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A method to map the land use in Africa by using satellite images

Application to Sampieri village (Burkina Faso)

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Summary

Because the cartography is often deficient, the use of satellite images is the best way to know the land use of Africa. But to extract a reliable map from these raw data is not an easy task. The aim of this study was to find a method to map the main landscape units, a method which can be easily reproducible. Satellite images were chosen according to the agricultural calendar, among those freely available, i. e. Landsat images. The results appear satisfactory on a local scale, where ground control points have been chosen. But the generalization to the entire images shows the limits to map the landscapes from satellite images. Ground survey points are to be chosen on the entire area. Thus, the advantage of satellite images to generalize the knowledge of land use disappears.

Key words:

Remote-sensing; Landsat; land use; Africa; vegetation indices.

1. Introduction

The present study was conducted in the perspective of a research project, Biosol (Biological stimulation of soil and socio-economic management of agrosystems in Burkina Faso, funded by the region Centre in France), which aims to promote new knowledge on the ecological intensification, to ensure environmental and socio-economic development in different regions of Africa. The first results showed that solutions are relevant only if they are based on a diagnosis and a rigorous and reliable inventory of the situation [1], which includes knowledge of land use.

This article aims to propose a method of characterization of land use in the absence of any pre-existing mapping, as it is often the case in Africa. Satellite images prove to be currently the most relevant way to know the landscape. Easily available

on the dates you want (from 1972), they require a time much shorter than the aerial photographs treatment, especially if the covered area is vast. We are particularly interested in Landsat images, some of which are free to access.

2. Materials and method

Sampieri is one of the three villages (Fig. 1), which were chosen by the research project Biosol to study different methods of ecological intensification, their environmental consequences and the conditions of support by the populations. Located in the East of Burkina Faso (Fig. 1), it's

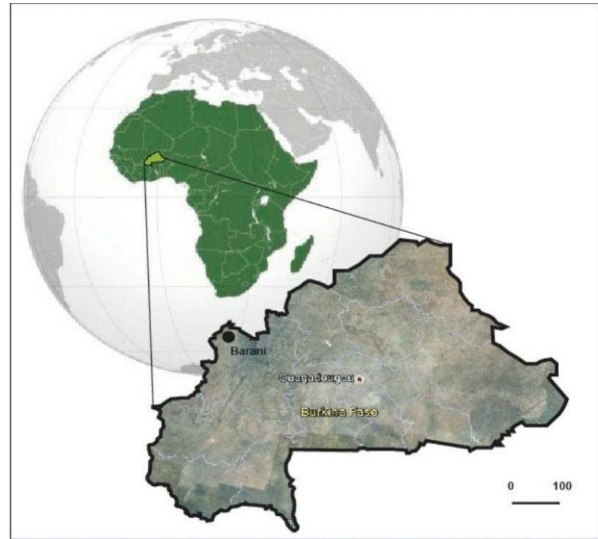


Fig. 1: Localization of the studied areas chosen by the research project Biosol

2.1 Materials

To select the best images, several criteria have to be considered. One of the most important is the resolution because the identification of the Earth's objects depends on it:

- the spatial resolution sets the pixel size and thus the size of the smallest object, which can be identified;
- the spectral resolution determines the number of bands, therefore the easiness of identifying the objects.

The choice depends on the aim of the research and on the specificities of studied areas; it depends also on the characteristics of objects which we intend to identify. Within the framework of this research, the objects are the main land use categories (cultivated land, spontaneous vegetation and bare land) and the focus is mainly on the fields, whose area is between 0.38 and 26 ha [3]. Thus the sensor should offer high spectral and spatial resolutions. Far to be the only one, Landsat 8 OLI/TIRS can work because its spatial resolution is 30 x 30 m and because it measures the luminance in the visible and infrared bands. Above all, the images taken from this sensor

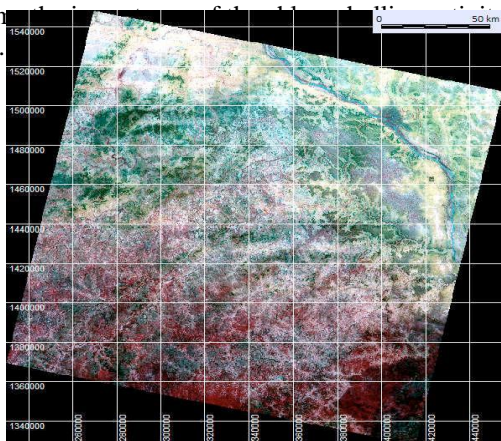
included in the Sudanosahelian climatic area (between isohyets 600 mm and 900 mm [2]). The main activity here is agriculture: traditional crops (beside sorghum, the most frequent, millet, fonio, beans, Bambara groundnuts, peanuts, sesame, hibiscus, corn, etc.) and animal husbandry.

