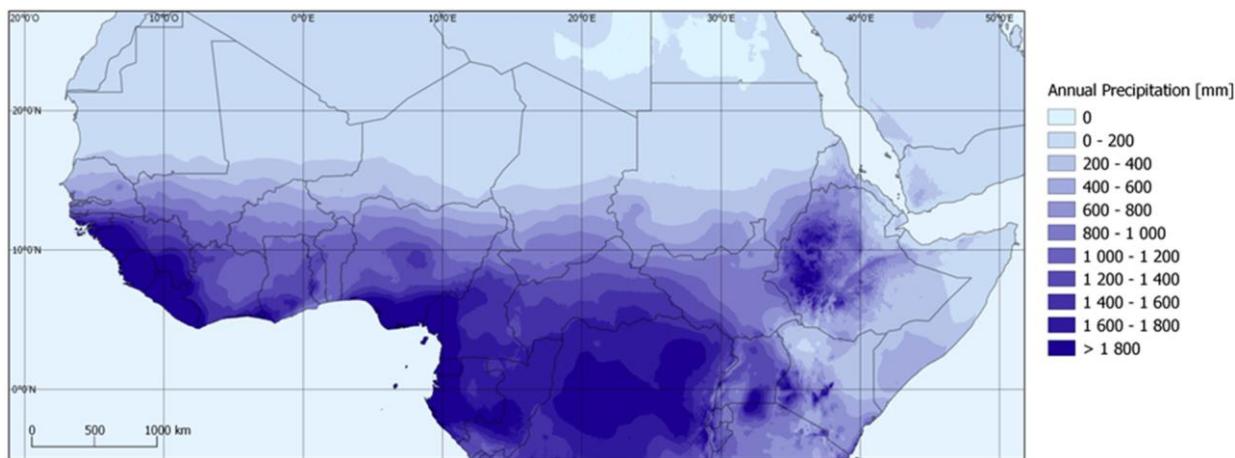


Figure 7 – Average annual rainfalls 1950 – 2000 (WorldClim – Global Climate Data)

#### 4.1.3 Biomass Accessibility

Accessible biomass is the expression of biomass production weighted by the distance to the nearest detected (surface water) or known (well, borehole) water point. The estimation of accessibility is based only on spatial distance parameters and does not take into account other accessibility aspects (financial, natural borders, administrative borders, etc.).

The presence of surface water is given by the SWB remote sensing outputs distributed by VITO. As with the DMP outputs, SWB outputs are in a ten days format, and the resolution is approximately 1x1 km. Artificial wells and water points whose position is known may be included as described in section 2.4.

The weighting of biomass production is done by creating a water presence weighting field for each of the available SWB 10-day periods. The weighting function – a Gaussian function depending on the distance to the water point – is described in the paragraph explaining how to calculate water accessibility in section 5.1.2.

## 4.2 Using the BioGenerator module

This chapter explains the settings and how to run the program.

### 4.2.1 Initializing disk space required

The first step is to download and prepare the DMP, NDVI and SWB data if the accessibility function is activated. This step is explained in section 3.2. The DeCompressor module must then be run to complete the database (see section 3.5).

The disk space required to run BioGenerator 2 is about 10 GB per year of data. It is the user’s responsibility to check that there is sufficient free disk space before running.

#### 4.2.2 Settings

The settings are accessible and can be edited in Param/BioGenerator\_Param.txt. file.

```
BioGenerator Parameters
0 2 3      Filtre_Flag NombreIterations Taille_Filtre (Default: 0 2 3)
10 9       Decade_Debut_Integration Decade_Fin_Integration (Default: 10 9)
0 15       Production_Min Production_Seuil (Default: 0 15)
0 30 50    Usable_Flag Conversion_Facteur_F0 Conversion_Facteur_F1 (Default: 0 30 50)
50          Alpha_VI (Default: 50)
0 30 100 30 1 Access_Flag Dist_Max Facteur_P1 Facteur_P1 Forages_Flag (Default: 0 30 100 30
1)
0 1         Masque_Profils (Default: 0 1)
1 1         Optimisation_Compression (Default: 1 1)
0 0         Sorties_Raw Garde_Ancien (Default: 0 0)
```

If the file is missing, or if the format is written incorrectly, an error message is reported when the BioGenerator is launched, and execution is blocked.

The settings accessible by the user are:

- The settings of the spatial smoothing function of all BioGenerator output maps. The filter used is an average filter on a circular sliding window. The filter assigns the central pixel the average of all pixels contained in the window defined by its radius in number of pixels. The filter parameters are the size and number of iterations (number of passes). This spatial filtering of output maps improves the visual occurrence by limiting, to some extent, abrupt local variations and eliminating spatial noise, but at the expense of resolution. While for a local scale study the filter should preferably be disabled, it can be enabled for a broader, regional scale study. It is preferable to favor a high number of passes (2 to 5 passes) with a reasonable window size (3 to 7 pixels).

##### Flag Filter (0: Off; 1: On)

This parameter activates or deactivates the filter.

##### Number of Iteration (Integer value between 1 and 25)

This parameter gives the number of passes of the filter.

##### Filter Size (Integer value between 1 and 11)

This parameter gives the radius of the circular sliding window in number of pixels.

- The integration period over the annual cycle defined by the first and last 10-day period. The values entered correspond to the 10-day period number between 1 and 36, the correspondence with dates is given in Table 4. If the values of the end-of-integration 10-day period is lower than that of the beginning of integration, the integration is carried out until the indicated 10-day period of the following year. By default, the integration period covers the growing season in the Sahel and West Africa subject to the West African monsoon from early April (Decade\_Debut\_Integration=10) to end of March (Decade\_Fin\_Integration=9). But, for example, if the user is interested in an analysis of the biomass production in September only, the Decade\_Debut\_Integration and Decade\_Fin\_Integration parameters should be respectively set at 25 and 27.

In the case where the value Decade\_Debut\_Integration is entered as 0, then the integration period is defined on the number of 10-day periods entered in Decade\_Fin\_Integration and until the last available DMP 10-day period. For example: if Decade\_Debut\_Integration=0 and Decade\_Fin\_Integration=9, the integration is done on 9 10-day periods since the 9 10-day periods preceding the last DMP 10-day period already downloaded.

#### Decade Debut Integration (Integer Value between 0 and 36)

This parameter gives the 10-day period of the integration start; the value 0 in the case of an integration prior to the last downloaded 10-day period.

#### Decade Fin Integration (Integer Value between 1 and 36)

This parameter gives the end of integration period. If the value 0 is entered in the parameter Decade\_Debut\_Integration, then Decade\_Fin\_Integration is the number of 10-day periods integrated up to the last downloaded 10-day period.

<b>Decade Number</b>	<b>Date</b>	<b>10-day period Number</b>	<b>Date</b>	<b>10-day period Number</b>	<b>Date</b>
<b>1</b>	01/01	<b>13</b>	01/05	<b>25</b>	01/09
<b>2</b>	11/01	<b>14</b>	11/05	<b>26</b>	11/09
<b>3</b>	21/01	<b>15</b>	21/05	<b>27</b>	21/09
<b>4</b>	01/02	<b>16</b>	01/06	<b>28</b>	01/10
<b>5</b>	11/02	<b>17</b>	11/06	<b>29</b>	11/10
<b>6</b>	21/02	<b>18</b>	21/06	<b>30</b>	21/10
<b>7</b>	01/03	<b>19</b>	01/07	<b>31</b>	01/11
<b>8</b>	11/03	<b>20</b>	11/07	<b>32</b>	11/11
<b>9</b>	21/03	<b>21</b>	21/07	<b>33</b>	21/11
<b>10</b>	01/04	<b>22</b>	01/08	<b>34</b>	01/12
<b>11</b>	11/04	<b>23</b>	11/08	<b>35</b>	11/12
<b>12</b>	21/04	<b>24</b>	21/08	<b>36</b>	21/12

Table 4 – Correspondence between the 10-day period number and the start date of the 10-day period

- The production threshold parameters allow for masking low production areas and areas where the growing season has not yet started sufficiently at the date of the last available 10-day period.

#### Production Min (Actual value, in kg/ha, positive or zero)

This parameter indicates the minimum annual average production value, expressed in kg/ha, below which the mask will be applied. In order to exclude desert areas from the analysis, the parameter can be set for example, at 50 kg/ha.

#### Production Threshold (Actual value between 0 and 100)

This parameter only influences the calculation of the anomaly of the current year. It defines a mask for areas where the growing season is not yet sufficiently advanced for reliable calculation of the anomaly. This parameter, expressed in %, indicates the production threshold that should normally be reached in relation to the average 10-day period. A more detailed explanation of this parameter is given in section 4.3.2.

- The biomass usability factor is configurable.

#### Utilisable Flag (0: Off, 1: On)

This parameter activates or deactivates the usability calculation. The usability of biomass is described in section 4.1.2.

Conversion Facteur F0 (Actual value, in %, between 0 and 100)

This parameter, expressed in %, is the conversion factor in Sahelian climate (South isohyet 600mm). The default value is 30%.

Conversion Facteur F1 (Actual value, in %, between 0 and 100)

This parameter, expressed in %, is the conversion factor in Sahelian climate (North isohyet 400 mm). The default value is 50%.

- The settings for calculating the vulnerability index (VI) is available. A more detailed description of the vulnerability index can be found in the chapter describing the BioGenerator outputs (section 4.3.3).

Alpha VI (Actual value, in %, between 0 and 100)

This parameter gives the proportion in % of the current year in the calculation of the vulnerability index. The default value i.e. 50%.

- The water availability factor of biomass is configurable. The calculation of biomass accessibility is described in sections 4.1.3 and 5.1.2.

Access Flag (0: Off, 1: On)

This parameter activates or deactivates the accessibility calculation.

Dist Max (Actual value, in km, greater than 0)

This parameter, expressed in km, gives the maximum distance of accessibility to a water point.

Conversion Facteur P1 (Actual value, in %, between 0 and 100)

This parameter, expressed in %, is the background accessibility factor for areas with aridity index from AI-5 to AI-7.

Conversion Facteur P1 (Actual value, in %, between 0 and 100)

This parameter, expressed in %, is the background accessibility factor for areas with aridity index from AI-1 to AI-2.

Forages Flag (0: Off, 1: On)

This parameter activates the inclusion of artificial boreholes in the accessibility calculation (see section 2.4).

- The mask setting activates the cutting of the *Geotiff* output raster files according to the MASK shapefile that defines the area of interest (see section 3.3). The profile setting enables saving the 10-day period DMP values in the attribute tables of the vector *Shapefiles* (see section 4.3.6).

#### Mask (0: Off, 1: On)

Activating or deactivating the mask of the area of interest.

#### Profiles (0: Off, 1: On) Activating

DMP profiles

- The optimization settings allow to accelerate the calculation time during successive BioGenerator executions, the intermediate steps being saved. On the other hand, the file volume stored on the disk is larger. The compression parameter allows reducing the size of the *Geotiff* raster file.

#### Optimization (0: Off, 1: On)

This parameter activates or deactivates the optimization function.

#### Compression (0: Off, 1: On)

This setting activates or deactivates the *Geotiff* output file compression function.

- The parameter of raw outputs is accessible. Those files are stored in the Output/Raw/Biomass/ directory in raw (.img) format with header (.hdr) file. A more detailed explanation of those outputs can be found in section 4.3.7.

#### Raw Output (0: Off, 1: On)

This setting activates or deactivates the raw outputs of all fields. Activating this parameter disables the Optimization parameter.

#### Keep Old (0: Off, 1: On)

This setting activates or deactivates the storage of files from a previous session. In case of storage, the new files created overwrite the old ones.

#### 4.2.3 Running the program

The installation of MATLAB Compiler Runtime R2016a is required before running the program. If necessary, it is required to run the installation program: Libs/Utils/MCR\_R2016a\_win64\_installer.exe.

The program is run by simply double-clicking on the executable file BioGenerator.exe. A runtime window opens, summarizing the settings used, all the identified 10-day periods used for calculation and the number of years that can be calculated from this series. A counter indicates the progress of the calculation as a percentage of the successive phases.

The Output/Biomass/Report/BioGenerator\_Report.txt file saves the information of the last run, including the time and date of the start of the calculation, in the text format.

Depending on the number of 10-day periods, the speed of the processor and speed of the hard drive and the options enabled, the calculation time may vary from 2 to 10 hours. The minimum system requirements are mainly the RAM available with a minimum of 2 GB available.

```
C:\WINDOWS\system32\cmd.exe - BioGenerator.exe
*****
*   BioGenerator 2 (v5.0)      *
* Action Contre la Faim (ACF-E)  *
*   Erwann Fillol (2017)       *
*   erwann.fillol@gmail.com   *
*****


Initialisation : OK

Filtre spatial : Nul
Integration : 0401 > 0321
Seuil Production : Min = 0 kg/ha ; Seuil = 15 %
Utilisabilite : Nul
Accessibilite : Nul
VI Vulnerabilite : 50 %
Decades : 19980401 > 20171101
Nombre de decades : 706
Annees : 1998 > 2017

Calcul principal : 100 %
Ecriture : 100 % (3/3)
Temps execution : 2 h 0 mm

Operations terminees.
```

Figure 8 – BioGenerator 2 (v5.1) module runtime window.

## 4.3 Output files

BioGenerator produces output files in three different formats: image format, spreadsheet format and vector format.

- Files in image format

The image or raster files are *geotiff* (.tiff), following a Lat/Lon geographical projection using the WGS-84 datum. The resolution is 30" of arc, or about 1x1 km. The window's boundary coordinates are given in Table 1. The data encoding is in 32-bits little endian floating point. If the option is activated, the files are compressed (lossless compression LZW).

- File in spreadsheet format

Files in spreadsheet (.csv) format can be viewed with a text editor or with a spreadsheet software such as Excel. The spreadsheet files correspond to the vectors defined in the ADM\_n and GEO\_n *shapefiles* and indicate the total biomass production and vulnerability index for each polygon of these vector files. The column separator is the semicolon.

- Files in vector format

Vector files are *shapefiles* (.shp) containing polygons with an attribute table. The projection is geographical Lat/Lon using the WGS-84 datum. The data produced in vector format *shapefiles* includes each of the ADM\_n and GEO\_n files, adding an attribute table containing, for each polygon, the total biomass production, the vulnerability index, as well as the average 10-day period value of DMP if the "profile" option is activated.

### 4.3.1 Biomass quantity maps

The output field of the quantity of biomass produced, equivalent to a yield and expressed in kg of dry matter per hectare ( $\text{kgMS.ha}^{-1}$ ), is given for each year in the series and for the average of those years.

The amount of yearly biomass produced is calculated as the cumulative daily productivity over the growing season  $\text{kg.ha}^{-1}\text{jour}^{-1}$ ) given by the DMP 10-day periods. The growing season of a year is defined by the user. The default settings define the growing season from the first 10-day period of April to the last 10-day period of March the following year, which corresponds to the West African rainy season or West African monsoon.

The produced biomass quantity calculated for the current year, and for which the DMP 10-day periods would not yet be available over the entire growing season, is supplemented, over the missing period, by the average productivity measured over previous years. Consequently, the biomass quantity map for the current year, depending on the number of 10-day periods available for that year, is an estimate of the actual total production.

The biomass quantity output files are in *geotiff* (.tiff) format, possibly compressed, in flat square Lat/Lon WGS-84 geographical projection and with a spatial resolution of 1x1 km. The file position is given in Table 5; the possible values are given in Table 6.

Files	Directory	Nomenclature
<b>Biomass year yyyy</b>		Biomass_yyyy.tif
<b>Biomass average</b>	Output/Biomass/Biomass/	Biomass_Mean.tif

Table 5 – Nomenclature of biomass quantity files

Value	Meaning	Unit
[0 , +∞[	Biomass quantity	( $\text{kg.ha}^{-1}$ )
-9999	Ocean, open water	-
-9995	Hiding value outside the area of interest	-

Table 6 – Table of possible values in the biomass quantity files

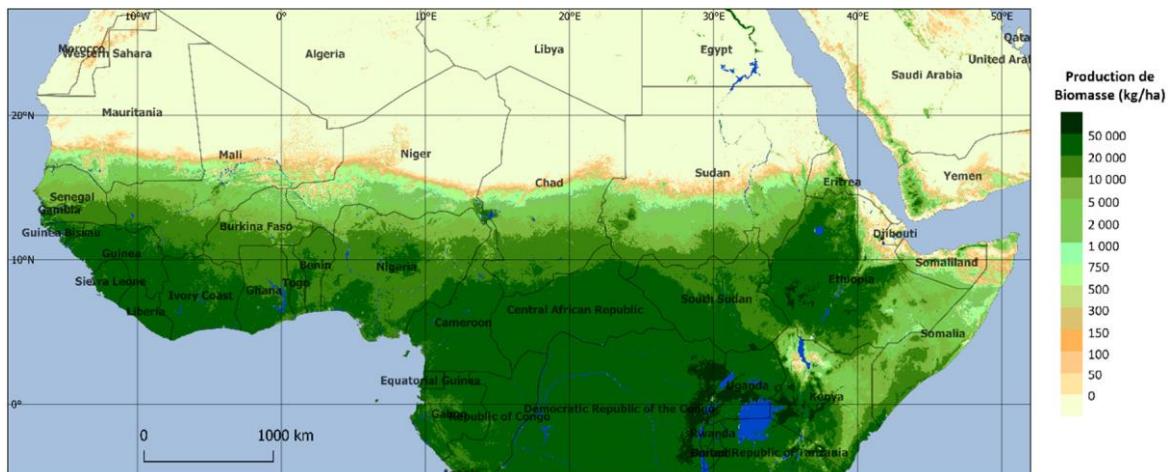


Figure 9 – Average biomass map 1998-2017

#### 4.3.2 Biomass anomaly map

The BioGenerator gives the biomass production anomaly for each year. The anomaly is a comparison of biomass production in the year under consideration with the average calculated over all available years. Two representations of the anomaly are produced:

- The anomaly (%) expresses as a percentage of the production ratio for the year considered compared to the average and with a maximum threshold at 200%.
- The sigma ( $\sigma$ ) anomaly expresses the difference of the year under consideration from the average in the number of standard deviations calculated over the period. Thresholding is carried out between -10 and +10.

In areas where production is always zero (desert areas), the output value of the anomaly file is set to -9998.

The current year is inherently not complete, i.e. not all the 10-day periods up to the end of the integration period (Decade\_Fin\_Integration) are necessarily available yet. For the current year, and only for that one, the anomaly is calculated from the 10-day periods available since the beginning of the growing season (Decade\_Debut\_Integration) up to the last 10-day period present in the database. In order to ensure that the value of the anomaly thus calculated remains meaningful, its calculation does not begin until a threshold of the average annual production, calculated over the integration period, has already been reached. That threshold is obtained from Production\_Seuil (%). Otherwise, if the threshold is not reached, the value -9997 is assigned to the pixel. In other words, this threshold corresponds to the

fact that, as of the date of the last available 10-day period, the growing season has not yet started sufficiently at that location to establish a significant anomaly calculation.

A second mask can be applied: the anomaly is calculated only on areas exceeding a minimum average production given by the Production\_Min parameter ( $\text{kg.ha}^{-1}$ ). The lower production areas are hidden with the value -9996. Table 7 shows the position of biomass anomaly files, while Table 8 gives the possible values in those files.

Files	Directory	Nomenclature
<b>Anomaly [%] year yyyy</b>	Output/Biomass/Anomaly	Anomaly_yyyy.tif
<b>Anomaly [<math>\sigma</math>] year yyyy</b>		AnomalySigma_yyyy.tif

Table 7 – Nomenclature of biomass anomaly files

Value	Meaning	Unit
[0 , 200]	Anomaly (%)	(%)
[-10 , +10]	Anomaly ( $\sigma$ )	( $\sigma$ )
-9999	Ocean, open water	-
-9998	Biomass always zero	-
-9997	Growing season not sufficiently started	-
-9996	Total average production too low	-
-9995	Hiding value outside the area of interest	-

Table 8 – Table of possible values in biomass anomaly files (%) and ( $\sigma$ )

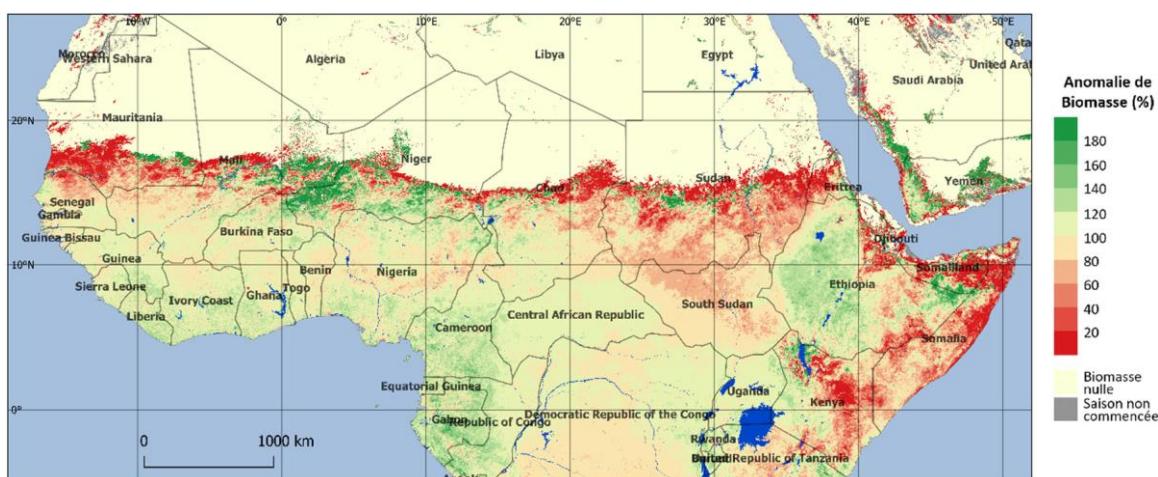


Figure 10 – Biomass production anomaly map for 2017

Figure 10 shows the biomass production anomaly map for the year 2017. The integration period chosen is from the beginning of April to the end of March. The average production is calculated over the period covered by the database. Areas appearing in green show excess biomass production, up to 200% of the mean production, while areas appearing in red show production below the average, up to 0% of the mean production. The areas marked *No Biomass* always have zero production over the period.

