SAVING LIVES
CHANGING LIVES

Irrigated fields along the Niger river (Mali)
Source Sentinel-2 © 2019 ESA/Copernicus

Case Study

MALI
Mopti region

Satellite imagery in conflict-affected areas

HOW TECHNOLOGY CAN SUPPORT WFP EMERGENCY RESPONSE

World Food Programme

April 2020

The past decade has witnessed a boom in the availability of satellite data whether from established space agencies or from the private sector. Unique in their ability to screen the entire Earth, satellites provide timely and objective data at a variety of spatial and temporal scales. In doing so, it can address a broad range of applications - e.g. agricultural monitoring, early warning of droughts, flood damage assessment, conflict and population dynamics monitoring, urban food security assessments.

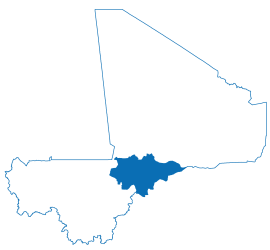
Schematic view of Sentinel-2 satellite spacecraft, deployed by the European Space Agency (ESA)

The increase in the types of satellite-derived information comes at a critical time for **WFP**. The organization is facing a number of interconnected, global or regional scale challenges such as natural disasters, widespread conflict, population movements or impacts of climate change.

To help meet the consequent spiralling increase in information requirements, **Earth Observation** (EO) has become a mainstay of WFP analytical work since 2010 and is currently used for a number of operational activities, among which seasonal monitoring, crop type mapping or monitoring asset creation activities.

This document presents how WFP Mali used Earth Observation data in hard-to-reach areas to overcome access constraints and territory vastness. By detecting **cropland abandonment** in 2019 across the region of Mopti, this pilot study enabled to identify affected localities and to assess physical impacts of the **widespread conflict**. The triangulation with insecurity data underscores a clear correlation between agricultural decline and reported violent events. Eventually, this study describes how such satellite-derived products were used in the operational context of Mali.


A village in Koro cercle (Mopti, Mali)
Credit WFP/Laure Boudinaud



CONTEXT

In 2019, the region of Mopti in central Mali faced a dramatic deterioration of its security situation. The presence of armed groups and self-defense militias, increasing criminality and intercommunal tensions triggered a spiral of violence. Such rising levels of insecurity have led to approximately 1,300 fatalities and tens of thousands of internally displaced people across the region in 2019 only.

In a context already fragilized at many levels - an economy marked by mounting demographic pressures, youth unemployment, soil degradation or scarcity of natural resources, exacerbated by repeated droughts, the impact of violence on food security is highly threatening : a loss of livelihoods for displaced populations and difficulties in cultivating fields and accessing markets for those that have remained in their villages become real and daunting prospects.

Approach

In order to provide a comprehensive overview of an area of interest, up-to-date granular data are essential. The satellite imagery used for this analysis provides details at 10 metre resolution, which enables results at village scale. A new image is captured every five to six days on any given point on Earth, which guarantees homogeneous, frequent and updated data for the whole area of interest.