The climate in Burkina Faso is characterized by two seasons, a dry one and a rainy one, which lasts 4-5 months in the Sudano-sahelian area [2]. This season (from May-June to September-October) is the period of cultivation. This piece of information had to be considered to choose the images, taken at the best dates, to obtain the greater discrimination between the three main land use categories. These were supplemented by an empirical knowledge, acquired on the ground:

- In June, because they have been recently planted, the cultivated lands can be distinguished more easily from herbaceous formations but can be mistaken for bare or few plant-covered lands on images.
- In September-October, the chlorophyllian activity is important; the crops are ready to be harvested and can be mistaken for herbaceous formations but these lands can now be better distinguished from bare lands.

Using images taken at these two periods allows removing any ambiguity between cultivated lands and other land use categories. J. L. Devineau and G. Serpantié [4], who also intended to map the Burkinabe landscapes by remote-sensing, using satellite images, advocated to add a third image, taken in January. In this study, the latter didn't appear because the aim was not to obtain a "fine discrimination of various plant groups" (Devineau and Serpantié, translated) but to identify the main land use categories. Thus, two images were acquired. We chose images from Landsat 8 OLI/TIRS, the only free and available images in 2013 (June, 7 and October, 13); this year was preferred because it's the one, during which the ground survey was conducted to know the land use in order to facilitate the identification of the clusters on the images and to validate the results.

The comparison of the two color composites (Fig. 2 and Fig. 3), which were created from each image, revealed the differences and thus the relevance of using these two images, chosen according to the agricultural calendar. The higher frequency of the red color on the color composite of October confirms the presence of bare lands at this period.



are freely available at the selected dates and they cover an area large enough to include the studied area, with a 185 km across track field of view.

Fig. 3: Color composite, using the green, red and near infrared bands – Image taken by Landsat 8 OLI/TIRS October 13, 2013

2.2 Method

The different bands of a given image are often correlated; in order to synthesize the information contained in these bands, new bands were created for each chosen image, with the advantage to reduce data to the most useful ones, according to the purpose of the study. These created bands are two indices:

- of vegetation: we used the Transformed Soil Adjusted Vegetation Index (TSAVI), chosen among different existing indices [5], because it proved to be the most relevant in the framework of this study (see below).

$$TSAVI = \frac{NIR - RED}{NIR + RED}$$

where

- NIR = reflectance in near infrared band (expressed reflectances)
- RED = reflectance in red (expressed reflectances)
- a = slope of soil line
- b = intercept the soil line

- of brightness: $(\sqrt{[(Rouge)^2 + (PIR)^2]})$

The vegetation index aims to stand out the vegetation and the brightness index aims at standing out the bare lands. The choice of these indices was strengthened by pre-existing research, those of J. L. Devineau and G. Serpantié [4]. Nevertheless, instead of TSAVI, these authors used NDVI (Normalized Difference Vegetation Index). This last index is the most commonly used vegetation index but it's not

necessarily the most adapted to the studied area.

It doesn't compensate for the soil effects and thus the signal produced by the only vegetation can be mixed up with this one of the soil [5]. That's why NDVI can change according to the soil types [6], particularly in semi-arid areas, where the vegetation cover is low. NDVI was tested in the framework of this study but TSAVI was preferred all the more since it offered a better discrimination between culture and spontaneous vegetation, at least for the local window. Another band was considered, the green band, which gives information about the chlorophyllian activity, especially because the most difficult task was to distinguish spontaneous vegetation (savannah) from cultivated land.

The three chosen bands – vegetation and brightness indices and green band – of the two images – of June and October – were processed into the framework of an automatic classification.

Because the method had to be easily reproducible, we have opted for an unsupervised classification, based on the Isodata method – aggregation around mobile centers – suggested by G. H. Ball et D. J. Hall [7].

