Geospatial Based Approaches for Monitoring and Assessing Natural Resources in Senegal

Abdoul Aziz Diouf, PhD

Centre de Suivi Ecologique
Research-Development program

aziz.diouf@cse.sn

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The Centre de Suivi Ecologique

1986
Project of Sahelian Pastoral Ecosystems Monitoring
- Create new skills
- Put in place monitoring procedures and processes
- Develop quality HR
- Access to cut-off equipment
- Limited interventions in the Ferlo

1993
Creation of Centre de Suivi Ecologique
- Consolidation of knowledge
- Institutionalization
- Involvement in national strategies
- Contribution to national capacity building in geomatics
- Interventions across Senegal

2022
Centre de Suivi Ecologique
- 1997: Agreement with the State, recognition of public utility
- 2010: First National Entity to implement the CC Adaptation Fund
- 2015: First National Implementing Entity of the Green Climate Fund
- 2016: ISO 9001 certification
- Interventions in several African countries

1997: Agreement with the State, recognition of Public Utility
Broad group of researchers and teachers

Confront the scientific knowledges and develop skills to support innovation

Multidisciplinary expertise of national and international institutions to tackle major issues raised by future contributions of livestock to the agricultural sector, environment, livelihoods and food security of the populations in the Sahel

www.ppzs.org
Senegal

Rainy season: July - October
Dry season: November - June

Population 2022(P): 17 738 795
Population women: 8 913 568
Population men: 8 825 227
Area (km²): 196 712
Density (Pers/km²): 90
Capitale: Dakar

Three climatic zones:
• humid to subhumid (south)
• subhumid to semi-arid (centre)
• semi-aride to arid (north)

Rainfall:
• from 1200 mm in the South to 300 mm in the North

Agriculture:
60% of households (in 2013)

www.ansd.sn/
Outline

1. Current applications
   1.1. Monitoring of vegetation growth
   1.2. Assessment of the forage biomass production
   1.3. Monitoring ephemeral waterbodies
   1.4. Assessment of the woody canopy cover
   1.5. Targets and end-users

2. Some ongoing research activities
   2.1. Monitoring of dry season forage biomass
   2.2. Assessment of herbaceous mass using UAV and photogrammetry
Current applications
Why forage biomass monitoring?

~ 60% of the population <-- livestock
~ 17 million heads (in 2015)

Pastoral livestock

Rangelands

Source of income

~30% of the population

>>> High variability in production and quality of forage biomass
Why forage biomass monitoring?

Forage biomass availability

Detection of areas with deficit or surplus

- Fuel reduction in protected areas & Fire prevention
- Livestock guidance & Rational use of natural resources
- Early warning for decision-makers

- Limiting the land degradation
- Monitoring of livestock feed security
Satellite data acquisition

**NDVI:** Normalized Difference Vegetation Index

**FAPAR:** Fraction of Absorbed Photosynthetically Active Radiation

**LAI:** Leaf Area Index
Monitoring of vegetation growth

Normalized Difference Vegetation Index (NDVI)

Expresses the chlorophyll activity of plants and is thus a metrics of the vegetation presence on the ground in a given area

$$\text{NDVI} = \frac{(\text{NIR} - \text{R})}{(\text{NIR} + \text{R})}$$

Where $\text{NIR}$ = % of reflectance in the Near Infra Red

$\text{R}$ = % of reflectance in the Red

$$3^{\text{rd}} \text{ dekad June 2017}$$

$$3^{\text{rd}} \text{ dekad July 2017}$$

$$3^{\text{rd}} \text{ dekad Aug. 2017}$$

$$3^{\text{rd}} \text{ dekad Sept. 2017}$$

Used to detect areas with chlorophyll activity
Monitoring of vegetation growth

Vegetation Condition Index (VCI)

VCI is used to rank, from 0 to 100, the level of vegetation growth in relation to the maximum value recorded for the same decade since 1999.

\[
VCI = \left[ \frac{(NDVI_{dek} - NDVI_{mindek})}{(NDVI_{maxdec} - NDVI_{mindek})} \right] \times 100
\]

Where \( NDVI_{dek} \) is the NDVI value of the study period; \( NDVI_{mindek} \) and \( NDVI_{maxdek} \) correspond to the minimum and maximum NDVI values of the same dekad, calculated on the historical series of SPOT-Vegetation/PROBA-V/Sentinel-3.