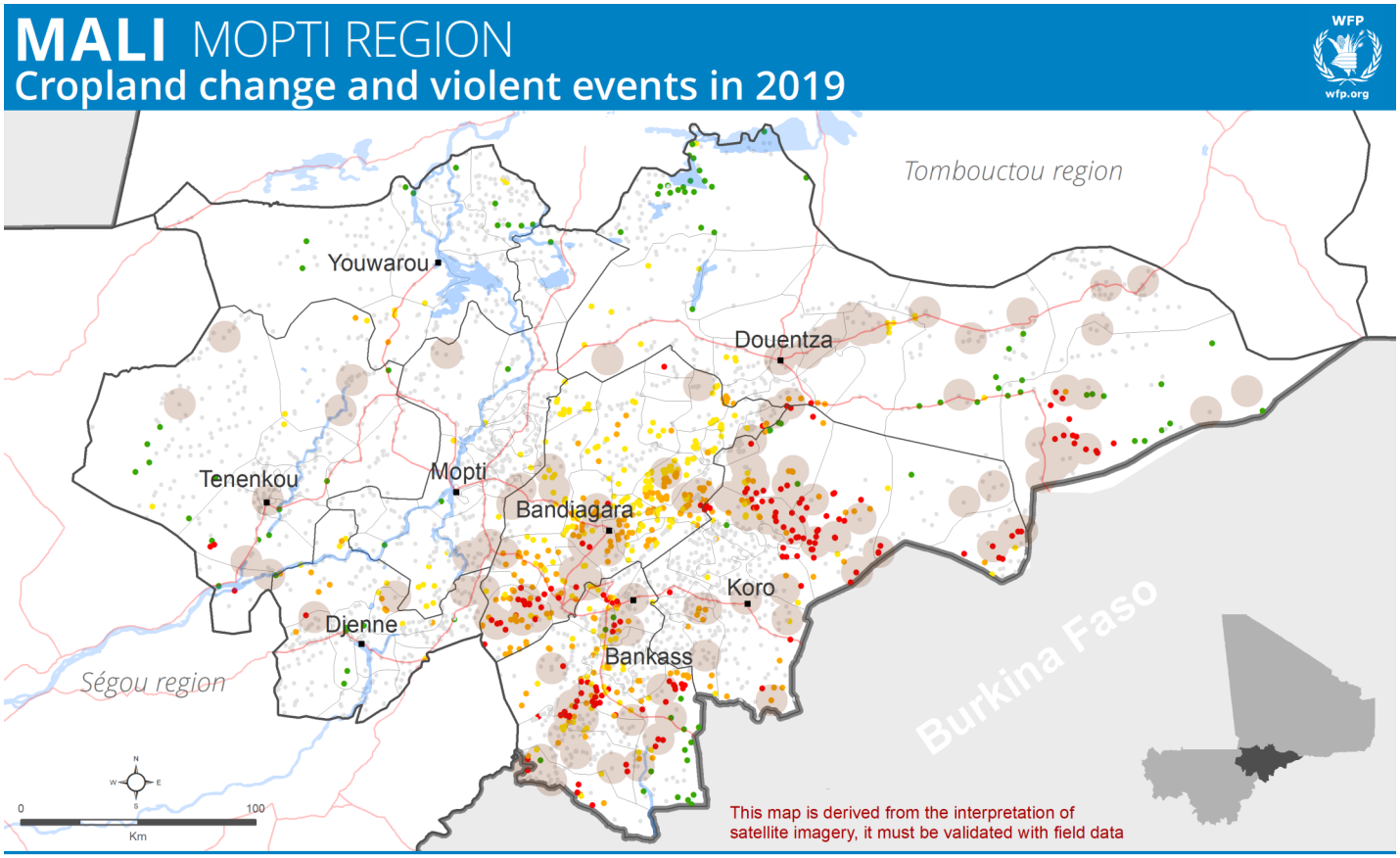
In theory, the period between June 15th and October 15th covers an agricultural cycle in the region of Mopti, from land preparation to early stages of harvesting. Satellite images acquired during this four-month period are processed in order to identify cultivated land for each year from 2016 to 2019. By using a semi-automated method developed for the purpose of this study, approximatively 3,200 localities were covered, measuring for each the degree of cropland change in the surrounding area between 2019 and a reference year prior to the conflict. This enables a meaningful regional-scale interpretation of the data to draw out patterns and identify **vulnerability hotspots**.

Map 1 shows the resulting product: in yellow, orange and red are the localities for which a **slight**, **medium** and **severe** cropland loss (respectively) were detected in 2019 compared to 2016 or 2017. Grey dots code for villages where no evident change was visible or where there is no agricultural land. Brown circles represent violent events reported by ACLED (see page 6 for more details) between April and October 2019.

KEY POINTS

- In total in 2019, **25%** of localities in the region of Mopti experienced a decrease in cultivated lands compared to pre-conflict years (2016, 2017).
- The cercles[1] most affected by medium and severe cropland diminutions are Koro, Bankass, Bandiagara and Douentza; these are the areas where **intercommunal tensions** have led to many acts of violence in the course of 2019.
- No evident change was detected in most localities of the western cercles of the region: Youwarou, Mopti, Tenenkou and Djenne experienced fewer cropland losses than east of Mopti region.
- For a minority of localities (3%), croplands have slightly increased in 2019 compared to pre-conflict years. This may be due to favourable climatic conditions, despite a late start of the rainy season. Another hypothesis, to be confirmed, is that it may be a consequence of population displacement.
- Violent events between April and October 2019 overlapped with the analysis results (Map 1) illustrates the correlation between insecurity and agricultural decline; **insecurity peaks** in 2019 heavily affected agricultural activities in the eastern part of the Mopti region.

1 Level 2 administrative division of Mali.



Map 1. Mopti region: cropland change and violent events in 2019

Methodology

INPUT DATASETS

Populated sites

For the determination of cropland change over Mopti region, a dataset of populated places was created based on the official list of villages used by the Malian Institute of Statistics (**INSTAT**) for the national census in 2009, enhanced by a combination of ancillary data (**OCHA** populated places[2], **OpenStreetMap**[3]). This dataset was improved through visual inspection using additional georeferenced datasets such as the High Resolution Settlement Layer[4] (**HRSL**), as well as Google Earth and Sentinel-2 imagery. The visual revision allowed to complete the populated sites geometry with additional places that were missing in the original dataset, ensuring all existing settled areas are covered in the study. The final database contains **3,166 populated places**.