The advantage of such a classification is also that no *a priori* knowledge on the land use is necessary – even though the validation of the classification can't be done without such knowledge – and that it is based more on spectral signatures of objects to be identified.

To get the more relevant results, we tested different combination of bands – the best including the bands mentioned above –, various number of desired clusters, knowing that the relevance of the results was judged according to control points, whose land use was studied on the ground.

The figure 1 synthesizes the method used (Fig. 4). We first tested it on a sub-image, a window on the village of Sampieri, where the ground control points are located. At the end of this stage, we obtained a local map of the land use. Then, the method was applied to the entire image but some adaptations were then required (see below).

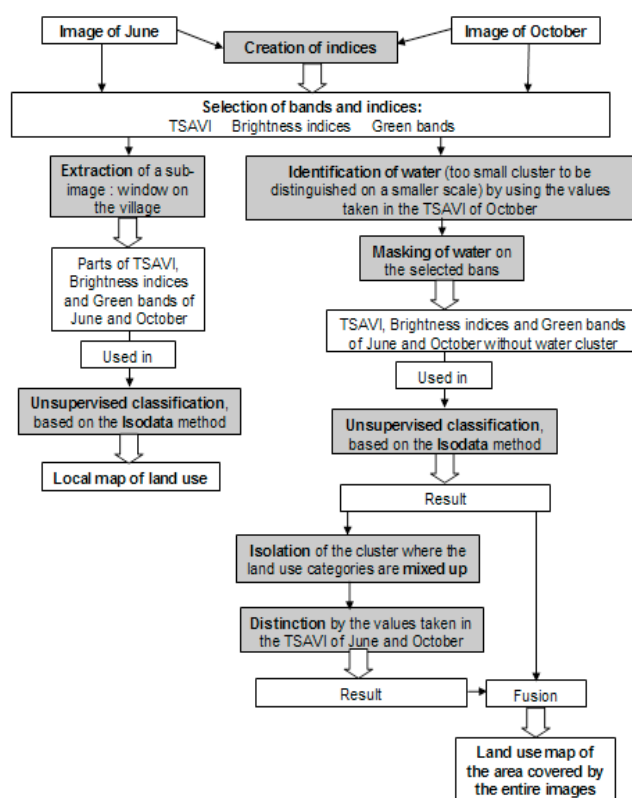


Fig. 4: Summary of the method

3. Results and discussions

Applied initially on the local window (Fig. 5), the processing was better calibrated thanks to the knowledge of the land use, which was learnt from the ground survey. This one also allows validating the result of the classification; for each ground control points, this result was compared with the reality of the land use on the ground. The concordance was obtained for each point, like for some of them taken in the cultivated lands (Fig. 6), in the lands covered by the spontaneous vegetation (savannah; Fig. 7) and in the bare lands (Fig. 8). This concordance proved the relevance of the obtained classification.