Used to detect areas with plant growth anomalies (for Early Warning)
Monitoring of vegetation growth

Vegetation growth anomalies (NDVI, VCI and SOS: start of season)

- 3rd dekad June 2017
- 3rd dekad July 2017
- 3rd dekad Aug 2017
- 3rd dekad sept 2017

LULC mask

Souilene, Dept. Dagana

AtchBali, Dept. Podor

SOS => detect areas with growing delay or advance (in dekads)
Assessment of the forage biomass production

Monitoring sites and field data collection

- 24 sites
- 3km*3km ~ 9 pixels SPOT-VGT
- Accessibility;
- Homogeneity of ecological conditions;
- Good representation of the landscape

- Sampling (mesures) -> end of the growing season (Octobre)

  - Herbaceous layer
  - Woody stratum
Assessment of the forage biomass production

Stratified sampling of the herbaceous layer

Transect length = 1000 meters

- Noting of frequency of four approximate production classes (or levels)
  - Class 1 (0 = bare soil)
  - Class 2 (1 = low production)
  - Class 3 (2 = fair production)
  - Class 4 (3 = high production)

- Collection and weighing of fresh biomass of 35 to 100 plot (1 meter square)
- Resampling of the four classes
- 3 samples of about 200 g taken for each class to the lab (Oven)
Systematic sampling of woody stratum

Along the 1000m transect

- Four circular plots sampled at the distance 200, 400, 600 et 800 m (every 2 years)
- Complete inventory (every 2 years)
- Cut leaves from ten twigs of each of the most representative species (annually)
- Weighing of fresh foliar mass of each species
Assessment of the forage biomass production

Linear regression model (traditional)

Calculation of NDVI integral and extraction

1. Growing season determined by visual analysis of decadal images

2. Weighed average of seasonal images

\[ \text{NDVI}_{\text{integrated}} = \frac{\sum_{i=1}^{t} \text{NDVI} \times X_i}{P} \]

Where

- NDVI = dekadal NDVI image,
- Xi = covered period by image = 10,
- P = number of day of considered period

Seasonal NDVI images
Assessment of the forage biomass production

Linear regression model (traditional)

Model calibration

Data table

<table>
<thead>
<tr>
<th>J</th>
<th>K</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCS</td>
<td>NDVI</td>
<td>Biotot</td>
</tr>
<tr>
<td>C1L5</td>
<td>0,4260</td>
<td>1230</td>
</tr>
<tr>
<td>C2L1</td>
<td>0,3030</td>
<td>940</td>
</tr>
<tr>
<td>C2L2</td>
<td>0,3811</td>
<td>1508</td>
</tr>
<tr>
<td>C2L3</td>
<td>0,4340</td>
<td>1829</td>
</tr>
<tr>
<td>C2L4</td>
<td>0,4100</td>
<td>1378</td>
</tr>
<tr>
<td>C2L5</td>
<td>0,5255</td>
<td>2287</td>
</tr>
<tr>
<td>C2L6</td>
<td>0,5949</td>
<td>2368</td>
</tr>
</tbody>
</table>

CSE result in 2013

\[ y = 11027x - 2776,7 \]

\[ R = 0,83 \]

\[ P = a \times NDVI + b \]

Performance measure = R² (good if near to 1)
Assessment of the forage biomass production

Intra-seasonal approach with non-linear models

Temporal smoothing
Cumulation

J = Cumul of July
JA = Cumul of July and August
JAS = Cumul from July to September
JASO = Cumul from July to October

Satellite data processing

NDVI, FAPAR, LAI (SPOT-VGT ProbaV)