#### 4.3.3 Vulnerability Index (VI) Map

The vulnerability index is created to compensate for a simple analysis per anomaly that compares the current year to all previous years, without considering the sequence of anomalies. Indeed, livestock farmers are more sensitive to a succession of droughts than to a single isolated event.

The VI principle is based on a recursive calculation described by equation (6). For each year, the input to the calculation of the  $VI_{Year}$  indicator is the sum of weighting between the anomaly of the year considered  $AN_{Year}$  and the vulnerability index calculated for the previous year ( $VI_{Year-1}$ ). The relative input of those two terms is given by the single  $\alpha_{VI}$  parameter.

The  $AN_{Year}$  anomaly is calculated as the ratio of the production of the year under consideration to the weighted and normalized average of previous years as described by equation (7).  $AN_{Year}$  can have a value between -1 for a year with high deficit and +1 for a year with high surplus.

The condition for the recursivity limit is given a zero-vulnerability value for the starting year of the series (equation (8)).

Thus constructed, the VI index is sensitive to a succession of negative or positive anomalies and is able to identify areas of high vulnerability with consecutive negative anomalies. Also, since the VI is calculated from previous years using a decreasing weighting, there is very little sensitivity to an overall trend.

$$VI_{Year} = \alpha_{VI} \times AN_{Year} + (1 - \alpha_{VI}) \times VI_{Year-1} \quad (6)$$

With:

$$AN_{Year} = \frac{\text{Biomasse}_{Year}}{\frac{\sum_{Y=Year}^{1998} (1 - \alpha_{VI})^{(Year-Y)} x \text{Biomasse}_Y}{\sum_{Y=Year}^{1998} (1 - \alpha_{VI})^{(Year-Y)}}} - 1 \quad (7)$$

And as a limit:  $VI_{1998} = 0$  (8)

Table 9 shows the trend according to the  $\alpha_{VI}$  coefficient of the number of years, including the current year, of which the input is greater than 1% in the calculation of the vulnerability index.

$\alpha_{VI}$	<b>0.1</b>	<b>0.2</b>	<b>0.3</b>	<b>0.4</b>	<b>0.5</b>	<b>0.6</b>	<b>0.7</b>	<b>0.8</b>	<b>0.9</b>
<b>Number of years</b>	23	14	10	8	6	5	4	3	2

Table 9 – Number of previous years with contribution greater than 1% based on the  $\alpha_{VI}$  coefficient.

Figure 11 shows the progression of the input of each of the previous years and the current year (Year 0) in calculating the VI for three different values of the  $\alpha_{VI}$  parameter: 25%, 50% and 75%.

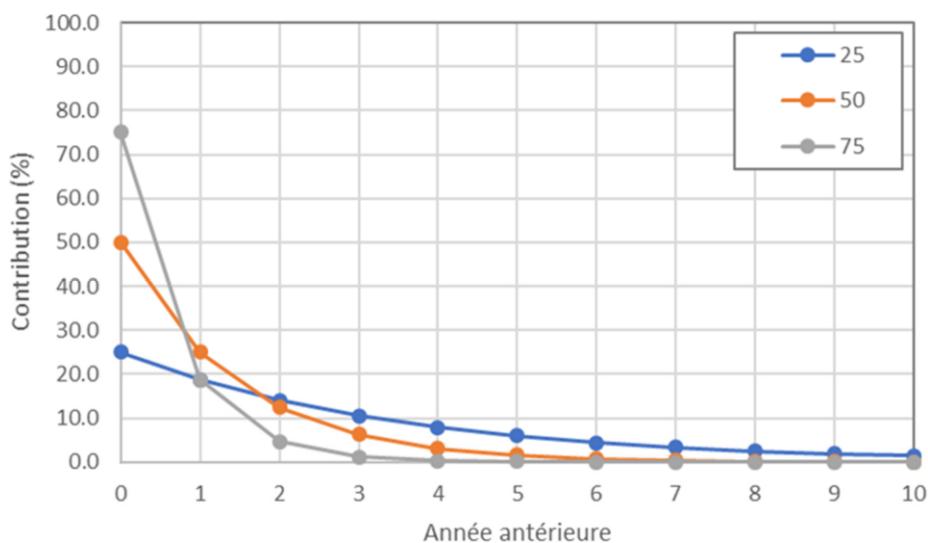


Figure 11 – Progression of previous years contribution to calculating the VI for  $\alpha_{VI} = 25, 50$  and  $75\%$

Due to its construction based on a sensitivity to the sequence of previous events in the year under consideration, the advantages of the vulnerability index over a simple calculation of the biomass anomaly are:

- Taking into account consecutive drought events
- Insensitivity to the long-term trend
- Low sensitivity to a dry or wet event far away in time
- Invariability of the vulnerability index of previous years when adding new 10-day periods

Files	Directory	Nomenclature
<b>VI year yyyy</b>	Output/Biomass/VI/	VI_yyyy.tif

Table 10 – Nomenclature of VI files

Value	Meaning	Unit
<b>[-1 , 1]</b>	VI	[Unit]
<b>-9999</b>	Ocean, open water	-
<b>-9998</b>	Biomass always zero	-
<b>-9997</b>	Growing season not sufficiently started	-
<b>-9996</b>	Total mean production too low	-
<b>-9995</b>	Hiding value outside area of interest	-

Table 11 – Table of possible values in VI files

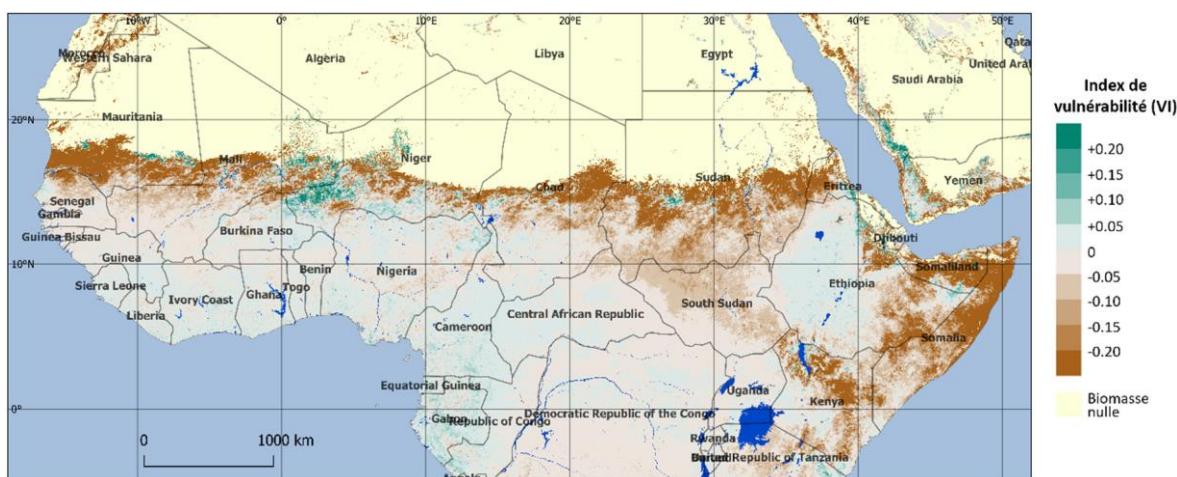


Figure 12 – Vulnerability Index Map for 2017

Figure 12 shows a map of the vulnerability index for the year 2017 based on the growing season in the Sahel (early April to End of March) and with a  $\alpha_{VI} = 50\%$  coefficient. On this map, the areas appearing brown have a VI below 0, which means a higher vulnerability. In those areas, biomass production has certainly been low for several consecutive years and close to the year 2017. On the other hand, the areas appearing in green have a positive VI coefficient, which means a favorable situation and have been so for several years.

#### 4.3.4 Map of statistical analysis settings

BioGenerator 2 calculates the output fields of interannual standard deviation of biomass production, interannual trend, and interannual time correlation. The interannual trend is given under two expressions of different units:

- Absolute trend expressed in  $\text{kg.ha}^{-1}.\text{year}^{-1}$
- Relative trend to the average expressed as  $\%.\text{year}^{-1}$

The temporal correlation is the  $R^2$  correlation coefficient between biomass production and the year. This correlation coefficient quantifies the stability of the time trend.

Files	Directory	Nomenclature
<b>Standard deviation (<math>\sigma</math>)</b>	Output/Biomass/Stat/	Sigma.tif
<b>Trend</b>		Trend.tif
<b>Trend (%)</b>		TrendPercent.tif
<b>Temporal Correlation (<math>R^2</math>)</b>		TrendR2.tif

Table 12 – Nomenclature of statistical analysis files

Value	Meaning	Unit
<b>[ -inf , +inf [</b>	Standard deviation	$(\text{kg.ha}^{-1})$
<b>[ -inf , +inf [</b>	Time trend	$(\text{kg.ha}^{-1}.\text{year}^{-1})$
<b>[ -inf , +inf [</b>	Time trend (%)	$(\%.\text{year}^{-1})$
<b>[0 , 1]</b>	Time Correlation $R^2$	No unit
<b>-9999</b>	Ocean, open water	-
<b>-9998</b>	Biomass always zero	-
<b>-9995</b>	Hiding value outside area of interest	-

Table 13 – Table of possible values in statistical analysis files

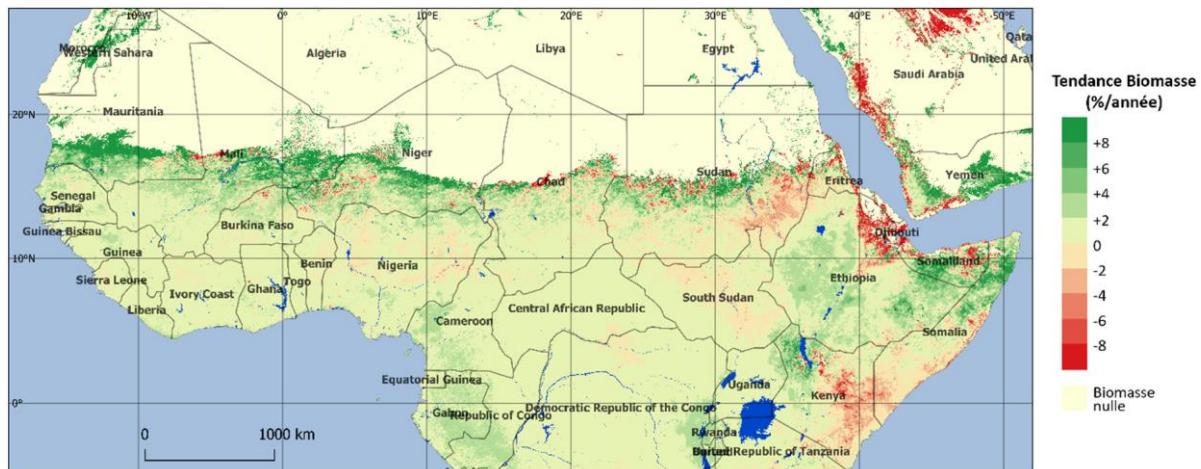


Figure 13 – Map of biomass production trend calculated between 1998 and 2017

Figure 13 shows the relative trend calculated between 1998 and 2017. On this map, the green area shows an increase in annual biomass production that can exceed +8%/year. In the areas in red, a decrease in biomass production of -8%/year is calculated. Between 1998 and 2017 there was a significant increase in biomass production, particularly in the Sahel region of West Africa.

#### 4.3.5 Biomass production and vulnerability index profiles

BioGenerator 2 generates output files for total biomass production and mean vulnerability index following the level 0, 1, 2 administrative divisions and following the user-defined polygons.

The output files, presented in Table 14 are in .csv format and the semicolon is used as a column separator. Those files can be opened directly by a spreadsheet software such as Excel.

Figure 14 and Figure 15 are showing extracts from those output files respectively for total biomass and for the mean vulnerability index following the level 0 administrative division (Country).

The quantity of biomass is the total quantity produced on the polygon, expressed in metric tons and considering the total surface area.

The vulnerability index is the average of the vulnerability index calculated on the entire polygon. For an area that is always desert, with zero production, the flag value -9999 is entered.

Fields	Polygons	Directory	File
<b>Biomass</b>	ADM_0	Output/Biomass/Report/	Biomass_ADM_0.csv
	ADM_1		Biomass_ADM_1.csv
	ADM_2		Biomass_ADM_2.csv
	GEO_3		Biomass_GEO_3.csv
	GEO_4		Biomass_GEO_4.csv
	GEO_5		Biomass_GEO_5.csv
<b>Vulnerability Index VI</b>	ADM_0		VI_ADM_0.csv
	ADM_1		VI_ADM_1.csv
	ADM_2		VI_ADM_2.csv
	GEO_3		VI_GEO_3.csv
	GEO_4		VI_GEO_4.csv
	GEO_5		VI_GEO_5.csv

Table 14 – Total biomass production and mean vulnerability index output files

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	
1	Source:	Lib\Ancillary\Img\ADM_0_img																							
2	Nb_entities:	9																							
3	Biomass_Prc [tons]																								
4																									
5	NAME	IDBIOHYDRO AREA[sqkm]	MEAN	BIO_1998	BIO_1999	BIO_2000	BIO_2001	BIO_2002	BIO_2003	BIO_2004	BIO_2005	BIO_2006	BIO_2007	BIO_2008	BIO_2009	BIO_2010	BIO_2011	BIO_2012	BIO_2013	BIO_2014	BIO_2015	BIO_2016	BIO_2017		
6	Chad	1	1268197	605576408	546979884	685509341	582048458	537307437	509831508	587612578	539025196	554149535	666993636	595779378	699358424	614522654	716215710	656705710	654206505	622745705	617572928	598911219			
7	Senegal	2	195555	182710964	139054683	176542409	179385494	151671243	122759390	167185360	173728450	184987083	165218239	166414435	226961857	211658874	234841324	195196352	224433333	214676246	173159933	18521479	184544198	175751146	
8	Niger	3	1182165	70249755	61233217	87649654	49120976	52485110	51378060	73580275	47847745	68293507	62052462	66336477	75834216	56434838	93824626	64230515	94393865	83038478	79737581	81236151	78204371	81246706	
9	Nigeria	4	908919	18040600	12380609	1254409	1256109	13380609	1388109	1332409	12897109	1312409	1305409	1305409	1305409	1305409	1305409	1305409	1305409	1305409	1305409	1305409	1305409		
10	Cameroon	5	468186	12376109	1145409	12376109	12376109	12376109	12376109	12376109	12376109	12376109	12376109	12376109	12376109	12376109	12376109	12376109	12376109	12376109	12376109	12376109	12376109		
11	Mali	6	1248110	443772569	378572152	466945312	408695885	359374903	316435358	433190355	370503770	393147972	403505809	417561587	533681814	507281141	538848476	432724346	491880211	46590520	504212779	470367342	437189120		
12	Burkina_Faso	7	274632	269632324	252362183	269732264	254987309	267291291	214156277	268678413	250540355	241737410	252887764	248118437	302742384	320755766	263909100	306759958	293773933	280940866	27878867	278229478	280949906		
13	Mauritania	8	1042035	31772381	17438580	34874017	24779143	18876524	84074704	34491841	23268979	25232978	35012761	40409709	44779189	54302206	51577082	40711022	42127044	40189103	21906240				
14	Gambia	9	11297	14549808	12006116	14392969	14589722	13134009	11512446	13803562	14236158	14249635	13574038	17195532	15778404	16721580	14922294	16563529	16272014	14248676	15025278	14810195	14060582		

Figure 14 – Extract from total biomass output file  
Output/Biomass/Report/Biomass\_ADM\_0.csv

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	
1	Source:	Lib\Ancillary\Img\ADM_0_img																						
2	Nb_entities:	9																						
3	Vulnerability [No Unit]																							
4																								
5	NAME	IDBIOHYDRCAREA[sqkm]	VI_1998	VI_1999	VI_2000	VI_2001	VI_2002	VI_2003	VI_2004	VI_2005	VI_2006	VI_2007	VI_2008	VI_2009	VI_2010	VI_2011	VI_2012	VI_2013	VI_2014	VI_2015	VI_2016	VI_2017		
6	Chad	1	1268197	0	0.088	-0.124	-0.123	-0.182	0.02	0.112	0.15	-0.051	-0.115	-0.009	0.037	-0.107	0.047	-0.078	0.022	-0.019	-0.026	-0.076	0.088	-0.125
7	Senegal	2	195555	0	0.043	0.046	-0.018	-0.125	-0.005	0.02	0.063	0.003	-0.004	0.07	0.062	0.082	-0.003	0.02	-0.001	-0.095	-0.064	-0.033	-0.052	
8	Niger	3	1182165	0	0.111	-0.197	-0.205	-0.295	-0.133	-0.242	-0.129	-0.151	0.018	-0.045	-0.205	0.031	-0.133	0.018	-0.028	-0.065	-0.052	-0.1	-0.08	
9	Nigeria	4	908919	0	0.018	0.001	-0.011	0	0.022	0.002	-0.002	-0.005	-0.01	0.036	0.032	0.028	-0.006	0.006	-0.001	-0.002	-0.023	-0.01	-0.006	
10	Cameroon	5	468186	0	0.023	0.008	0.013	0.018	0.015	0.016	-0.001	0.012	0.007	0.003	0.034	0.02	0.001	0.009	0.004	0.008	0	-0.004	0.01	
11	Mali	6	1248110	0	0.129	-0.083	-0.144	-0.241	-0.088	-0.116	-0.096	-0.056	-0.006	-0.018	-0.061	0.058	-0.073	-0.02	-0.055	-0.11	-0.006	-0.064	-0.099	
12	Burkina_Faso	7	274632	0	0.018	-0.025	-0.052	-0.084	0.018	-0.01	-0.003	-0.001	0.011	0.061	0.041	0.054	-0.022	0.016	0.008	-0.02	-0.016	-0.017	-0.016	
13	Mauritania	8	1042035	0	0.149	-0.053	-0.186	-0.413	0.056	-0.182	-0.155	-0.096	0.022	-0.054	0.021	0.163	-0.21	-0.037	-0.047	-0.251	-0.098	-0.129	-0.291	
14	Gambia	9	11297	0	0.059	0.031	-0.006	-0.049	0.004	0.023	0.007	-0.001	0.058	0.034	0.034	-0.005	0.013	0.008	-0.032	-0.019	-0.02	-0.026		

Figure 15 – Extract from total biomass output file  
Output/Biomass/Report/VI\_ADM\_0.csv

In each of the files, a header recalls the source *shapefile*, the number of entities located and the unit of output values. For the production of total biomass, the unit is the metric ton of dry matter.

From these output files, it is possible to trace the temporal progression of the total

biomass and the average vulnerability index at different administrative levels (ADM\_n) and user polygons (GEO\_n). Figure 16 is an example of profiles measured for Mali between 1998 and 2017.