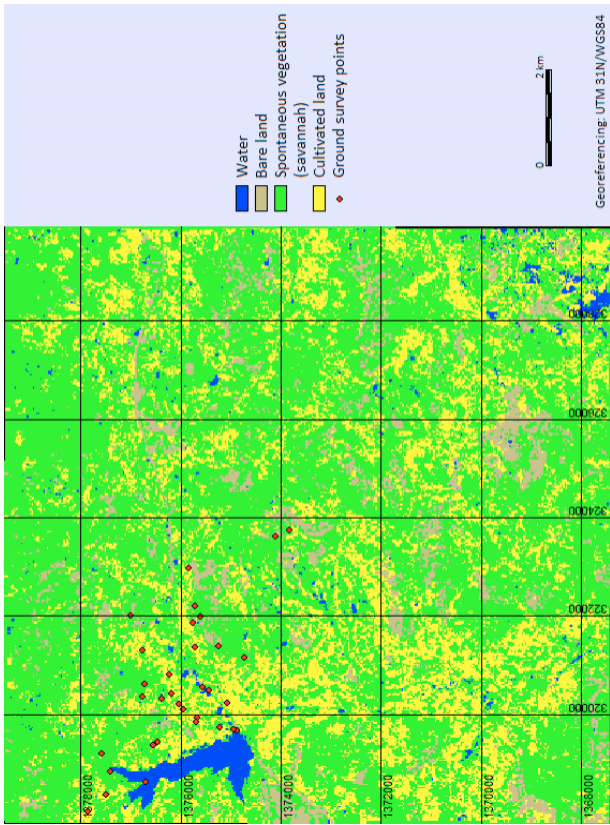


Fig. 5: Land use map, Sampieri, 2013 – Classification obtained by

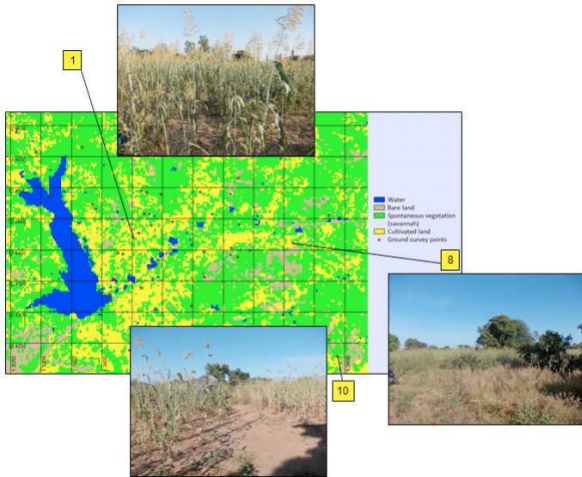


Fig. 6: Validation of the classification by all ground control points – examples of some points taken in the cultivated lands (planted to sorghum; shots: J. L. Yengué, 2013)

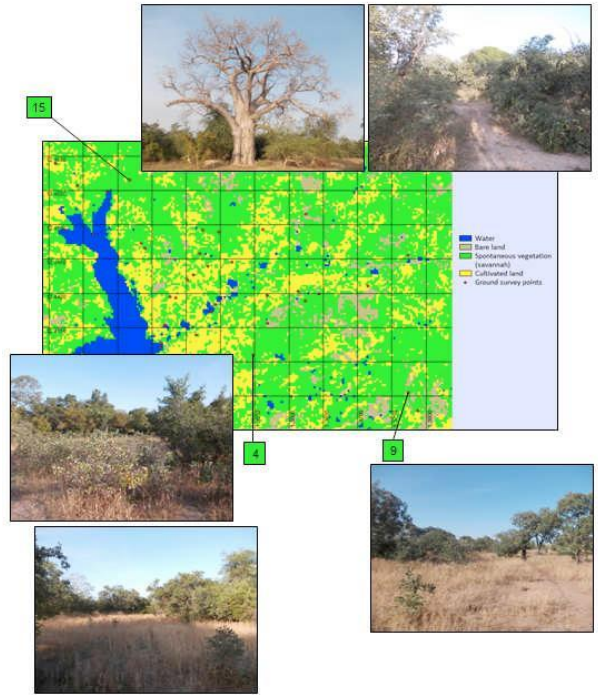


Fig. 7: Validation of the classification by all ground control points – examples of some points taken in the bare lands (Shots: J. L. Yengué, 2013)

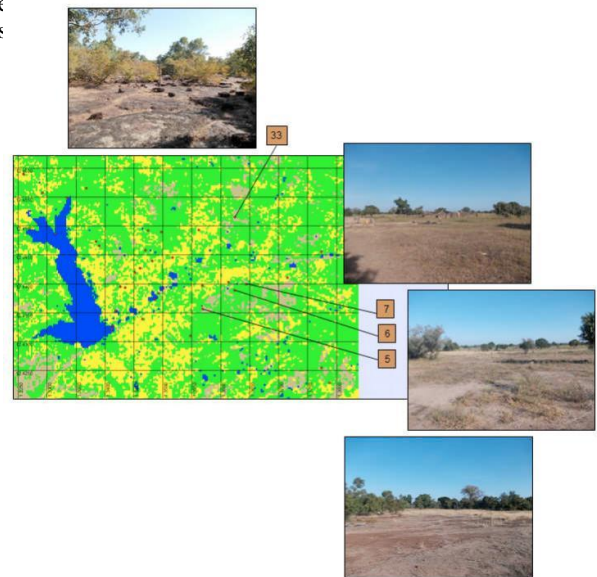


Fig. 8: Validation of the classification by all ground control points – examples of some points taken in the bare lands (Shots: J. L. Yengué, 2013)

After having identified and masked “water” cluster, too small to be distinguished on a smaller scale by unsupervised classification, the same processing was applied to the entire image (Fig. 4) but it ended up in a quite different result, disappointing at a village scale (Fig. 9); that’s why some adaptations were then required.