Decadal images

http://land.copernicus.eu/
Assessment of the forage biomass production

Intra-seasonal approach with non-linear models

Equation et statistical performance of selected models

<table>
<thead>
<tr>
<th>Variable</th>
<th>Equation</th>
<th>$R^2$</th>
<th>RMSE (kg.MS/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>fapar_JASO</td>
<td>$Y = 669.1 \times \exp(X \times 0.22)$</td>
<td>0.66</td>
<td>769.25</td>
</tr>
<tr>
<td>ndvi_JAS</td>
<td>$Y = 403.2 \times \exp(X \times 0.41)$</td>
<td>0.62</td>
<td>806.31</td>
</tr>
<tr>
<td>ndvi_JA</td>
<td>$Y = 750.8 \times (X^{1.37})$</td>
<td>0.56</td>
<td>866.40</td>
</tr>
<tr>
<td>lai_J</td>
<td>$Y = 2420.8 \times (X^{0.46})$</td>
<td>0.58</td>
<td>851.22</td>
</tr>
</tbody>
</table>

- LAI (lai_J) most suited for biomass forecasting at the beginning of the season
- NDVI (ndvi_JA et ndvi_JAS) most suited for the mid season
- FAPAR (fapar_JASO) works better at the end of the season
- Increasing performance of models along the season
Assessment of the forage biomass production

**Approach with multi-linear regression models**

**Phenological variables from FAPAR Time Series**

- **Start of season** = 20%
- **End of season** = 50%
- **Numb. of iterations** = 2
- **Adaptation strength** = 2
- **Windows size** = 4 decades

**TIMESAT**

- ECONorth
- ECOeast
- ECOwest
- ECOsouth

**11 phenological metrics**
Assessment of the forage biomass production

Approach with multi-linear regression models

Equation and statistical performance of models

<table>
<thead>
<tr>
<th>Region</th>
<th>Estimation Model of Total Biomass (B)</th>
<th>Adj. R²</th>
<th>MAE (kg·DM/ha)</th>
<th>NMAE (%)</th>
<th>n/n_test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study area</td>
<td>Model_SA: [ B = 424.13 \times \text{LINTG} - 100.91 \times \text{LOS} + 39.80 \times \text{RDERIV} + 293.71 ] 0.67 608 26.0 263/39600</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Model_EW: [ B = 4594.18 \times \text{PEAK} - 129.09 \times \text{SOS} + 1866.17 ] 0.62 641 27.3 263/39600</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ecoregion</th>
<th>Estimation Model of Total Biomass (B)</th>
<th>Adj. R²</th>
<th>MAE (kg·DM/ha)</th>
<th>NMAE (%)</th>
<th>n/n_test</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECOnorth</td>
<td>[ B = 1703.10 \times \text{PEAK} + 1644.92 \times \text{BVAL} + 432.94 ] 0.24 427 31.0 121/18600</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECOeast</td>
<td>[ B = 463.02 \times \text{LINTG} - 296.29 \times \text{LOS} - 152.37 \times \text{SOS} + 5969.39 ] 0.49 575 23.1 65/9800</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECOwest</td>
<td>[ B = 3341.72 \times \text{PEAK} + 282.87 \times \text{PMID} - 7125.91 ] 0.15 589 19.1 44/6600</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECosouth</td>
<td>[ B = 603.53 \times \text{LINTG} + 52.83 \times \text{RDERIV} - 325.30 \times \text{LOS} + 1944.04 ] 0.31 51 3 33/5000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Assessment of the forage biomass production

Operational system for forage assessment

- Linear model (NDVI)
- Nonlinear model (NDVI, FAPAR, LAI)
- Multilinear model (FAPAR)

Dry season  |  Rainy season  |  Dry season

Veg. Ind.