Satellite imagery

Sentinel-2 is an Earth Observation mission operated by the European Space Agency (ESA). It systematically acquires optical imagery at high spatial resolution, mapping the entire Earth surface every five days. Archive imagery is freely accessible from 2015 onwards, via an online platform[5]. Sentinel-2 imagery is a powerful tool for landscape monitoring; its pixel size being 10 metres, it enables to detect features such as rivers, settlement or cropland. Moreover, by exploring archive data, one can "go back in time" and compare a current situation with a previous year for an area of interest. Two Sentinel-2 images over the same area are presented below, showing a significant decrease in cultivated lands between 2017 and 2019.

PROCESSING STEPS

Sentinel-2 spectral characteristics allow to "see" outside of the human vision range, such as near-infrared, providing enhanced ways for detecting vegetation. The **Normalized Difference Vegetation Index** (NDVI) is commonly used in remote sensing as an indicator of live green vegetation presence. It is calculated from the values of the red and near-infrared imagery bands.

For the present analysis, Sentinel-2 images acquired during the agricultural season (15th June till 15th October) were processed into yearly composite maps for 2016, 2017, 2018 and 2019 (an example is shown in Page 5, Image 2). Such products depict for each pixel the NDVI temporal evolution throughout the growing season, allowing to single out different landcover types, and so to identify croplands. By comparing the composite maps for 2019 and a baseline year (2016 or 2017), the status of crop change could be visually determined for each populated site.

This was conducted via Google Earth Engine[6], an online platform which combines a multi-petabyte catalog of satellite imagery and geospatial datasets with planetary-scale analysis capabilities.

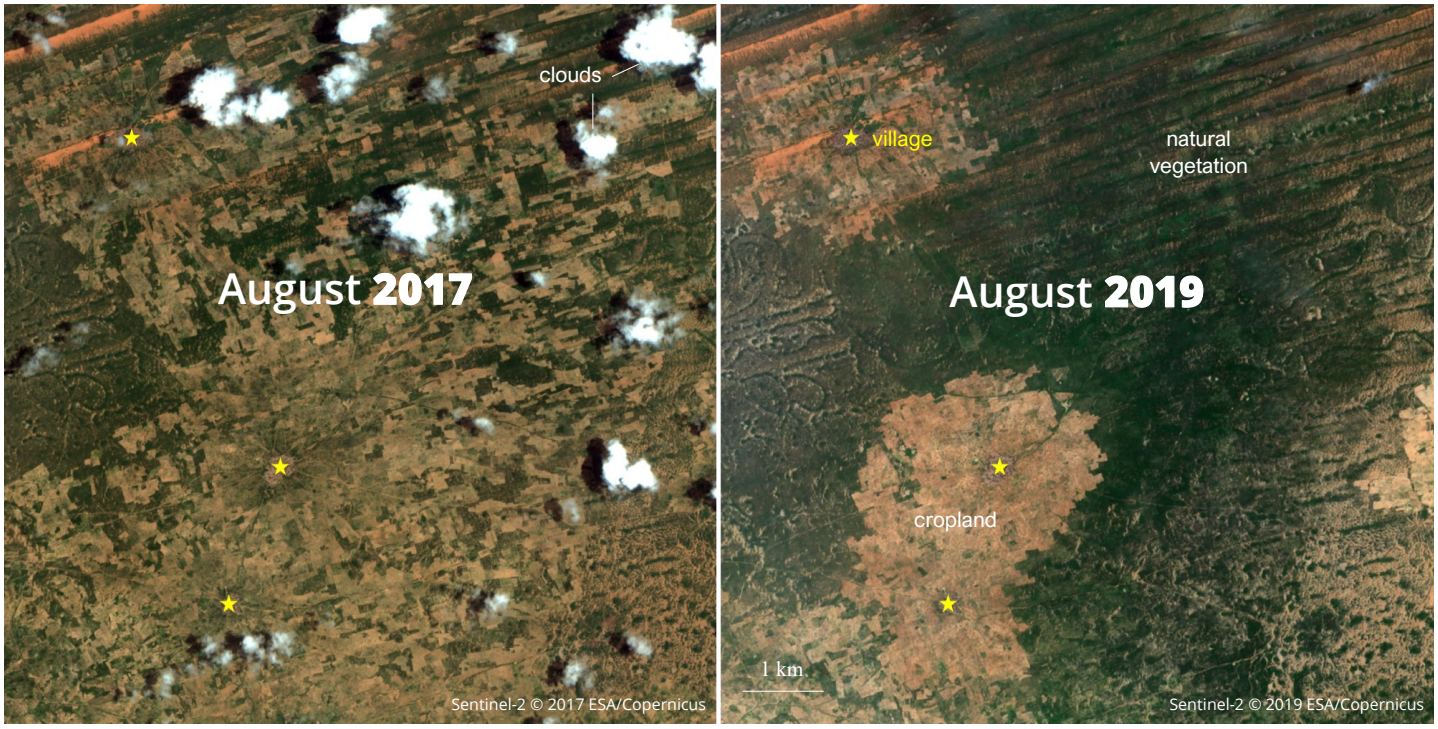


Image 1. Cropland abandonment detected from space for three villages in Koro cercle
In 2017 (left), cultivated fields are visible (in beige) as far as 10 kilometres away from habitations (star), singling out from the surrounding natural vegetation in dark green. In 2019 (right), cultivated fields are considerably reduced and concentrated in proximity to habitations due to movement restrictions imposed by armed actors.