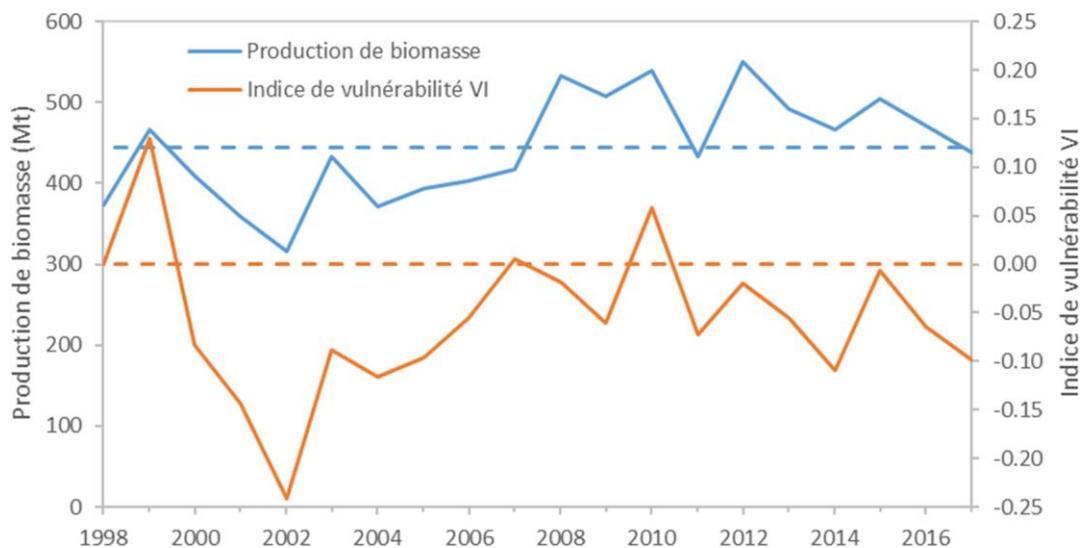


Figure 16 – Time profiles of total biomass production and average vulnerability index for Mali

#### 4.3.6 Outputs in vector format

BioGenerator generates vector outputs of biomass production and vulnerability index values. The vector polygons used are ADM\_0, ADM\_1, ADM\_2 and GEO\_3, GEO\_4 and GEO\_5 as described in paragraph 3.3.

The outputs in vector format *shapefile* (shp) are located in the Output/Biomass/Shape/ directory. The attribute table contains the information already described in section 4.3.5 concerning .csv outputs.

If the “Profiles” option is activated (see section 4.2.2.), the attribute table is completed by the 10-day average biomass production values on each polygon. These production values are weighted by accessibility and usability factors if the features are enabled (see section 4.2.2). In addition to those 10-day values, the attribute table records, for each of the 36 10-day periods of the year, the interannual statistical values of maximum, minimum and average production, as well as the standard deviation. Table 15 lists all the variables listed in the attribute table of the BioGenerator’s output vector files.

Name	Description	Frequency	Unit
<b>Area</b>	Polygon area	Once	Km <sup>2</sup>
<b>YEAR_FIRST</b>	First year of the series		Year
<b>YEAR_LAST</b>	Last year of the series		
<b>BIO_MEAN</b>	Mean biomass annual production		Metric tons of dry matter
<b>BIO_yyyy</b>	Annual biomass production in year yyyy	Annual	
<b>VI_yyyy</b>	Annual vulnerability index in year yyyy		Unitary
<b>DMP_MEA_dd</b>	Average interannual 10-day period production for 10-day period dd (*)	Decadal 36 values	
<b>DMP_MIN_dd</b>	Minimum interannual 10-day period production for 10-day period dd (*)		kg.ha <sup>-1</sup> .jour <sup>-1</sup>
<b>DMP_MAX_dd</b>	Maximum interannual 10-day period production for 10-day period dd (*)		
<b>DMP_STD_dd</b>	Interannual standard deviation of 10-day period production for 10-day period dd (*)		
<b>DMP_FIRST</b>	First 10-day period of the time series (*)	Once	yyyydd
<b>DMP_LAST</b>	Last 10-day period of the time series (*)		
<b>DMP_yyyydd</b>	Decadal production for 10-day period dd in year yyyy (*)	Decadal	kg.ha <sup>-1</sup> .jour <sup>-1</sup>

Table 15 – Composition of the attribute table of BioGenerator output vector files (\* only if the “profiles” option is enabled)

Figure 17 shows a vector display of the vulnerability index for 2017. In this figure, for the Niger inner delta, the baseline vector is at administrative level 2 (department).

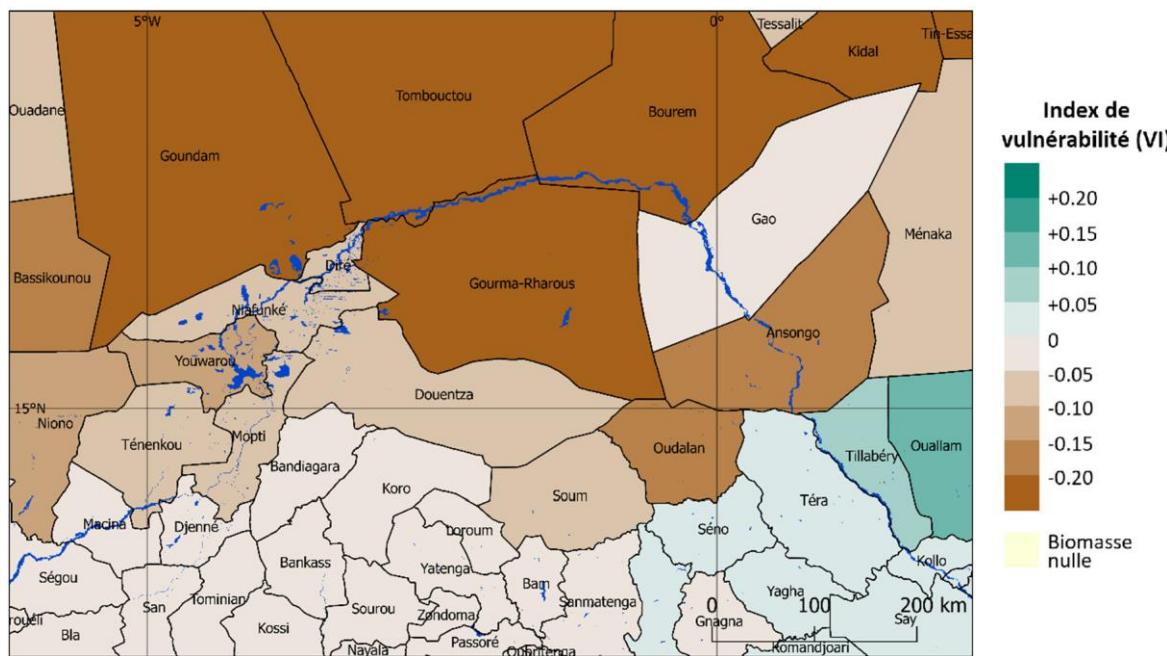


Figure 17 – Vectorial representation of the Vulnerability Index (VI) for the second administrative level (department) in Niger inner delta.

#### 4.3.7 Raw outputs

By activating the option in the settings, it is possible to keep the raw files from the intermediate calculations of BioGenerator 2.

Those files are in raw format and come in the form of an image file (.img) and a header file (.hdr). The size of the files is the same as the one of the input files (Table 1). The data encoding is in 32 bits little endian floating point. The flag value -9999.0 means no data.

Those raw output files can be used by advanced users for further studies, in particular on 10-day period time profiles, for development, cross-checking and debugging.

It is important to note that this option, in addition to an increased calculation time, results in a much larger output file size: about 15 GB more per year of data.

The description of those files, as well as their location, are given in Table 16.

Name	Description	Directory	Nomenclature
Annual biomass	Annual Biomass	Data/Raw/Biomass/Biomass/	Biomass_yyyy
Average biomass	Average calculated on the number of years available	Data/Raw/Biomass/Biomass/	Biomass_Mean
Annual anomaly	Ratio of annual biomass of average biomass	Data/Raw/Biomass/Anomaly/	Anomaly_yyyy
Annual anomaly [σ]	Biomass deviation to the mean standard deviation	Data/Raw/Biomass/Anomaly/	AnomalySigma_yyyy
Vulnerability Index	Vulnerability Index	Data/Raw/Biomass/VI/	VI_yyyy
Standard deviation	Interannual standard deviation	Data/Raw/Biomass/Stat/	Sigma
Trend	Annual trend calculated over the period	Data/Raw/Biomass/Stat/	Trend
Trend %	Annual trend calculated over the period and expressed in %	Data/Raw/Biomass/Stat/	TrendPercent
Time correlation	Annual biomass correlation coefficient	Data/Raw/Biomass/Stat/	TrendR2
DMP filter	Values of filtered DMP	Data/Raw/Biomass/Filter/DMP/	DMP_yyyymmdd
NDVI filter	Values of filtered NDVI	Data/Raw/Biomass/Filter/NDVI/	NDVI_yyyymmdd
Cumulative DMP	Values of cumulative DMP over the growing season	Data/Raw/Biomass/Cumul/	Cumul_yyyymmdd
DMP type	Values of DMP over the mean year (typical year)	Data/Raw/Biomass/Type/DMP/	DMP_mmdd
NDVI type	Values of NDVI over the mean year (typical year)	Data/Raw/Biomass/Type/NDVI/	NDVI_mmdd
Weighted DMP	Value DMP filtered and weighted by water accessibility	Data/Raw/Biomass/Ponderate/	DMP_yyyymmdd
Accessibility	Weighting Values by water availability	Data/Raw/Water/WaterAccess /	WaterAccess_yyyymmdd
Average accessibilit	Typical values of weighting by water accessibility	Data/Raw/Water/WaterAccessType/	WaterAccessType_mmdd

Table 16 – All raw data from BioGenerator and meaning

## 4.4 Validation of biomass values

Comparison of biomass maps with biomass quantity measurements *in situ* allows a validation of the BioGenerator outputs.

A series of *in situ* biomass measurement campaigns were carried out by CESBIO (Centre d’Etude Spatial de la BIOsphère) in Mali for the years 1999-2002, by DDP (Division Développement Pastoral) in Niger between 1998 and 2015 and the CSE (Centre de Suivi Ecologique) in Senegal between 2010 and 2015.

All years and all sites combined, a set of 962 point measurements on about 60 sites was used for the validation work. The sites are distributed into grassland to sparse grassland and croplands with production values (or yield per hectare) of biomass ranging from 0 to 7000 kg.ha<sup>-1</sup>. Figure 18 shows the location of those sites.

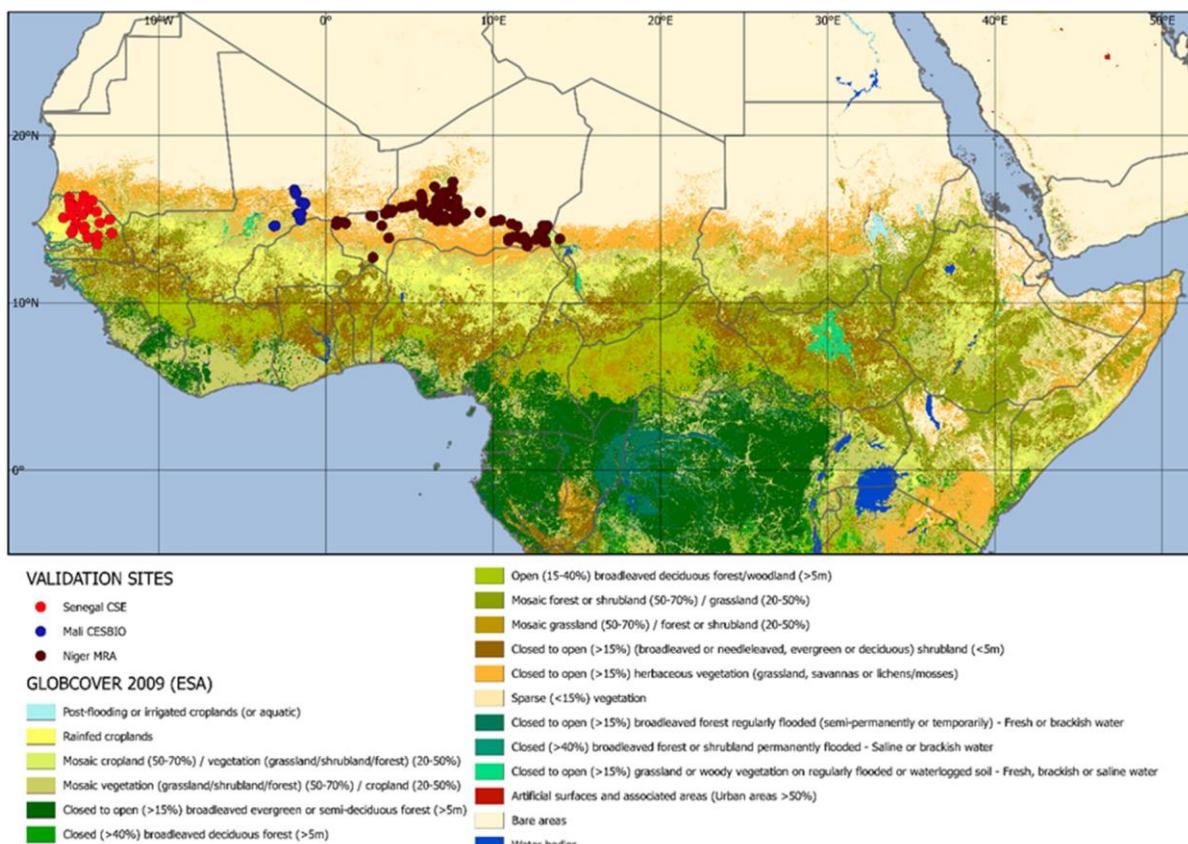


Figure 18 – Location of biomass measurement sites

The linear regression comparison shows an overall correlation coefficient ( $R^2$ ) of 0.86 and a mean square error RMSE = 393 kg.ha<sup>-1</sup> (Table 17).

	Year	Number of measurements	$R^2$	RMSE (kg.ha <sup>-1</sup> )
<b>CESBIO Mali</b>	1999	7	0.46	449
	2000	12	0.80	228
	2001	10	0.98	263
	2002	12	0.77	268
	<b>Total</b>	<b>41</b>	<b>0.83</b>	<b>296</b>
<b>DDP Niger</b>	1998	23	0.32	464
	1999	14	0.66	344
	2000	44	0.18	383
	2001	50	0.42	403
	2002	56	0.36	375
	2003	30	0.41	378
	2004	44	0.37	261
	2005	52	0.42	404
	2006	50	0.74	280
	2007	42	0.13	448
	2008	48	0.48	415
	2009	61	0.17	396
	2010	48	0.69	412
	2011	57	0.29	390
	2012	49	0.56	453
	2013	53	0.49	466
	2014	49	0.64	417
	2015	54	0.61	412
	<b>Total</b>	<b>824</b>	<b>0.53</b>	<b>399</b>
<b>CSE Senegal</b>	2010	12	0.95	455
	2011	20	0.98	338
	2012	12	0.95	444
	2013	18	0.97	368
	2014	14	0.99	210
	<b>Total</b>	<b>97</b>	<b>0.96</b>	<b>379</b>
	<b>Total SPOT-VGT</b>	<b>824</b>	<b>0.83</b>	<b>392</b>
	<b>Total PROBA-V</b>	<b>138</b>	<b>0.92</b>	<b>399</b>
	<b>Grand Total</b>	<b>962</b>	<b>0.86</b>	<b>393</b>

Table 17 – Validation summary table

The *Root Mean Square Error* is a statistical indicator that characterizes the accuracy of an estimation. It is calculated according to equation (9).

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (\text{Biomass}_{\text{estimated}} - \text{Biomass}_{\text{measured}})^2}{n}} \quad (9)$$

Where n is the number of biomass measurement points.

Over this range of biomass quantity values, the dispersion of values does not show significant bias. In this sense, the biomass quantity values from BioGenerator 2 seem realistic.

There is no significant difference when the SPOT-VEGETATION is switched to the PROBA-V satellite in 2014. Correlation and square error values remain comparable.

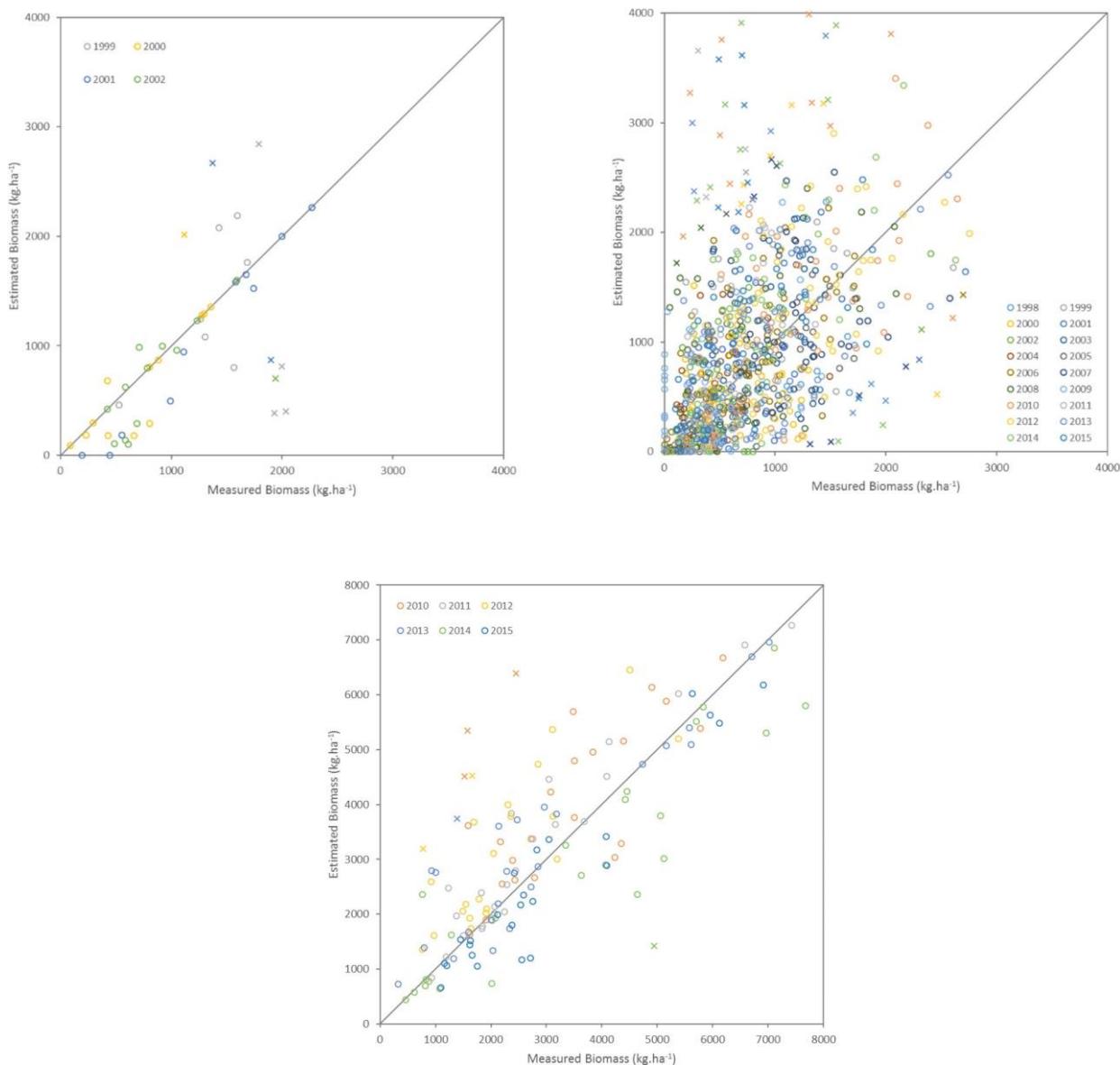


Figure 19 – Scatter diagrams  
(Mali on the left, Niger on the right and Senegal at the bottom)

## 4.5 Examples of use

This section presents three examples of how the BioGenerator 2 program can be used. This first example concerns the creation of a biomass production anomaly map for the current year (2017). A second example shows the creation of a time profile of biomass production on the Gourma-Rharous “Circle” (administrative level 2). Finally, the creation of maps of accessible and inaccessible average in northern Mali is shown.

### 4.5.1 Creating a Biomass Anomaly Map

The first example shows how to create a map of the biomass production anomaly for the current year (2017) in Northern Mali without taking into account accessibility and usability factors.

1. Downloading the new NDVI and DMP 10-day periods: The new available 10-day periods must be downloaded according to the instructions in Chapter 3.
2. BioGenerator settings: The most important parameters are those defining the integration period. They must control the vegetation growing period (rainy season). In Mali, under the West-African monsoon regime, the numbers of 10-day periods 10 and 9 are chosen respectively for Decade\_Debut\_Integration and Decade\_Fin\_Integration. To calculate the total biomass production, the usability and accessibility options must be disabled: (0 for Utilisable\_Flag).
3. Program running: Following the instructions in section 4.2.3
4. Using GIS software to create the map: Using GIS software such as QGIS allows displaying and formatting the map. A QGIS project template (including styles) can be found in the GIS/QGIS Project/ directory. The *geotiff* file to be retrieved is the file of biomass production anomaly expressed in % for the year 2017 as described in section 4.3.2.

