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Photo: Gardening near a lake in Burkina Faso.
Credit: Ollivier Girard/CIFOR.

Small-Scale Irrigation Mapping (SSIM) as a tool for improving and validating irrigated area maps: contextual approach and lessons learnt in Burkina Faso

Mathieu Chaix-Bar, Jennie Barron, Steve Cinderby, Howard Cambridge, Joanne Morris

Technical report

With the support of:

Key messages

- The use of SSIM has improved the map of small-scale irrigation in Burkina Faso; according to the newly developed map, the total area under small-scale irrigation in Burkina Faso ranges from 32,000 hectares (ha) to 154,000 ha, which is much higher than indicated by existing maps.
- The map provides a means of validating the results of the decision-support tool “Targeting Agricultural Water Management Interventions (TAGMI)” for expansion of small-scale irrigation.
- The methodology is accessible to users who do not have a high level of expertise in Geographical Information Systems (GIS) and Remote Sensing (RS).
- Uncertainty in this methodology can be reduced by improved data on land cover and better knowledge of cropping patterns.

Introduction

Recent rapid expansion of private small-scale irrigation provides an opportunity to improve livelihoods and food security, but requires knowledge of where it is happening, in order to sustainably manage water use. Concerns are rising regarding the negative impacts of unchecked expansion of irrigation on downstream water quality and availability, particularly when using sub-optimal practices (de Fraiture et al. 2014; Domenech and Ringler 2013; Shah 2007). Therefore, for informed planning of potential sustainable irrigation expansion, policy makers and resource managers at the national level are interested in maps of the current extent of small-scale irrigation. Although several maps of irrigated areas have been produced for Burkina Faso, these maps, often of 250 meter (m), 300 m or 1 kilometer (km) resolution, are of too low resolution to account for scattered irrigation on areas smaller than 1 hae. Small-scale irrigation in Burkina Faso is typically carried out on individual plots of less than a quarter of hectare, with a small proportion on groups of fields no larger than one hectare, implying that existing maps are not reliably capturing the true extent and distribution of small-scale irrigation in the country.

In response to the need for an improved map, which captures small-scale irrigation on areas less than one hectare, a new methodology was developed and tested for mapping irrigation at high resolution throughout Burkina Faso. The method called Small-Scale Irrigation Mapping (SSIM) tool, uses a time series of 30-m Landsat 8 imagery combined with ground truthing data and local knowledge collected along a transect across three of the four agro-climatic zones in Burkina Faso to carry out an informed unsupervised classification.

The results of the mapping exercise are presented here, with reflections on the opportunities it provides for improving knowledge of small-scale irrigation in countries with incomplete irrigation inventories. The new small-scale irrigation map was used to validate the results of the decision-support tool Targeting Agricultural Water Management Interventions (TAGMI), which calculates the varying spatial likelihood of long-term success of an intervention at district level across the country.

Research context and methods

Ground truthing

Two main approaches were used in collecting data for the study: ground truthing and satellite image processing. First, ground truthing data was collected between November 27 and December 18, 2014 across Burkina Faso using two Garmin GPS etrex, two tablets and an electronic form application for smartphone (Forms, Device Magic). Overall, 1,407 ground-truthing points were taken (619 for irrigated areas and 788 for other land covers) and 25 reservoirs or dams were visited. The ground-truthing data was collected by two operators along a transect crossing all three agro-ecological zones, and intensive sampling and survey was carried out in five focal areas indicated on the map (Figure 1).