2 Available at *www.data.humdata.org/dataset/sahel-administrative-boundaries*
3 Available at *www.openstreetmap.org*
4 Source: © 2016 CIESIN and Facebook Connectivity Lab. Available at *www.ciesin.columbia.edu/data/hrsl*
5 *www.scihub.copernicus.eu*
6 *www.code.earthengine.google.com*

To illustrate the importance of the processing steps as described above, Image 2 shows an example of the resulting NDVI composite map for the 2019 growing season (right), compared to the most recent satellite image available on Google Earth for the same area (left). The latter does not allow to conclude on the presence of cultivated fields while the Sentinel-2 composite does, cropland appearing in dark blue.

To detect possible changes, such composites from different years are visually compared. Each populated site is thus classified into one of the following cropland change categories: *slight increase*, *no change*, *slight decrease*, *medium decrease* and *severe decrease*.

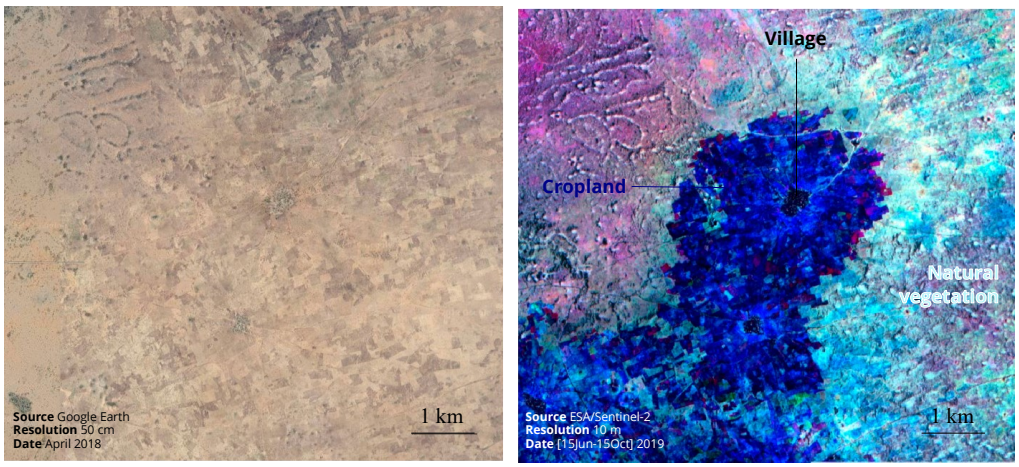


Image 2. Composite image derived from 24 satellite images compared to a single-date Google Earth image
Left: Google Earth satellite image showing the surroundings of two villages located in the cercle of Koro (Mali). Right: 2019 composite map derived from twenty-four Sentinel-2 images acquired between June 15th and October 15th, used for the detection of cropland change: villages appear in black, cultivated fields in dark blue around the settlements, singling out from surrounding natural vegetation in cyan blue.

Results

SUMMARY TABLE

While no visible change was detected for the majority of the 3,166 analysed localities (72%), Koro, Bankass, Douentza and Bandiagara are the most affected cercles by medium to severe cropland diminutions in 2019: respectively 25%, 22%, 10% and 35% of localities impacted.

Cercle	Sites	Slight increase		No change		Slight decrease		Medium decrease		Severe decrease	
		Sites	%	Sites	%	Sites	%	Sites	%	Sites	%
Bandiagara	581	0	0%	228	39%	152	26%	173	30%	28	5%
Bankass	437	16	4%	279	64%	45	10%	45	10%	52	12%
Djenne	285	7	2%	248	87%	10	4%	19	7%	1	0%
Douentza	418	36	9%	307	73%	36	9%	23	6%	16	4%
Koro	490	7	1%	340	69%	20	4%	38	8%	85	17%
Mopti	383	4	1%	366	96%	12	3%	1	0%	0	0%
Tenenkou	346	13	4%	317	92%	5	1%	8	2%	3	1%
Youwarou	226	10	4%	209	92%	6	3%	1	0%	0	0%
Region	**3,166**	**93**	**3%**	**2,294**	**72%**	**286**	**9%**	**308**	**10%**	**185**	**6%**