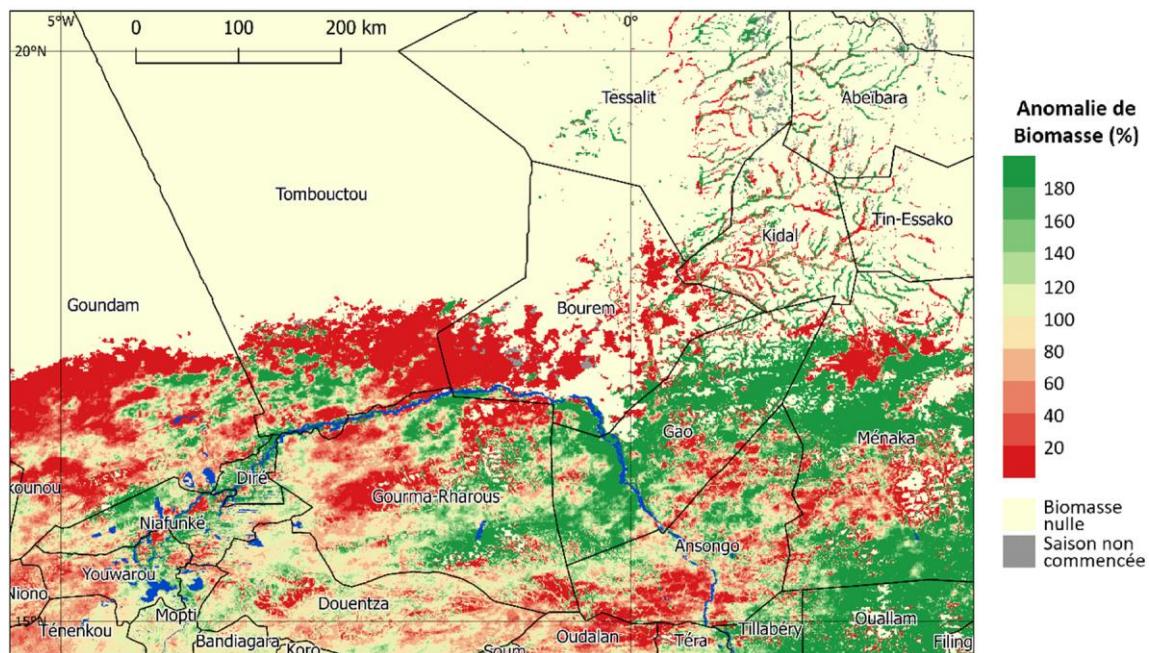


Figure 20 – Biomass production anomaly in North Mali for the year 2017 compared to the average calculated between 1998 and 2017.

#### 4.5.2 Creating a time profile on an administrative entity

This second example of using BioGenerator 2 follows the first and aims to create a time profile of biomass production on a level 2 administrative entity (department or circle). Here, the *circle* of interest is Gourma-Rharous. The vulnerability index profile is also superimposed onto the total biomass production profile.

5. Opening output files in a spreadsheet: .csv files refer to administrative level 2 (ADM\_2) for biomass and VI (section 4.3.5). In those files, directly accessible on a spreadsheet such as Microsoft Excel, the lines corresponding to the Gourma-Rharous *circle* generate, for the first file, the total biomass production for each year, and for the second, the vulnerability index VI.

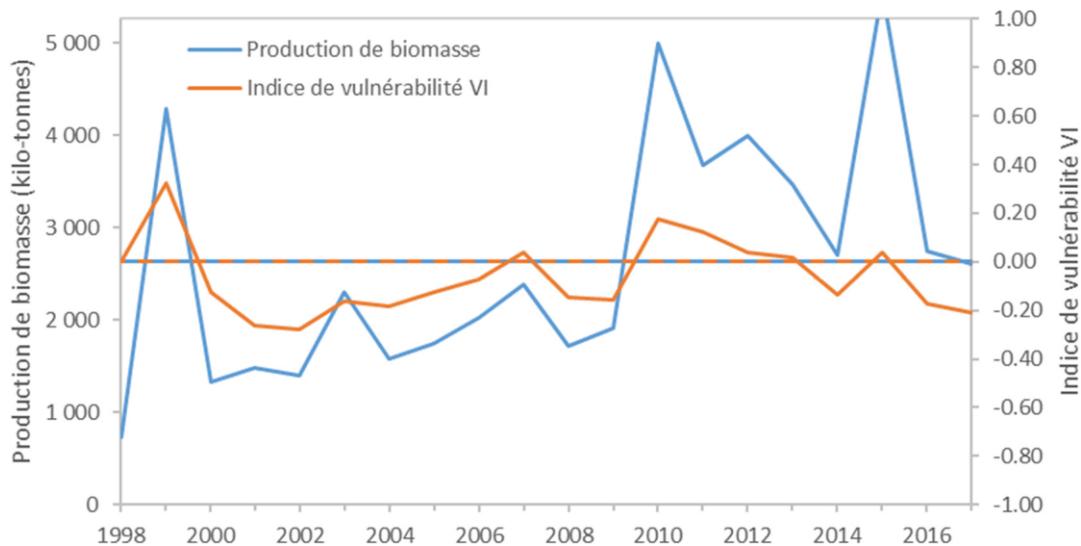


Figure 21 – Time profile of total biomass production and vulnerability index on the Gourma-Rharous circle.

#### 4.5.3 Creating accessible and inaccessible biomass maps

This last example follows the two others. The aim here is to create an accessible biomass map, i.e. weighted by distance from surface water points and wells. A second objective is to create a map of inaccessible biomass, i.e. too far from a natural or artificial water point. Inaccessible biomass is defined as the difference between total biomass and accessible biomass - these two maps are for North Mali – and the average biomass calculated over the entire period (1998-2017).

6. Saving the total average biomass: The total average biomass from the previous BioGenerator 2 session (section 4.5.1) must be saved in a temporary directory. This file is the “Average Biomass” as described in section 4.3.1. We will call that file TotalBiomass.

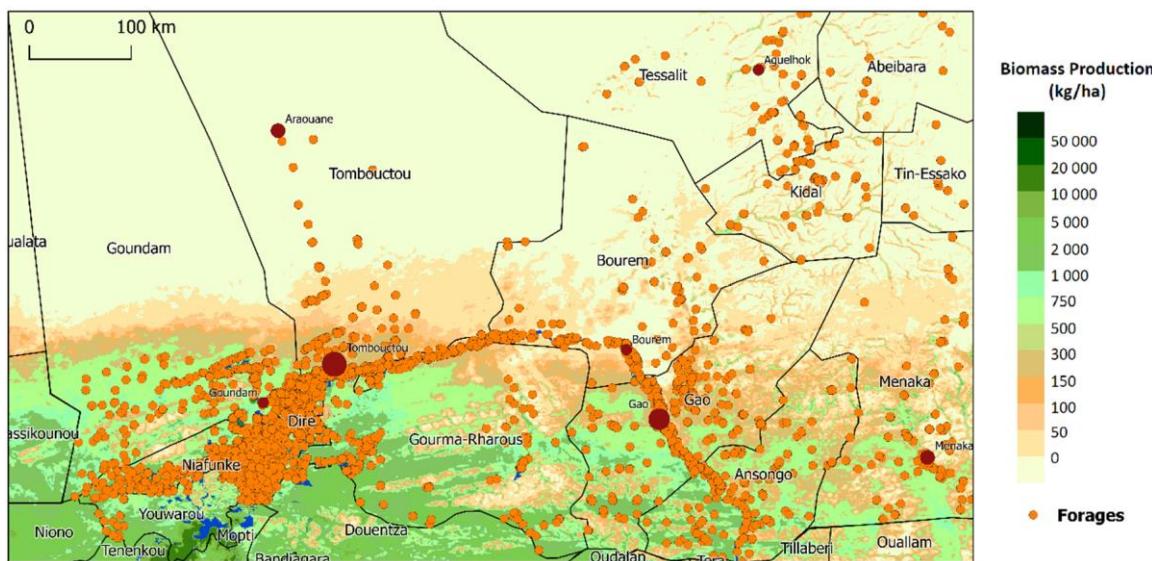


Figure 22 – Total biomass produced on average between 1998 and 2017 in Northern Mali

7. **BioGenerator 2 configuration:** A second run of BioGenerator 2 is required to calculate the average biomass available. To do so, the configuration involves activating the accessibility function (1 for Access\_Flag) and using the standard distance weighting parameters as explained in sections 4.1.3 and 4.2.2. The use of artificial water points is also activated (1 for Forages\_Flag).
8. **Running the program:** Following instructions in section 4.2.3
9. **Calculating inaccessible biomass:** This second run of the BioGenerator 2 produces the map of the average accessible biomass (“Mean Biomass” file as described in section 4.3.1). We shall call that file BiomassAccessible. The use of QGIS “raster calculator” allows for calculating inaccessible biomass according to equation (10).

$$\text{Biomass}_{\text{Inaccessible}} = \text{Biomass}_{\text{Total}} - \text{Biomass}_{\text{accessible}} \quad (10)$$

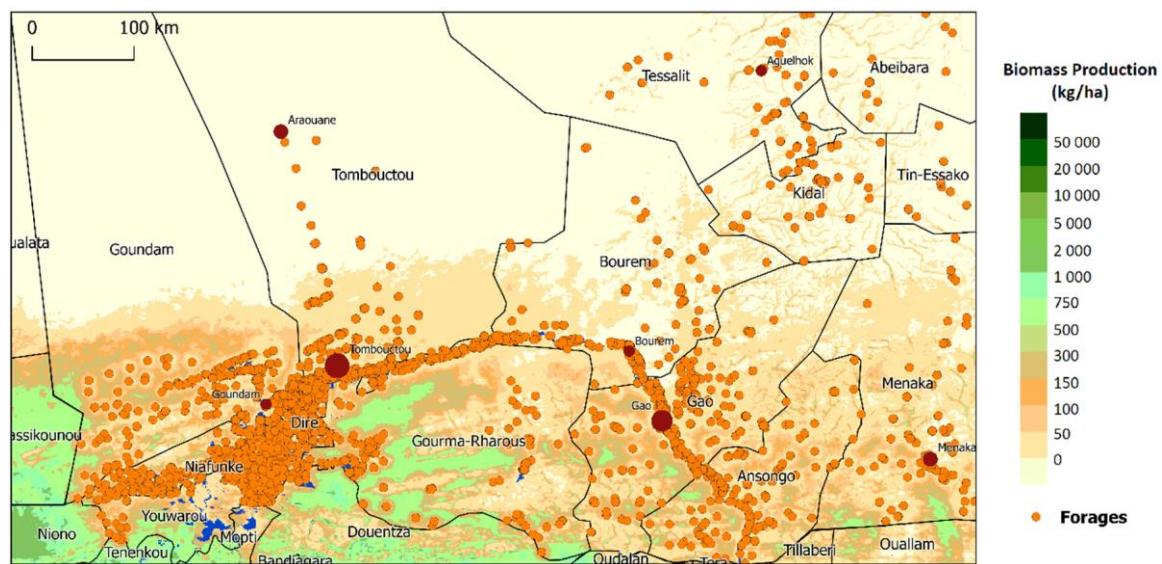


Figure 23 – Average inaccessible biomass between 1998 and 2017  
for Northern Mali

## 5 HydroGenerator

Water, along with grazing land, is an essential resource for pastoralists and nomadic herders. In the Sub-Saharan zone, ponds and surface water points are periodically filled during the rainy season. The filling rate and duration of the water body are related to the amount and distribution of rainfall.

The HydroGenerator module is a tool capable of generating annual index maps describing surface water accessibility calculated from data obtained from the VEGETATION sensor embarked on the SPOT series of satellites replaced since 2014 by the PROBA-V satellite. Accessibility is a spatial index sensitive to the time of presence of surface water and weighted by distance to water points. The water accessibility index also includes the length of water points, but also their spatial distribution. This real-time surface water accessibility monitoring tool complements the knowledge of the amount of accessible pastureland provided by the BioGenerator module.

In its v3.0 version, HydroGenerator incorporates the functionalities previously embodied by the PondMonitor software for real-time monitoring of the filling rate of ponds and water points. PondMonitor no longer exists and is fully incorporated into HydroGenerator.

The spatial scope of HydroGenerator covers the whole of Sub-Saharan Africa (Figure 1).

This chapter explains the methodology, the installation and use of the HydroGenerator module, as well as the different spatial frames.

### 5.1 Operating principles

The methodology is based on the use of SWB (*Small Water Bodies*) outputs in the form of a 10-day period at 1x1 km resolution and informing in a Boolean way of the presence of surface water. Artificial wells and water points of known position may be included as described in section 2.4.

HydroGenerator has two main features:

- The calculation of water surface areas on polygonal vectorial divisions and the 10-day period monitoring
- The production of annual maps of the water accessibility factor

### 5.1.1 Water surface area calculation

The HydroGenerator module allows for real-time monitoring of the, on the one hand, progression of the spatial extension of water points of interest and, on the other hand, the total surface covered by water both in an administrative division and in a region defined by the user.

Using this water presence information, HydroGenerator develops time profiles that provide real-time statistical information on the filling rate of ponds and surface water points.

The information on the filling rate is given by the area covered by water and compared with the normal situation. The normal situation is calculated as the seasonal average of the surface area for all available years since 1998.

### 5.1.2 Water availability calculation

Using this point-in-time water presence information, HydroGenerator produces annual maps that provide statistical information on the filling time of ponds and surface water points over an annual cycle weighted by the distance to the water point. The closer the position considered to the water point and the more this water point is present during the period considered or integration period, the higher the accessibility index. The maximum of accessibility index 1 is reached at the exact position of a water point that is always present.

The reference annual cycle is defined by default according to the vegetation growing season from early April to late March of the following year, and the user can also set the integration period of their choice.

The weighting according to the distance to the water point is established according to a 2D Gaussian set by a single parameter: the range. Typically, the range is the maximum distance a herder is able to travel to a water point, i.e. around Range\_Max= 30km. beyond that distance, the factor is lower than 1%.

Figure 24 shows the rate of that weighting function.

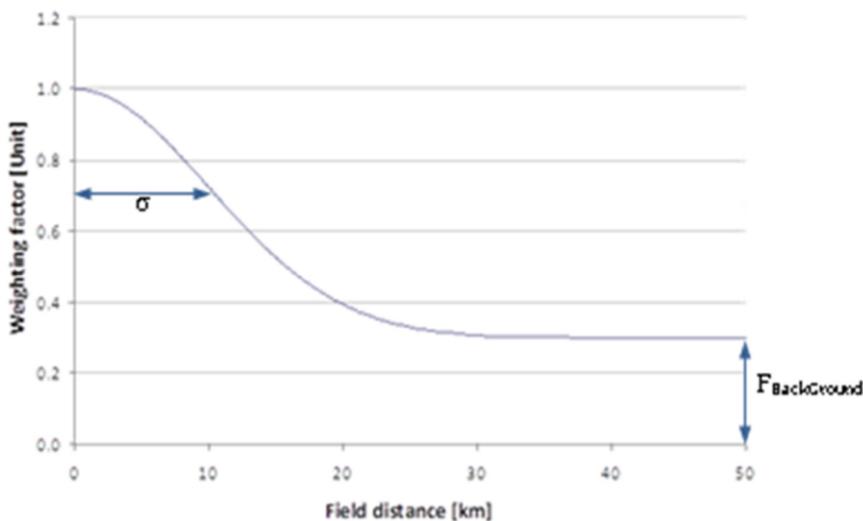


Figure 24 – Gaussian weighting of the water presence index as a function of distance from the water point

$$F(d) = (1 - F_{Background}) \times e^{\frac{d^2}{2\sigma^2}} + F_{Background} \quad (11)$$

Where:

- d is the distance to the water point
- σ is the determining factor for the Gaussian weighting rate
- FBackground is the minimum weighting coefficient

In areas under the influence of several water points, the value of accessibility to the nearest water point is used.

Optionally, a minimum FBackground accessibility value can be considered. This FBackground value can progress in a configurable way according to the aridity index classes. FBackground allows to integrate the notion that in the more humid South, water access is usually good, whereas in the North, accessibility to water is very strongly linked to the detection of surface water. The FBackground coefficient varies according to the aridity index AI (Figure 25):

- For areas in the North, arid to hyper-arid ( $AI < 2$ ), where the impact of water presence is very significant:  $F_{Background}=0.3$  or 30%.

- For areas to the South, sub-humid ( $AI>5$ ), where the impact of water presence is little or not significant:  $F_{Background}=1.0$  or 100%.

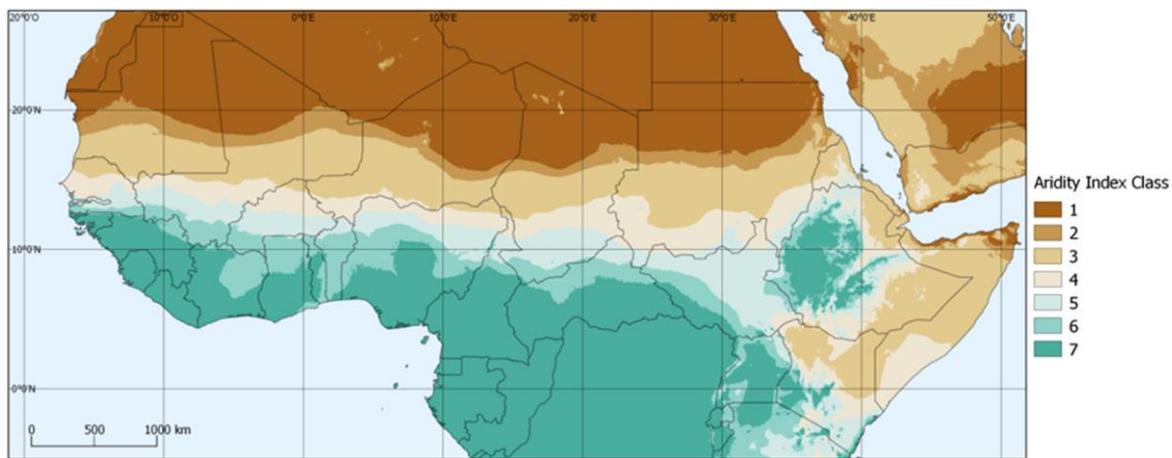


Figure 25 – Aridity Index Classes

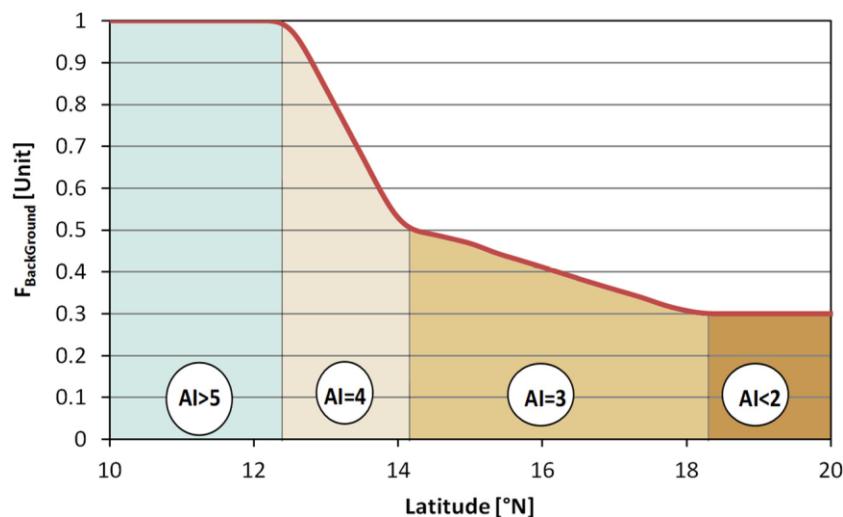


Figure 26 – Progression of the  $F_{Background}$  factor as a function of latitude.  
Example for a South-North transect at  $0^{\circ}$  of longitude.

The accessibility factor is thus calculated for each of the available SWB 10-day periods. Then, an average over the integration period is performed, and thus the annual water access mean for each pixel is obtained.

## 5.2 Using the HydroGenerator module

The use of the HydroGenerator is very similar to the use of the BioGenerator 2 module, and is based on a structure of directories and of input and output files.

### 5.2.1 Initialization and disk space required

The first step is to download and incorporate the new SWB data into the database if necessary. To do so, the use of the DeCompressor module is explained in Chapter 3.

The disk space required to run HydroGenerator is approximately 1 GB per year of data. It is the user’s responsibility to check that there is sufficient disk space before runtime.

### 5.2.2 List of water points

The list of water points of interest for which the 10-day and real-time profiles will be produced must be entered in the Param/PondMonitor\_List.txt. file. This file must follow a strict nomenclature.

