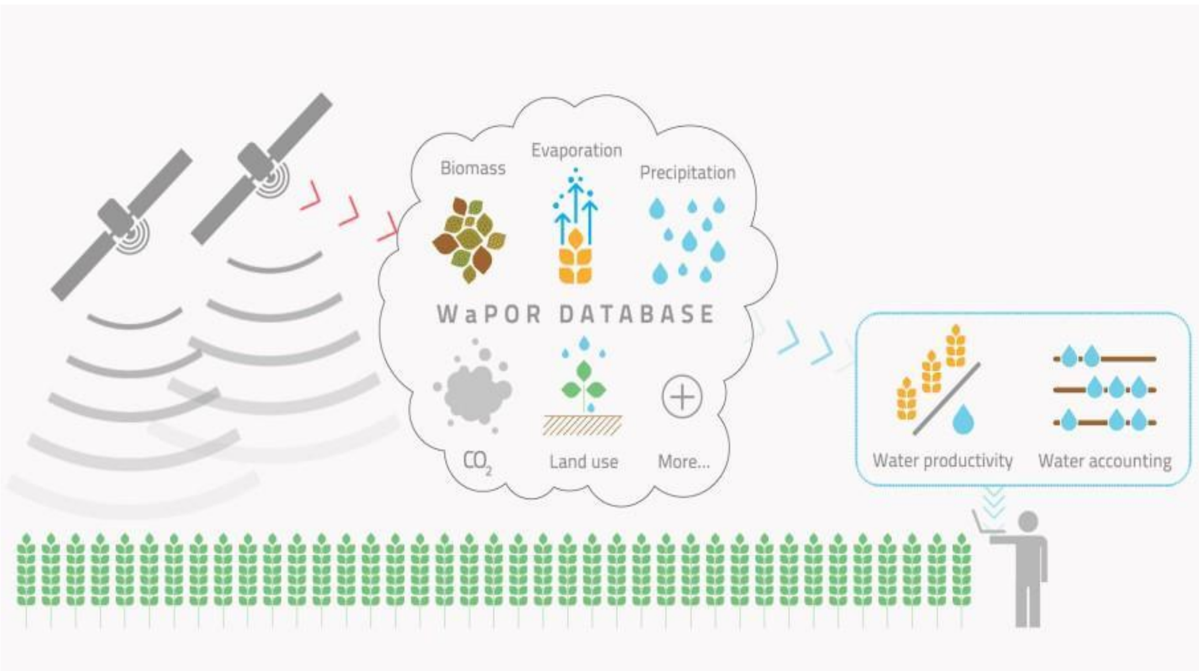
Transhumance web application based on WaPOR FAO's remote sensing portal for monitoring land and water productivity

Step report



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Contents

Abstract

The availability of pastoral resources is a major concern for pastoralism in many African countries. This particular problem, which is acute in transhumant pastoral areas, can result in overgrazing which could damage the environment and lead to conflicts. To overcome this issue, FAO, through APROSHE proposes to develop an application for mapping resources on transhumance in Mali and Burkina Faso. Such a tool aims to visualize the availability of forage and water resources to livestock in both countries.

The adopted framework consisted of collecting data through the project partners and the literature review, defining the method for generating internal App data including the dry matter availability equations, and designing the alpha version of the transhumance App and its functioning including the graphical user interface.

The collected data include but are not limited to biomass, land cover and use, precipitation, river network, protected areas, roads, villages and towns, water points, veterinary positions, livestock numbers, boarding docks, livestock markets, transhumance corridors, bush fires, and animal density. These data along with some internally generated information such as the NDVI, irrigated and evergreen areas, are combined with the WAPOR Net Primary Production (NPP) and the dry matter availability equations to derive the total usable biomass in rainy and dry seasons respectively. These resources were used to develop a graphical user interface in Google Earth Engine (GEE), with nineteen tools and widgets, and offer many possibilities to the end users.

1. Context

Recent national consultations under the auspices of FAO in Burkina Faso, Chad, Mali and Senegal have identified specific sectoral applications that could help solve key problems in the areas of land productivity and water from remote sensing. For pastoralism, the availability of pastoral resources was a major issue raised in all countries consulted. This particular problem, which is acute in transhumant pastoral areas, can result in overgrazing.

Assessing forage resource needs, availability, and spatial and temporal distribution is a key step towards better rangeland management. In the Sahel, the fodder - and food-balance sheets in place offer annual dry matter analyses, which have some limitations. FAO proposed an improved methodology and tool, the Feed Balance Sheet, which has been tested in several countries, including Burkina Faso. The application of this tool was the subject of a regional workshop and recommendations for further FAO technical assistance to the technical units of ministries.

2. Consultation specifications

The estimation of fodder availability can be improved from information on the location of water points and the delimitation of transhumance areas. The WaPOR portal, developed by FAO for monitoring land and water productivity in Africa and the Middle East, uses remote sensing to provide near real-time estimates of biomass and therefore indirectly forage production.

On this basis, FAO proposes to develop an application for mapping resources on transhumance rangelands. Such a tool aims to visualize the availability of forage and water resources available to livestock. More specifically, the application should contribute to (i) an assessment of monthly and seasonal forage availability and forage balance; and (ii) information on (available) means of support for transhumance.

The proposed application based on WaPOR will be built on Google Earth Engine (GEE). GEE has the decadal Net Primary Production (NPP) provided by WaPOR, allowing the calculation of biomass. This calculated biomass must be adjusted to obtain the available and usable part. A coefficient of 30% is often applied to the biomass calculated to derive the available and usable share. Recent research recommends that this coefficient be based on the knowledge of local experts. A similar approach (application of the coefficient) is generally used for the determination of the forage value. In addition, a distinction according to the types of land use (natural vegetation and cultivated land) is also necessary to take into account the seasonality that characterizes the region and the type of animal feed; For example, specific coefficients are required for each agricultural sub-product.

To account for the seasonality of transhumance (and biomass production and availability of agricultural sub-products) in countries of interest, feed availability will be produced on a monthly basis, allowing for seasonal aggregations.

Overall, the application will integrate, in the best possible way, the improved forage balance methodology as recommended in the FAO guidelines (2020). In addition to the fodder balance, transhumance is based on several factors such as water availability, the availability of veterinary stations, the presence of cattle markets, and transhumance corridors. Factors deemed relevant by the institution in charge of livestock as well as by transhumant herders and transhumance experts will be provided by the application as additional resources.

The implementation of the improved forage balance method, as recommended by FAO guidelines, involves close collaboration with local livestock experts, in particular for the determination of coefficients such as dynamic daily feed intake, livestock number and rations, conversion of biomass to fodder, etc. WaPOR-based resources (via GEE) and expert knowledge will serve as the basis for creating a first draft of the application. This first preliminary version will mainly involve the production of biomass and fodder.

Based on the first draft, an iterative stakeholder consultation process will be launched. The draft application will be presented and recommendations from stakeholders on additional resources to be added to this draft will be collected. The preliminary version will be gradually improved until an approved version is released. Experts and organizations of transhumant breeders will be involved throughout the improvement, evaluation and validation phases.

3. Data collection

The list of the collected data is provided in Table 1 below. Some data are accessed from the WaPOR platform while others are obtained from external sources, mainly from the project partners from Burkina Faso and Mali. The details of these data are provided in the following sub-sections.

Table 1: List of data collected and sources

Data	Source
Biomass	WaPOR
Land cover and use	WaPOR, World Dynamic Images
Precipitation	WaPOR, CHIRPS
River network	GEE
Protected areas	GEE
Roads	GEE
Villages and towns	GEE
Water points	DGEAP, DNPIA
Veterinary positions	DGEAP, DNPIA
Livestock numbers	DGEAP, DNPIA

Boarding dock	DGEAP
Livestock markets	DGEAP, DNPIA
Transhumance corridors	Digitalised from map (FAO-CIRAD, 2012)
Animal density	FAO (https://www.fao.org/livestock-systems/global-distributions/en/)

3.1. Data from project partners

The data obtained from the project partners are the transhumance corridors, the veterinary positions, the livestock numbers, the boarding docks, and livestock markets in Burkina Faso and Mali. Details about these data are provided below:

- **Transhumance corridors**

  The transhumance corridors were digitalized (FAO-CIRAD, 2012). A buffet of 15 km around each corridor was created hypothesising that the transhumant and their livestock may not be allowed to go beyond 15 km. Figure *1* shows the corridors in the two countries. No corridor is available in northern Mali which corresponds to the desert as well as in the southwest of the country. Most of the transhumance corridors crossed the neighbouring countries of the study area. In addition, the transhumance corridors in Burkina Faso crossed one another.

