Fusing Sentinel-2 and Sentinel-1 Data in Google Earth Engine for Road Infrastructure Mapping in Data-Scarce and Conflict Environment

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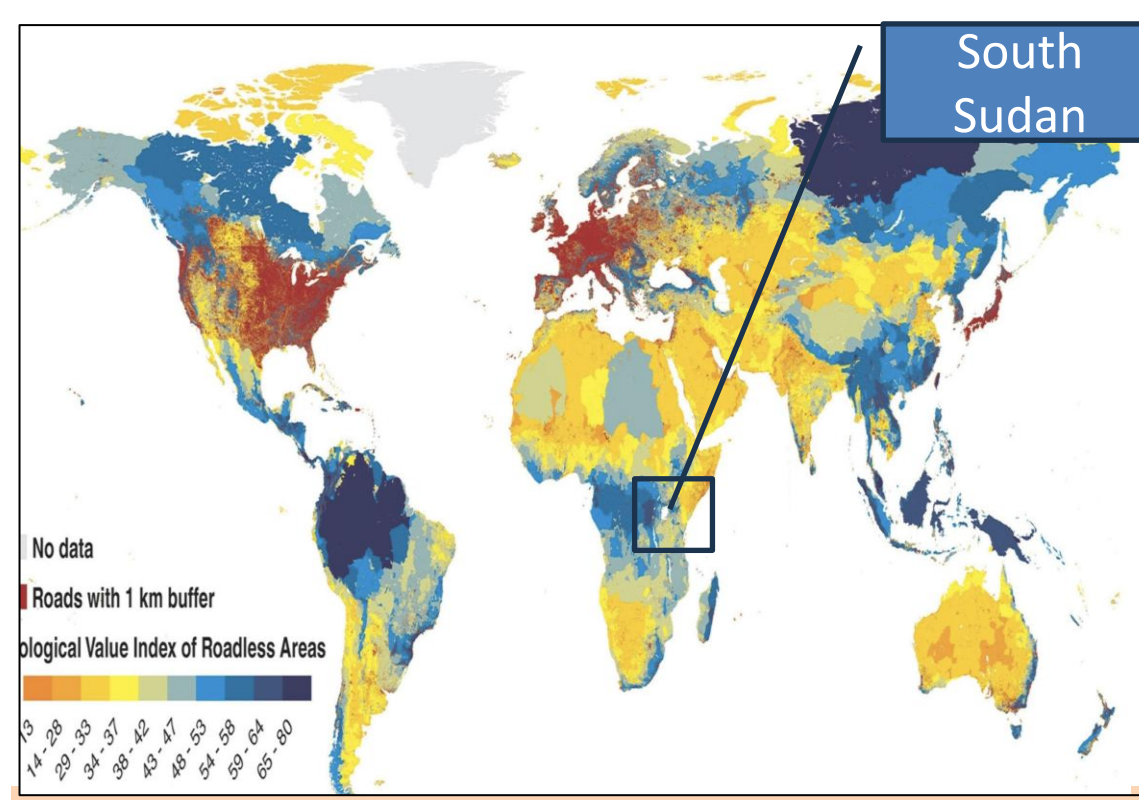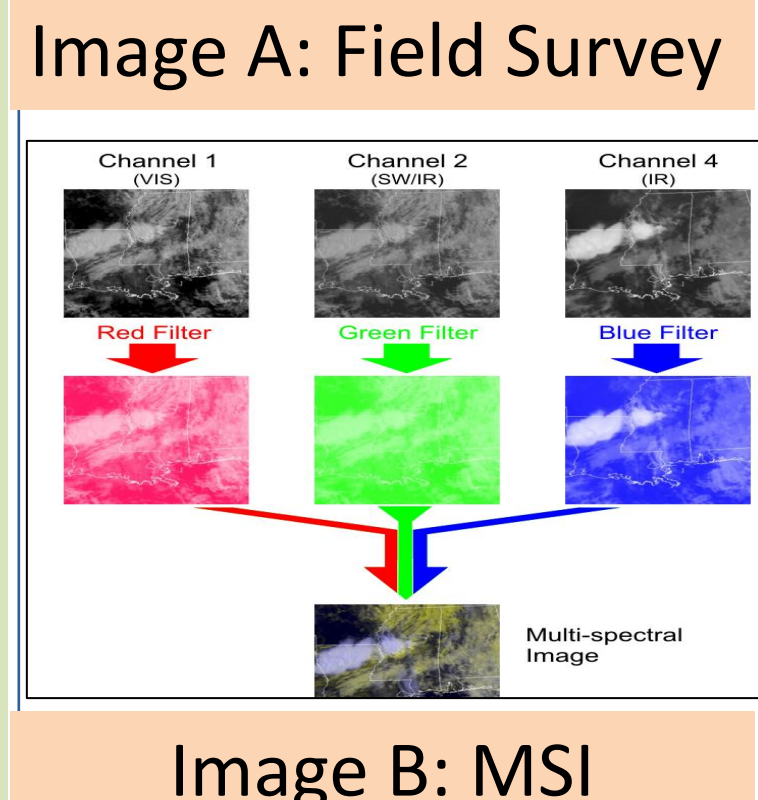
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Abstract

Accurate road infrastructure data is vital for planning, mobility analysis, and disaster response, yet in conflict-affected and data-scarce environments such as South Sudan, authoritative sources are scarce and often outdated. Traditional field surveys remain difficult due to insecurity and cost, while optical imagery is frequently obscured by persistent cloud cover. This study presents a cloud-resilient, low-cost workflow for road mapping in Juba County that fuses Sentinel-1 Synthetic Aperture Radar (SAR) and Sentinel-2 optical imagery within Google Earth Engine (GEE). Imagery from December 2024 to March 2025 (Sentinel-2) and the full 2024 year (Sentinel-1) was composited using pixel-wise median stacking with selected bands (B2, B3, B4, B8, B11, B12). Four fused tiles were exported to QGIS for marging, visualization, digitization, and comparison with OpenStreetMap (OSM), Geofabrik, and Google Satellite data. A Select–Zoomed-In road network visibility analysis (RNVA) demonstrated enhanced detection of paved and unpaved roads compared to single-source data. Results revealed numerous unmapped segments and outdated classifications in existing datasets. The integration of Informed Volunteered Geographic Information (IVGI), derived from the researcher's local knowledge of Juba roads, further improved classification accuracy. The outputs provide a GeoAI-ready dataset for future automated road surface detection, contributing to closing data gaps in fragile regions.