Maximum

Growing

Senescence

JAN  |  FEV  |  MAR  |  APR  |  MAY  |  JUN  |  JUL  |  AUG  |  SEP  |  OCT  |  NOV  |  DEC

1  |  2  |  3  |  4
Assessment of the forage biomass production

Operational system for forage assessment

Examples of map shared with end-users (i.e. Natural resource managers, livestock and rangeland managers)
Forage stock and feed balance

Assessment of the forage biomass production

Current situation (March 2022)

Projected situation (JJA 2022)

Feed balance is monthly updated along the dry season

Monitor feed balance status in administrative unit (i.e. level-3)
Monitoring ephemeral waterbodies

System development and calibration

Field data

Landsat-8 and Sentinel-2

Modified Normalized Difference Water Index (MNDWI)

Tethys Platform

Ponds location

Polarization area of ponds

Global view of WENDOU geoportal

Focus view of one pond and products associated
Monitoring ephemeral waterbodies

Validation process

<table>
<thead>
<tr>
<th>% of vegetation cover</th>
<th>True detection</th>
<th>False detection</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 25%</td>
<td>15</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>25 and 75%</td>
<td>10</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>&gt; 75%</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>26</td>
<td>10</td>
<td>36</td>
</tr>
</tbody>
</table>

Calculated Chi-2 (2.78) is lower than the theoretical one (7.82)

>>> Independence between detection and vegetation cover rate with only 5% chance of error
Monitor the water availability for ~300 ponds across the Ferlo area

Shared information with pastoralists via local radio and/or SMS
Monitoring ephemeral waterbodies using earth observation data in Ferlo (Senegal)

**Abstract**
This project is located in the Sahelian zone of Senegal dedicated to studying ephemeral waterbodies, which are very fragile and respond rapidly to physical, hydrological, and climatic change. Monitoring the water and land is crucial to understanding the long-term impact of change. While data on ephemeral waterbodies has been collected by aerial photography, it has been very fragmented. The project aims to develop a method to identify ephemeral waterbodies using earth observation data and to characterize this water. The project will use a method combining water body detection with statistical analysis of the image data.

**Context**
The Sahelian zone in Senegal is a very important area in terms of biodiversity, vegetation, and agriculture. However, the current situation of climate change, drought, and desertification makes this area vulnerable to various environmental issues. The project's main objective is to develop a method to identify ephemeral waterbodies using earth observation data and to characterize this water.

**Rationale**
The project is crucial to understand the Sahelian zone's water cycle, due to its unique ecological and bioclimatic features. Drought and desertification are common problems in this zone, leading to severe water scarcity. The project aims to develop a method to identify ephemeral waterbodies using earth observation data and to characterize this water.

**Main objective**
Combine the earth observation data and the aerial photography to identify ephemeral waterbodies. The project will use a method combining water body detection with statistical analysis of the image data.

**Specific objectives**
- More information on ephemeral waterbodies is available, which are very fragile and respond rapidly to physical, hydrological, and climatic change. Monitoring the water and land is crucial to understanding the long-term impact of change.
- The project aims to develop a method to identify ephemeral waterbodies using earth observation data and to characterize this water.

**Expected results**
- The results will be published in scientific journals and presented at international conferences.
- The project will contribute to understanding the Sahelian zone's water cycle, due to its unique ecological and bioclimatic features. Drought and desertification are common problems in this zone, leading to severe water scarcity.

**Anticipated impacts**
- The results will be used to improve water resource management in the Sahelian zone.
- The project will contribute to understanding the Sahelian zone's water cycle, due to its unique ecological and bioclimatic features. Drought and desertification are common problems in this zone, leading to severe water scarcity.