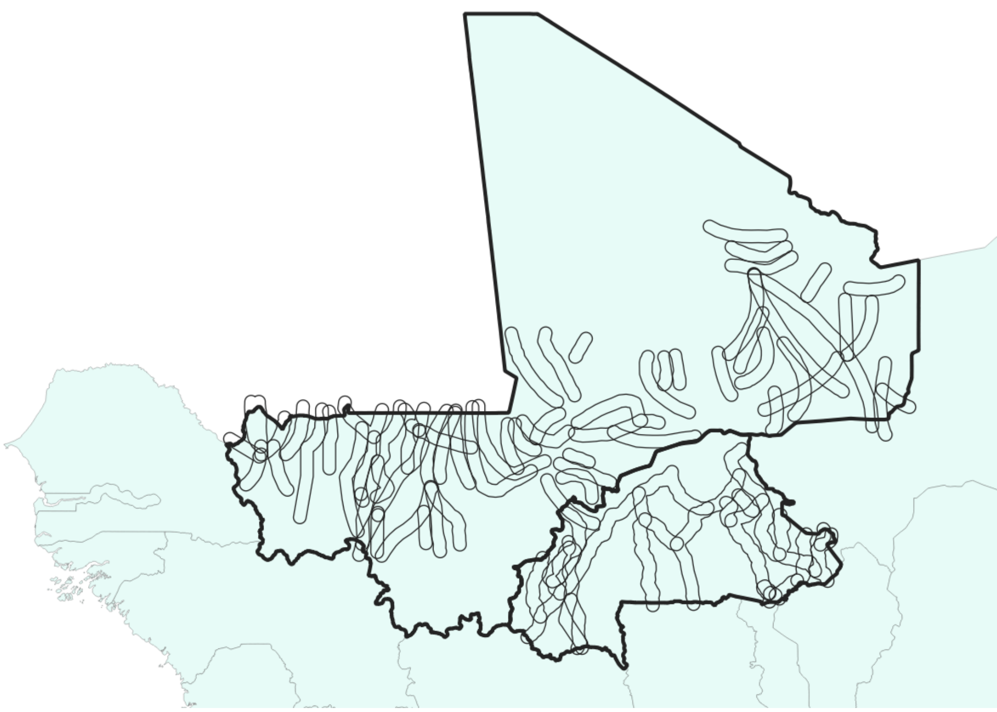

Figure 1: Transhumance corridors in Burkina Faso and Mali

- **Veterinary positions**

Veterinary positions are spread along the corridors with a total of 114 in Burkina Faso and 120 in Mali (Table 2). The data collected does not indicate the status of the veterinary positions in Mali. In contrast in BF, 68.42% of the veterinary positions are in good condition and functional, 15.79% are not working and the status of the remaining 15.79% is unknown. Figure *2* shows the spatial pattern of the Veterinary positions which are well spread throughout the corridors in both countries except in the eastern part of Mali. In BF, the corridors crossing the border of Ghana do not have veterinary facilities.

Table 2: Statistics on the status of the veterinary positions

Country	**Status**	**Numbers**	**Percentage (%)**
Burkina Faso	Working	78	68.42
	Not working	18	15.79
	Unknown	18	15.79
	Total	**114**	**100**
Mali	Working	-	-
	Not working	-	-
	Unknown	-	-
	Total	**120**	**100**

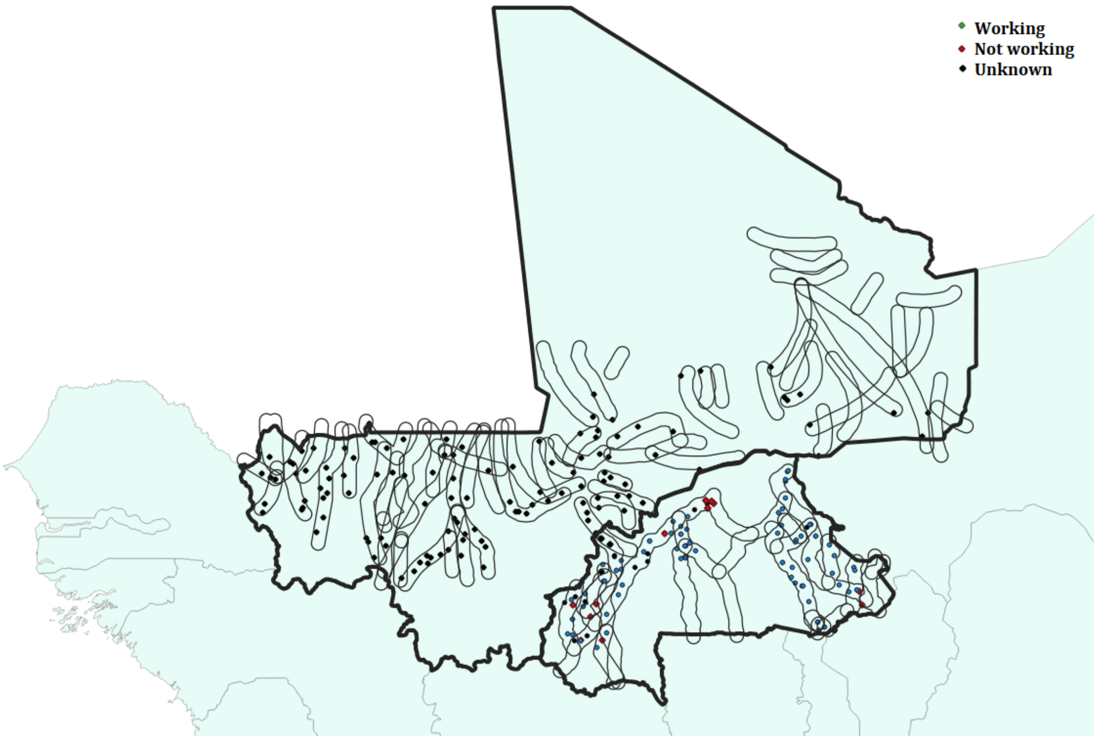

Figure 2: Veterinary position along the transhumance corridors in Burkina Faso and Mali

- **Boarding dock**
  The data on the boarding docks was not available from Mali. In Burkina Faso, a total of 40 boarding docks are available along the transhumance corridors with 55% in good condition, 18% not working and 28% in unknown status (Table 3). The corridors crossing the border of Ghana from Burkina Faso do not have boarding dock (Figure *3*).

Table 3: Statistics on the status of the Boarding docks

Country	Status	Numbers	Percentage (%)
Burkina Faso	Working	22	55
	Not working	7	18
	Unknown	11	28
	Total	40	100
Mali	Working	-	-
	Not working	-	-
	Unknown	-	-
	Total	**-**	**-**

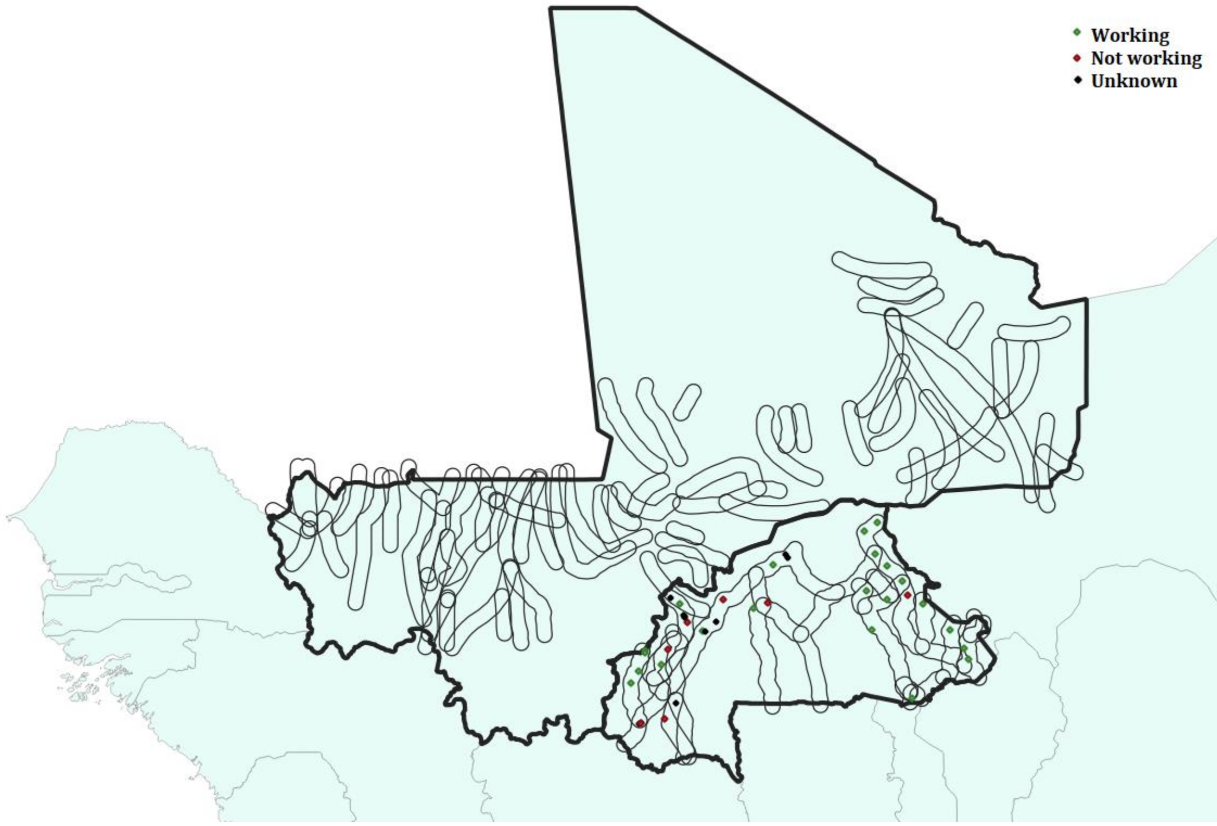

Figure 3: Boarding docks along the transhumance corridors in Burkina Faso

- **Livestock markets**

A total of 81 and 462 markets are available along the transhumance corridors respectively in Burkina Faso and Mali (Table 4). The status of these livestock markets is unknown in Mali while in Burkina Faso, 70.37% of them are working, and 17.28% not working. Figure 4 indicate the spatial repartition of the livestock markets in both countries. The livestock markets are very limited in the eastern Mali and the centre south of Burkina Faso.