ID	Lat_min	Lat_max	Lon_min	Lon_max	Adm_lev	Adm_Cod	Name
0001	15.6830	15.8970	-1.4600	-1.2630	0	00000	GOSSI
0002	19.3710	19.5040	0.56700	0.87900	0	00000	AGUELHOK
0003	16.0130	16.2900	-12.683	-12.424	0	00000	M'BOUT
0004	0.00000	0.00000	0.00000	0.00000	2	00014	KIDAL
0005	0.00000	0.00000	0.00000	0.00000	0	00138	MALI
0006	19.7285	19.7897	0.97970	1.09720	0	00000	IN'TANOUT
0007	12.9200	13.2520	-10.444	-10.241	0	00000	MANANTALI
0008	15.4984	15.6073	-0.5175	-0.4381	0	00000	IN'TILLIT
0009	11.5911	11.7564	42.3321	42.4724	0	00000	LAC_ASSAL
0010	11.2036	11.2883	42.5319	42.6649	0	00000	GRAND_BARRA
0011	11.0367	11.2859	41.6600	41.9038	0	00000	LAC_ABBE

The first ID column is the water point identifier value. It is this identifier that will be reused as the label and nomenclature of the output files.

The Lat\_min, Lat\_max, Lon\_min and Lon\_max columns respectively provide the minimum and maximum latitudes expressed in degrees North (°N), and the minimum and maximum longitude, in degrees East (°E) of the area to be considered. In the case where zero values are entered for all four fields, the entire *Sub\_Sahara* window is considered.

The Adm\_Lev and Adm\_Cod columns provide the possibility to track water points in an administrative boundary (ADM\_n) or a user-defined vector polygon (GEO\_n). Adm\_Lev (0 to 5) shows which level must be used (see section 3.3), and Adm\_Cod shows which mask value should be used. The value of the mask corresponds to the IDBIOHYDRO column in the attribute table of the vector file. An Adm\_Cod value other than 0 implies the use of the selected mask file.

If a mask is selected (Adm\_Cod different from 0) at the same time as a spatial window is defined (Lat\_min, Lat\_max, Lon\_min and Lon\_max not all equal to 0), then the spatial intersection of this window with the mask is considered.

### 5.2.3 Parameter setting

Those parameters can be accessible and edited via the Param/HydroGenerator\_Param.txt file.

```
HydroGenerator settings
30          Dist_Max_km (Default: 30)
10  9      Decade_Debut_Integration Decade_Fin_Integration (Default: 10 9)
0   0  0  Facteur_P1 Facteur_P1 Forages_Flag (Default: 0 0 0)
1   1  0  Optimisation Compression Mask (Default : 1 1 0)
1   1      Sorties_Raw Garde_Ancien (Default: 0 0)
```

- The coefficient of the spatial buffer weighting function: this function sets the “range” of a water point. This is, schematically, the maximum distance that a herder can travel to find a water point Dist Max km (Actual value, in km, between 0 and 100)
- The integration period over the annual cycle defined by the first and last 10-day period. The values entered correspond to the 10-day period number between 1 and 36, the correspondence with the dates is given in Table 4. In the event that the value of the end-of-integration 10-day period is lower than that of the beginning of integration, the integration is carried out until the following year’s 10-day period. The integration period must be at least two 10-day periods. For example, in the case where the analysis focuses on the entire year in the Sahel, the default values (Decade\_Debut\_Integration=10 and Decade\_Fin\_Integration=9) are used. In the case where the analysis focuses only on the rainy season for the Sahel (July-October), the parameters used will be 19

and 30. If the analysis is for the hot, dry season (March-May), the settings will be 7 and 15.

If the value Decade\_Debut\_Integration is set to 0, then the integration period is set from the number of 10-day periods entered in Decade\_Fin\_Integration and up to the last SWB 10-day period available and already downloaded and integrated into the database. For example: if Decade\_Debut\_Integration=0 and Decade\_Fin\_Integration=9, the integration is done over the 9 10-day periods since the 9 10-day periods preceding the last SWB 10-day period already downloaded.

#### Decade Debut Integration (Integer Value between 0 and 36)

This parameter shows the integration start 10-day period; the value 0 in the case of a backward integration of the last downloaded 10-day period.

#### Decade Fin Integration (integer value between 1 and 36)

This parameter shows the 10-day period of integration end. If the value 0 is entered in the 10-year-period\_Start\_Integration setting, then 10-year-period\_End\_Integration is the number of 10-day periods integrated up to the last downloaded 10-day period.

- Parameter for setting the FBackGround factor and activating the consideration of artificial boreholes.

#### Conversion Facteur P1 (Actual value, in %, between 0 and 100)

This parameter, expressed in %, is the background accessibility factor for areas with aridity index from AI-5 to AI-7.

#### Conversion Facteur P1 (Actual value, in %, between 0 and 100)

This parameter, expressed in %, is the background accessibility factor for areas with aridity index from AI-1 à AI-2.

#### Forages Flag (0: Off, 1: On)

This parameter activates the consideration of artificial boreholes in the calculation of the accessibility (see section 2.4.).

- The optimization settings allow for accelerating the calculation time during successive HydroGenerator module runtime – the intermediate steps being saved. On the other hand, the file volume stored on the disk is larger. The compression parameter allows reducing the size of *geotiff* output raster files. The masking parameter activates the *geotiff* output raster files according to the MASK *shapefile* which sets the area of interest (see section 3.3).

#### Optimization (0: Off, 1: On)

This parameter activates or deactivates the optimization function.

#### Compression (0: Off, 1: On)

This parameter activates or deactivates the *geotiff* output files compression function.

#### Mask (0: Off, 1: On)

Activation or deactivation of the mask of the area of interest.

- The raw output setting is accessible. Those files are stored in the Output/Raw/Water/ au format raw (.img) directory with header (.hdr) file.

#### Outputs Raw (0: Off, 1: On)

This parameter activates or deactivates the raw outputs of all possible value fields: 0 (Off); 1 (On).

#### Keep Old (0: Off, 1: On)

This parameter activates or deactivates the storage of files from a previous session. If storage is enabled, the new files created will overwrite the old ones.

### 5.2.4 Program runtime

The installation of MATLAB Compiler Runtime R2016a is required before running the program. If necessary, it is required to run the installation program: Libs/Utils/MCR\_R2016a\_win64\_installer.exe.

The program is run by simply double-clicking on the executable file HydroGenertaor.exe. A runtime window opens summarizing the settings used and all the 10-day periods identified and used for the calculation as well as the number of

years that can be calculated with these series. A counter indicates the progress of the percentage calculation.

The calculation phases follow one another until the end of the runtime. The Output/Water/Report/HydroGenerator\_Report.txt file saves the information of the last runtime, including the time and date of the start of calculation, in text format. Depending on the number of available 10-day periods, the speed of the processor and hard disk, and the parameters used, the calculation time is about 2 to 3 hours. The minimum system requirements relate mainly to the available RAM, with a minimum of 2 GB.

```

*****
*   HydroGenerator (v4.0)      *
* Action Contre la Faim (ACF-E) *
*   Erwann Filliol (2017)      *
*   erwann.filliol@gmail.com   *
*****
Initialisation : OK
Integration    : 0811 > 1101
Accessibilité : Dmax = 30.00 km
Background     : P0 = 0 % ; P1 = 0 %
Nombre points  : 27
Decades        : 19980411 > 20171101
Années         : 1998 > 2017
Nombre decades SWB: 705

Calcul du masque : 100 %
Calcul access.  : 100 % (2/2)

Calcul principal : 100 %
Ecriture        : 100 % (4/4)
Temps execution : 1 h 1 mm

Operations terminées.

```

Figure 27 – HydroGenerator module runtime window (v4.1)

### 5.3 Output files

HydroGenerator generates output files in three different formats: image format, spreadsheet format, and vector format.

- Files in image format

The image files are in *geotiff* (.tiff) format, following Lat/Lon geographical projection using the WGS-84 datum. The resolution is 30'' arc, or about 1km. The window's boundary coordinates are given in Table 1, or, if the option is activated, the spatial window is reduced to the area of interest set by the MASK file.

The data encoding is real 32-bit low weight header format (*32 bits little endian floating point*). Optionally, output files can be compressed.

- Files in spreadsheet format

Files in spreadsheet (.csv) format can be viewed with a text editor or with spreadsheet software such as Excel. The column separator is the semicolon.

- Files in vector format

Vector files are *shapefiles* (.shp) containing polygons with an attribute table. The projection is geographical Lat/Lon and using the WGS-84 datum.

### 5.3.1 Mean average water presence maps

The HydroGenerator module generates image files of water presence maps. The statistical average of water presence is represented in two distinct ways:

- The number of years, expressed as a percentage of the number of complete years during which the SWB pixel is detected in water at least once after filtering. This statistic provides the frequency of occurrence of the water pixel.
- The average number of 10-day periods, expressed as a percentage of the number of 10-day periods in the integration period during which the SWB pixel is detected. The calculation is made only for complete years. The statistics gives the average time, or period, for the occurrence of the water pixel.

Image files are in *geotiff* (.tif) format.

Files	Directory	Nomenclature
<b>Frequency</b>		Frequency.tif
<b>Period</b>	Output/Water/Map/	Period.tif

Table 18 – Nomenclature of average water presence files

Value	Meaning	Unit
[0 , 100]	Frequency of occurrence of the water point	Percentage of the number of years
[0 , 100]	Period of occurrence of the water point	Percentage of the number of 10-day periods
-9999	Ocean, open water	-
-9995	Mask value outside the area of interest	-

Table 19 – Meaning of the average water presence statistics files

These image files of the average water presence statistics can also be used to visualize the pools and water points that are detected by the SWB. Those image files can be used to set the coordinates of the water points of interest entered in the water point list file as described in section 5.2.2.

Figure 28 and Figure 29 show, at two levels of scale, the frequency of occurrence of water points, year after year. In other words, dark blue, i.e. for values close to 100%, is for the water points that appear every day. This statistical calculation of frequency of occurrence is done without regard to the duration of occurrence of the water point during the season.

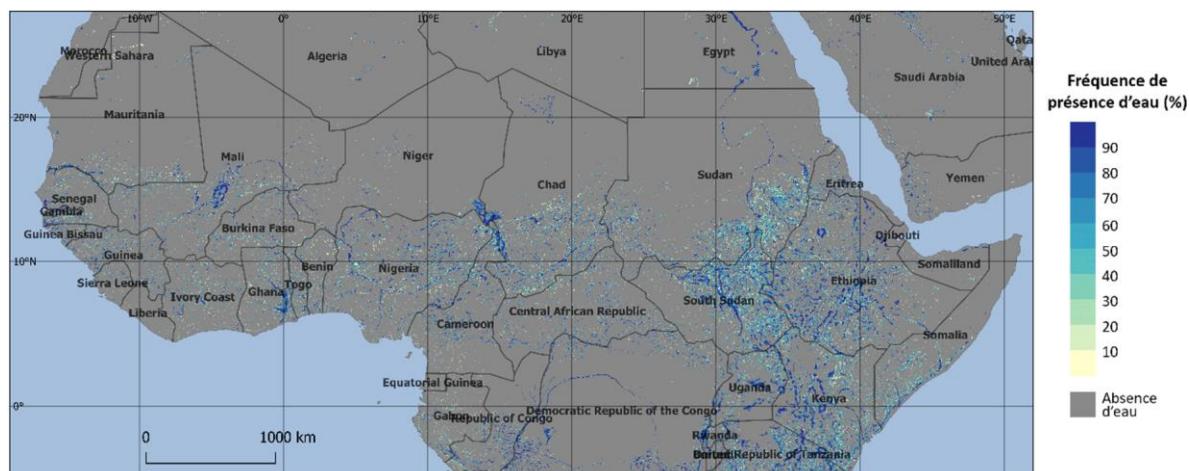


Figure 28 – Map of interannual frequency of water point occurrence in percentage calculated between 1998 and 2017

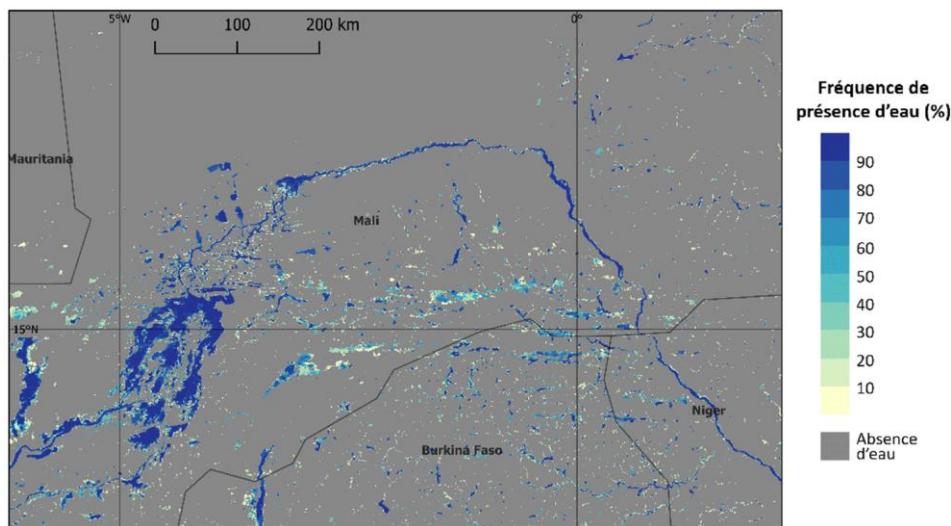


Figure 29 – Focus on North Mali interannual frequency of water point occurrence in percentage calculated between 1998 and 2017

### 5.3.2 Average water accessibility index

HydroGenerator generates a map of water accessibility index calculated on average for all available years.

The unit of accessibility index is in Gaussian format factor as a function of the distance to the water point averaged over the period of time considered, called integration period. A minimum value of 0 for the index corresponds to a total absence of water in a given range by the parameter Range\_Max, while a maximum value of 1 corresponds to a permanent presence of water in the considered position.

In open water areas (oceans), the value is set at -9999. If the feature is enabled, the area outside the area of interest set by the mask is set to -9995 (see section 3.3).

Files	Directory	Nomenclature
<b>Average accessibility index</b>	Output/Water/Access/Mean/	Access_Mean.tif

Table 20 – Nomenclature of the mean accessibility file

Value	Meaning	Unit
[0 , 1]	Accessibility Index	No unit
-9999	Ocean, open water	-
-9995	Mask value outside area of interest	-

Table 21 – Table of possible value in mean accessibility

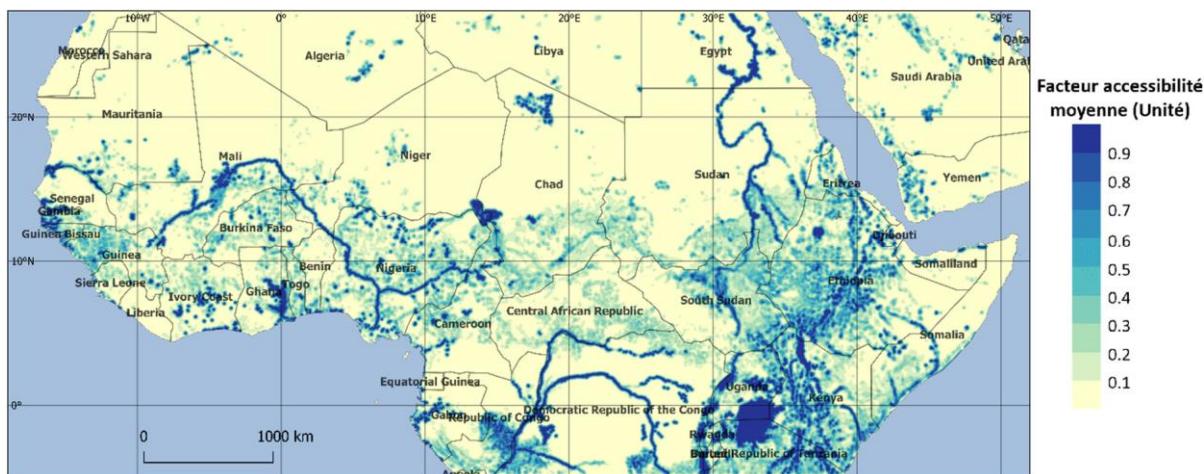


Figure 30 – Water Accessibility Index Map on average calculated for all available years (1998-2017)

Figure 30 shows the average water accessibility index calculated between 1998 and 2017. On this map, the blue areas correspond to places that are often close to water points, while the yellow areas are showing places that are always far from water points.

### 5.3.3 Annual anomaly maps of water accessibility index

The HydroGenerator module generates water accessibility anomaly files for each year in the database.

The anomaly is the ratio of the water availability index calculated over the year *yyyy* according to the integration period parameters with respect to the average of this index calculated over the same period for all available years. The anomaly is expressed as a percentage (%) with a maximum threshold of 200%. In areas where water accessibility is always zero (desert areas), the output value of the anomaly file is set to -9998.

For the current year, and for which the SWB 10-day periods are not necessarily available over the entire integration period, anomalies are calculated only for the available period.

In open water areas (oceans), the value is set to -9999.

If the feature is enabled, the areas outside the area of interest defined by the mask are set to -9995 (see section 3.3).

Files	Directory	Nomenclature
<b>Accessibility Anomaly</b>	Output/Water/Access/	AccessAnomaly_yyyy.tif

Table 22 – Nomenclature of water accessibility anomaly files

Value	Meaning	Unit
[0 , 200]	Anomaly [%]	[%]
-9999	Ocean, open water	-
-9998	Accessibility always zero	-
-9995	Masking value outside the area of interest	-

Table 23 – Table of possible value in water accessibility anomaly files

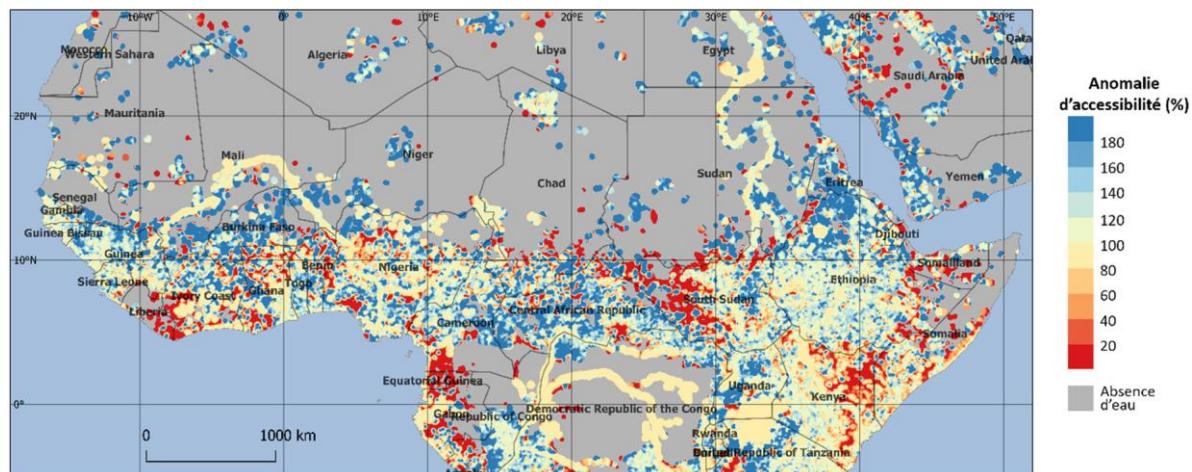


Figure 31 – Water accessibility anomaly map from 2017 March to compared to the average calculated between 1998 and 2017.

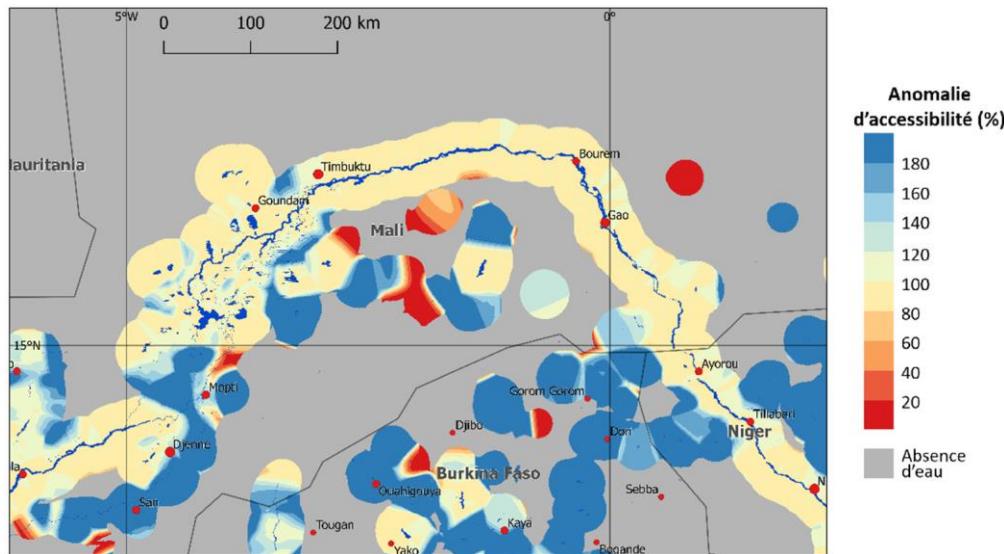


Figure 32 – Water accessibility anomaly map of the Niger inner delta for the months of March to May of the year 2017

In Figure 31 and Figure 32, representing water accessibility anomaly maps for the months of March to May (dry season) in 2017, the red areas have much lower than normal accessibility, while the blue areas have much higher than normal accessibility and the yellow areas have near normal accessibility. On these maps, the grey areas are always inaccessible over the period, i.e. no water points have ever been detected in the vicinity of the location over the entire period considered: here the period from March to May between 1998 and 2017.