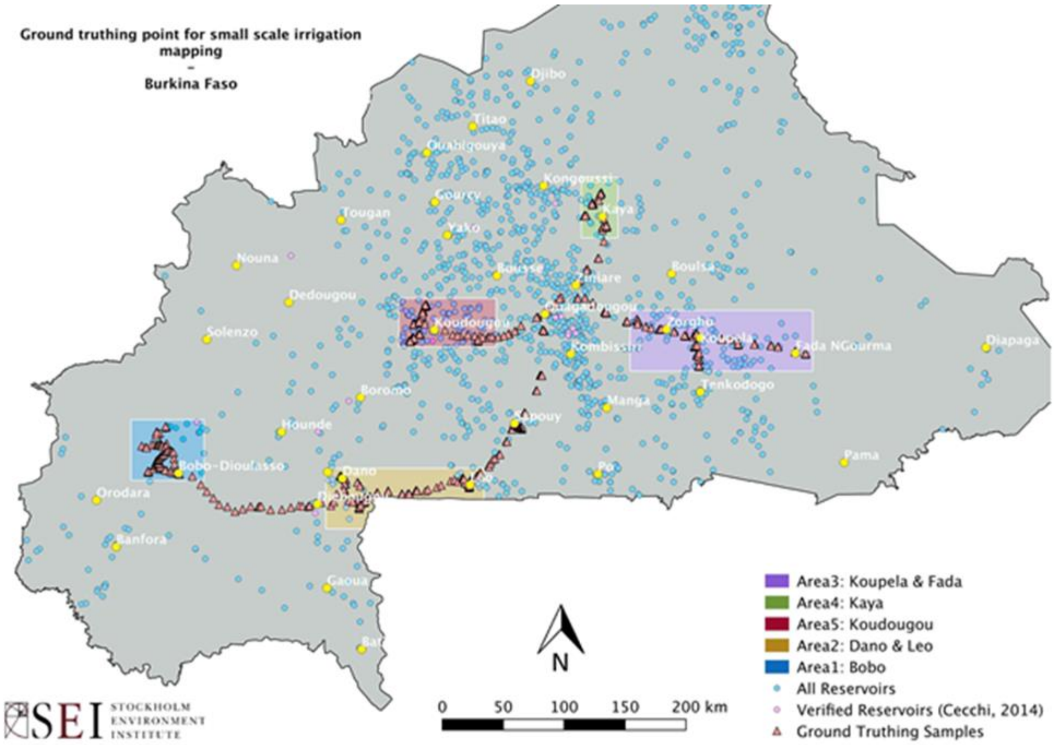

Figure 1: Ground-truthing points collected along three transects and four areas of focus.

Two sampling protocols were designed: one for points around irrigated areas where small reservoirs were identified and selected from Google Earth imagery. In most cases, two transect lines were drawn (heading downstream and upstream from the dam wall) to define the starting and ending points of the transects. In areas where the characteristics of the irrigated areas were not straightforward, the direction of the transect line was adapted to the local distribution of the irrigated area, as seen in Figure 2. The second sampling protocol was for points along the roads, where GPS coordinates were recorded at 50 m and 250 m.

Figure 2: Transect lines adapted to the local distribution of the irrigated areas.

Image processing

Landsat 8 imagery was downloaded for the whole of Burkina Faso for the period between October 2013 and May 2014, representing the dry season. The season analyzed with the satellite imagery is not the same as the season in which the ground truthing was carried out (November to December 2014), due to the Landsat 8 thermal sensor being out of service between December and March 2015. The image analysis followed four main stages (Figure 3): 1) calculate the normalized difference vegetation index (NDVI); 2) identify surface water and create a 1.5-km buffer zone; 3) identify irrigated areas within the buffer using two methods: NDVI classes to select irrigated vegetation and NDVI standard deviation to identify harvested irrigated areas; and 4) perform accuracy assessment using the ground-truthing points.