Table 4: Statistics on the status of the livestock markets

Country	**Status**	**Numbers**	**Percentage (%)**
Burkina Faso	Working	57	70.37
	Not working	14	17.28
	Unknown	10	12.35
	Total	81	100
Mali	Working	-	-
	Not working	-	-
	Unknown	-	-
	Total	**462**	**100**

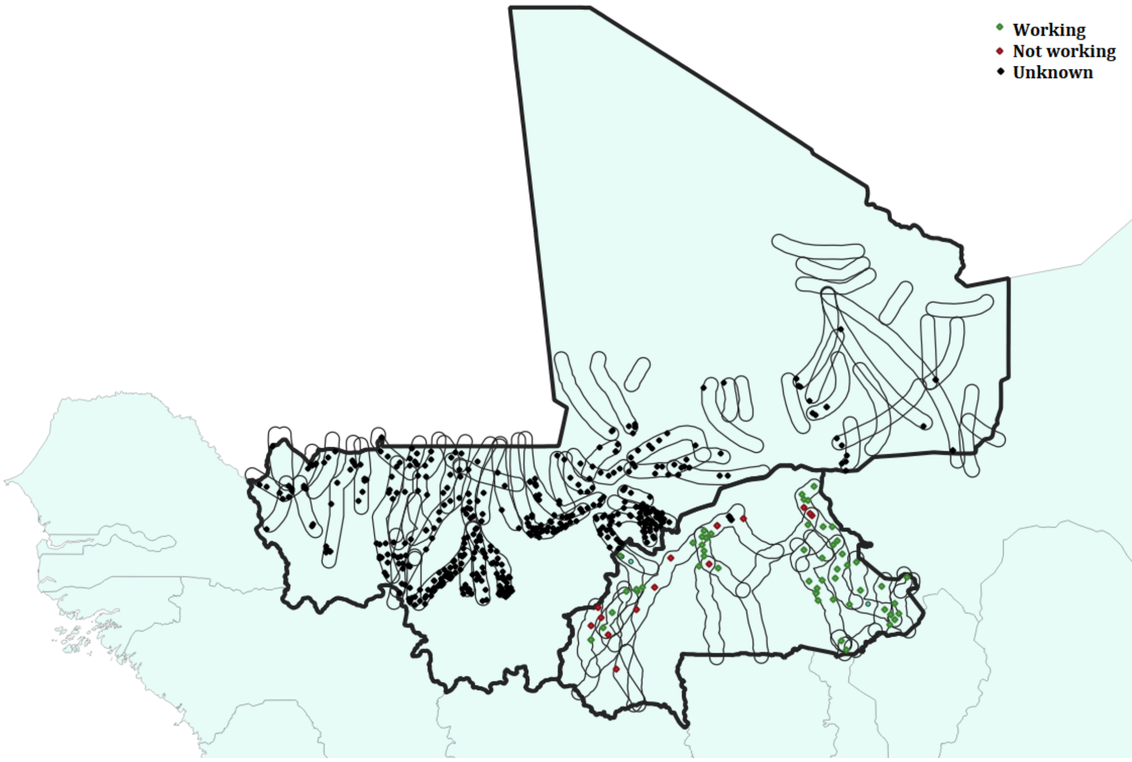

Figure 4: spatial distribution of livestock markets in Burkina Faso and Mali

- **Water Points**

Water points are water supply sources along the transhumance corridors previously defined. In Burkina Faso, 62.67% of the water points (WP) are providing the services while 24.33 are not working. The status of 13% of the water points in Burkina Faso is unknown. In Mali, no information about the water points' status is available, as seen in Table 5. Figure 5 shows the spatial repartition of the WP along the corridors. The density of the WP is very high in the southwestern part of Mali compared to the centre and northern parts of the country. The north of Mali corresponds to the desert with no hydraulic infrastructures. Comparatively to Mali, the density of WP is low. It is spread throughout the country except in the central part.

Table 5: Statistics on the status of the water points

Country	Status	Numbers	Percentage (%)
Burkina Faso	Working	188	62.67
	Not working	73	24.33
	Unknown	39	13.00
	Total	**300**	**100**
Mali	Working	-	-
	Not working	-	-
	Unknown	-	-

	Total	**7308**	**100**

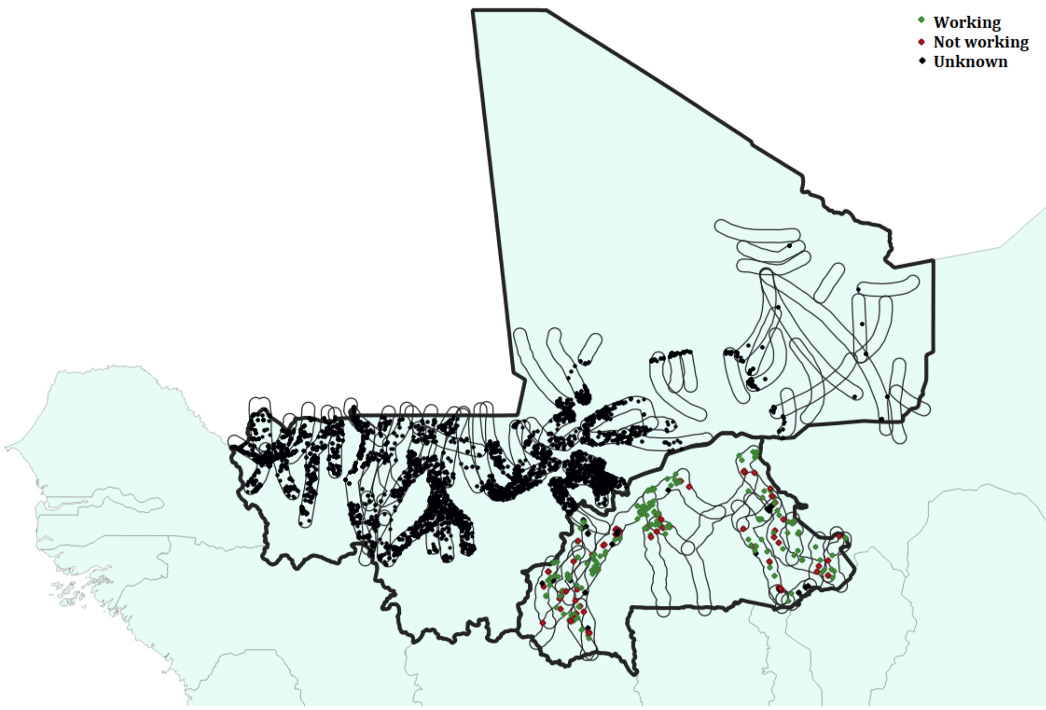

Figure 5: Spatial repartition of the water points in the transhumance corridors.

3.2. Remotely sensed raw data

- **River network**

Dynamic river network was considered based on the seasonality of the flow. It was derived from the world hydro shed database (ee.FeatureCollection('WWF/HydroSHEDS/v1/FreeFlowingRivers')) considering permanent and non-permanent rivers. Figure 6 provides the river network in Burkina Faso and Mali, and a zoom in to show some details about this data.

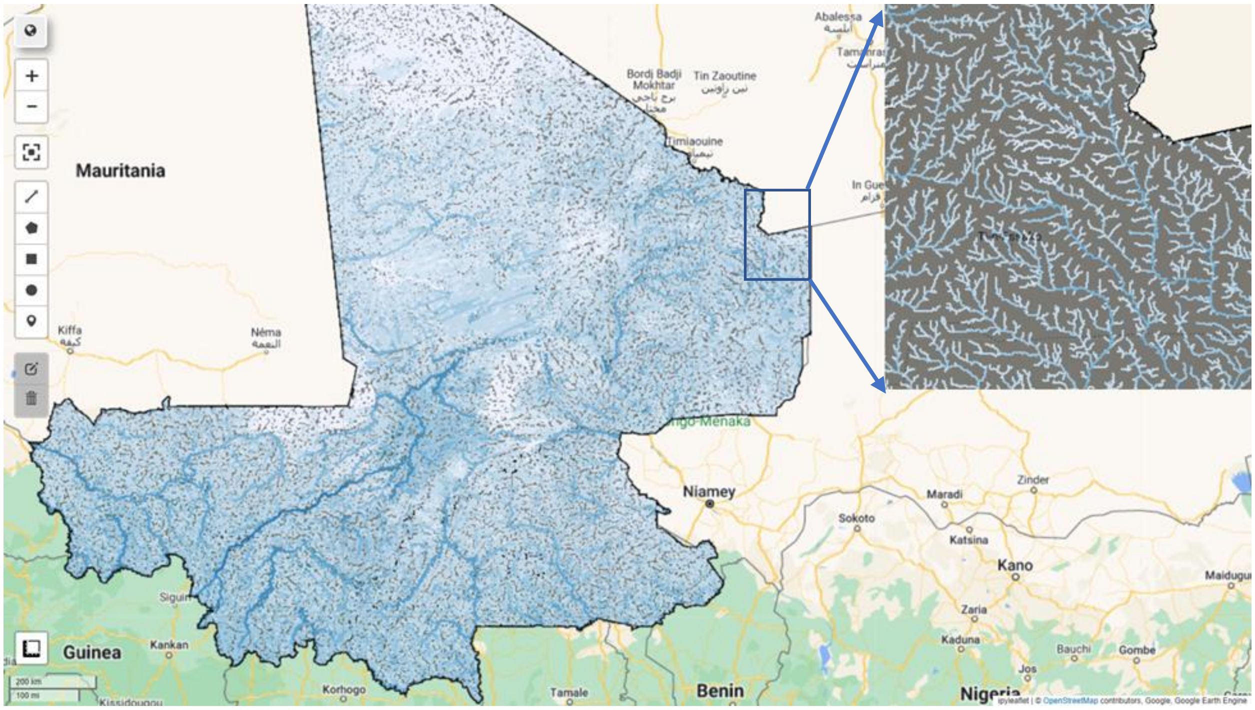

Figure 6: Dynamic river network

- **Protected areas**

The protected areas are obtained from GEE using the following command: ee.FeatureCollection("WCMC/WDPA/current/polygons"). Figure 7 displays the protected areas in Mali and Burkina Faso and the surrounding countries.