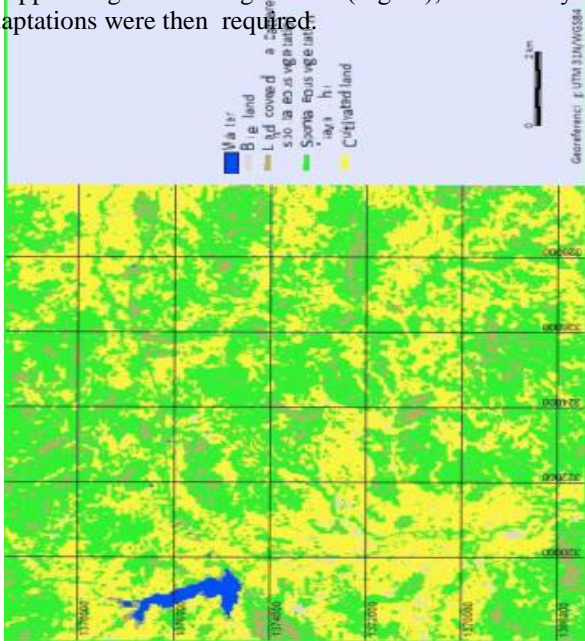


Fig. 9: Land use map, Sampieri, 2013 – Classification obtained by generalizing the processing used for the window (fig. 5) to the entire images, extract (window on Sampieri)

This disappointing result can be explained by the fact that the entire images include different landscape units from those included in the only local window.

Thus, to solve this problem, we tried to change the number of desired clusters but it was a failure; we had then to look for a new method or a solution to improve the predefined method. We had to go back to the upstream of the processing and to analyze indices and bands. It appeared that some mixing-up, some failures could be removed thanks to the distinction of the values taken by the objects to be identified in TSAVI. This vegetation index was therefore used to improve the clusters of the best classification, which suffered from mixing-up, to separate the land use categories included in the same cluster (Fig. 4). The result of this processing was then added to the one of the classification, to replace the unsatisfactory clusters, after having masked them. At the end of this fusion, we obtained a map of land use at the scale of the area covered by the entire images (Fig. 10); from this one, a sub-image at the scale of Sampieri was extracted (Fig. 11) to compare it with the first map obtained by processing on the local window (Fig. 5) and to validate this new classification.

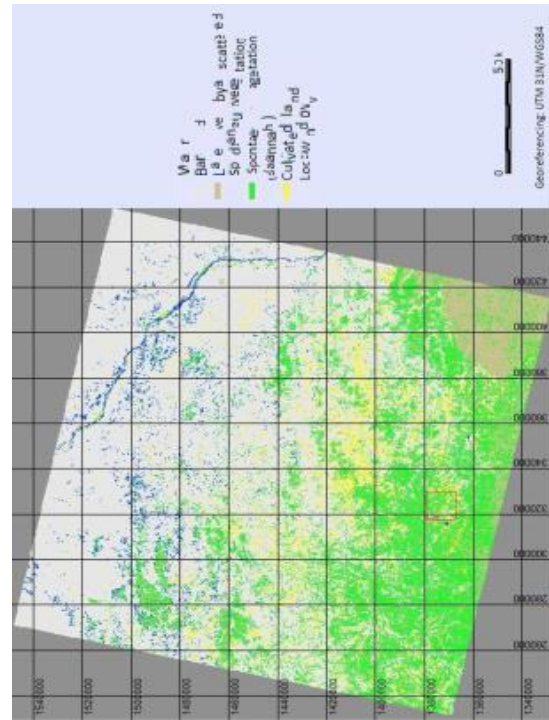


Fig. 10: Land use map, Sampieri, 2013 – Classification obtained by adapting the processing to the entire images, extract (window on Sampieri)

