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WORKING PAPER

Detection of Open-Air Weekly Markets Using Remote Sensing Techniques

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Open-air markets play a vital role in food security, nutrition, and local economies, yet their spatiotemporal dynamics remain poorly understood. This study explores the use of Sentinel-1 SAR data to detect open-air markets operating weekly by identifying consistent changes in backscatter properties. The method was tested in regions with known market locations, including San Francisco el Alto, Guatemala, and Montpellier, France, where it successfully identified market activity and related patterns. It was then scaled to a national level in Rwanda by limiting the analysis to bare soil and built-up areas using Google Dynamic World V1 land cover data. The results were promising, identifying several markets and providing a foundation for further refinement. However, the approach requires improvements to differentiate markets from other areas with weekly patterns, such as parking lots and construction sites, and thorough validation across diverse contexts. This study demonstrates the potential of remote sensing to characterize open-air markets and their temporal dynamics, contributing valuable data to food system models in data-scarce regions.

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Introduction

Open-air markets play a critical role in fostering food security, nutritional diversity, and local economic development, particularly in developing and rapidly urbanizing regions. These markets serve as vital hubs for low- to middle-income households, providing access to fresh, diverse, and often indigenous foods that contribute to improved dietary outcomes (Baraka et al., 2022). In sub-Saharan Africa, for example, open-air markets remain the primary food source for many urban and peri-urban residents (Hannah et al., 2022). Additionally, they support the local economy by facilitating direct sales and short supply chains, promoting environmental sustainability, cultural heritage, and rural development (Bareja-Wawryszuk & Gołębiewski, 2014). Globally, their adaptability and integration into urban and rural food systems underline their importance in shaping sustainable and inclusive food environments. However, despite their critical role, we have a very limited understanding of the locations and temporal dynamics of these markets in both rural and urban landscapes. This lack of data makes it challenging to study their integration within the broader food supply chain at the national level, hindering efforts to optimize their contribution to food security and economic resilience.

The aim of this study is to develop and test a remote sensing-based approach to identify open-air markets operating once or twice a week, using freely available satellite data.

Objectives

- **Data Identification:** Identify freely available remote sensing data and appropriate methods that can effectively support the identification of open-air markets.
- **Method Testing in Known Environments:** Test and validate the proposed method in regions with known open-air market locations.
- **National Scale Testing:** Apply the method at a national scale in Rwanda to assess its broader applicability and scalability.

In the following document, we outline the implementation of our approach to detecting open-air markets operating once or twice a week using remote sensing techniques. Specifically, we utilized Sentinel-1 Synthetic Aperture Radar (SAR) data to identify pixels with consistently significant deviations in backscatter properties, indicative of changes in surface structure, during specific days of the week. This document details the methodology, data processing steps, and preliminary results of this approach, with a focus on its application at a national scale in Rwanda.

Method

Data

For this study, we utilized Sentinel-1 Synthetic Aperture Radar (SAR) data, which is freely available and offers a spatial resolution sufficient to detect changes at a relatively small scale. The high temporal frequency of Sentinel-1, combined with its ability to capture data irrespective of weather conditions or time of day, makes it particularly suitable for monitoring temporary activities like weekly open-air markets. We hypothesize that market-related activities, such as the presence of trucks and cars parked near the market, temporary stands, and large gatherings of people, result in observable changes in the surface texture of the pixels. These changes are expected to have a significant enough impact on the SAR signal backscatter to allow for the identification of market locations and their operational days.

Approach

We compiled all available Sentinel-1 SAR data (*S1 Mission*, n.d.)from January 2019 to the present, covering multiple temporal snapshots for each location. For each pixel, we computed the median backscatter value for every day of the week to establish a weekly baseline. The methodology focused on identifying pixels exhibiting significant deviations from the overall time-series median. Specifically, a pixel was flagged as having significant deviation if its median for a given weekday $\tilde{x}_d$ value exceeded the overall median $\tilde{x}_o$ by a factor greater than the standard deviation $\sigma_o$of all the pixel's observations multiplied by a threshold parameter α.

$$detected\ if\ |\tilde{x}_d - \tilde{x}_o| \geq \sigma_o \alpha$$

This threshold was treated as a free parameter, allowing us to fine-tune the sensitivity of the detection process. By focusing on consistent, periodic deviations, we aimed to isolate signals likely associated with market activities, such as parked vehicles, temporary structures, and increased human activity, while minimizing noise from other temporary events.