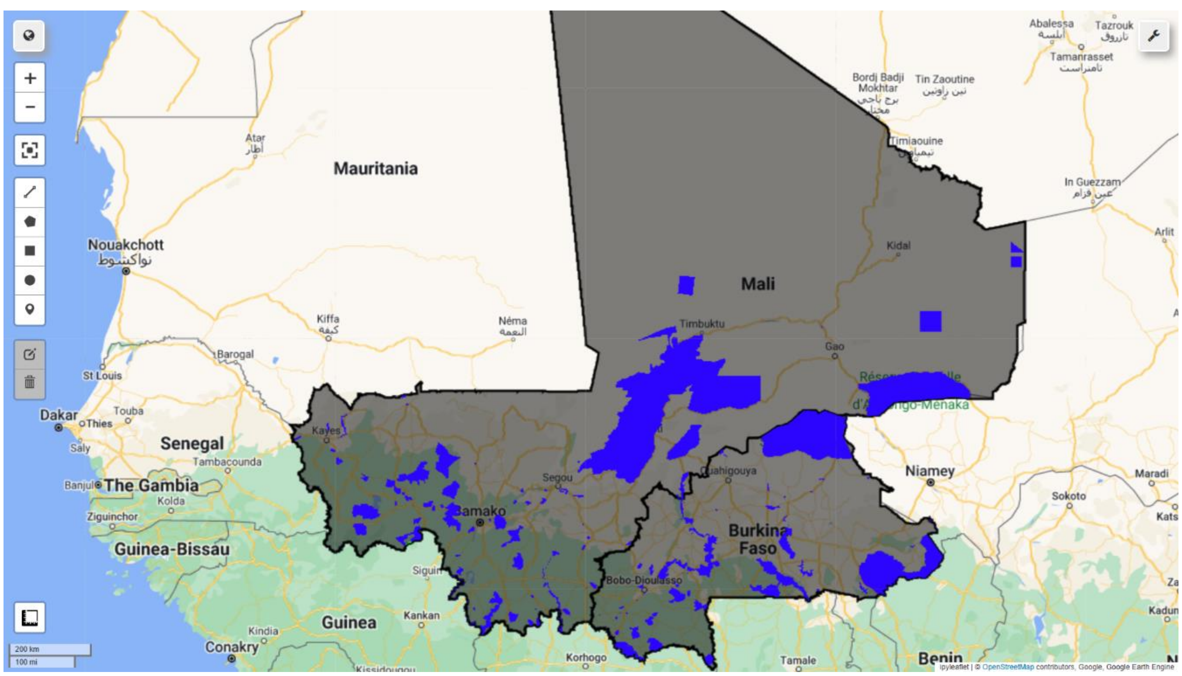

Figure 7: Protected areas in Burkina Faso and Mali

- **Roads, villages and towns**

The roads, villages and towns details are available from google map. As far as the user zooms in, the detail about this information appears. An example is provided below and zoomed in part of Burkina Faso to show some details about the roads, villages and towns (Figure 8).

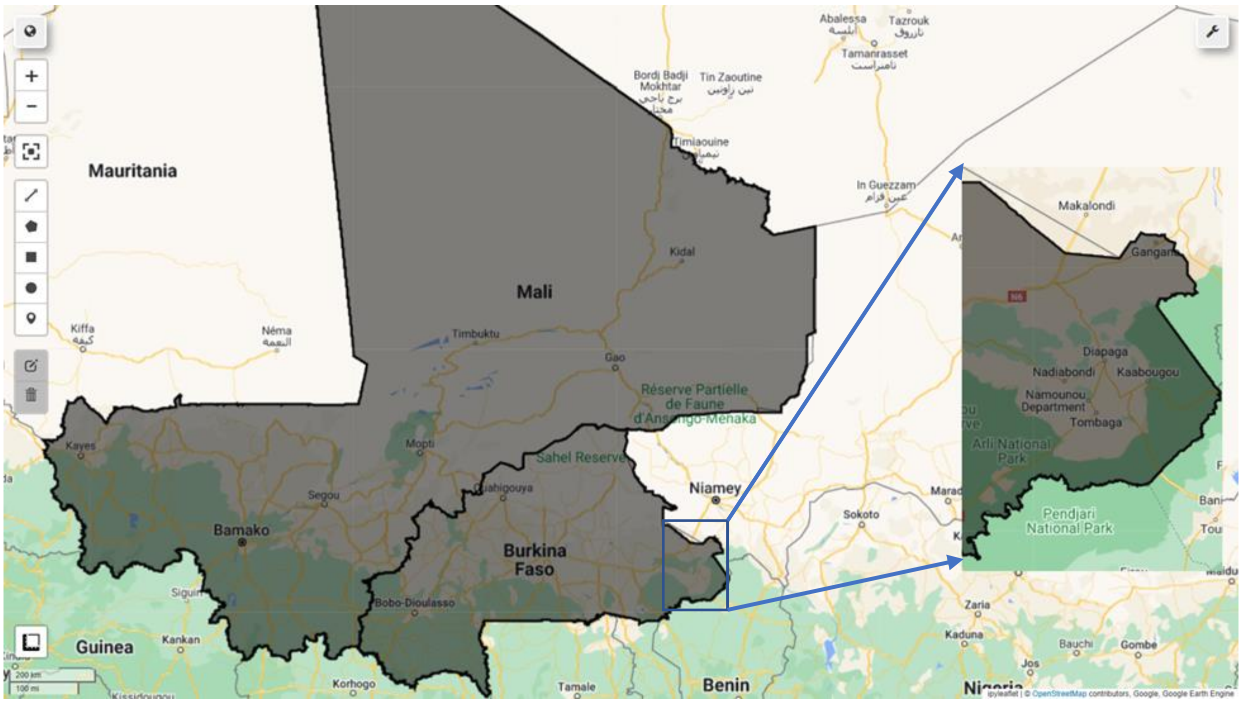

Figure 8: Roads, Villages and towns

- **Dynamic world image**

Dynamic World is a 10m near-real-time (NRT) Land Use/Land Cover (LULC) dataset that includes class probabilities and labels information for nine classes. The Dynamic World Near Real-time (NRT) Image Collection includes LULC predictions for Sentinel-2 L1C acquisitions from 2015-06-23 to the present where the CLOUDY_PIXEL_PERCENTAGE metadata is less than 35%. The Image Collection is continuously updated in near real-time with predictions generated for new Sentinel-2 L1C harmonized images as they become available in Google Earth Engine. The images can be accessed via using: ee.ImageCollection("GOOGLE/DYNAMICWORLD/V1"). The Figure 9 provides an example of the land use classes in Mali and Burkina Faso.