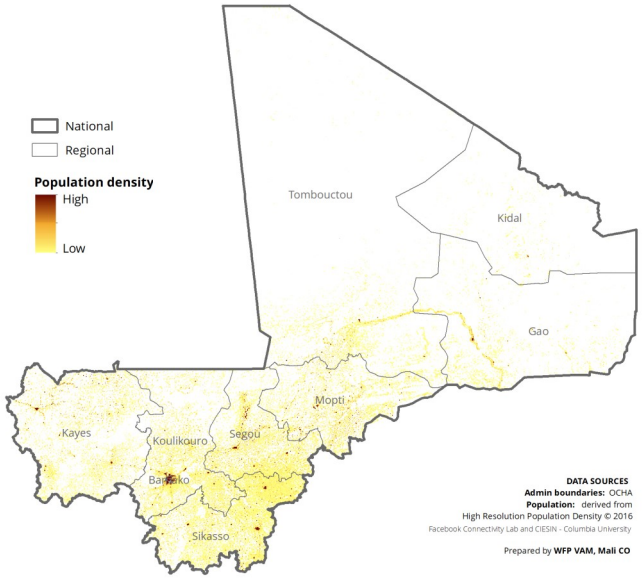
Table 1. Affected localities by the different cropland change types in 2019, per cercle

POPULATION ESTIMATES

In 2019, the region of Mopti had a population of approximatively 3 million[7]. To assess the possible impact of cropland losses in terms of population rather than in numbers of localities, several credited population datasets that depict the distribution of the population were analysed. The *High Resolution Population Density* maps[8] represent estimates of population counts per pixel at a 30 metre resolution. Based on this dataset, Map 2 shows the spatial distribution of the population in Mali. It was selected to provide population estimates in affected areas of the Mopti region.

For each category of cropland change, the projected population estimated to live within the corresponding areas of influence was calculated within a 2 kilometre buffer around populated sites.

In total, **130,000** people are estimated to live within an area affected by severe cropland loss (4.3% of the total population), out of which 50,000 in Koro cercle and 35,000 in Bankass cercle. In addition to this, **215,000** people are estimated to be or to have been in areas affected by a moderate loss (7.2%) and **260,000** by a slight one (8.6%). On the other hand, around **200,000** people would have benefited from a slight cropland increase in 2019.



Map 2. Population distribution in Mali

7 Source: Direction Nationale de la Population, Mali (DNPop 2019)
8 Source: © 2018 CIESIN and Facebook Connectivity Lab. Available at *data.humdata.org/dataset/highresolutionpopulationdensitymaps*

Triangulation with contextual data

Cropland abandonment, as visible from space, is one of the many consequences of the widespread violence in central Mali. Damaged infrastructure and abandoned villages were also spotted during the satellite imagery analysis. To better understand how this correlates to the security context, datasets such as georeferenced violent events in 2019, infrastructure damage or displacement are analysed with regards to the cropland changes. Eventually, results are cross-checked with official agricultural evaluations.

INSECURITY

In June 2019, when land preparation and planting were underway, a peak in both significant violent incidents and the number of fatalities was recorded in the region of Mopti. As shown in the map resulting of the satellite analysis (Page 2), most of the severe and medium cropland losses occurred in localities where violent events were reported between April and October 2019 (source : **ACLED** data, see box below).

The *Armed Conflict Location & Event Data project* (ACLED) provides georeferenced data on armed conflict events, allowing to map crisis areas. It was used as a reference to evaluate the geographic distribution of violent events with respect to localities under analysis in this study. Three event types were considered: *remote violence / explosions, battles* and *violence against civilians*.

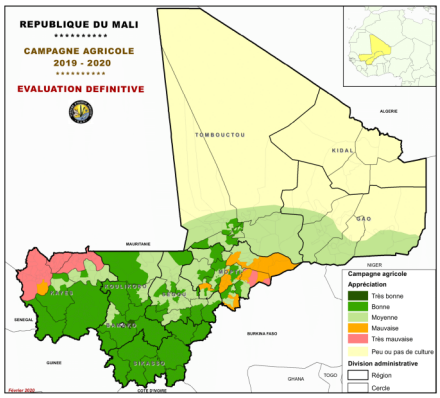
Available at *www.acleddata.com/data*

During that period, 190 of the 305 violent events reported for Mali occurred in the Mopti region, 90% of which in the four eastern cercles of the region: Bandiagara, Bankass, Douentza and Koro. Due to the presence of multiple armed groups, intercommunal violence was exacerbated in those four cercles and the general security context has been highly volatile.

On the other hand, Tenenkou, Mopti, Youwarou and Djenne cercles recorded significantly fewer violent events during the same period. The presence of one non-state armed group deeply rooted in those cercles, implying high criminality but allowing a relatively calm situation[9], may partly explain a more normal roll-out of agricultural activities, in addition to the local geography of western Mopti (flooded areas, irrigated fields).