### 5.3.4 Surface area time profiles

The output files for time profiles are Output/Water/Report/Water\_Pond\_ID.csv, where ID is the water point identifier as defined in the list of water points (see section 5.2.2). The following information is indicated at the top of the file:

- The name of the water point as defined in the list of water points
- The latitude ( $^{\circ}$ N) and longitude ( $^{\circ}$ E) coordinates of the barycenter of the water point
- The maximum and minimum normal seasonal extensions in  $\text{km}^2$ .

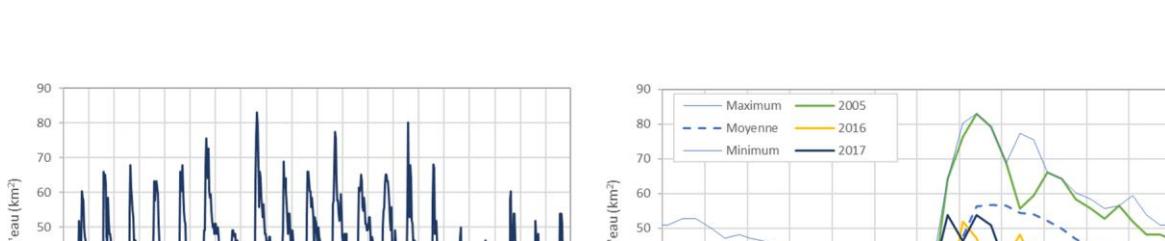
The time profile of the water point extension is represented in two distinct ways in two consecutive blocks. The first block is a representation by years; the second is a

representation of the continuous profile. The representation by years provides an interannual comparison and with the normal (*Mean*), minimum (*Min*), maximum (*Max*) and standard deviation (*Std*) annual profiles. These statistical profile values are calculated for each 10-day period over all available full years.

The graphs on the right of Figure 34 and Figure 35 are showing examples of interannual comparisons. The graphs on the left of the same figures show the continuous profiles over the entire available period.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	
1	Name:	Gossi																										
2	Lat(degt):	15.81																										
3	Lon(degt):	-1.321																										
4	Max(sqkm):	83.02																										
5	Min(sqkm):	34.63																										
6																												
7	Dated	Date	Mean	Min	Max	Std																						
8	1	01-janv	38.43	24.52	50.94	8.58	39.62	42.45	34.9	31.15	37.73	50.94	42.45	46.22	47.17	45.28	50	43.39	28.3	28.3	27.35	26.41	37.73	24.52				
9	2	11-janv	36.74	22.64	52.83	8.09	36.79	38.67	33.96	48.11	33.96	45.28	49.03	45.28	49.03	45.28	52.83	42.45	29.24	26.41	29.47	35.84		22.64				
10	3	21-janv	31.49	21.04	52.96	8.96	31.49	34.44	32.41	31.15	32.41	45.43	48.93	31.15	45.43	48.93	31.15	32.41	29.24	26.41	29.47	35.84		21.69				
11	4	01-févr	35.6	19.81	50	10.14	36.79	32.07	34.9	31.15	33.96	50	32.07	45.28	44.33	47.16	48.11	48.11	45.28	30.18	19.81	19.81	24.52	32.07	20.75			
12	5	11-févr	32.96	11.32	47.16	11.31	35.8	33.01	35.84	30.18	32.07	47.16	45.28	46.22	45.28	36.79	45.28	45.28	17.92	18.86	22.64	11.32	20.75					
13	6	21-févr	32.22	11.3	48.11	11.37	34.9	32.07	34.9	33.01	31.13	44.33	23.58	47.16	43.39	45.28	48.11	36.79	43.39	21.69	14.15	22.64	23.58	11.32	20.75			
14	7	01-mars	31.87	10.37	47.16	10.85	30.18	34.8	24.52	29.24	30.18	45.28	43.39	44.33	47.16	45.28	45.28	20.75	22.64	23.58	11.32	20.75						
15	8	11-mars	30.66	14.07	48.11	9.93	30.18	32.07	23.58	31.13	30.18	45.28	43.39	44.33	47.16	45.28	45.28	10.37	11.32	22.64	23.58	11.32	20.75					
16	9	21-mars	28.45	13.2	44.33	9.4	25.47	31.13	31.13	22.64	26.41	42.45	25.47	44.33	37.73	31.13	37.73	29.24	42.45	22.64	13.2	22.64	13.21	25.47	16.03			
17	10	01-avr	26.36	4.72	44.33	10.87	31.13	29.24	29.47	35.09	24.52	39.62	20.75	41.5	29.24	44.33	37.73	29.24	16.04	10.38	19.81	16.98	29.24	4.72				
18	11	11-avr	22.87	2.8	38.67	10.56	12.26	25.47	27.35	22.64	15.09	24.52	37.73	19.81	38.67	19.81	38.67	27.36	32.07	10.37	9.43	16.98	12.26	29.24	2.83			
19	20	21-avr	20.84	6.36	37.9	8.87	20.75	25.47	21.69	17.92	18.86	36.79	17.92	24.52	33.01	33.01	21.7	27.35	8.49	6.6	13.21	10.38	13.21	20.57				
20	21	01-mai	19.74	2.8	38.67	10.56	12.26	25.47	27.35	22.64	15.09	24.52	37.73	19.81	38.67	19.81	38.67	27.36	32.07	10.37	9.43	16.98	12.26	29.24	2.83			
21	22	11-mai	15.52	3.77	32.07	8.66	6.6	18.86	18.86	18.86	10.38	24.52	25.47	13.21	17.92	14.15	31.13	4.72	3.77	10.38	6.6	22.64	5.66					
22	23	21-mai	15.68	0	28.3	7.58	7.55	11.3	16.98	16.03	12.26	6.6	21.7	10.38	28.3	18.87	22.64	14.15	22.64	18.03	3.77	0	9.43	6.6	22.64	5.66		
24	25	01-juin	9.43	0	23.58	6.97	16.04	7.55	11.32	7.55	7.55	0	12.26	0	12.26	0	17.92	6.6	23.58	15.09	3.77	2.8	0	9.43	7.2	13.21	5.66	
26	27	11-juin	8.81	0	22.64	6.62	0.84	10.38	4.49	0	0	0	12.26	0	12.26	0	17.92	6.6	23.58	15.09	3.77	2.8	0	8.49	7.7	10.38	5.66	
28	29	21-juin	7.21	0	33.01	5.31	12.21	0	11.32	33.01	0	0	0	0	0	0	17.92	6.6	23.58	15.09	3.77	2.8	0	8.49	7.7	10.38	5.66	
30	31	01-juil	16.55	0	40.94	11.51	21.7	0	9.43	40.56	4.72	21.58	8.49	12.26	8.49	12.26	22.64	23.58	15.09	3.77	33.03	6.6	7.55	8.49	5.66	22.64	37.73	
32	33	11-juil	24.34	2.83	41.5	11.75	27.35	2.8	8.49	41.5	6.6	41.5	34.9	34.9	34.9	15.09	27.35	21.7	26.41	40.56	16.04	24.52	15.09	23.58	14.52	37.73		
34	35	21-juil	33.96	6.6	64.15	15.93	27.36	22.64	6.6	48.11	21.7	49.05	34.9	64.15	10.37	25.47	27.35	24.53	33.96	54.72	57.55	29.24	19.81	38.67	29.24	53.77		
36	37	01-août	47.5	8.49	80.19	17.66	39.82	66.04	8.49	83.2	48.22	42.45	42.45	42.45	42.45	76.41	22.64	53.77	51.13	33.96	50	80.19	67.93	42.45	32.07	46.22	31.13	46.23
38	39	21-août	42.41	12.31	83.2	20.75	32.07	54.1	12.26	48.22	42.45	42.45	42.45	42.45	42.45	60.59	51.88	51.88	51.88	51.88	51.88	51.88	51.88	51.88	51.88	51.88	51.88	51.88
40	41	21-août	56.87	36.79	79.24	10.86	46.22	65.09	67.92	62.26	60.37	75.47	45.28	59.05	60.05	67.92	57.54	61.32	55.66	52.83	48.11	47.17	46.22	60.37	36.79	50.94		
42	43	01-sept	56.46	38.68	68.87	11.18	41.51	62.32	61.32	63.2	63.2	68.87	49.05	68.87	63.2	67.92	60.37	62.26	67.92	48.11	49.99	40.56	41.51	41.51	38.68			
44	45	21-sept	54.32	34.9	77.36	11.6	46.22	47.37	58.49	61.32	67.92	64.15	49.05	55.66	61.32	60.37	77.36	61.32	65.09	64.15	51.88	34.9	38.68	42.45	48.11	34.9		
46	47	01-oct	54.1	33.01	75.47	12.03	60.57	45.28	54.72	59.43	60.37	72.64	48.11	59.43	62.32	60.37	75.47	65.09	55.89	62.32	46.22	35.94	40.56	42.45	35.94	34.9		
48	49	21-oct	53.97	33.01	66.09	12.03	58.49	52.82	54.72	54.72	54.72	60.37	48.11	59.43	59.43	60.37	75.47	65.09	55.89	62.32	46.22	35.94	34.9	33.77	33.96	34.9		
50	51	01-nov	49.76	32.07	64.15	10.24	57.54	51.86	46.22	48.22	51.86	58.49	48.11	64.15	60.37	58.49	57.54	55.66	63.2	46.22	40.56	33.96	34.9	33.77	33.96	32.07		
52	53	21-nov	48.3	29.24	56.37	10.29	49.99	48.21	46.22	44.33	50.94	43.39	48.49	56.6	55.66	57.54	55.66	57.54	54.71	60.37	43.39	33.01	36.79	31.13	47.16	30.18		
54	55	01-déc	44.43	29.24	58.49	9.89	47.16	48.21	46.22	42.45	42.45	54.71	44.33	55.66	48.11	52.83	53.77	50.94	55.66	48.22	30.18	30.18	30.18	42.45	29.24	29.24		
56	57	21-déc	42.41	26.41	55.66	9.36	44.22	46.22	42.45	42.45	44.33	51.88	40.39	51.88	51.88	40.39	51.88	38.79	32.07	26.41	31.13	42.45	27.35					
58	59	01-janv	39.22	23.58	53.77	9.11	40.56	41.5	29.24	34.9	36.79	48.11	42.45	48.11	40.39	51.88	53.77	50.94	55.66	33.96	21.69	31.13	30.18	44.33	27.35			
60	61	21-janv	42.25	21.69	59.43	10.64	42.45	33.96	40.56	38.67	40.56	50.94	42.45	51.88	51.88	50.94	55.66	33.96	21.69	31.13	30.18	44.33	27.35					
62	63	21-mars	39.72	23.58	53.77	9.11	40.56	41.5	29.24	34.9	36.79	48.11	42.45	48.11	40.39	51.88	53.77	49.05	44.34	31.13	27.35	29.24	41.5	23.58				
64	65	21-déc	38.77	23.58	50.94	8.96	40.56	41.5	25.47	30.18	36.79	50.94	42.45	48.11	40.39	50.94	47.17	49.05	40.39	33.96	27.35	42.45	23.58					
66	67	21-janv	38.77	23.58	50.94	8.96	40.56	41.5	25.47	30.18	36.79	50.94	42.45	48.11	40.39	50.94	47.17	49.05	40.39	33.96	27.35	42.45	23.58					

Figure 33 – Output files for a water point (Gossi pond)



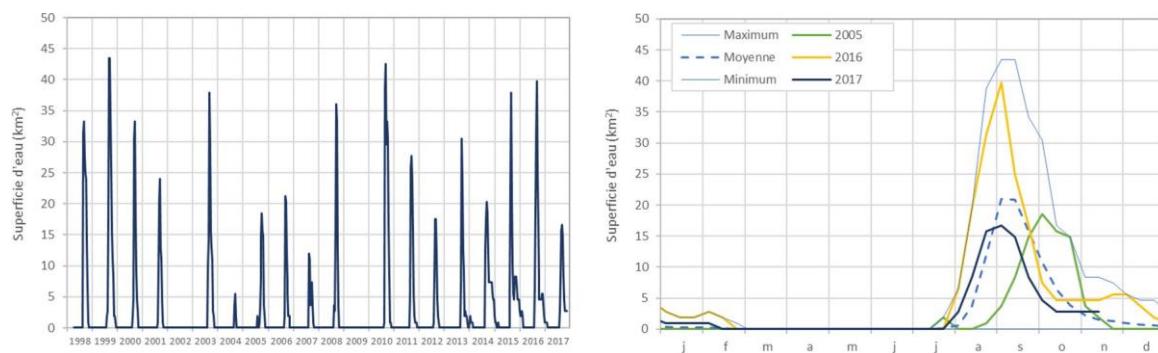


Figure 35 – Time profile of water surface area in Aguelhok, Mali, in continuous representation (left), and interannual comparison (right).

### 5.3.5 Time profiles of annual water anomaly

HydroGenerator produces output files of the average annual water presence anomaly according to the administrative division ADM\_n and following the limits set by the GEO\_n user.

The output files, presented in Table 24, are in .csv format and the semicolon is used as a column separator. These files can be opened directly by a spreadsheet software such as Excel.

Fields	Polygon	Directory	File
<b>Annual Anomaly of water presence</b>	ADM_0	Output/Water/Report/	Water_ADM_0.csv
	ADM_1		Water_ADM_1.csv
	ADM_2		Water_ADM_2.csv
	GEO_3		Water_GEO_3.csv
	GEO_4		Water_GEO_4.csv
	GEO_5		Water_GEO_5.csv

Table 24 – Output files of annual water anomalies

Figure 36 shows an extract from the output file for water accessibility according to the administrative level 0 (Country). In each of the files, a header recalls the source mask file, the number of entities and the unit of output values.

The water anomaly is expressed as a % of the average surface area of water presence. The flag value -1 is shown in areas where water is never detected (area always zero).

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
1	Source:	ADM_0																						
2	Nb_entites	9																						
3	Water Anom (%)																							
4	Name	BIOHYDRO[Area sqkm] Mean sqkm	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017		
5	Chad	1 1268197 2633.93	85.71	105.13	112.23	110.47	103.42	67.81	71.36	69.89	78.77	93.52	99.8	101.11	80.25	95.96	78.68	108.83	131.83	126.77	134.08	144.4		
6	Senegal	2 1955535 1290.84	56.53	80.26	108.4	95.87	97.91	58.15	78.47	84.99	86.67	81.21	89.24	90.37	96.34	102.53	93.55	110.38	128.93	136.16	162.65	144.05		
7	Niger	3 1183000 245.84	153.06	99.55	77.49	9.8	33.1	46.47	42.39	53.91	45.59	50.34	59.5	111.21	50.43	112.58	29.93	124.26	122.51	120.99	120.99	120.99		
8	Nigeria	5 998919 6952.25	74.85	98.87	103.06	107.45	103.58	89.79	76.6	76.86	81.27	94.53	80.79	99.99	93.98	106.16	93.88	121.01	126.67	111.71	118.6	131.86		
9	Cameroon	5 468186 2554.81	74.95	89.78	145.64	115.44	101.26	97.77	98.7	73.84	71.82	99.99	102.27	92.57	99.62	98.6	88.06	91.35	107.56	90.5	103.46	158.83		
10	Mali	6 1248110 1093.12	64.58	77.19	114.07	114.2	79.96	57.77	74.77	60.27	68.3	82.96	83.55	87.12	94.83	119.61	81.82	112.56	144.15	138.32	179.01	164.97		
11	Burkina_Faso	7 274632 372.39	54.44	51.23	66.76	46.38	50.47	53.11	92.86	68.15	49.53	106.26	57.46	109.1	70.91	78.38	135.96	184.62	125.38	229.33	236.22			
12	Mauritanie	8 1042035 386.72	24.12	27.15	88.75	92.32	86.74	14.02	40.12	28.3	42.45	53.96	59.3	56.7	71.81	78.49	80.68	118.41	225.38	234.2	318.56	258.55		
13	Gambia	9 112597 636.15	64.94	91.37	104.36	102.8	96.14	59.18	97.48	106.51	92.14	89.13	93.91	91.34	91.81	101.66	99.45	104.56	122.87	125.52	135.12	129.64		

Figure 36 – Extract from the Output/Water/Report/Water\_ADM\_0.csv water presence file

From these output files it is possible to trace the time progression of the anomaly in water presence on average in the different administrative levels (ADM\_n.shp) or in the user polygon (GEO\_n.shp). Figure 37 is an example of profiles calculated for Mali.

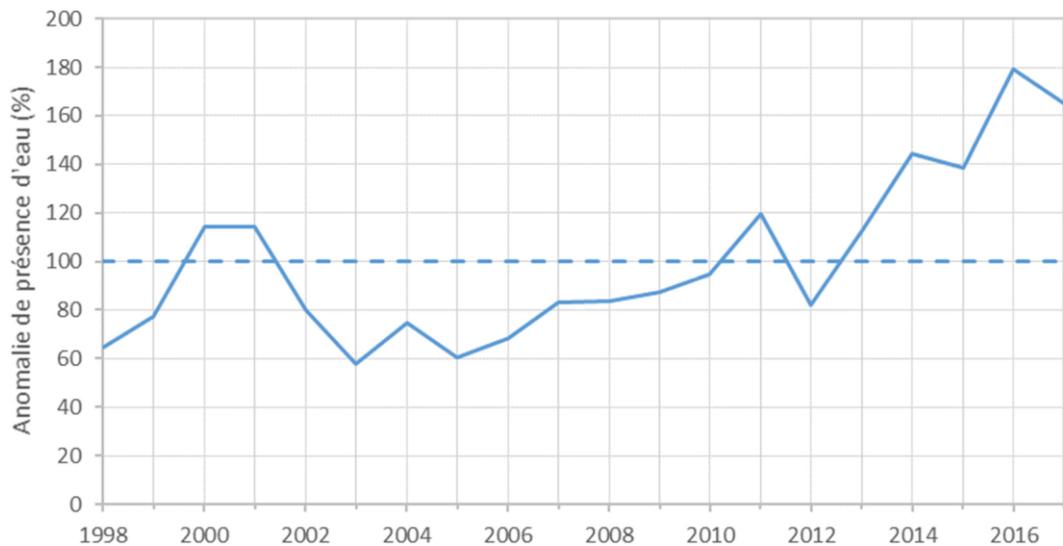


Figure 37 – Time profile of the annual anomaly in water presence, calculated over the period from early April to end of March for Mali.

### 5.3.6 Annual water accessibility anomaly time profile

HydroGenerator produces output files of average water accessibility anomaly according to levels 0, 1, and 2 administrative boundaries, and following the polygons set by the user.

Fields	Polygon	Directory	File
<b>Water Accessibility</b>	ADM_0	Output/Water/Report/	Access_ADM_0.csv
	ADM_1		Access_ADM_1.csv
	ADM_2		Access_ADM_2.csv
	GEO_3		Access_GEO_3.csv
	GEO_4		Access_GEO_4.csv
	GEO_5		Access_GEO_5.csv

Table 25 – Water accessibility anomalies output files

The output files, presented in Table 25, are in .csv format and the semicolon is used as a column separator. Those files can be opened directly using spreadsheet software such as Excel.

Figure 38 shows extracts from the output file for water accessibility according to administrative boundary level 0 (Country). The header recalls the source mask file, the number of entities located and the output unit of value.