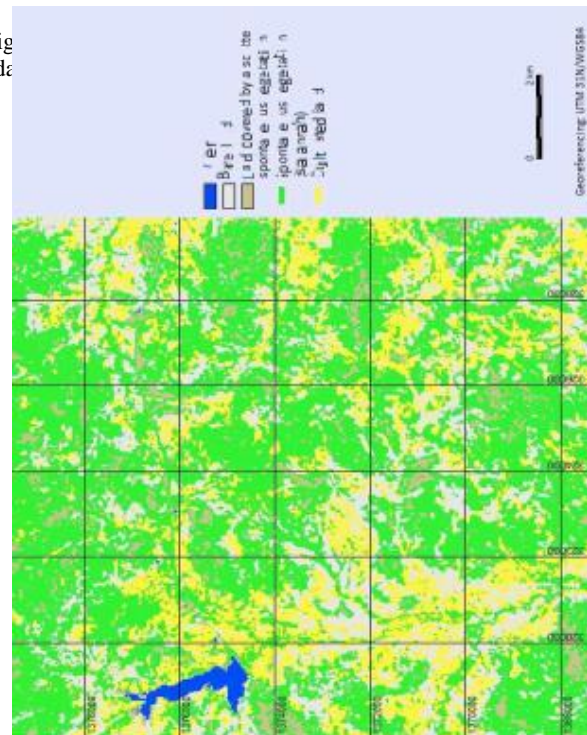


Fig. 11: Land use map, Sampieri, 2013 – Classification obtained by adapting the processing to the entire images, extract (window on Sampieri)

To validate it, this classification, obtained by adapting the processing to the entire images, was confronted to the ground control points taken in the studied village, as for the first local map (Fig. 6, Fig. 7 and Fig. 8). But it was not sufficient to judge its relevance. The area surveyed on the ground, where the control points were taken, is relatively small, quite smaller than the area covered by the entire images (Fig. 10). The reality of the land use on this scale had to be taken into account. Nevertheless, it was not possible to conduct a ground survey on this entire area, because this one is too vast (170 x 185 km). Essentially based on Google Earth image, the knowledge of the land use on such a small scale was thus imprecise but it was considered to validate the classification, as to identify the clusters. Because this vast area includes different landscape units from those included in the only local window, the map obtained (Fig. 10 and Fig. 11) is a compromise between the land use in the village and in the entire area covered by images.

On these two scales, the result is not completely satisfactory; the bare lands, for example, differ from these identified by processing on a local scale: too small, they're now included in "land covered by a scattered spontaneous vegetation" and other bare lands appear according to the land use knowledge on a small scale, whereas they have been classified as savannah on the figure 5. These lands, which concern a large area at the scale of the images (Fig. 10), are not really bare but more exactly covered by spontaneous vegetation, more scattered than on the "land covered by scattered spontaneous vegetation".

Because the result is a compromise, not completely satisfactory, because it is different from the result obtained for the local window, in spite of the improvement attempts, we can affirm that the generalization of the land use knowledge from a local scale to a smaller scale, basing on satellite images, shows its limits, especially when different landscape units are included on the smaller scale. The solution could be to process separately the parts of images corresponding to the different landscape units. It was tested for the unit, which includes the studied village, using a larger window, but the result was also different from the one which had been obtained at a local window; that's why, because the aim was to find a method easily and quickly reproducible, this solution was not kept.

4. Broadening

To verify if the method defined and applied to Sampieri area is easily and quickly reproducible, it was tested on another area, including Bandougou, a village near Orodara also chosen by the research project Biosol. Located in the South-west of Burkina Faso (Fig. 1), this village is included in the Sudanese climatic area (from 900 mm to 1300 mm of annual precipitation [2]), where the rainy season is slightly longer (6 months) than in the Sudano-sahelian area (4-5 months), including Sampieri. Like in this one, the main activity is agriculture;

crops here are mango trees, palm trees (*Borassus*), cashew, Bambara groundnuts, hibiscus, corn, orange trees... (Fig. 12).

As the crops, the spontaneous vegetation (Fig. 13) and thus the landscapes differ from those of Sampieri; applying the defined method to Bandougou area, in a different context of land use, all the results are thus very different.



Perennial crops (here, mango trees) are particularly frequent in Bandougou. The landscape is characterized by scattered trees and open fields.



Fig. 12: Cultivated land in Bandougou – examples taken at the level of some ground control points (Shots: J. L. Yengué, 2013)



In Bandougou, the spontaneous vegetation differs from the one, which is less dense and has less dr...