AGRICULTURAL SEASON EVALUATION

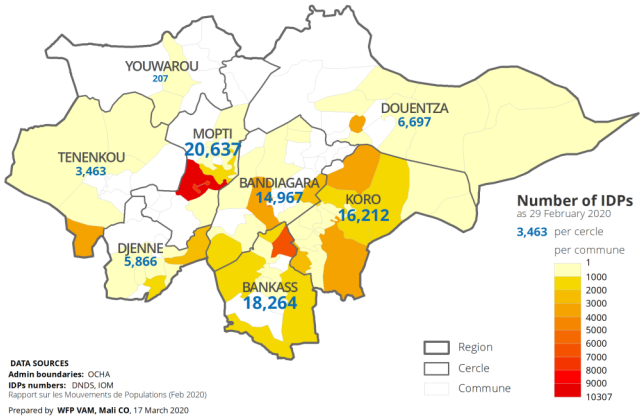
The early warning system of the Malian food security commissary (SAP) prepared a map showing the evaluation of the 2019-2020 agricultural campaign. It confirms a bad to very bad appreciation of the agricultural season in most of Douentza cercle (east), Koro cercle (north), Bandiagara cercle (south) and Bankass cercle (south).



Map 3. Evaluation of the 2019-2020 agricultural campaign, Mali (February 2020)

DISPLACEMENT

Over **86,000** people were **internally displaced** (IDPs) in Mopti region in February 2020[10], approximatively 40% of the total for Mali. Map 4 shows the number of IDPs per cercle and per commune as of 29 February 2020. The majority is located in the three cercles most affected by violent events and cropland changes (Koro, Bankass and Bandiagara) as well as Mopti cercle.

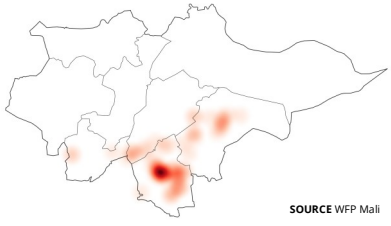


Map 4. Number of IDPs per cercle and per commune (February 2020)

Many IDPs have sought to reach major towns where the security situation tends to be safer. Around 18,000 IDPs are in Mopti and Socoura communes (where Mopti town and Sévaré are located). Moreover, the communes of Bankass, Bandiagara, Douentza and Koro towns host approximatively 17,500 IDPs in total. However, an equally large amount of IDPs are spread out across the region, living with **host communities** in rural areas, who may themselves have difficulties in accessing food resources.

DAMAGED VILLAGES

In addition to cropland losses, over one hundred villages were detected with satellite imagery as likely destroyed or **damaged** in the course of 2019. This was confirmed with Very High Resolution (VHR) satellite images for sixty localities; for the remainder, no recent VHR imagery was available to validate the interpretation from Sentinel-2 images. Damaged localities are specifically located in the southeast part of the region (Map 5). In most cases, a severe or even a total loss of cultivated land was detected around those villages.



Map 5. Heatmap of damaged villages in 2019 (January 2020)

9 Source: MINUSMA, JMAC report (August 2019).
10 Source: UNHCR/IOM. Available at *data2.unhcr.org/en/country/mli*

Field validation

Field interviews were conducted in November 2019 to gather evidence from villagers in the cercles of Bandiagara, Bankass and Koro, identified as affected by significant cropland losses. In doing so, the analysis team was able to test the interpretation of remote sensing data against ground truth. Due to the security context and access restrictions, the scope of the survey was limited and qualitative interviews were conducted in only four villages. Yet, the information that was collected echoes the results derived from satellite imagery, and confirms cropland losses as well as settlement damages caused by violent attacks.

Map 6. Villages visited in November 2019

SOME COMMUNITIES ARE CONFINED INTO THEIR VILLAGE.

Many inhabitants left their villages in the course of 2019 to escape from the deteriorating security situation, following direct or indirect violent threats. Some joined bigger towns, considered as safer, while others have sought refuge in rural areas with host communities, who often struggle to survive themselves. The village of Birga-Peulh (Koro cercle) is under the protection of the Malian armed forces; for that reason, hundreds of people from surrounding villages moved there in 2019 to benefit from the military protection. Host and displaced communities are confined in the village: they cannot access markets, cultivate distant fields or reach neighbouring localities. The village of Déri faces similar difficulties, albeit without the permanent presence of Malian armed forces. On the other hand, in Sadia-Dogon (Bankass cercle), interviewees said they could access markets.

FARMERS COULD NOT CULTIVATE NORMALLY DUE TO MOVEMENT RESTRICTIONS.