**Methodologic Approach**
- A project designed with the help of stakeholders.
- The project aims to develop a method to identify ephemeral waterbodies using earth observation data and to characterize this water.
- The project will use a method combining water body detection with statistical analysis of the image data.
## Methodology used to model woody canopy cover (%WCC)

### Overall flowchart

<table>
<thead>
<tr>
<th>2015-2017 Sentinel–1 data</th>
<th>2015-2017 Sentinel–2 data</th>
<th>WCC measured in the field (96 plots)</th>
<th>Supplementary WCC measured using CEO (47 plots)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monthly median composites of VV and VH bands</td>
<td>Monthly greenest pixel composite</td>
<td>Plot level WCC measurements</td>
<td></td>
</tr>
<tr>
<td>16 satellite-derived metrics</td>
<td>Training set - 70% random split</td>
<td>Test set - 30% random split</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Random Forest Regression</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Model accuracy assessment and interpretation</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Map of WCC</td>
</tr>
</tbody>
</table>

### CE0: Collect Earth Online

### VV: Vertical-Vertical polarization

### VH: Vertical-Horizontal polarization

**Anchang et al. 2020**

[Collect Earth Online (https://collect.earth/)](https://collect.earth/)
Assessment of the woody cover

Model performance and computed product

Anchang et al. 2020

Map of percent %WCC in Senegal, predicted from combined radar and optical remote sensing metrics (40 m x 40 m)

Random forest model training (N = 104) and validation (N = 39) accuracy for %WCC estimates in Senegal

Useful product for forest cover monitoring and land degradation assessment
Assessment of the woody cover

Canopy Cover (%) 

Woody Biomass (Kg/ha)
Targets and end-users

- Multidisciplinary working group (GTP)
- National Technical Committee on Early Warning System
- Directorate of Water and Forests (DEFCCS)
- Directorate of livestock
- NGOs
- Farmers' organizations
- Projects: PRAPS, …
- AUC, WAEMU, ECOWAS

For more information, please see in following web site

www.cse.sn
Ongoing research activities
Monitoring of dry season forage biomass

Google Earth Engine application

CAI : Cellulose Absorption Index
NDVI : Normalized Difference Vegetation Index

Unmixing process
(démêlange)

PPI : Pixel Purity Index

EO-1 Hyperion [30m]  MODIS

MOD09GHK [Daily, 500m]
MOD43B [16days-NBAR, 1km]

\[
\text{NDVI} = \frac{\rho_{\text{NIR}} - \rho_{\text{RED}}}{\rho_{\text{NIR}} + \rho_{\text{RED}}}
\]

and

\[
\text{CAI} = [0.5 \cdot (\rho_{2.0} + \rho_{2.2}) - \rho_{2.1}] \cdot 10
\]

\[
f_{\text{PV}}: \text{SM}_{\text{NDVI}} = 0.814; \text{SM}_{\text{SWIR3/ SWIR2}} = 0.318
\]
\[
f_{\text{NPV}}: \text{SM}_{\text{NDVI}} = 0.297; \text{SM}_{\text{SWIR3/ SWIR2}} = 0.490
\]
\[
f_{\text{NPV}}: \text{SM}_{\text{NDVI}} = 0.170; \text{SM}_{\text{SWIR3/ SWIR2}} = 1.02
\]

Guerschman et al. 2009
Monitoring of dry season forage biomass

Google Earth Engine application

Synthesize 500 m Hyperion data (spatial aggregation)

Calculate NDVI and CAI

Synthesize 500 m MODIS reflectance (convolution)

Regression analysis of NDVI and CAI against MODIS bands 1-7 and indices from MODIS bands

Application of best model to daily MODIS (MOD09GHK)

Application of best model to MODIS NBAR (MOD43B4) to create 6 year time series

Guerschman et al. 2009

End of rainy season

Middle of dry season

End of dry season

All dates
Monitoring of dry season forage biomass
Qualitative monitoring of forage biomass availability during the dry season in Senegal
Monitoring of dry season forage biomass

PhD research for improving the approach (Mrs Lo)

DRY SEASON FODDER ASSESSMENT ACROSS SENEGALESE RANGELANDS USING SENTINEL-2, LANDSAT-8 AND MODIS DATA

Field data collection

Dry season forage biomass for more accurate feed balance calculation

Taking photo on the sample plot and collecting the biomass

Statistical modeling

5-fold cross validation with 3 repeats.

Simple linear regression  Multilinear regression  Random Forest  Gradient Boosting Machines

Mapping of the dry-season fodder biomass