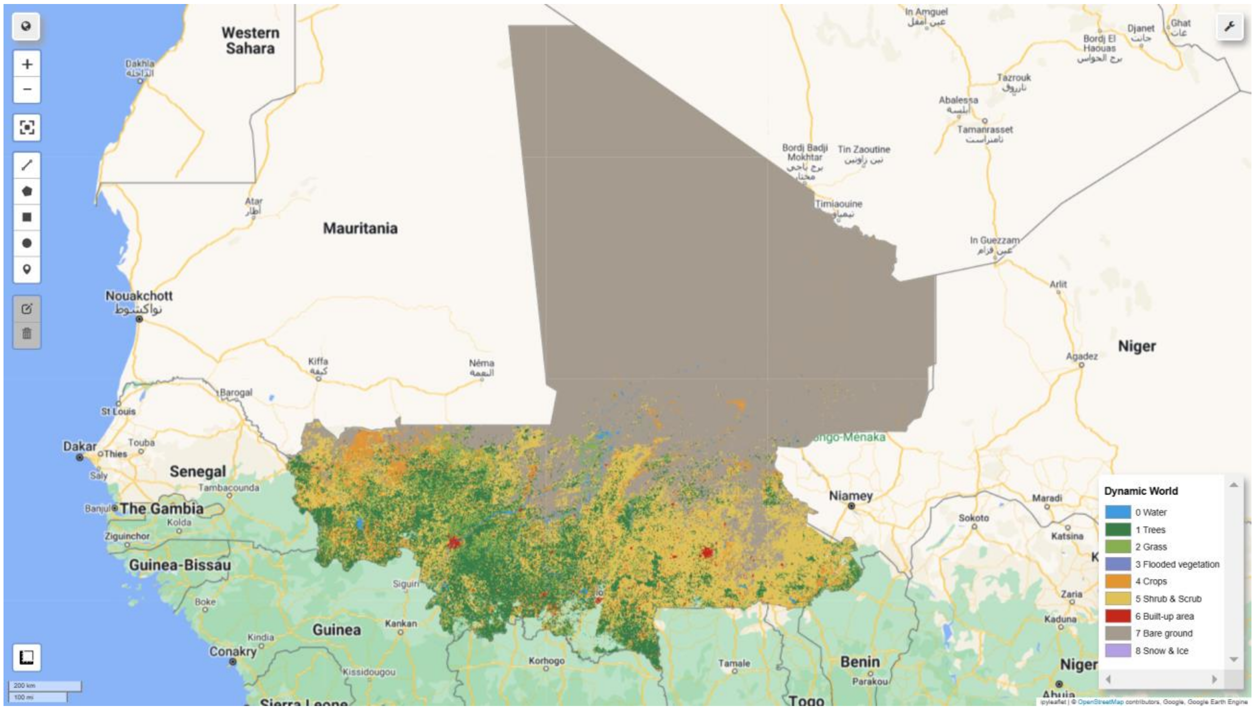

Figure 9: Land use classes in Mali and Burkina Faso

- **CHIRPS Precipitation data**
  Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) is a 30+ year quasi-global rainfall dataset. CHIRPS incorporates 0.05° resolution satellite imagery with in-situ station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring. It can be accessed via the following code: ee.ImageCollection('UCSB-CHG/CHIRPS/DAILY'). Figure 10 provides the annual rainfall for the year 2021 in the study area.

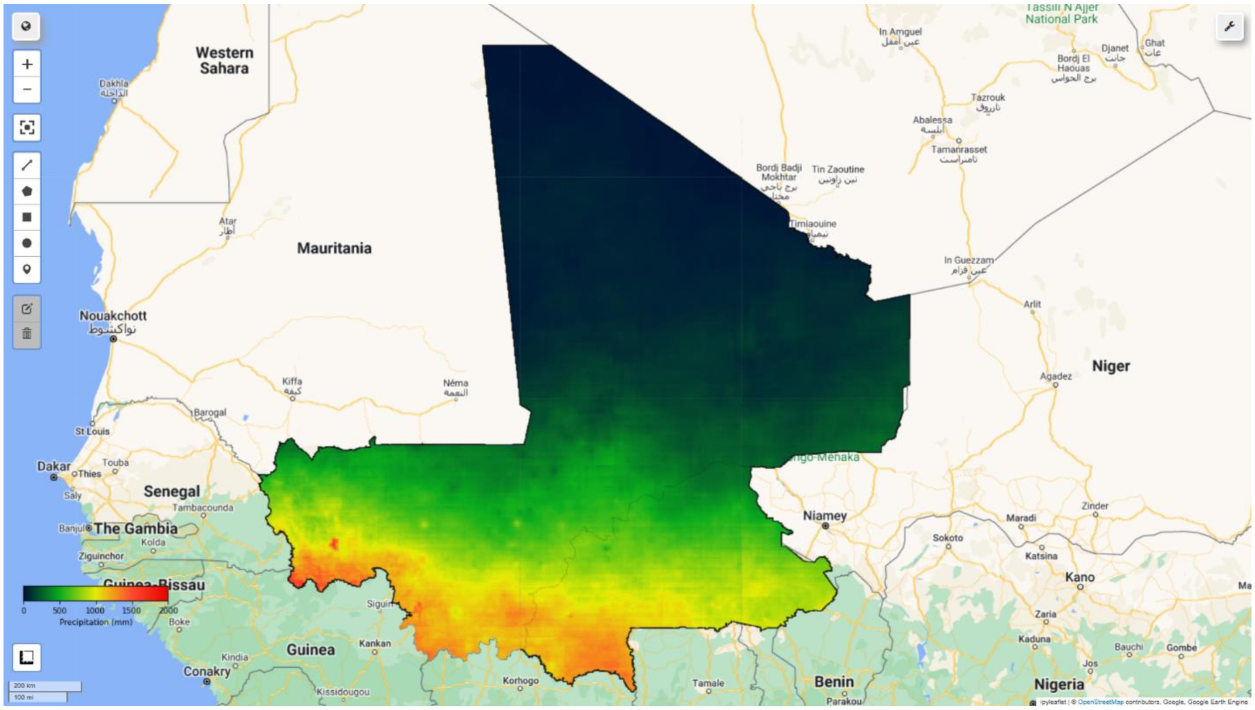

Figure 10: Total annual rainfall data of 2021 from CHIRPS for Burkina Faso and Mali

- **Animal density**

The following three figures were extracted from the global distribution of cattle, goats and sheep respectively in 2015 expressed initially in total number of heads per pixel (5 min of arc) according to the Gridded Livestock of the World database (v4). For a better visualisation, the dataset were reset to the numbers of heads per square kilometre for distribution to account for the very high heterogeneity in the average spatial resolution of the input data. The highest number of animal heads are located in the north east of Burkina Faso while the lowest is located in the northern Mali.

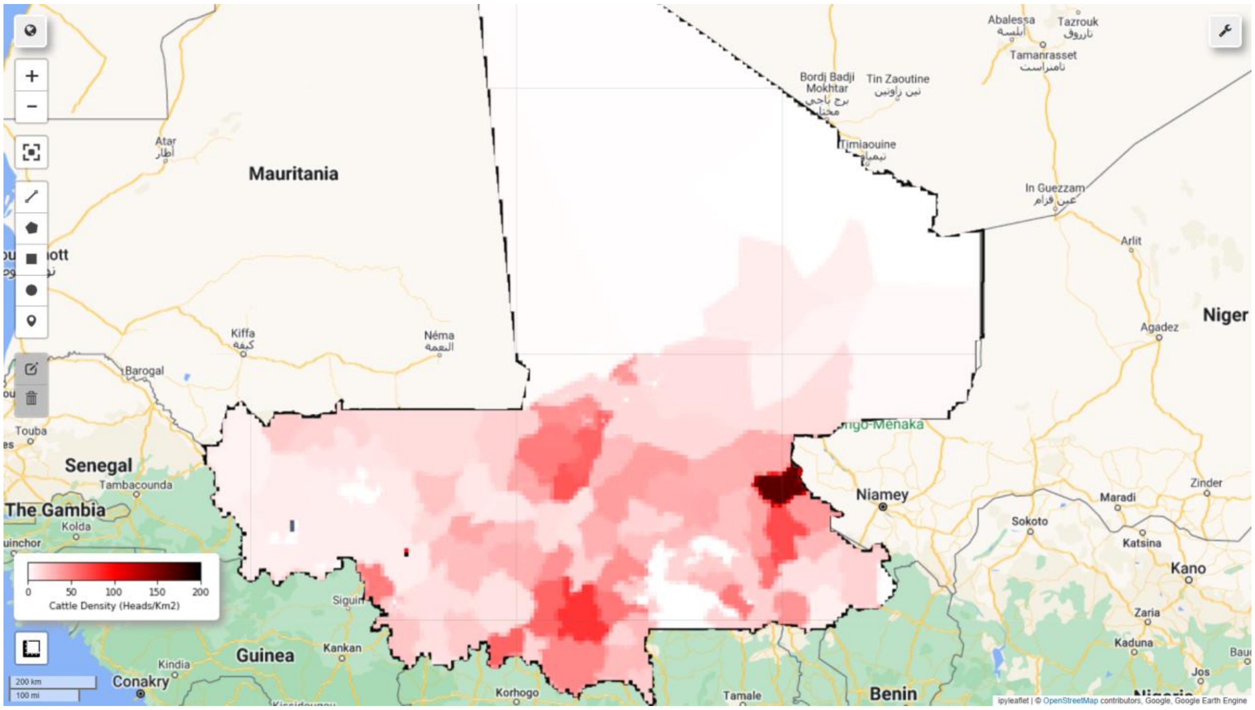

Figure 11: Global Cattle distribution in 2015 *in Mali and Burkina Faso* (Gilbert et al., 2022a)