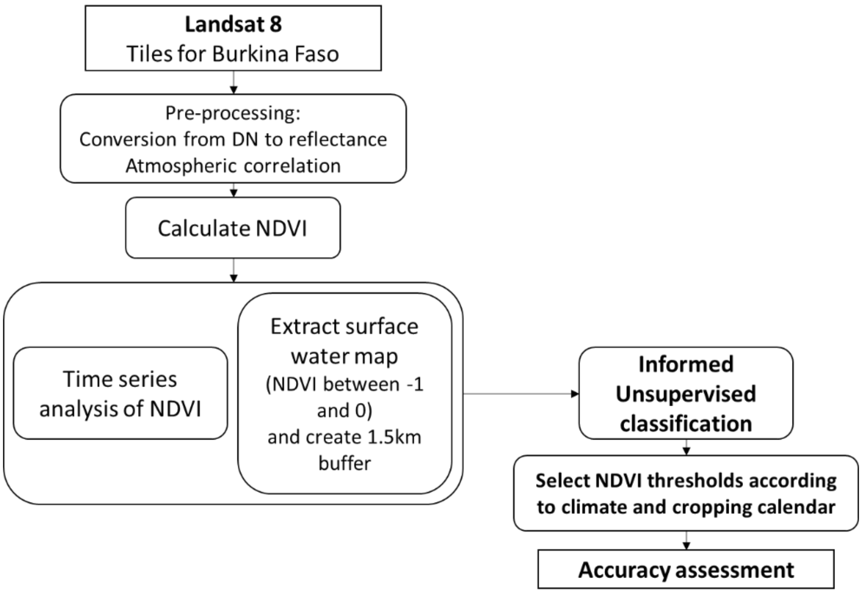

Figure 3: Diagram of the remote-sensing analysis process.

The map produced, of small-scale irrigation, shows the area that was under irrigation during November 2013 to February 2014. Using six different algorithms over the entire country and a conglomerate of the most accurate methods for the final map, the total area under irrigation in Burkina Faso was assessed to range from 32,000 ha to 154,000 ha. These figures are higher than what has been shown on previous maps, which estimated between 25,000 ha to 42,000 ha based on data from 2005 or earlier.

In some areas, the results' goodness of fit is evident when comparing the map with Google Earth for well-known small-scale irrigation sites, as identified from the ground-truthing exercise (Figure 4). The data for Burkina Faso on Google Earth contributes to the good performance. However, in doing same exercise for the whole country, in some areas, particularly in the south or near big rivers and gallery forest, the algorithms did not make the distinction between irrigated area and riverine vegetation.

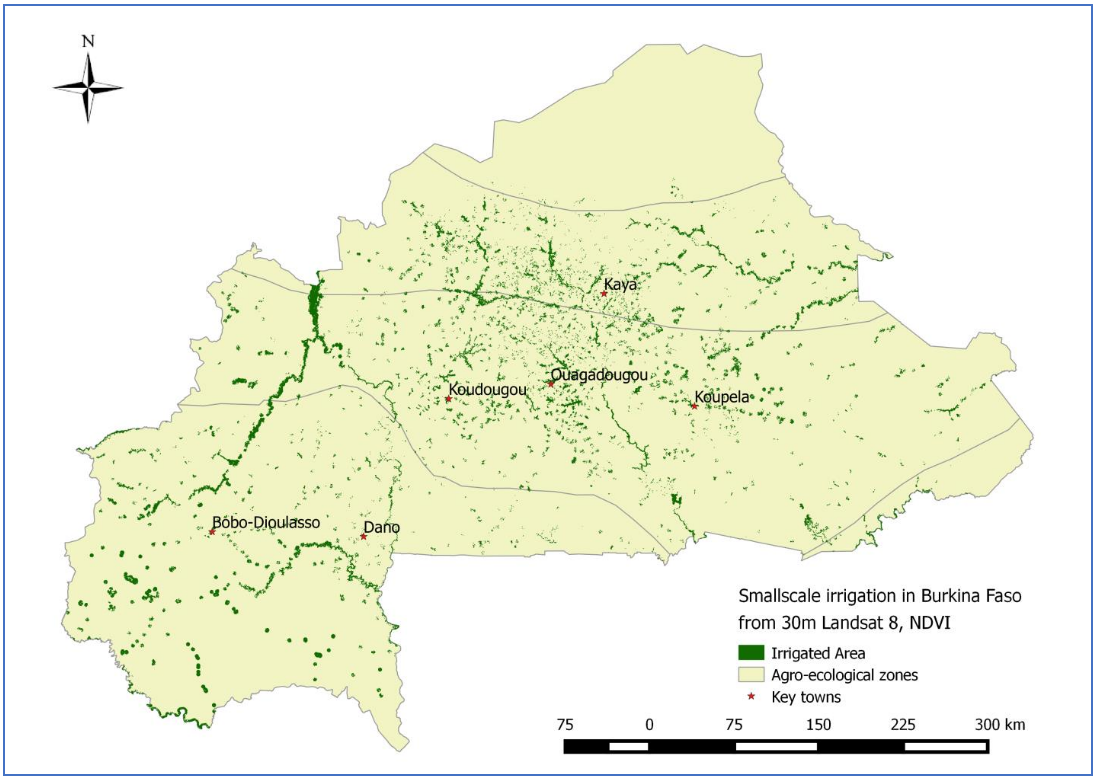

Figure 4: Map of small-scale irrigation in Burkina Faso.