Case study: Regions with known open-air market locations

To validate the proposed method, we first applied it to regions with well-documented open-air market locations and predictable weekly activity patterns.

San Francisco el Alto, Guatemala

Our initial test was conducted in San Francisco el Alto, Guatemala, home to the largest indigenous market in the country, which operates exclusively on Fridays. This market features distinct activities such as an animal market, the sale of traditional products, food, and fresh vegetables, making it an ideal location to test the sensitivity of the method. The market's unique size and significance provided a robust case for identifying the distinct weekly backscatter changes using Sentinel-1 SAR data.

Montpellier, France

The method was subsequently implemented in Montpellier, France, in areas known for their weekly market activities. The primary focus was on the *Marché aux Arceaux*, a popular food market operating on Wednesdays and Saturdays, as well as the smaller-scale flea market, *Les Jeudis d'Antigone*, which takes place on Thursdays. These markets offered a diverse test environment with varying scales and types of activities, providing an opportunity to assess the method's ability to distinguish between different market-related dynamics.

Case study: National scale implementation in Rwanda

Rwanda faces significant challenges in food and nutrition security, with low household dietary diversity contributing to high malnutrition and stunting rates. Open-air markets are essential for providing access to diverse, nutrient-rich foods, including indigenous options, which can improve dietary outcomes. However, there is limited data on the availability and temporal patterns of these markets, making it difficult to fully understand their role in the food system and address gaps effectively (Baraka et al., 2022).

To explore the potential of our method at a national scale, we applied the developed Sentinel-1 SAR-based approach across the entirety of Rwanda. To streamline the analysis and focus on areas where markets are most likely to operate, we limited the scope to regions identified as bare soil or built-up land cover using the Google Dynamic World V1 dataset (Brown et al., 2022). By targeting these land cover types, the method was able to narrow down potential market sites and minimize processing time while retaining the ability to detect significant weekly changes in backscatter properties associated with market activity.

Results

Case study: Regions with known open-air market locations

The implementation of the method in regions with well-documented open-air market locations produced promising results. Both San Francisco el Alto, Guatemala, and Montpellier, France, exhibited distinct and consistent signals corresponding to their known market days, as illustrated in Figure 1 and Figure 2.