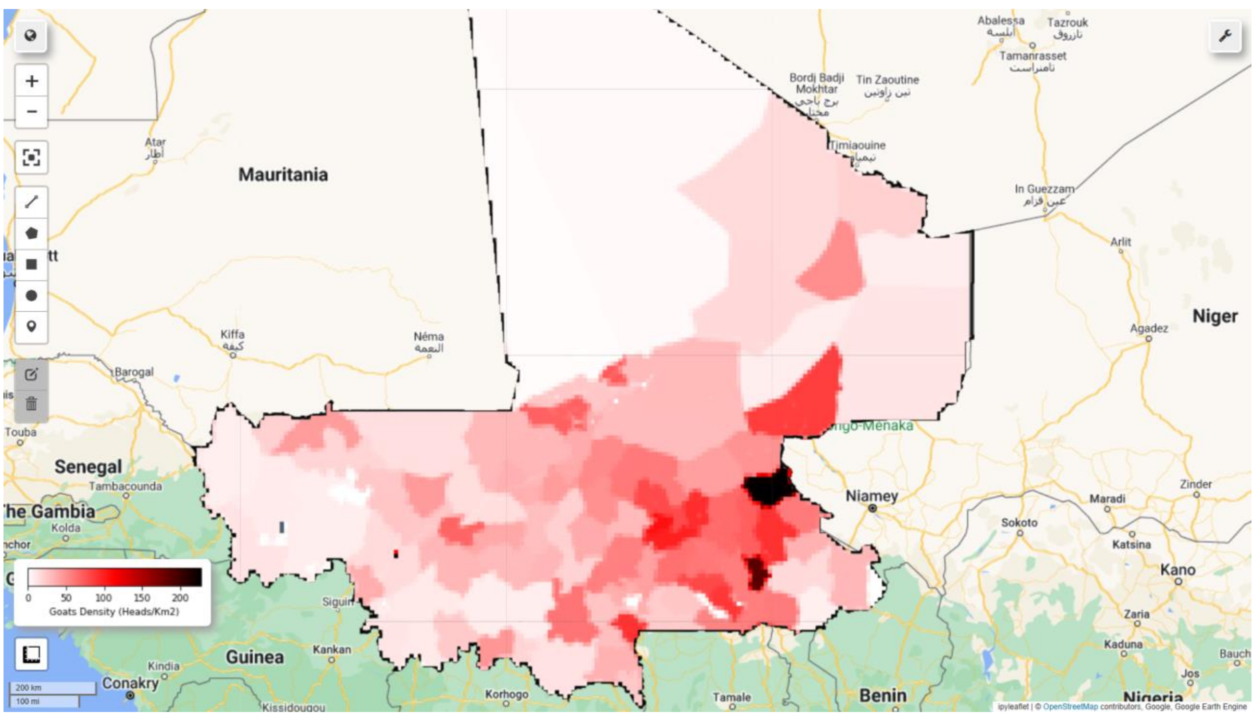

Figure 12: Goats distribution in 2015 in Mali and Burkina Faso (5 minutes of arc) (Gilbert et al., 2022b)

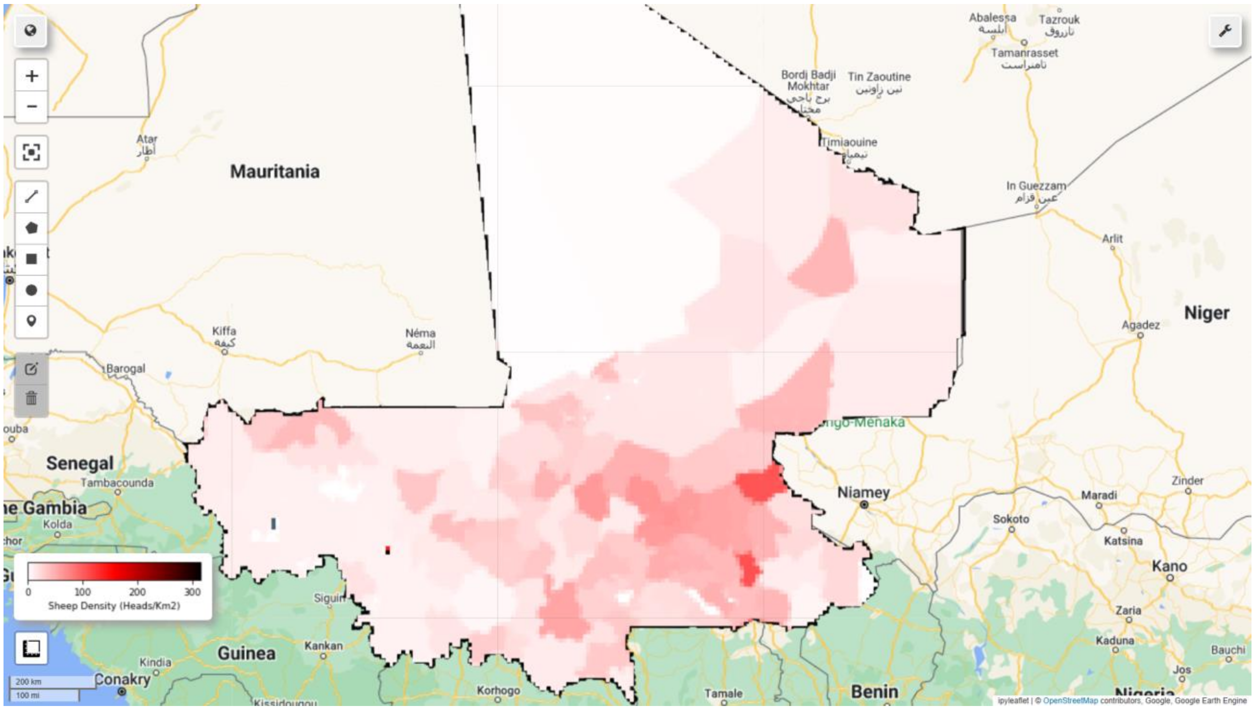

Figure 13: Sheep distribution in 2015 in Mali and Burkina Faso (Gilbert et al., 2022c)

4. Method for generating internal app data

4.1. NDVI, irrigated and evergreen areas computation

The identification of irrigated croplands was done based on two approaches described respectively by Wu & de Pauw (2011) and in WaPOR. The methodology described by Wu and Pauw (2011) is indicated as below:

- Atmospheric correction of the multispectral bands of Landsat TM images and conversion of digital number into reflectance; followed by the calculation of NDVI;
- Conversion of the thermal band into temperature (Ts) for both wet and dry season images;
- Differencing and thresholding technique application on the NDVI of wet and dry season images to separate the significantly changed areas (for example, irrigated land and rainfed cropland where ΔNDVI < - 0.25 or ΔNDVI > 0.25) from the non-significant phenological land cover change such as evergreen forests, maquis, or permanent tree crops (e.g., -0.25 < ΔNDVI < 0.25);
- In the identified significantly changed area, a logical operation (NDVI ≥ 0.5) AND (T≤ 301°K) was applied on NDVI and Ts images to differentiate the irrigated areas from the non-irrigated lands. The thresholds of NDVI and Ts may be slightly different from scene to scene and from wet to dry season. In areas without evergreen forests or maquis, step 3 was skipped.

The methodology used in WaPOR considers the NDVI and the seasonal phenological information for identifying the land cover types. After this step, the differences between irrigated and non-irrigated crops are made using precipitation and ET. It is hypothesised that croplands with higher ET could be due to intensive water usage.

4.2. WAPOR NPP computation

This subsection on Net Primary Production (NPP) was derived from WaPOR2 Methodology paper (FAO, 2018). NPP is a fundamental characteristic of an ecosystem, expressing the conversion of carbon dioxide into biomass driven by photosynthesis. NPP is part of a family of definitions describing the carbon fluxes between the ecosystem and the atmosphere. Gross Primary Production (GPP) represents the carbon uptake by the standing biomass due to photosynthesis. NPP is derived from satellite imagery and meteorological data.

NPP is delivered for all three levels on a decadal basis, where pixel values represent the average daily net primary production for that specific dekad in gC/m 2/day. Typical values for NPP vary within the region between 0 and 5.4 gC/m²/day (NPP), or 0 to 120 kgDM/ha/day (DMP), although higher values can occur (theoretically up to 320 kgDM/ha/day).

The figure 14 indicates the variables used to compute the NPP. For the current work, the NPP was derived directly from WaPOR and was not therefore computed.

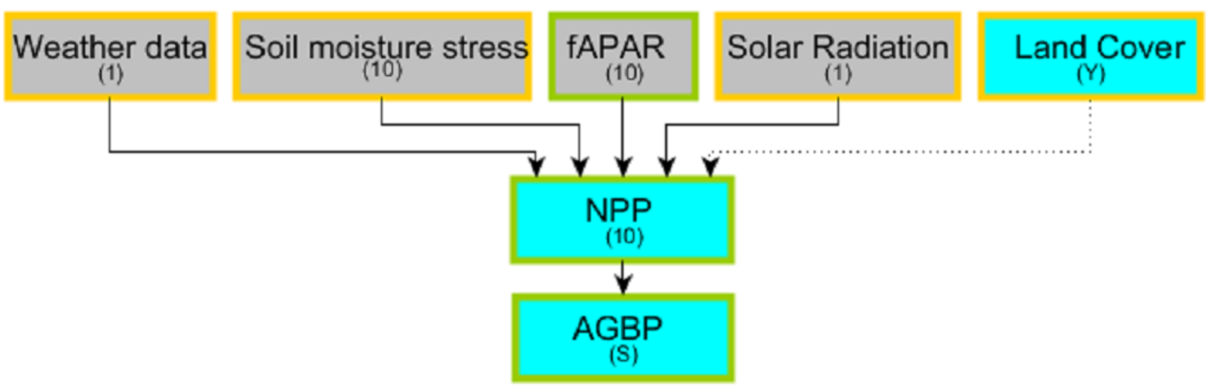

Figure 14: Net primary production in relation to other data components (FAO, 2018)

From the figure above, the following can be derived:

- Calculating Net Primary Production requires daily input from Weather data and Solar radiation and dekadal input from fAPAR and Soil moisture stress.
- Seasonal or annual land cover is an indirect input as light use efficiencies are dependent on land cover.
- A soil moisture stress reduction factor is incorporated to adjust for water stress.
- No external data source is required to calculate Net Primary Production.
- NPP is produced on a decadal basis.
- Decadal NPP is used as input to calculate Above Ground Biomass Production.