Interviewees from all visited villages explained that they were unable to cultivate normally in 2019, due to the widespread violence that shook the region in the course of 2019. By fear of attacks, farmers could only access agricultural fields close to habitations. Image 3 shows the delimitation beyond which villagers could neither access nor cultivate in 2019, due to the presence and threats of armed men. Depending on the locality, the imposed limit was between 500 metres and 2 kilometres away from habitations and cropland surface losses estimated by villagers ranged from 50 to 85%. The abandoned village of Ouo Ouro showed no evidence of cultivation at all.

Image 3. Delineation beyond which villagers could not cultivate in 2019
A man stands on a harvested agricultural field, about 500 metres from habitations. On the left, natural vegetation has covered up fields that villagers used to cultivate before, but could not access in 2019 due to intercommunal violence.

> *"Armed men are surrounding villages, forbidding us to go to markets, forbidding us to get food aid, stealing our cattle (...). It's as if our villagers are being strangled, condemned to die from hunger."* [1]

SIGNIFICANT SETTLEMENT DAMAGE.

Many abandoned, damaged or even destroyed structures were observed during the ground data collection mission. The area between Birga-Peulh and neighbouring village Birga-Dogon was abandoned as most of the structures were destroyed in the course of 2019. Lights or water-pumps had also been deliberately damaged. The two neighbouring villages of Sadia-Dogon were completely abandoned, with roofless structures and destroyed settlements. Finally, the village of Ouo Ouro, located south of Bandiagara cercle, was also abandoned; most of its infrastructure appeared to be damaged, as shown in the pictures below. The village's alleys and surroundings were covered by natural vegetation. Burnt objects and walls, as well as the absence of roofs are many indications of the violence that was perpetrated in the village throughout 2019.

> *"Several hamlets whose harvest had been burned in late 2018 were too fearful to plant in 2019. They're sowing hunger and misery to drive out the population".* [2]

Human Rights Watch interviews (1) with a community leader (Koro cercle), October 13, 2019, and (2) with an elder from Bankass cercle, April 22, 2019.
SOURCE : Human Rights Watch report "How Much More Blood Must Be Spilled?" Atrocities Against Civilians in Central Mali, 2019 (February 10, 2020)

Conclusions

MAIN FINDINGS

> In 2019, the deteriorating security situation in the region of Mopti heavily curtailed agricultural activities, due to the restriction of physical access to fields, or due to the displacement of entire communities. Fields that used to be cultivated before the security crisis were abandoned for fear of violence in hundreds of localities, with different degrees of loss.

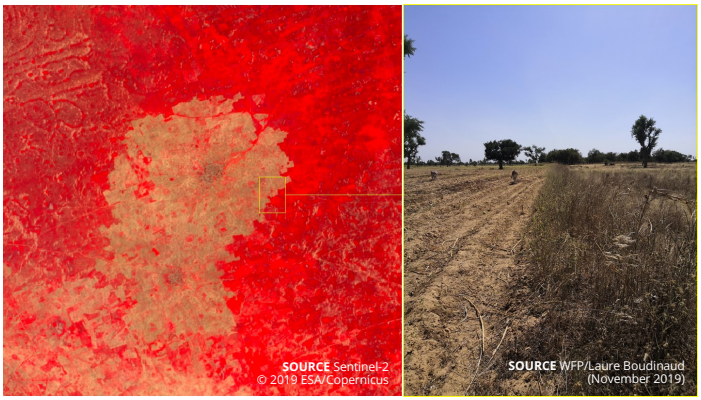


Image 4. Satellite image showing the impact of movement restrictions
The satellite image (left), dated from August 18th 2019, shows natural vegetation in red, while cultivated fields appear beige. The field picture (right), taken on November 21st, shows the limit beyond which farmers could not access to cultivate.

> In addition to displacement, the spiral of violence has led to a less visible but equally important threat to food security: entire communities are confined to their villages. For those populations, who were forced to abandon agricultural fields, harvest will not be sufficient to feed everyone through 2020. In both cases, displaced or confined, populations rely almost entirely on humanitarian assistance, and should be equally prioritized for food assistance and livelihoods support.

> The employed methodology enabled a regional-scale interpretation of Earth Observation data, drawing out patterns from a number of landscape changes that can be detected from space: significant reductions of cropland areas; damaged and abandoned infrastructures; as well as neatly delimitated cropland areas, concentrated around villages in the proximity to habitations (Image 4).

HOW WAS THIS ANALYSIS USEFUL?