The final improved irrigation map was used to validate the results of the TAGMI model for small-scale irrigation in Burkina Faso. This model was developed at an earlier time, under the CGIAR Challenge Program for Water and Food project in the Volta Basin. The validation method used was a simple accuracy assessment where irrigated area percentages were calculated and classified into three classes (low, medium and high), using geometric interval classification in ArcGIS.

For each district, the TAGMI result was compared to the irrigated area percentage, and the results suggest that approximately half of the time the predicted potential for irrigation is higher than the actual realized irrigation (Figure 5). The comparison highlights how the highest levels of actual irrigation follow the main rivers of Burkina Faso (the White Volta and the Black Volta), with low levels of actual irrigation found in the southeast of the country (Est and Centre-Sud regions). By comparison, TAGMI overestimates the likelihood of success of agricultural water management (AWM) interventions in the drier eastern region and the eastern districts of Mouhoun Region, yet underestimates the likelihood of success in the very northern districts of Centre-Nord region and in the western districts of Mouhoun Region.

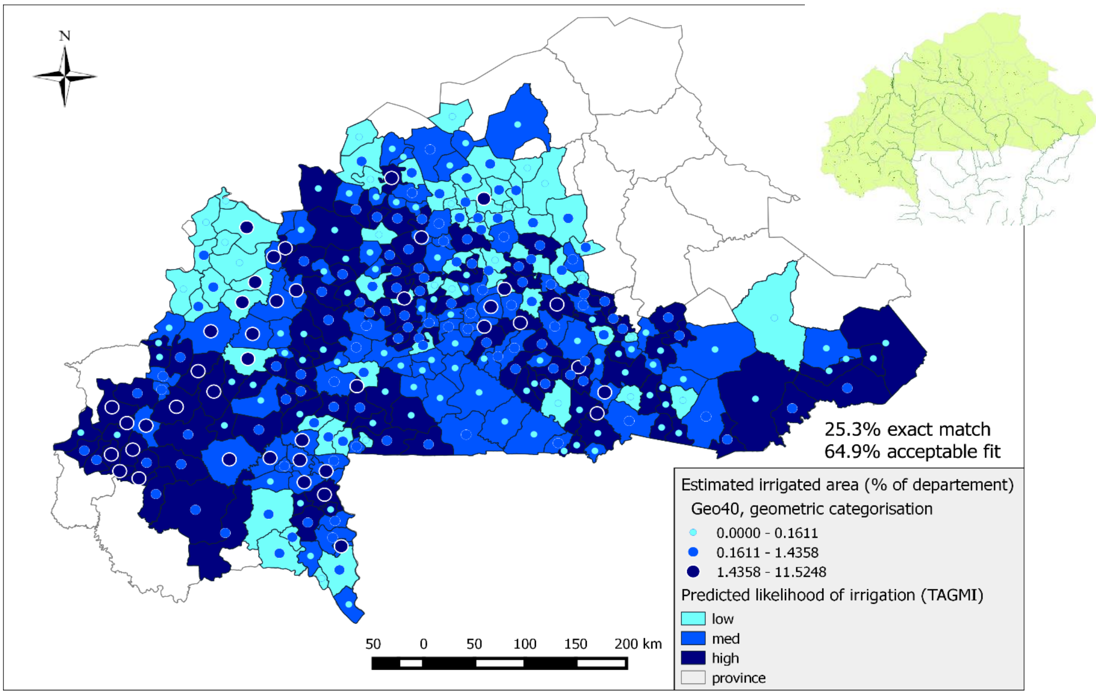

Figure 5: Validation of TAGMI's estimated likelihood of success for small-scale irrigation in Burkina Faso. TAGMI's estimated likelihood of success per district (shading) is compared to percentage of area irrigated per district, classified into low, medium and high (shaded dots). Inset shows large rivers in the Volta Basin.