Accessibility is expressed as a percentage of the average accessibility index (unit). The flag value -9999 is indicated on areas where the accessibility index is always zero.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	
1	Source:	Lib\Ancillary\Img\ADM_0.img																							
2	Nb_entities:	9																							
3	Water_Acces[%]																								
4	NAME	IDBIOHYD	AREA(skm)	ACCESS_MEAN	ACCESS_1998	ACCESS_1999	ACCESS_2000	ACCESS_2001	ACCESS_2002	ACCESS_2003	ACCESS_2004	ACCESS_2005	ACCESS_2006	ACCESS_2007	ACCESS_2008	ACCESS_2009	ACCESS_2010	ACCESS_2011	ACCESS_2012	ACCESS_2013	ACCESS_2014	ACCESS_2015	ACCESS_2016	ACCESS_2017	
5	Chad	1	1268197	0.057	80.701	93.29	101.54	95.688	98.988	82.796	85.472	87.093	91.561	98.895	102.918	102.056	92.54	95.638	92.751	113.024	127.318	116.021	118.234		
6	Senegal	2	195555	0.137	83.324	86.815	94.201	96.189	89.118	79.851	100.496	98.857	97.051	91.263	98.08	100.75	99.312	104.542	98.941	111.333	121.353	106.185	122.92	115.413	
7	Guinea	3	116254	0.058	83.722	93.87	96.333	97.208	88.208	78.488	98.065	85.016	80.741	91.269	98.512	101.077	93.841	103.203	141.171	108.189	147.079	110.779	112.146	110.996	
8	Nigeria	4	908919	0.265	87.813	97.64	99.92	103.358	99.05	96.521	89.124	89.04	94.127	94.529	91.779	97.766	96.523	99.514	97.645	109.777	122.394	110.146	112.29		
9	Cameroun	5	468186	0.184	110.771	94.814	114.575	104.331	95.07	95.764	102.976	84.1	86.045	100.568	99.927	97.927	100.799	96.674	95.47	91.681	112.301	97.113	101.267	122.649	
10	Mali	6	1248110	0.059	90.2	92.078	96.373	92.596	94.707	88.645	95.107	88.347	92.737	94.173	97.328	100.71	95.213	101.004	95.04	107.54	118.85	113.41	121.858	117.712	
11	Guinée Faso	7	27000	0.057	64.932	71.86	71.86	70.117	69.027	76.496	70.117	70.117	70.117	70.117	70.117	70.117	70.117	70.117	70.117	70.117	70.117	70.117	70.117		
12	Mauritanie	8	1042035	0.026	80.195	83.745	96.12	100.234	94.408	67.915	80.138	76.151	78.149	88.116	92.851	84.608	95.463	104.587	91.944	106.83	147.734	137.17	145.122	137.038	
13	Gambie	9	11297	0.599	94.216	96.951	98.131	98.175	97.979	96.323	104.914	98.886	97.414	97.852	99.822	101.132	101.154	99.447	103.67	99.415	109.274	102.818			

Figure 38 – Extract from the Output/Water/Report/Access\_ADM\_0.csv water accessibility output file

From these output files, it is possible to obtain the time progression of the anomaly of the mean water accessibility at the various administrative levels and in the user polygons. Figure 39 is an example of profile calculated for Mali.

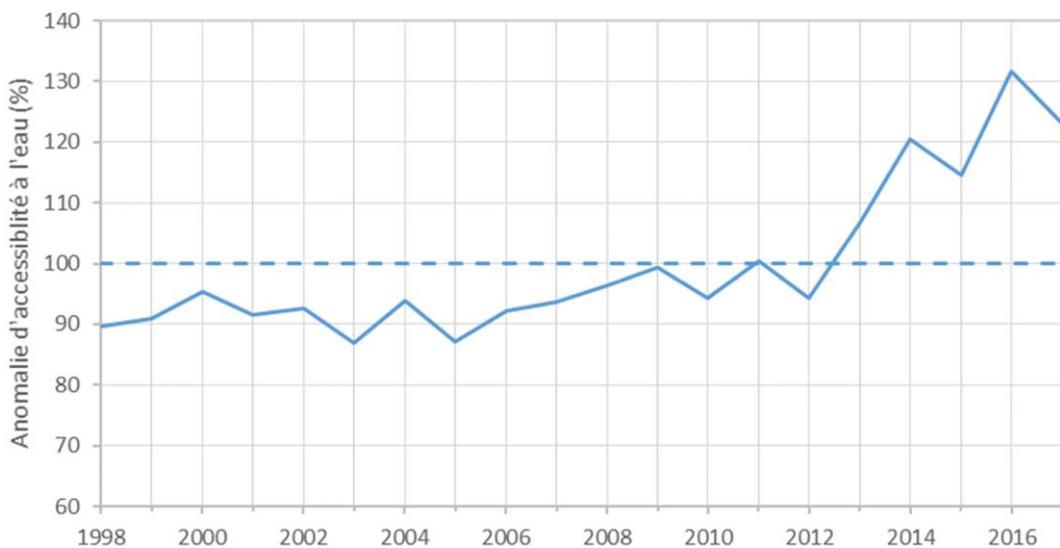


Figure 39 – Time profile of the water accessibility anomaly index, calculated for the dry period from early March to end of May, for Mali

### 5.3.7 Vector outputs

HydroGenerator produces vector outputs of the annual anomaly values in the water availability index. The polygons used are ADM\_0, ADM\_1, ADM\_2, as well as GEO\_3, GEO\_4, GEO\_5 and WATER as described in paragraph 3.3.

The *shapefiles* (.shp) vector outputs are located in the Output/Water/Shape/ directory. The attribute table contains the information already described in paragraph 5.3.6 regarding .csv outputs.

If the “Profiles” option is activated (see section 4.2.2), the attribute table is completed with the 10-day period water surface area values for each polygon comprised in the vector file. In addition to the 10-day values, the attribute table shall record, for each of the 36 10-day periods of the year, the interannual statistical values of average, minimum, and maximum surface area, and standard deviation. Table 26 identifies the variables listed in the attribute table of HydroGenerator output vector files.

The WATER file is used to monitor the 10-day period progression in real time of the water points surface area; each of the water points being defined by a polygon in the WATER.shp *shapefile* (see paragraph 3.3.). In the attribute table of the HYDRO\_WATER.shp output file, only the columns concerning the 10-day water areas and 10-day filling statistics appear.

Name	Description	Frequency	Unit
<b>Area</b>	Polygon area	Once	Km <sup>2</sup>
<b>YEAR_FIRST</b>	First year of the series		Year
<b>YEAR_LAST</b>	Last year of the series		
<b>A_MEAN</b>	Average interannual water accessibility		No unit
<b>A_ANO_yyyy</b>	Annual anomaly of water accessibility	Annual	%
<b>W_MEAN</b>	Interannual average water surface area for the integration period	Once	km <sup>2</sup>
<b>W_ANO_yyyy</b>	Annual anomaly of water surface area	Annual	%
<b>SWB_MEA_dd</b>	Interannual average of 10-day period water surface area for 10-day period dd	Decadal 36 values	km <sup>2</sup>
<b>SWB_MIN_dd</b>	Minimum interannual water surface area for 10-day period dd		
<b>SWB_MAX_dd</b>	Maximum interannual water surface area for 10-day period dd		
<b>SWB_STD_dd</b>	Interannual standard deviation of water surface area for 10-day period dd		
<b>SWB_FIRST</b>	First 10-day period of the time series	Once	yyyydd
<b>SWB_LAST</b>	Last series of the time series		
<b>SWB_yyyddd</b>	Water surface area for 10-day period dd in year yyyy	Decadal	km <sup>2</sup>

Table 26 – Composition of the attribute table of HydroGenerator output vector files

Figure 40 shows a vectorial display of the anomaly in the water accessibility index for the dry period from March to May 2017. In this figure, for the inner Niger delta, the reference cartographic boundary is at administrative level 2 (department or *circle*). This map shows a positive anomaly in the water accessibility index over the southern part of the Niger delta. This result corroborates the positive reading for 2017 for Mali already visualized on Figure 39.

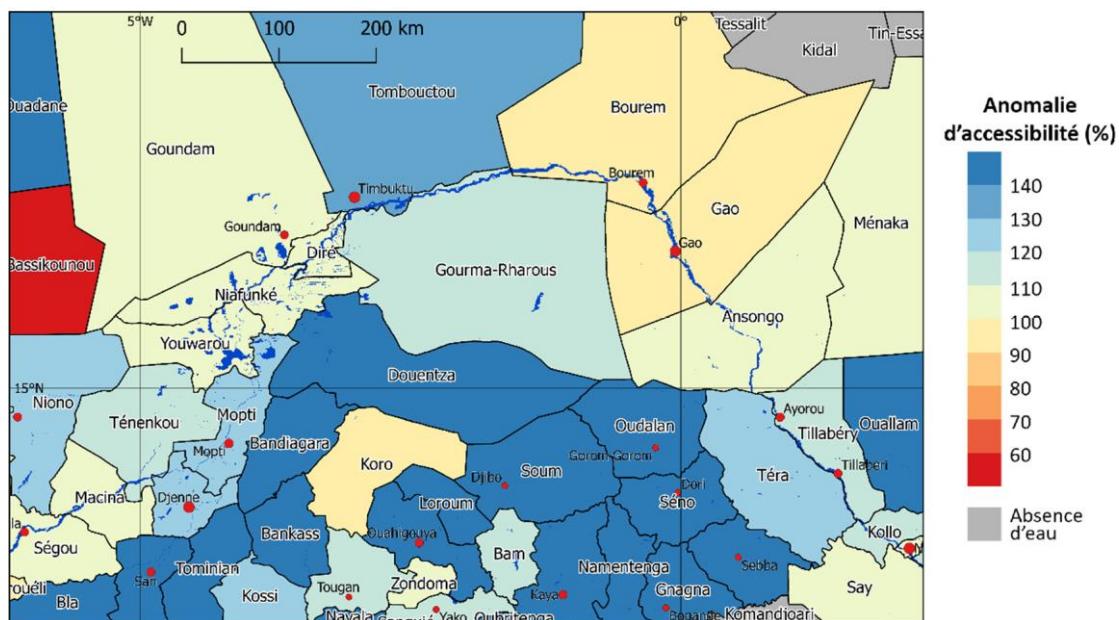


Figure 40 – Water accessibility anomaly map for the year 2017, in vector representation, on level 2 administrative division, in the inner Niger delta, calculated for the dry period from early March to end of May, compared to the average calculated between 1998 and 2017.

Figure 41 shows a vectorial display of the water anomaly from March to May 2017. The average presence of water is calculated over the period 1998 to 2017. In this figure, for the inner Niger delta, the reference vector is the administrative level 2 (department or *circle*).

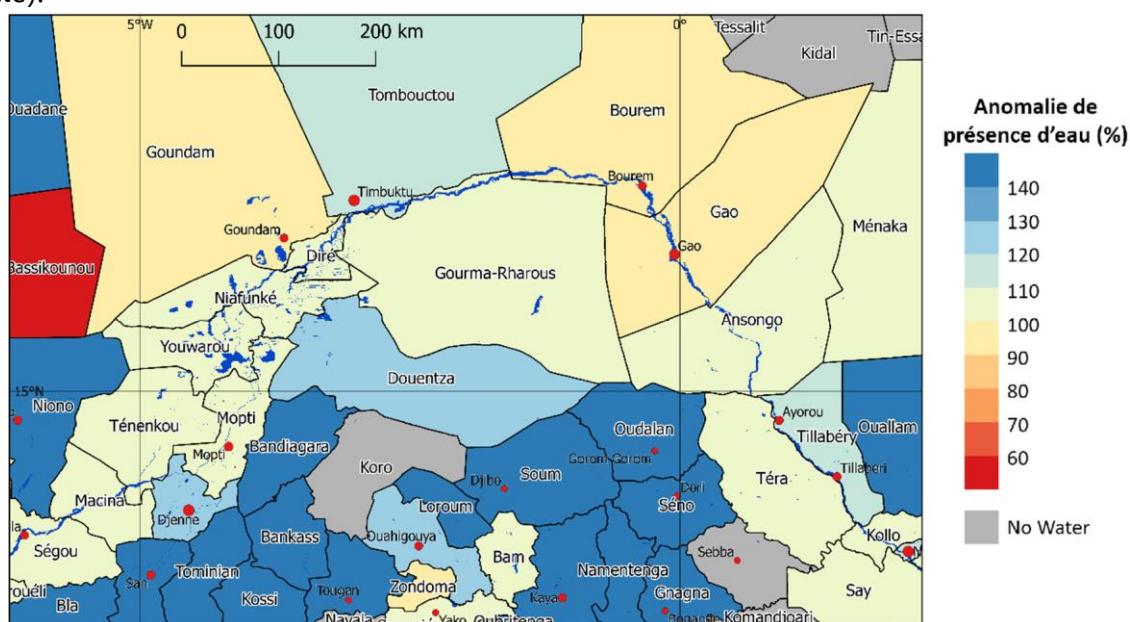


Figure 41 – Water presence anomaly for the period from March to May 2017 compared to the average calculated between 1998 and 2017.

Figure 41 shows the anomaly in water presence for the year 2017, over the dry season period from March to May, for each of level 2 administrative units (department or *circle*). The map shows in blue the areas where water is more present and in red the areas where it is less present compared to the average calculated between 1998 and 2017. On grey areas, water is never detected during the period. Unlike the calculation of water accessibility as done by HydroGenerator (see Chapter 5), this water anomaly calculation does not take into account the distribution of water for the data considered but only the surface area.

## 5.4 Example of use

This section shows some examples of how to use the HydroGenerator module. The stages are described step by step.

### 5.4.1 Creation of the water accessibility anomaly map

This example of use shows how to draw up a water accessibility anomaly map for the months of March to May 2017, corresponding to the hot, dry period in the Sahel. This analysis provides useful information for measuring water accessibility conditions during the hot and dry season, generally the hardest period for pastoralists in the Sahel.

1. Downloading and incorporating new, available SWB 10-day periods: New 10-day periods must be downloaded according to the instructions in Chapter 3.
2. Parameter setting: The choice of parameters is important to determine the integration period of the accessibility anomaly calculation. Following the instructions in section 5.2.3 and based on Table 4, the Decade\_Debut\_Integration and Decade\_Fin\_Integration must be set respectively at 7 and 15 to cover the months from March to May.
3. Program runtime: The program execution is carried out according to the instructions in section 5.2.4
4. Using GIS software to create the map: Using GIS software such as QGIS allows to display and format the map. A QGIS project template can be found in the GIS/QGIS

Project/ directory. The *geotiff* file to retrieve and display is the water accessibility anomaly file for 2017 as described in section 5.3.3.

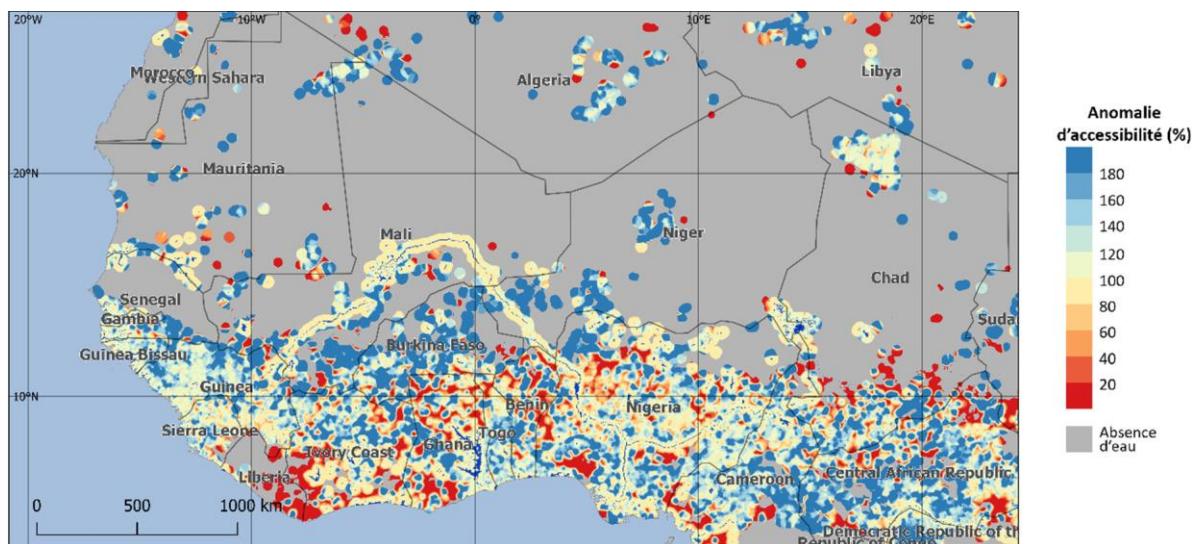


Figure 42 – Anomaly in water accessibility for the months of March, April and May 2017 in West Africa

#### 5.4.2 Monitoring the filling rate of pond

This example of usage shows how to establish the time profile of the filling rate of a new water point. This new water point is Lake Faguibine in the Timbuktu region of Mali.

1. Downloading and incorporating the new available SWB 10-day periods: The new available 10-day periods must be downloaded according to the instructions in Chapter 3.
2. First HydroGenerator runtime: A first run is required to create the statistical water presence maps from which the new water point to be included in the list will be located. Here, the use of the default settings is recommended, in particular the Decade\_Debut\_Integration and Decade\_Fin\_Integration which must cover a full year.
3. Viewing the frequency of water point occurrence: Viewing the “frequency” *geotiff* file (see section 5.3.1) in a GIS software such as QGIS allows to identify the water point of interest, here Lake Faguibine, and to record the coordinates of minimum and maximum latitudes and longitudes delineating the position of the water point (Figure 43).

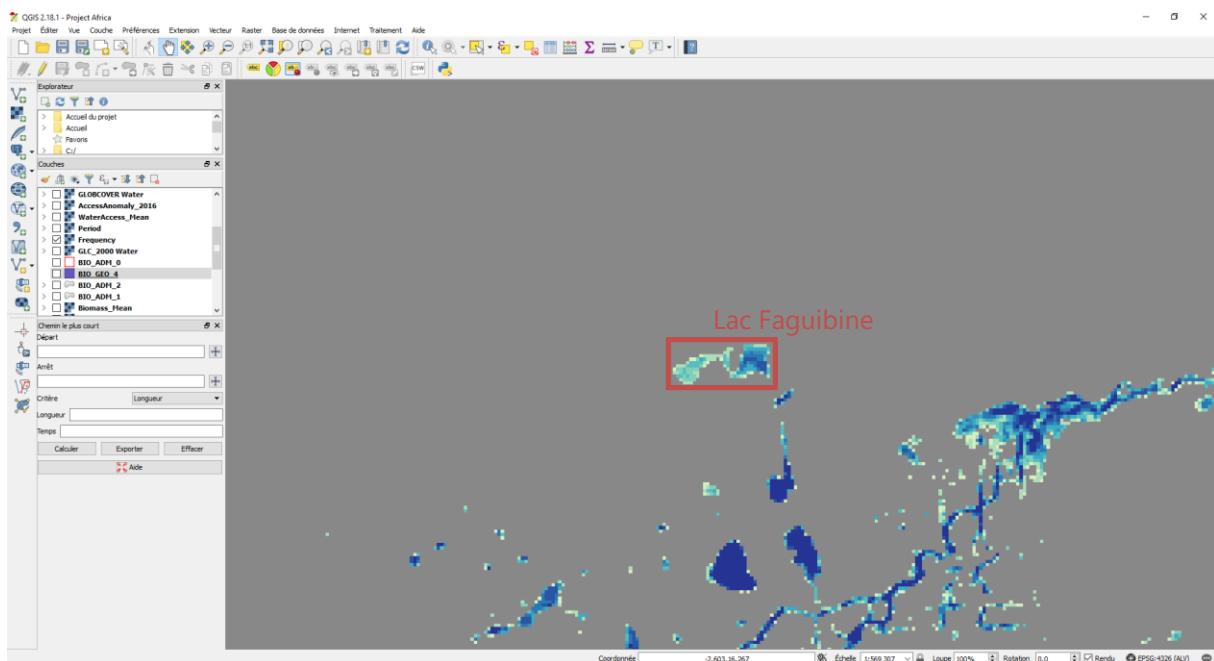


Figure 43 – Viewing the frequency map of water point occurrence with QGIS, locating Lake Faguibine

4. Editing the water point file: The coordinates of this new water point of interest must be entered in the list file of water points of interest (section 5.2.2). Here, the new water point takes ID 12. We are only interested in the area delineated by the coordinates, therefore the parameters Adm\_Lev and Adm\_Cod must be set to 0.

ID	Lat_min	Lat_max	Lon_min	Lon_max	Adm_lev	Adm_Cod	Nom
0001	15.6830	15.8970	-1.4600	-1.2630	0	00000	GOSSI
0002	19.3710	19.5040	0.56700	0.87900	0	00000	AGUELHOK
0003	16.0130	16.2900	-12.683	-12.424	0	00000	M'BOUT
0004	0.00000	0.00000	0.00000	0.00000	2	00014	KIDAL
0005	0.00000	0.00000	0.00000	0.00000	0	00138	MALI
0006	19.7285	19.7897	0.97970	1.09720	0	00000	IN'TANOUT
0007	12.9200	13.2520	-10.444	-10.241	0	00000	MANANTALI
0008	15.4984	15.6073	-0.5175	-0.4381	0	00000	IN'TILLIT
0009	11.5911	11.7564	42.3321	42.4724	0	00000	LAC_ASSAL
0010	11.2036	11.2883	42.5319	42.6649	0	00000	GRAND_BARRA
0011	11.0367	11.2859	41.6600	41.9038	0	00000	LAC_ABBE
0012	16.7191	16.8303	-4.0490	-3.7748	0	00000	LAC_FAGUIBINE

5. Running HydroGenerator: A new run of HydroGenerator is required to perform the calculations taking into account this new water point of interest. Particular attention must be paid to the configuration of the Decade\_Debut\_Integration and Decade\_Fin\_Integration, which must cover an entire year, focusing the rainy season. Here, we keep the default parameters that properly center the West-African monsoon (Decade\_Debut\_Integration=10 and Decade\_Fin\_Integration=9).