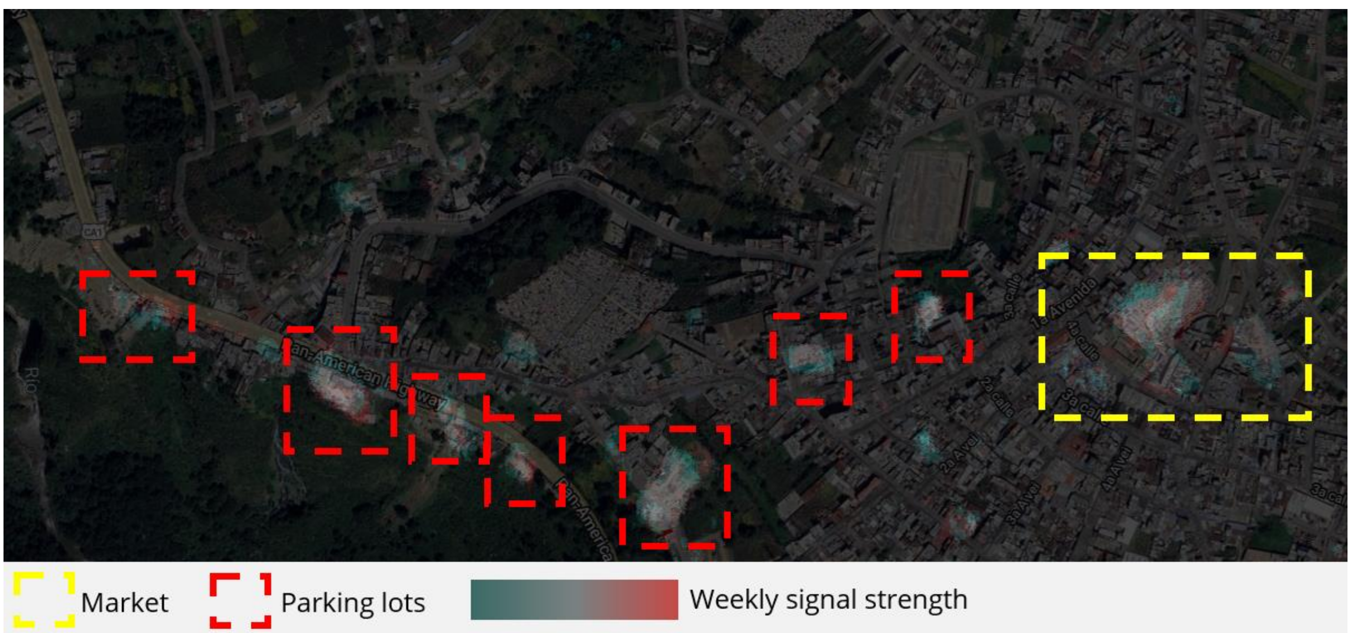

Figure 1 Implementation in San Francisco el Alto showing signal strength at city level, highlighting the market and related parking lots

In San Francisco el Alto, the analysis also detected strong signals in parking lots associated with the market, where trucks and cars gather on market days, further confirming the method's sensitivity to market-related activities. While some areas showed noise or signals that could not be conclusively linked to weekly market activity, these occurrences were relatively few. Overall, the results demonstrate the method's ability to effectively identify weekly open-air market dynamics in diverse contexts, with minimal interference from unrelated activities.