Discussion and recommendations

Despite using high-resolution data for the remote sensing (RS) map, it is still a challenge to identify irrigated vegetation. This mapping exercise highlighted that even Landsat images at 30-m resolution are too coarse to identify smaller irrigated plots; where small-scale irrigation occurs in scattered fields, the NDVI signal may be too weak to be identified at 30-m resolution. Access to a high-resolution land cover map would allow the creation of a forest mask, which would significantly reduce the misclassification of riverine vegetation. Moreover, access to a reliable shallow groundwater map would allow the 1.5-km buffer around surface water to be expanded to include areas that may be irrigated from shallow wells.

Cropping patterns and timings may shift from year to year, with farmers irrigating different plots or leaving plots fallow. That means there may be some discrepancy between the RS images from October 2013 to February 2014 and the ground-truthing points that were collected in November and December of 2014. This discrepancy was made necessary by a technical fault in some of the remote-sensing images from the 2014–2015 season. The map can be further improved by gathering more knowledge about the irrigated cropping calendar and how it changes across the country and by using very high-resolution imageries such as those from Sentinel-2. This will inform better targeting of the NDVI time-series analysis that classifies irrigated area based on the harvest time of irrigated crops.

To assist wider use of this methodology in other countries or by other users, it would be helpful to create a set of recommendations of algorithm settings to use according to the context, including climatic conditions, vegetation cover and cropping practices. In order to create that, it would be necessary to do further testing on smaller areas to detect which algorithm settings to suggest for which contexts, to maximize the irrigated vegetation identified while minimizing interference with riverine and gallery vegetation.

A follow-up workshop for end users of the TAGMI model, held in Accra in September 2015, raised concerning views on the limitations of the tool. The limited number and variations of technologies that can be assessed with the tool were particularly debated. The users highlighted that small-scale irrigation is a combination of water-lifting and water-distributing technologies, for each of which there are several options and several possible combinations. For future development, it should therefore be considered to redesign the TAGMI model to cater for all the combinations of small-scale irrigation technologies in order to be fully useful.

Lessons learned and implications

The SSIM tool has proved to be very efficient for capturing small-scale irrigation in certain locations when validating the small-scale irrigation map against known sites using high-resolution imagery in Google Earth. However, misclassification of riverine vegetation, scattered irrigation and other features is still a challenge. Notwithstanding, when assessed against over 1,400 ground-truthing points, the map has shown a balanced accuracy of 70% for the whole of Burkina Faso, ranging from 55% to 73% by agro-ecological region. The map estimated over 100,000 ha of small-scale irrigation across Burkina Faso, which is far higher than figures reported by existing maps.

The methodology is accessible to users without high-level expertise in RS or GIS. The exercise highlighted that using a combination of ground-truthing data and high-resolution RS data was the better method for producing the small-scale irrigation map, given the challenge of using Landsat images at 30-m resolution, which struggled to identify scattered fields of less than one pixel. Local knowledge is also necessary to zone the country according to cropping patterns and wetness, so that the algorithm for classifying irrigated pixels is run at an appropriate interval in each zone to catch shifting harvest times across the country.

The study has, by developing a map of small-scale irrigation from RS, provided a means of validating the results of the TAGMI model for small-scale irrigation. Using maps with one algorithm for all of Burkina Faso to validate the TAGMI tool, the proportion of actual irrigation was found to match fairly well the likelihood of success given by the TAGMI model in 64% of districts. Approximately half of the time, the predicted potential for irrigation was higher than the actual realized irrigation, but lower than the actual irrigation in the very northern departments of Centre-Nord Region and in the western districts of Mouhoun Region. The latter results may be affected by misclassification of riverine vegetation along the Mouhoun River.

This exercise supports the assessment that the TAGMI model is best used as an initial scoping tool for use at large scales, such as at country scale, to aid during the site selection phase in targeting where to carry out more detailed scoping and suitability testing. Despite its limitations, the TAGMI tool addresses the demand for holistic assessments that include both socio-economic as well as biophysical aspects, in contexts where statistics for many of the required variables are only readily accessible for the whole country, at regional or provincial levels, and very rarely at a finer scale. Moreover, collecting district or municipal level data can be difficulty and time-intensive, but the TAGMI tool can highlight regions or provinces within which to prioritize collecting data at smaller scales for further suitability assessment.

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Further reading

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Acknowledgments

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