**6. Viewing the output file, and time profile:** The final step is to view the file in a spreadsheet such as Microsoft Excel and draw the time profile. The output file is retrieved using the method described in section 5.3.4. The file can be read with Excel.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA
<b>1</b> Nom du point : <b>LAC_FAGUIBINE</b>																										
<b>2</b> Len( <i>date</i> )	177																									
<b>3</b> Len( <i>solm</i> )	3-924																									
<b>4</b> Max( <i>solm</i> )	146.44																									
<b>5</b> Min( <i>solm</i> )	71.09																									
<b>6</b>																										
<b>7</b>																										
<b>8</b>	Dekad	Date	Mean	Min	Max	Std	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
9	1	01-jenv	64.33	57.26	76.04	6.43	67.59	72.28	76.04	73.22	70.4	68.55	71.34	68.53	60.08	58.2	65.71	58.2	60.08	60.08	57.26	62.89	57.26	57.26	57.26	
10	2	11-jenu	65.76	57.26	79.79	7.78	69.46	79.79	77.91	76.98	72.28	70.41	67.59	59.14	58.2	69.47	60.08	61.96	61.02	57.26	62.89	57.26	57.26	57.26		
11	3	21-jenu	65.91	57.26	72.25	7.25	70.4	81.97	85.77	72.27	68.55	60.08	58.2	59.14	57.26	60.08	61.96	61.02	57.26	62.89	57.26	57.26	57.26			
12	4	01-avr	65.91	57.26	83.55	8.16	71.34	83.55	80.73	76.98	74.16	64.77	69.47	68.53	60.08	58.14	63.83	64.77	63.83	60.08	59.14	57.26	57.26	57.26		
13	5	11-avr	68.8	57.26	99.5	10.39	72.28	99.5	77.91	78.85	70.4	63.83	69.47	60.08	57.26	66.65	63.83	68.83	57.26	59.14	61.02	57.26	57.26	62.89		
14	6	21-avr	67.09	57.26	103.26	11.38	73.22	103.26	81.67	77.91	70.4	65.71	63.83	66.65	61.02	58.2	74.16	63.83	62.89	57.26	60.08	59.14	57.26	57.26		
15	7	01-mai	66.57	57.26	104.2	11.66	73.22	104.2	84.49	76.98	63.83	64.77	63.83	61.02	60.08	57.26	68.53	60.85	57.26	57.26	59.14	57.26	57.26	57.26		
16	8	11-mai	66.8	57.26	103.26	12.58	70.4	103.26	84.49	76.98	63.83	64.77	63.83	61.02	60.08	57.26	68.53	60.85	57.26	57.26	59.14	57.26	57.26	57.26		
17	9	21-mai	68.2	57.26	110.77	13.94	73.22	110.77	90.12	86.36	61.96	69.47	62.89	62.9	59.14	65.71	68.53	70.4	57.26	69.47	59.14	57.26	57.26	58.2		
18	10	01-avr	70.01	57.26	118.28	12.8	83.55	118.28	89.18	86.36	63.83	81.67	61.02	57.26	68.53	72.28	70.4	58.2	57.26	57.26	57.26	57.26	57.26	57.26		
19	11	11-avr	75.05	57.26	119.21	19.26	96.49	95.75	95.75	63.83	95.75	61.96	62.9	59.14	57.26	88.24	68.53	81.42	57.26	69.47	57.26	57.26	57.26	57.26		
20	21	21-avr	79.13	57.26	119.21	20.26	98.01	119.21	98.01	98.01	63.83	98.01	60.08	57.26	88.24	68.53	81.42	57.26	69.47	57.26	57.26	57.26	57.26	57.26		
21	22	01-mai	82.37	57.26	154.24	26.29	97.62	126.72	134.26	95.5	66.65	115.66	59.14	61.96	61.96	61.02	101.58	90.12	105.07	57.26	73.22	57.26	57.26	57.26		
22	23	11-mai	82.7	57.26	154.24	26.29	104.2	91.05	66.65	112.64	59.14	61.96	61.02	68.53	107.95	92.93	109.83	57.26	76.97	57.26	57.26	57.26	59.14			
23	24	21-mai	80.12	57.26	157.99	25.62	89.17	127.11	136.11	104.2	60.08	112.64	61.96	61.02	69.46	102.32	76.03	60.08	102.32	69.46	102.4	76.97	57.26	57.26		
24	25	01-juin	76.79	57.26	154.24	24.65	85.42	124.85	134.24	100.44	66.65	57.26	92.93	61.02	60.08	63.83	65.71	105.26	104.2	57.26	73.22	57.26	57.26	57.26		
25	26	11-juin	75.76	57.26	154.24	24.65	84.49	123.98	137.08	98.17	61.96	57.26	92.93	61.02	60.08	63.83	65.71	105.26	104.2	57.26	73.22	57.26	57.26	57.26		
26	27	21-juil	75.52	57.26	158.93	23.89	85.42	118.4	138.93	92.93	66.65	58.2	105.13	60.08	61.96	63.83	102.32	73.22	57.26	87.5	72.28	57.26	57.26	57.26		
27	28	01-avr	75.8	57.26	141.74	24.11	84.48	118.4	141.74	95.75	64.77	60.08	102.32	62.9	61.96	63.83	61.02	99.5	67.26	87.5	72.28	57.26	57.26	57.26		
28	29	11-avr	76.27	57.26	145.4	24.56	83.54	117.34	145.4	97.61	61.02	108.89	61.96	63.83	61.02	57.26	101.98	88.16	87.5	72.28	57.26	57.26	57.26			
29	30	21-avr	77.82	57.26	146.44	24.94	77.91	105.13	146.44	104.2	68.53	58.2	117.71	61.02	64.77	65.71	57.26	105.26	88.75	98.87	57.26	69.47	57.26	57.26		
30	31	01-avr	77.82	57.26	146.44	24.94	77.91	105.13	146.44	104.2	68.53	58.2	117.71	61.02	64.77	65.71	57.26	105.26	88.75	98.87	57.26	69.47	57.26	57.26		
31	32	11-avr	79.13	57.26	159.87	23.23	79.79	91.99	139.87	108.89	88.36	63.83	109.83	61.02	66.65	66.65	60.08	102.32	81.67	99.5	57.26	76.04	57.26	57.26		
32	33	21-avr	79.51	57.26	128.78	22.2	69.46	73.22	126.73	110.77	96.69	64.77	117.34	61.02	64.77	67.39	74.16	105.13	88.36	98.56	57.26	72.28	57.26	57.26		
33	34	01-sept	76.79	57.26	164.24	28.07	67.59	104.2	98.56	104.2	67.59	67.59	65.71	72.28	57.26	97.62	91.05	95.56	57.26	84.48	57.26	57.26	57.26			
34	35	11-sept	76.79	57.26	164.24	28.07	67.59	104.2	98.56	104.2	67.59	67.59	65.71	72.28	57.26	97.62	91.05	95.56	57.26	84.48	57.26	57.26	57.26			
35	36	21-sept	70.36	57.26	91.05	11.94	57.26	59.14	75.1	82.61	82.42	66.65	72.28	68.53	63.83	66.65	82.61	91.05	89.18	57.26	88.36	57.26	57.26	62.89		
36	37	01-oct	68.67	57.26	91.99	10.31	57.26	61.96	72.28	77.91	78.73	66.65	65.71	68.53	64.77	67.59	76.97	75.04	57.26	91.99	57.26	57.26	61.02			
37	38	11-oct	64.68	57.26	82.61	6.98	57.26	61.96	72.28	68.53	69.47	61.02	61.96	68.53	65.71	67.59	64.77	58.2	65.71	74.16	71.34	57.26	72.28	57.26		
38	39	21-oct	65.76	57.26	82.61	6.98	57.26	61.96	72.28	68.53	69.47	61.02	61.96	68.53	65.71	67.59	64.77	58.2	65.71	74.16	71.34	57.26	72.28	57.26		
39	40	01-nov	62.75	57.26	75.1	6	57.26	63.83	71.34	68.53	69.47	57.26	63.83	68.53	61.96	58.2	72.28	75.3	67.59	57.26	69.47	57.26	57.26	59.14		
40	41	11-nov	62.24	57.26	75.28	5.31	57.26	67.39	71.34	66.65	68.53	69.47	57.26	63.83	68.53	61.96	58.2	72.28	67.59	67.59	57.26	69.47	57.26	57.26	58.2	
41	42	21-nov	62.7	57.26	57.26	5	57.26	67.39	70.4	63.83	68.53	69.47	57.26	63.83	68.53	61.96	58.2	72.28	67.59	67.59	57.26	69.47	57.26	57.26	57.26	
42	43	01-dec	62.55	57.26	51.3	5.31	57.26	67.39	70.4	61.96	67.39	69.47	57.26	63.83	68.53	61.96	58.2	72.28	67.59	67.59	57.26	69.47	57.26	57.26	57.26	
43	44	11-dec	69.34	57.26	76.04	5.55	62.89	76.04	69.47	65.71	66.65	68.53	72.28	68.53	61.96	58.2	60.08	57.26	62.89	57.26	57.26	57.26	57.26	57.26		
44	45	21-dec	63.49	57.26	73.22	5.77	64.77	73.22	73.22	69.47	66.65	68.53	72.28	68.53	61.96	58.2	61.02	60.08	57.26	61.02	57.26	57.26	57.26			

Figure 44 – Spreadsheet output file for the “Lake Faguibine” water point

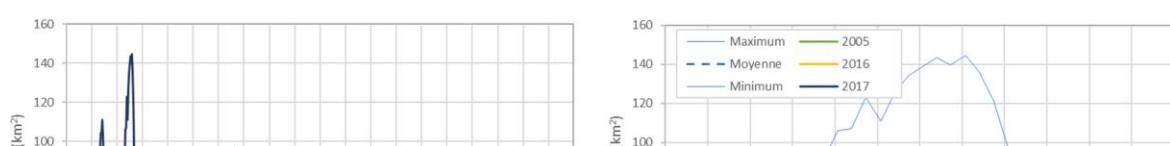


Figure 45 – Time profile of Lake Faguibine filling rate

### 5.4.3 Creating a statistical vector map for water presence

This example describes how to establish a vector map at administrative level 1 (region) for water anomaly during the March to May dry season for the year 2017.

1. Downloading and incorporating the new available SWB 10-day periods: The new available 10-day periods must be downloaded according to the instructions in Chapter 3.
  2. Parameter setting: The choice of parameters is important to determine the integration period of the anomaly calculation. Following the instructions in section 5.2.3 and based on Table 4, the Decade\_Debut\_Integration and Decade\_Fin\_Integration parameters should be set at 7 and 15 respectively to cover the months of March to May.
  3. Program runtime: Following the instructions in section 5.2.4
  4. Using GIS software to create the map: Using GIS software such as QGIS allows you to display and format the map. A QGIS project template can be found in the GIS/QGIS Project/ directory. The *shapefile* to be retrieved is the water anomaly vector file HYDRO\_ADM\_1.shp as described in section 5.3.7. In this file, the attribute table shows the water presence anomaly for each of the available years and expressed as a % compared to normal. The vector file should then be displayed by selecting the column of the attribute table corresponding to the water presence anomaly for 2017 (see Table 26) in an appropriate color gradient.

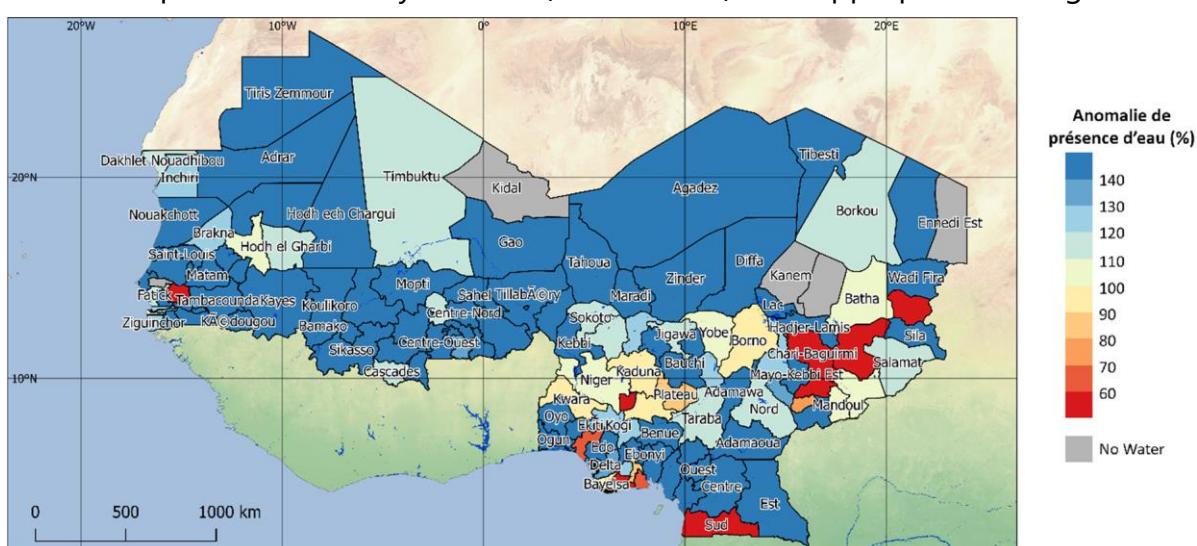


Figure 46 – Surface water anomaly for the months of March, April and May 2017 in West Africa

## 6 AutoRun

The AutoRun module (v1.2) is a program that allows DeCompressor, BioGenerator and HydroGenerator to be executed automatically. With the objective of real-time production, AutoRun manages the successive launch of programs as soon as new DMP, NDVI and SWB 10-day periods are available.

### 6.1 Operating Principles

DMP, NDVI and SWB 10-day data are normally available from the day after the end of the covered 10-day period (see Chapter 2). In other words, from the 1<sup>st</sup>, 11<sup>th</sup> and 21<sup>st</sup> of each month, a new DMP, NDVI or SWB 10-day period may be available for download.

The AutoRun program, synchronized with the system clock, is on standby, waiting for those periods. When new 10-day periods are likely to be available, AutoRun will launch the DeCompressor program every hour to check the availability of new 10-day periods and attempt to download.

In the case of a successful download of a new DMP 10-day period, AutoRun launches the BioGenerator program. Similarly, in the case of a successful download of a SWB 10-day period, the HydroGenerator program is executed.

The AutoRun program also has a function to copy the outputs after each runtime of BioGenerator and HydroGenerator. This copy function allows you to push the files to a database such as GeoServer for example. The list of copied files can be found in the File\_Push.txt file. The copy behaves like the file copy function of the system, except that no error messages are communicated (see section 6.2.2).

### 6.2 Parameter setting

The DeCompressor, BioGenerator and HydroGenerator programs run their respective parameters as described in the chapters relating to each of the programs (sections 3.4, 4.2.2 and 5.2.3).

### 6.2.1 General AutoRun settings

The AutoRun settings allow you to activate either the BioGenerator or the HydroGenerator program. These parameters can be accessed and edited via the Param/AutoRun\_Param.txt file.

```
AutoRun Parameters
1   1      BioGenerator HydroGenerator (Default: 1 1)
0           FilePush (Default: 0)
```

#### BioGenerator (0: Off, 1: On)

This parameter activates or deactivates the BioGenerator program

#### HydroGenerator (0: Off, 1: On)

This parameter activates or deactivates the HydroGenerator program.

#### FilePush (0: Off, 1: On)

This parameter activates or deactivates the BioGenerator and HydroGenerator outputs copying function.

### 6.2.2 Settings of the copy function

The Param/File\_Push.txt file contains a list of source and target files. The path of the source file is relative, while the path of the target file is absolute.

```
Output\Biomass\Anomaly\Anomaly_2018.tif
Y:\data_dir\data\Biomass\SAH_BiomassAnomaly2018_ef_v0\SAH_BiomassAnomaly2018_ef_v0.geotiff
Output\Biomass\Anomaly_2018.tif Y:\data_dir\MetaDownload\BiomassAnomaly2018.tif
```

In this example, the Anomaly\_2018.tif file will be copied to the file SAH\_BiomassAnomaly2018\_ef\_v0.geotiff and to the BiomassAnomaly2018.tif. file.

### 6.3 Program Runtime

The installation of MATLAB Compiler Runtime R2016a is required before running the program. If necessary, it is required to run the installation program: Libs/Utils/MCR\_R2016a\_win64\_installer.exe.

The execution of the program is done simply by double-clicking on the executable file

AutoRun.exe. A runtime window opens and recalls the last 10-day periods integrated by BioGenerator and HydroGenerator if these programs are activated in the configuration.

In a first step, AutoRun will run DeCompressor, then BioGenerator and HydroGenerator if they are enabled in the configuration.

In a second step, during the standby phase for the new availability of 10-day periods, the window displays the date and time.

Every day at midnight, the DeCompressor program is executed even outside the availability periods of new 10-day periods.

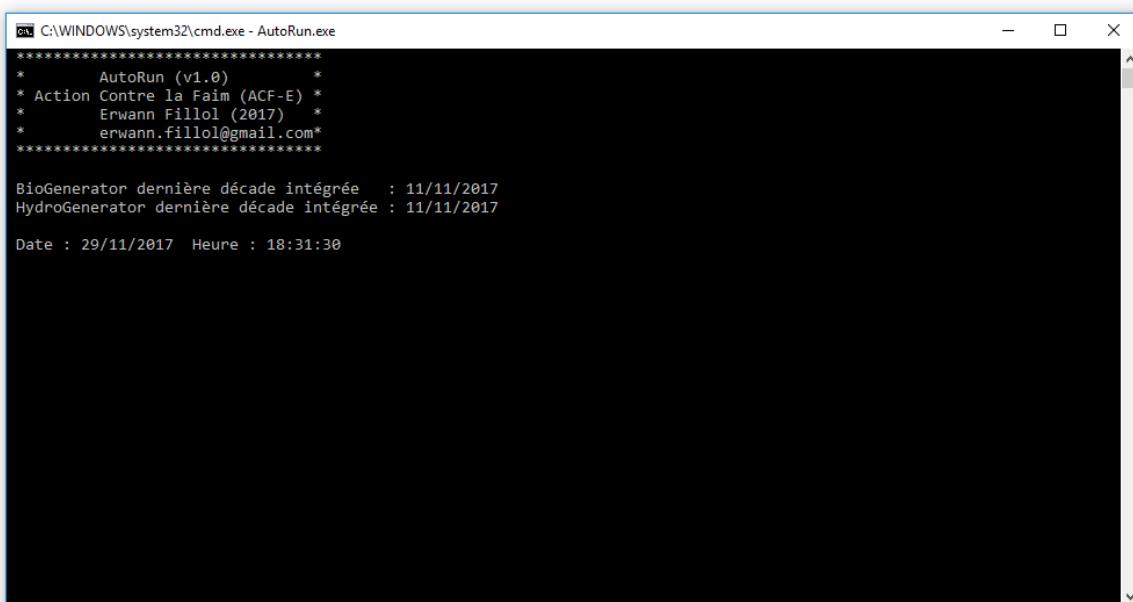


Figure 47 – AutoRun window waiting for new 10-day periods

## 7 ClearAll

The ClearAll program (v1.0) allows to delete all the result files and intermediate calculation files produced by the DeCompressor, BioGenerator and HydroGenerator programs. Only compressed files, directly from the download of the source database, are not affected.

Following the execution of ClearAll, and before executing the BioGenerator or HydroGenerator program, it is advisable to launch the DeCompressor program (see section 3.5) in order to restore the *shapefiles* and decompress the source database.

The execution of ClearAll is done simply by double-clicking on the ClearAll.exe file. No parameter is required and the files are irreversibly deleted.

## 8 Conclusion

Tools are developed and used by Action Against Hunger (ACF) for its food crisis early warning system in the Sahel, and for assistance in the developing and maintaining pastoral activities.

Those tools are mainly based on global and real-time satellite information from the acquisitions of the SPOT-VEGETATION and PROBA-V satellites and have been continuously available since April 1998.

The main use is given by the BioGenerator 2 module able to generate biomass production maps over Sub-Saharan Africa and calculate an anomaly in this production. The vulnerability index VI derived from this anomaly calculation makes it possible to identify, immediately at the end of the rainy season, sensitive areas where grazing may not be enough to cover the needs of livestock farmers during the dry season.

The HydroGenerator module provides information on the presence of surface water, available and accessible to farmers for their herds. Real-time monitoring of the filling rate of ponds and water points of pastoral interest provides relevant information on the possibilities of receiving herds in grazing areas in the dry season.

Finally, the combined use of biomass and surface water information allow viewing areas that do not sufficiently have artificial water points. This information is relevant to assist in developing new boreholes.

## 9 Contact

For any additional information requests, or to report malfunctions in the AutoRun (v1.2), DeCompressor (v2.1), BioGenerator (v5.1) and HydroGenerator (v4.1) modules, please contact the program designer directly.

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