Fig. 13: Spontaneous vegetation (savannah) in Bandougou examples taken at the level of some ground control points (Shots: J. L. Yengué, 2013)

The method defined for the processing of Sampieri images showed limits, because the results varied according to the considered area. However, this method needing only adaptation appeared to be the best one, of those we tested. That's why the same processing – using TSAVI, brightness indices and green bands of the June and October images in an unsupervised classification – was applied to draw a map of the land use in Bandougou and its area. The aim was also to know if the same problem appears, if the results also depend on the considered area, between the village area and the area covered by the entire images, to know if the generalization based on satellite images is reliable or if, for all studied areas, it needs adaptations. Two images taken from Landsat 8 OLI/TIRS in June and October 2013 were chosen – June, 3 and October, 25. From them, sub-images including Bandougou were first extracted and processed.

A difference should be noticed between Sampieri and Bandougou: a new land use category appears in this area; the cultivated land had to be separated in annual crops and

Even if it was defined in the absence of these crops, because it had first been defined to learn about Sampieri landscapes, the method allowed obtaining a quite satisfactory land use map on a village scale, validated by the ground survey (Fig. 14), at the level of control points taken during this one, as for the Sampieri map.

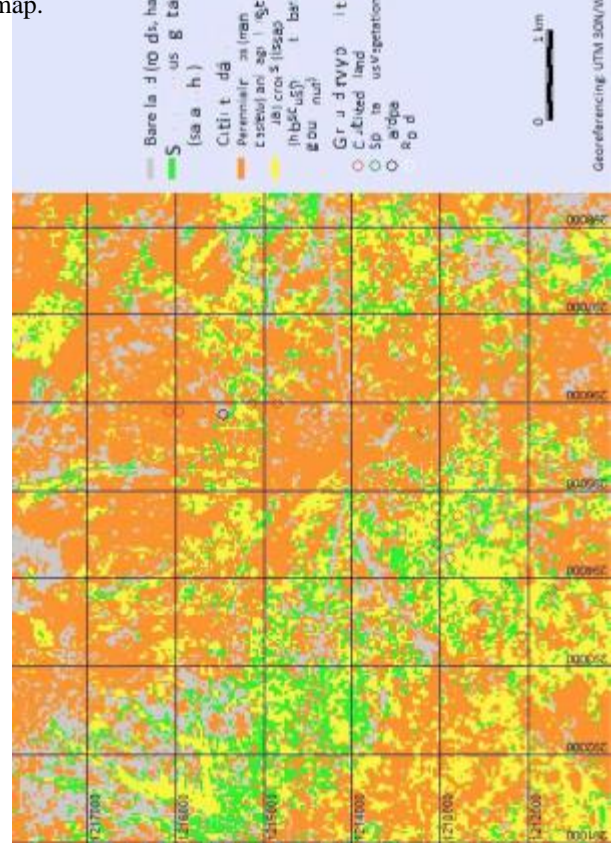


Fig. 14: Land use map, Bandougou, 2013 – Classification obtained by processing on a window of the images, on a local scale

The reproducibility of the method was thus demonstrated on a local scale; could we come to the same conclusion on a smaller scale? According to the result obtained for Sampieri, the answer was *a priori* negative – or, at least, the method needed adaptations – and this revealed true; but, for the two studied areas, we came to another kind of conclusion, not in terms of land use knowledge but in terms of generalization possibilities, using image satellites.

Indeed, the processing used for the local window, centered on Bandougou (Fig. 14), was applied to the entire images, changing only the number of desired clusters to obtain the best result but this one (Fig. 15 and Fig. 16) is different. In Bandougou (Fig. 15), the perennial crops are less vast, quickly replaced by annual crops, and a new land use category had to

perennial crops, frequent in Bandougou (Fig. 12).

gallery forests – on the figure 15, some of these forests appear inside Bandougou because of mixing-up between these forests and the perennial crops. Thus, we came to the same conclusion than for Sampieri; the method, satisfactory for a local window, needs adaptations when it's applied to the entire images, extract (window on Bandougou) of