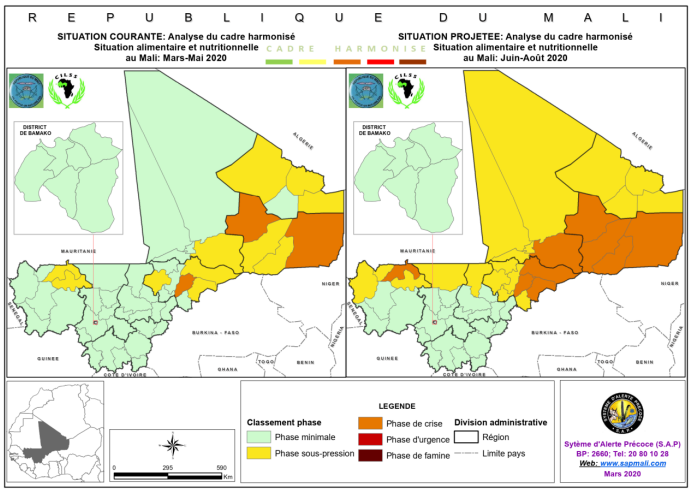
Early warning for early action

The results were used during the Cadre Harmonisé[11] (CH) sessions in October 2019 and March 2020, especially for hard-to-reach areas, where traditional survey data could not be collected normally. The CH is the bi-annual **food security analysis**, led by the national early warning system in collaboration with line ministries, and with the support of all food security partners. The remote sensing results contributed in estimating 535,279 persons in *Crisis* or *Emergency* phases for the 2020 lean season[12].

The unprecedented level of spatial precision provided by these results feeds into **humanitarian response** mechanisms and strategic decision-making, as a tool to better target vulnerable communities at village-scale. The list of localities that were identified as most affected by agricultural decline helped WFP, the Food Security cluster and other partners to plan their emergency response as early as March (three months ahead of the theoretical lean season).

Advocacy

The evidence generated by satellite imagery, in areas where little to no up-to-date data is available, brings to light the gravity of the situation in central Mali, thus mobilizing humanitarian partners and the government alike, as well as the support of regional and international donors.



Map 7. Cadre Harmonisé results (analysis conducted in March 2020)

11 Equivalent of the Integrated Food Security Phase Classification in the West African region
12 Cadre Harmonisé analysis results (March 2020) available at *www.fscluster.org/mali/document/ch-resultats-cadre-harmonise-mars-2020*

The way forward

LESSONS LEARNED

Technology effectiveness

Remote sensing of cultivated areas is a powerful and cost-effective tool to generate information about the location and timing of agricultural activities in hard-to-reach areas, which may indicate physical security, or lack thereof. In particular, where there are limited options for detecting the effects of conflict, the integration of satellite technology offers a solution to help cope with a lack of timely, long-term, homogeneous and reliable ground information.

Suitability of Earth Observation data

An ever-growing, free-of-charge dataset of high-resolution satellite imagery is available to support a broad range of applications. The enhanced characteristics (spatial, temporal and spectral) of Sentinel-2 satellite data are well-suited to monitor cropland changes, more specifically in a country like Mali where agriculture is mostly unmechanized and fields size can be relatively small.

Methodology acceptance

New technologies might face mistrust from traditional technicians, who can be dubious about the innovative method's soundness. Technology appetite should not be taken for granted from all stakeholders: some education on remote sensing must be carried out to help counterparts accept the methodology and understand what can be obtained from it.

Confrontation with official data

To validate the results and ensure their acceptance by national agencies and other partners, a significant triangulation with official datasets and other data sources is essential.

Breaking down barriers

The remote sensing analysis brought together a variety of expertise from several WFP units, as well as from external partners, security officers, and the analysis unit of the peacekeeping mission in Mali.

LIMITATIONS

Study scope

Other livelihoods, also preponderant in the area of interest (e.g. pastoralism) were not monitored with satellite imagery considering the numerous limitations in doing so without reliable field data to cross-check, and as such were not taken into account in this study.

Technical limitations

The interpretation of satellite imagery does not replace field surveys; results should be further investigated with communities to evaluate the economical and societal impacts of those changes. Moreover, the satellite imagery used in this study has a spatial resolution of 10 metres, which implies there are limitations in what can be observed: features smaller than 10 metres may not appear clearly or may not appear at all. Additionally, optical satellite images may be covered with clouds, which challenges their interpretation.

Following direct threats, inhabitants of Déri in Koro cercle could not cultivate normally nor access markets in 2019

RECOMMENDATIONS

1 > STRENGTHEN the technical capacity of government, national early warning systems and partners in using satellite-derived data, to ensure appropriation of the technology and its integration into existing national information systems and decision-making mechanisms.

2 > INVOLVE line ministries, technical services and all partners with a participatory approach upfront at key steps of the analysis and a broad validation afterwards, in order to ensure adequate appropriation of the satellite-derived results by all counterparts.

3 > REFINE the methodology with further research from specialised institutions; possible developments are the extraction of cultivated surface area numbers or a complete automation of data processing steps.

4 > EXPLORE how to combine with climate-oriented applications to support a multi-purpose early warning analysis, such as the detection of seasonal anomalies, droughts or flood monitoring.

5 > EXPAND to other contexts by replicating a similar exercise in other conflict-affected countries where WFP is operating, and run it over time to consistently feed humanitarian response with updated information.

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