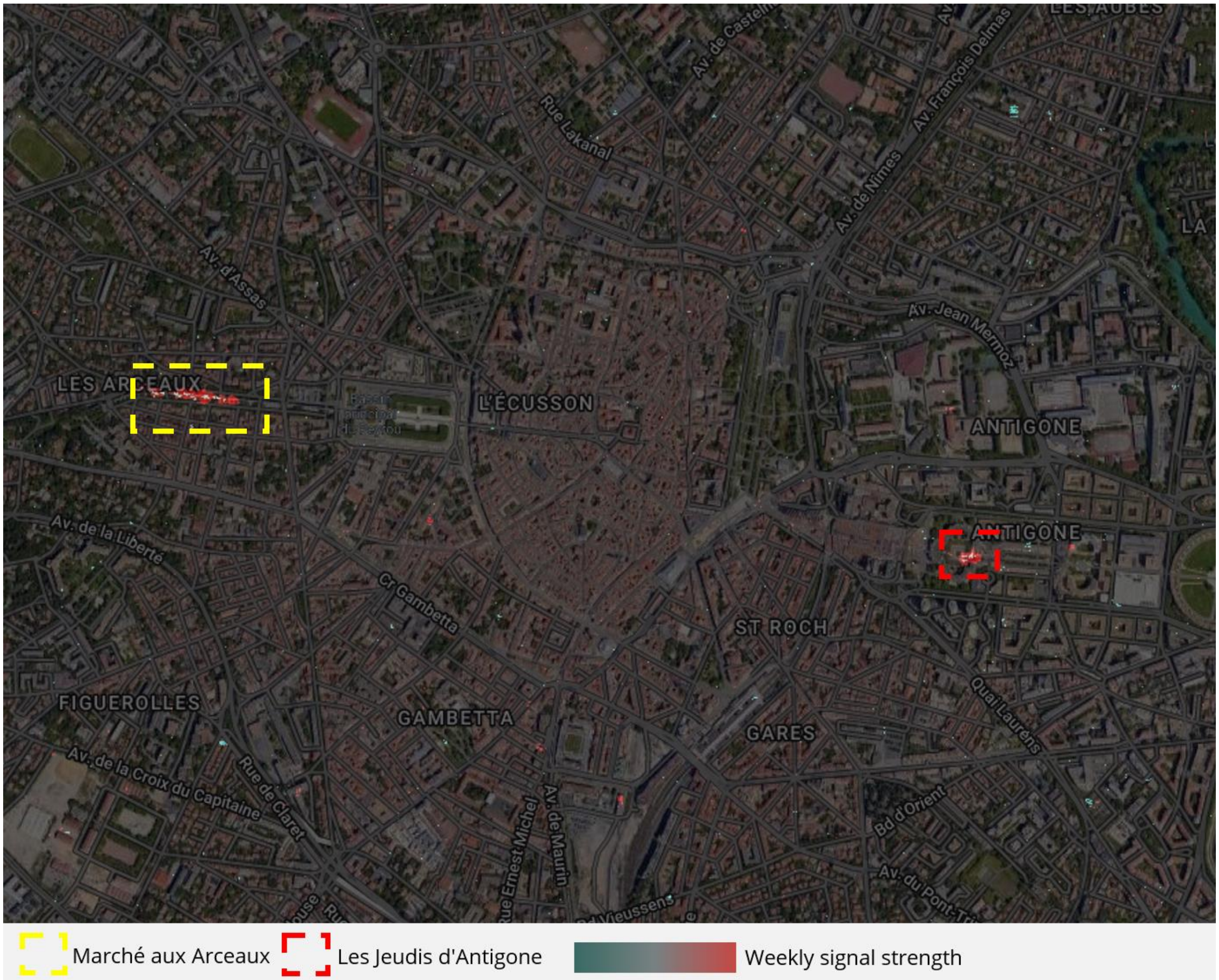

Figure 2 Implementation in Montpellier showing signal strength at city level and both markets highlighted

Case study: National scale implementation in Rwanda

The method was successfully applied at a national scale in Rwanda, leveraging the relatively light processing requirements and narrowing the scope to regions classified as bare soil or built-up land cover using the Google Dynamic World V1 dataset. This focused approach allowed for efficient processing within Google Earth Engine, completing the analysis in approximately one hour.