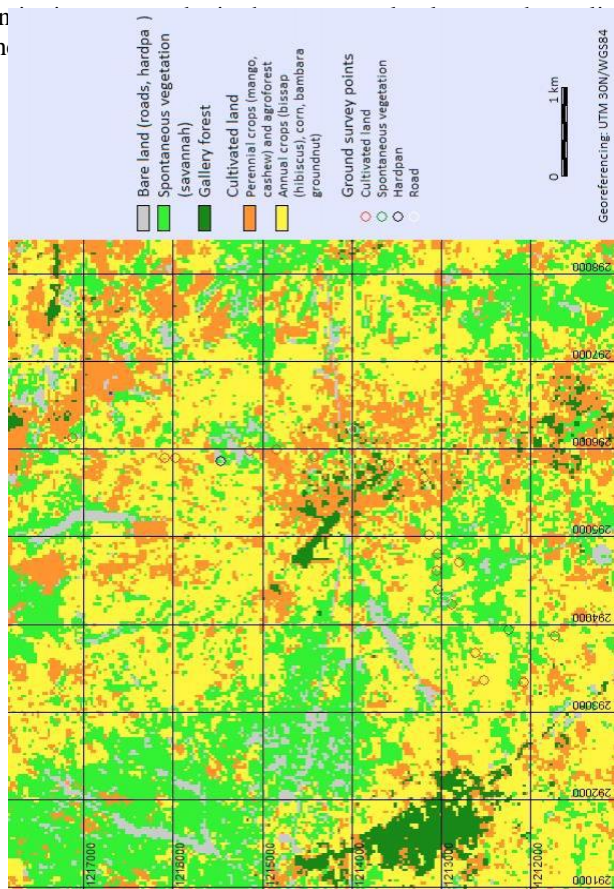


Fig. 15: Land use map, Bandougou, 2013 – Classification obtained by generalizing the processing used for the window (fig. 14) to the entire images, extract (window on Bandougou)

be created:

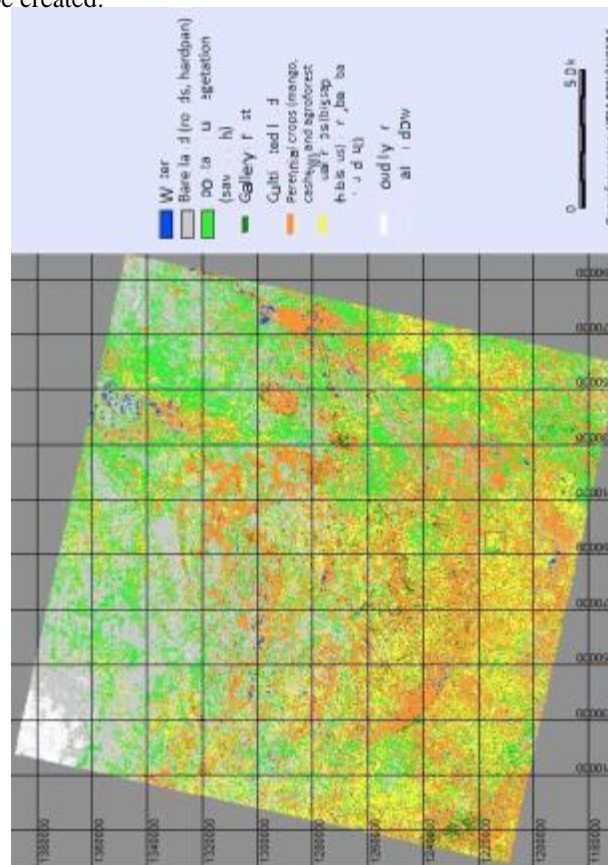


Fig. 16: Land use map, Bandougou, 2013 – Classification obtained by generalizing the processing used for the window (fig. 7) to the entire images

5. Conclusion

We defined a method that appears satisfactory on a local scale; the results for the studied villages windows are close to the reality of the land use on the ground, for the main study area – Sampieri – as for the complementary one – Bandougou –, which allows validating the processing and verifying its reproducibility. Based on an unsupervised classification, the method can be easily applied to other sites of Burkina Faso, or of West Africa, where the climatic conditions and vegetation are comparable to those of the studied areas. It allows knowing the main land use categories around villages, in the absence of any available map, generalizing the knowledge achieved by a ground survey, which remains essential, as for any study based on remote-sensing. Apart from this, the method only requires the use of images at two periods of the agricultural calendar, being freely available, taken by Landsat sensors.

It uses TSAVI, brightness indices and the green bands of the two images. Nevertheless, satisfactory on a local scale, the method becomes disappointing – or, at least, needs adaptations – when it's applied to the entire images; new land use categories appear and some of those identified on the village window become marginal. The results are different according to the considered area, between a window on the studied village and the entire images. The generalization to a smaller scale without any ground survey can't give reliable results. The advantage of satellite images, which allow generalizing the knowledge on landscapes, thus disappears.

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