Calculating NPP requires daily input from Weather data (Tmin/Tmax) and Solar radiation, as well as decadal inputs from fAPAR and Soil moisture stress. Land Cover is an indirect input as Light Use Efficiency (LUE) is land cover specific. The method to compute Net Primary Production is based on Monteith (1972), which describes ecosystem productivity in response to solar radiation. The equation is expressed as follows (FAO, 2018):

$$NPP = S_c R_s \varepsilon_p fAPAR\ SM \varepsilon_{lue} \varepsilon_T \varepsilon_{CO2} \varepsilon_{AR} [\varepsilon_{RES}]$$

S_c	Scaling factor from DMP to NPP [-]
R_s	Total shortwave incoming radiation [GJ T/ha/day]
ε_p	Fraction of PAR (0.4 – 0.7µm) in total shortwave 0.48 [JP/JT]
$fAPAR$	PAR-fraction absorbed (PA) by green vegetation [JPA/JP]
SM	Soil moisture stress reduction factor
ε_{lue}	Light use efficiency (DM=Dry Matter) at optimum [kgDM/GJPA]
ε_T	Normalized temperature effect [-]
ε_{CO2}	Normalized CO2 fertilization effect [-]
ε_{AR}	Fraction kept after autotrophic respiration [-]
ε_{RES}	Fraction kept after residual effects (including soil moisture stress)[-]

The practical approach for NPP computation can be formulated as follows (the subscripts 1 and 10 indicate daily and decadal products, Nd is the number of days in each decade):

$$NPP_{10} = fAPAR_{\ 10}.SM\varepsilon_{lue}.NPP_{max,10}$$

With

$$NPP_{max,10} = \left\{\sum NPP_{\ max,1}\right\} / N_d$$

4.3. Dry matter availability computation

Equation presented in Figure 15 were used in this app to determine the usable biomass based on pastures and wood, crops and crop residues. For crops, the set of input data are the area (AA) from the dynamic world (WD) images, yields for rainy season (BB) and dry season (CC) derived from WaPOR, MS content (EE) and percentage of aerial dry matter (FF). This information is used to deduce biomass production (KgMS) for the rainy and dry seasons.

For crop residues, the set of input data are percentage of aerial dry matter (AAA), usability factors (BBB). This information is used to calculate the biomass accessible in KgMS for the two seasons.

For pastures and woods, the input data are the area (A) derived from the DW images, the rate of degradation in the dry season (B), and the yield usable in the rainy season (D) derived from WaPOR. From this information, the yield in the dry season, and the usable biomass in the rainy as well as dry seasons are determined.

Finally, the total usable biomass in KgMS for the two seasons is determined by summing the one from pastures and woody on the one hand; and crop residues on the other hand for the two seasons respectively. The processes are described in the Box below.

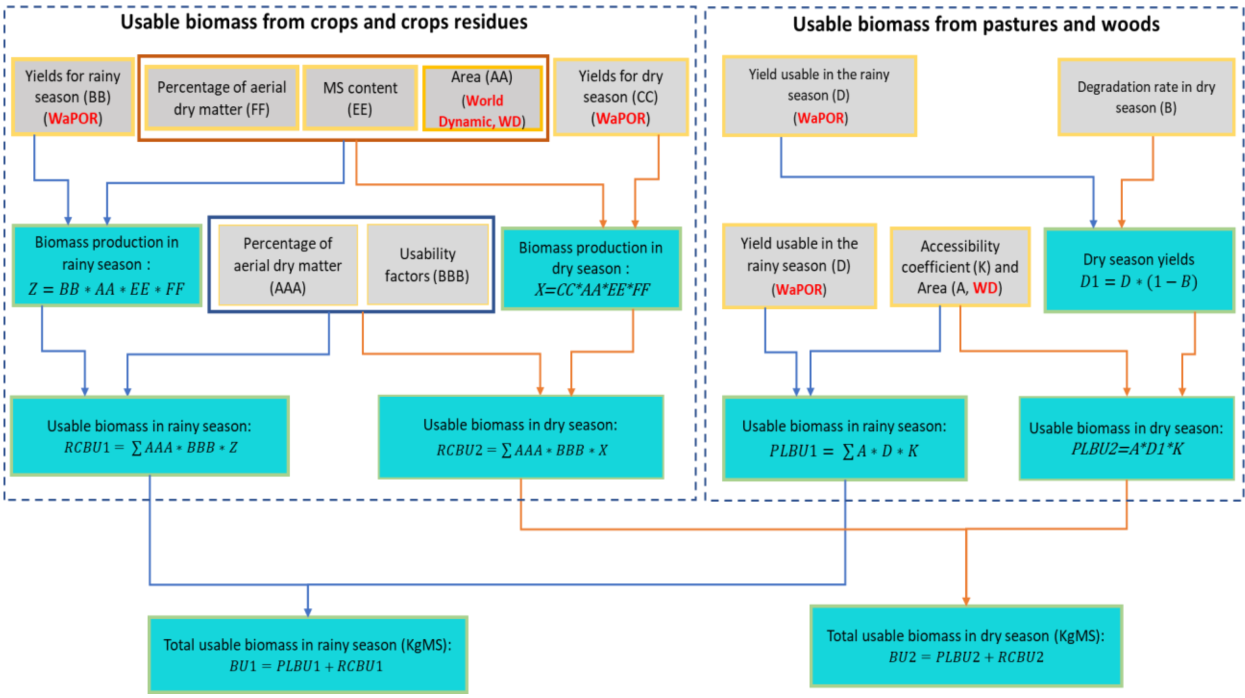

Figure 15: Overview of the methodology used to compute available and accessible Biomass

5. The alpha version of the app and its functioning.

5.1. Graphical user interface

The user interface of the App is presented in the figure 16. It is essentially composed of three windows:

- a window for defining the calculation parameters of the available resource layers (green box). It allows to specify the period for the calculation of dry matter production as well as the values of coefficients controlling dry matter availability.
- A cartographic visualization/mapping window of the layers of different resources required for transhumance (blue box). The visualization of transhumance corridors, areas with high production and availability of dry matter, livestock markets, etc. is done in this window. Also, resource availability calculations for any user-defined area will be displayed in the same window.
- A window for defining the user's region of interest and exporting the results (red box). It allows the user to upload a shapefile of his study area or to choose an administrative region of interest

and display the availability of resources.

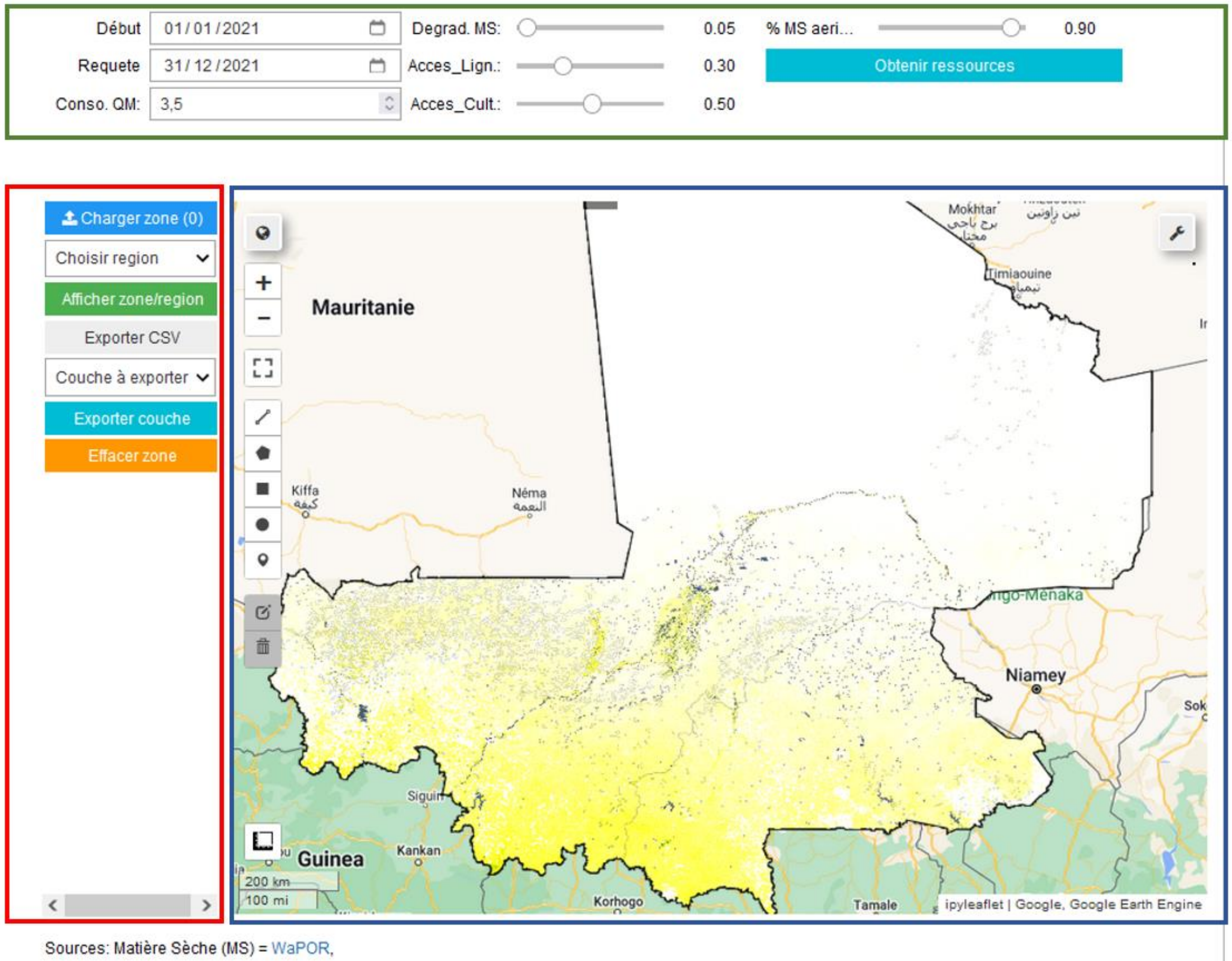

Figure 16: The graphical user interface of the transhumance App

5.2. Tools and widgets

A series of tools and widgets (Figure 17) allow the user to define the parameter values to be applied during his query; to load or define his region/zone of interest and to control the resources to be displayed in the mapping window. The main tools and widgets are:

1. The start date of the period on which the production and accessibility of resources will be calculated.
2. The end date of the period on which the production and accessibility of resources will be calculated. This date also defines the query date. The query date will be used among others to determine (i) the presence of surface water in near real time -10 days, (ii) the land use map over the last 12 months, (iii) the occurrence of fires over the last 60 days, etc.
3. The rate of dry matter degradation produced over the period of the query.
4. The accessibility coefficients of the dry matter produced on cultivated land.
5. The accessibility coefficients of the dry matter produced on natural vegetation areas.

6. The coefficient of distribution of the net primary production between the root zone and the aerial part of plants and crops.

7. Button to execute the calculation of resources over the query period and according to the defined parameters (3 to 6).

8. The list of calculated and visualizable resource layers.

9. The display area (Mapping area) of the calculated resources.

10. The box displaying available resources in the user’s region of interest

11. The Zoom for enlarging and reducing the resource layer display area

12. Full screen mode button

13. User's area of interest (zip format) loading tool

14. User’s administrative area of interest selection tool. This tool is to be used alternatively to tool 13.

15. User's area of interest mapping tool. The same tool will display the availability of resources for the area of interest in the window 10.

16. CSV format export button of the user's area of interest available data

17. Resources to be exported as image selector

18. TIF format export button of resource available in the user’s area of interest.

19. User’s area of interest eraser.

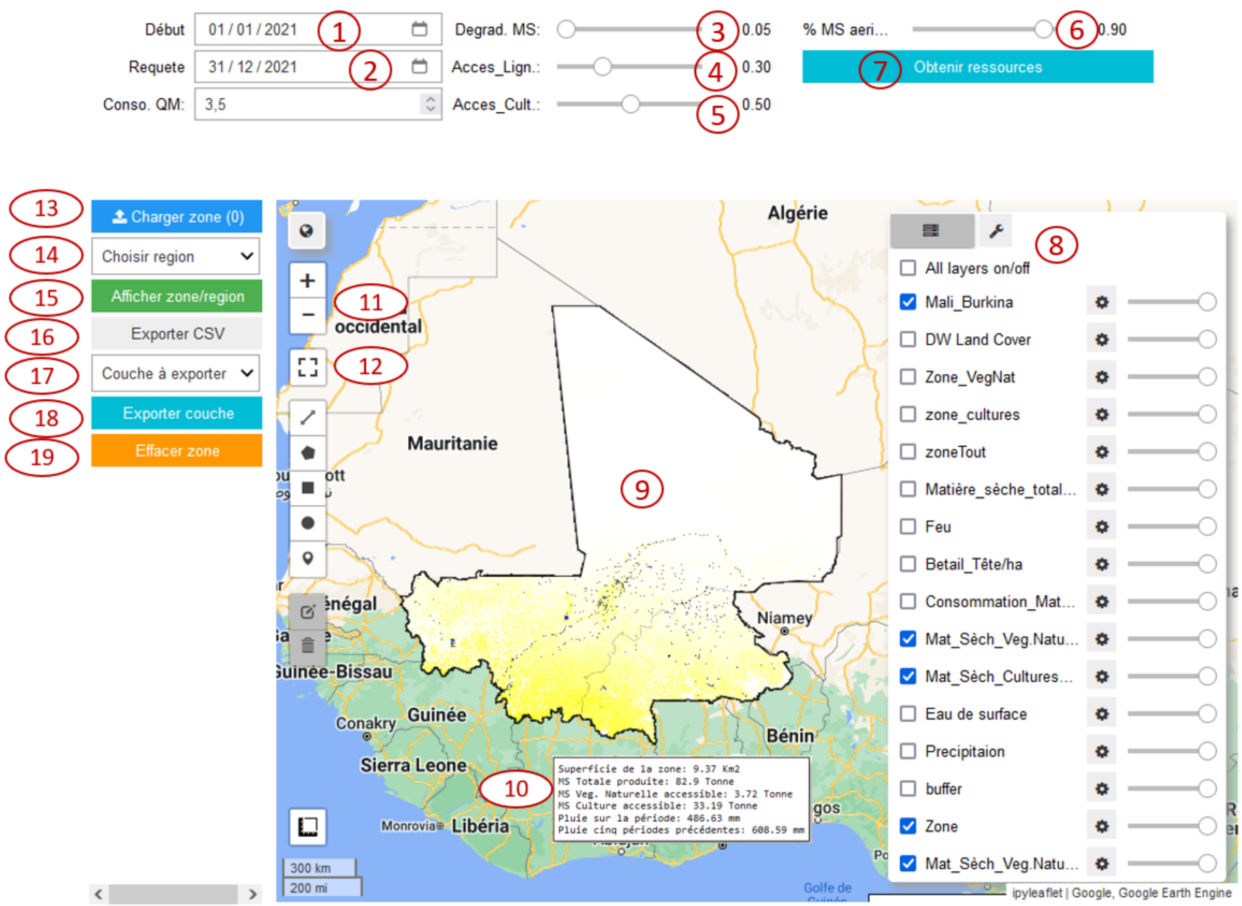

Figure 17: Main tools and widgets of the graphical user interface of the transhumance App

6. Conclusion

This work aims to develop a transhumance App indicating the availability of water and forage resources in Mali and Burkina Faso along the transhumance corridors. For this purpose, a number of datasets were collected from the project partners in Mali and Burkina Faso. For most of the point data collected, information on the infrastructure status (functioning or not) is available in Burkina Faso but not in Mali. In addition to the raw data collected, information such as the yield for rainy and dry seasons was derived from the WaPOR database along with dry matter availability equations to compute the total usable biomass for both seasons. All the data are incorporated in the alpha version of the App which has numerous tools and widgets.

The current version of the App needs to be validated by FAO and the project partners in Mali and Burkina Faso and will be improved based on the comments, suggestions and needs expressed during the workshop planned in March 2023 in both countries.

7. References

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Annex: Feedback from the FAO which is already taken into account

1. Nous nous sommes mis d'accord sur les changements suivants sur l'application :

    a. Comme discuté en fin de réunion la semaine dernière, certains coefficients pour lesquels les données sont collectées par l'unité d'élevage seront laissés «à définir par l'utilisateur ». Cela permettra à l'unité d'élevage d'utiliser cette application lors de leurs travaux avec les ministères en insérant les données qu'ils ont collectés. Ces coefficients sont (voir également diapo 6 ci-jointe, coefficients entourés par Anne et ses commentaires):

        i. Percentage of aerial dry matter,

        ii. Usability factors (BBB),

        iii. Degradation rate in dry season (B) et

        iv. Accessibility coefficient (K) and Area (A, WD).

    b. L'application se concentrant sur la partie disponibilité uniquement des « Feed balance sheet », le terme « feed balance sheet » devra donc être remplacé par « Dry matter availability ».

    c. Pour la même raison, les données utiles pour le calcul de la « demande » seront mises à part dans un groupe « données additionnelles » (par ex. la distribution du bétail)

    d. Est-il possible d'ajouter un lien vers le document de méthodologie de l'unité d'élevage ?

e. Est-il possible d'ajouter une fonction permettant de cumuler la biomasse disponible par unité administrative ? Cette fonction permettra d'extraire les données de WaPOR pour leur utilisation dans l'outil excel de l'unité d'élevage.

f. Optionnel : explorer le possible développement d'une fonction permettant de comparer les précipitations de l'année à la moyenne et l'impact potentiel sur la biomasse disponible.

2. Lorsque ces changements auront pu être fait, nous organiserons une session de travail avec Anne et Gregorio pour voir en détail les questions restantes et améliorer les liens avec leur outil et si possible les estimations (énergie, protéine : cf commentaires d'Anne diapo 6).

3. L'idée est que Anne et Grégorio participent aux prochains ateliers (février/mars selon l'avancement des modifications ci-dessus), comme ils l'avaient fait pour les ateliers précédents et présentent leur outil à la suite de la présentation de cette application pour que le lien et la continuité entre les 2 soit claire pour les partenaires nationaux. De la même manière, ils feront des ateliers (dans 6 pays) dans le cadre d'un de leur projet et nous inviterons à présenter cette application.