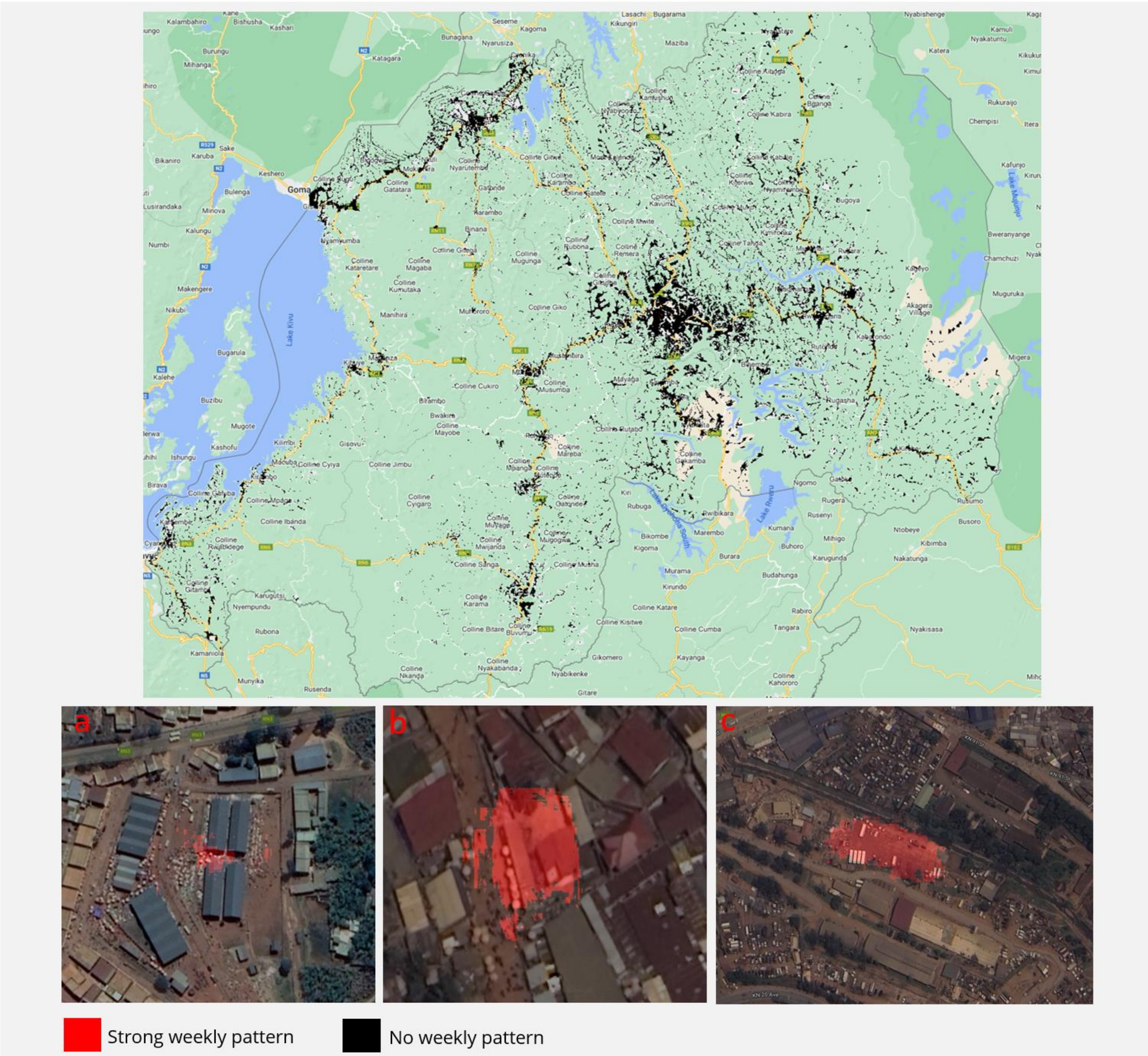

Figure 3 National scale implementation and zoom on a) Market in Ntunga (30.351455060670375, -1.9621266685633973), b) market in Kigali (30.053700636590303,-1.9594181919812008), c) parking lot in Kigali (30.046739554054916, -1.942177169497231)

The results, as shown in Figure 3, are promising. Several markets were identifiable through a visual review of the data, validated against high-resolution imagery. However, the analysis also detected areas with weekly patterns unrelated to markets, such as parking lots and construction sites. Despite these false positives, the method demonstrates significant potential for identifying open-air markets on a large scale.

Discussion and next steps

The results from both the regional case studies and the national-scale implementation in Rwanda demonstrate the potential of using remote sensing to identify open-air markets operating on a weekly basis. In regions with known markets, such as San Francisco el Alto and Montpellier, the method successfully detected clear signals corresponding to market activity, including ancillary activities such as parking for trucks and cars. Similarly, the application at the national scale in Rwanda produced promising results, with several markets identifiable based on a combination of the analysis and high-resolution imagery. These findings highlight the capability of the approach to capture weekly patterns and its scalability for broader applications.

While the initial results are promising, the method has several important limitations. Firstly, the approach identifies any area exhibiting a weekly pattern, including non-market-related locations such as parking lots and construction sites. As such, further characterization of these areas is required to reliably distinguish markets from other weekly activities. Secondly, while the approach showed success in identifying markets in test regions, it requires thorough validation to ensure accuracy and reliability across diverse geographic contexts. Validation efforts should include comparisons with ground-truth data and local knowledge to refine the method and minimize false positives.

The preliminary results of this study demonstrate the potential of using remote sensing, specifically Sentinel-1 SAR data, to detect weekly open-air markets. While the findings are still very preliminary the exploratory nature of this study provides a promising foundation for further refinement. Given this is the first attempt to implement such a technique, there is considerable room to improve detection accuracy through methodological advancements.

The current approach relies on areas exhibiting consistent weekly patterns, always occurring on the same day of the week. However, it is feasible to adapt the method for monitoring other temporal patterns of varying frequencies. Moving forward, several key avenues for improvement and exploration include testing whether high-frequency weekly patterns can be better quantified, integrating daily imagery such as Planet Level 2 data to monitor market dynamics more precisely, and incorporating very high-resolution imagery to characterize markets in greater detail. Additionally, leveraging complementary datasets such as cellphone metadata, social media activity, or WiFi signals (Reymondin et al., 2024) could enhance detection accuracy and enrich the analysis of market activity.

Ultimately, the insights derived from this method could significantly improve the ability to characterize the locations and temporal dynamics of open-air markets in both rural and urban settings. These findings have the potential to inform larger-scale food system models, contributing to a better understanding of when, where, and from where food is available in data-scarce regions of the world.

Access to the Script

The script used to implement this methodology and generate the data is publicly available. You can access the code and instructions for running the analysis on Google Earth Engine at the following link:

https://code.earthengine.google.com/345c04a7de982127050acd13eba3d58a.

This script allows users to replicate the analysis, customize parameters such as thresholds, and apply the method to different regions or datasets. Feedback and contributions to improve the script are welcome

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