Keywords: Data-scarce environments, GeoAI, Informed Volunteered Geographic Information, Road mapping, Sentinel fusion

Introduction

- **Road Inventory Challenges in Conflict-affected Regions**
- ✓ Geospatial road data are **scarce**, **outdated**, **fragmented** and often **absent** or **under-represented** in many authoritative global data sets (DIVA GIS, GRIP, etc.)
- Conventional methods are **difficult to practice** despite their known limitations

Image A: Field Survey

Image B: MSI

Map 1: World's Roadless Areas

Image C: VHR Image

Methods and Materials

Figure 1 . Methodology Workflow Diagram

Study Area

Map 2. Location Map of Juba County South Sudan

GEE and QGIS Data Processing

GEE Sentinel-2 / Sentinel-1 Fusion and QGIS Integration

- Sentinel-1 SAR (2024) + Sentinel-2 optical (Dec 2024–Mar 2025).
- Pixel-wise median compositing + band stacking (B2, B3, B4, B8, B11, B12 + SAR) in GEE.
- Exported fused tiles processed in QGIS for digitization and validation
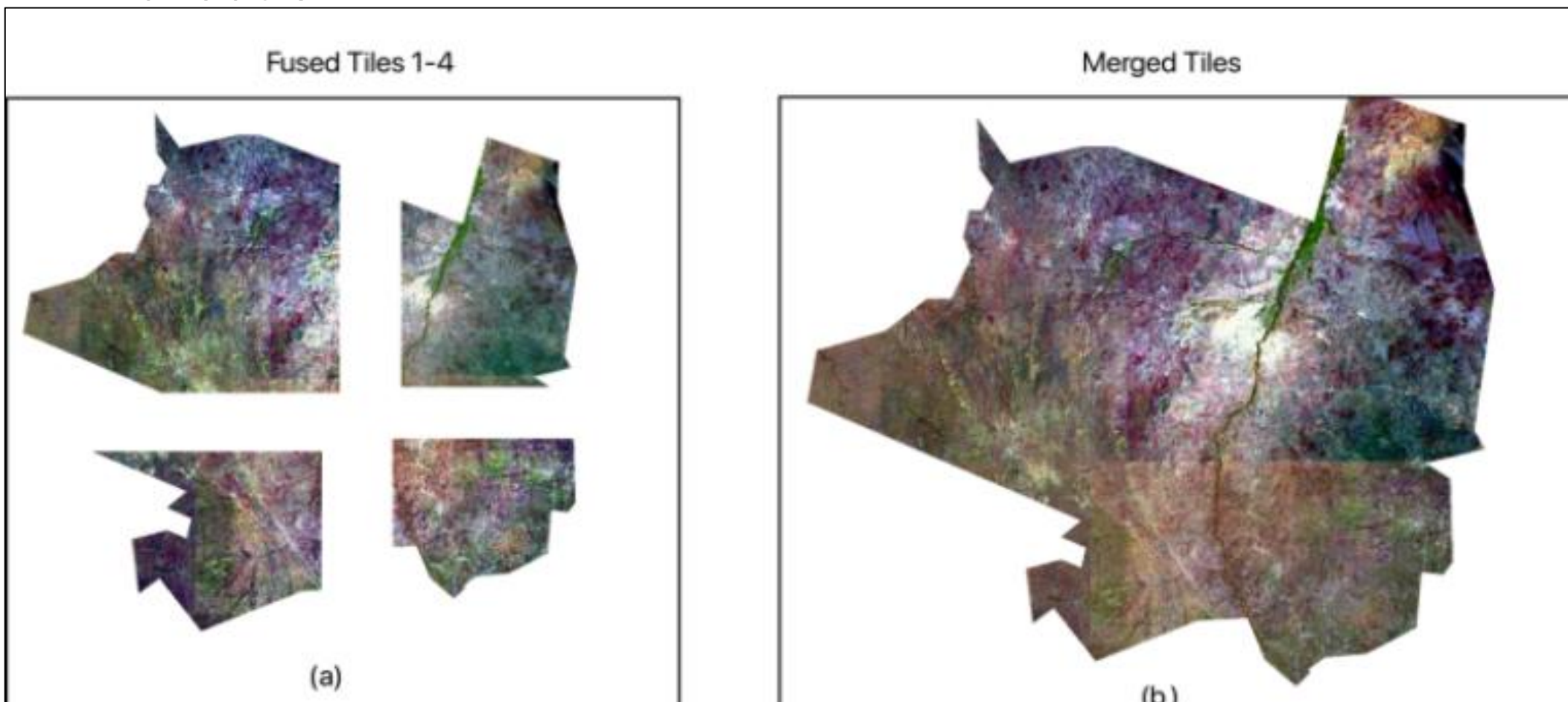
Figure 2: GEE Fused Image Tiles and QGIS Merged Image

QGIS Image Analysis

- Digitization and Informed VGI local knowledge input for identification of Unmapped or missing roads in datasets, but revealed by fused Sentinel images and road classification
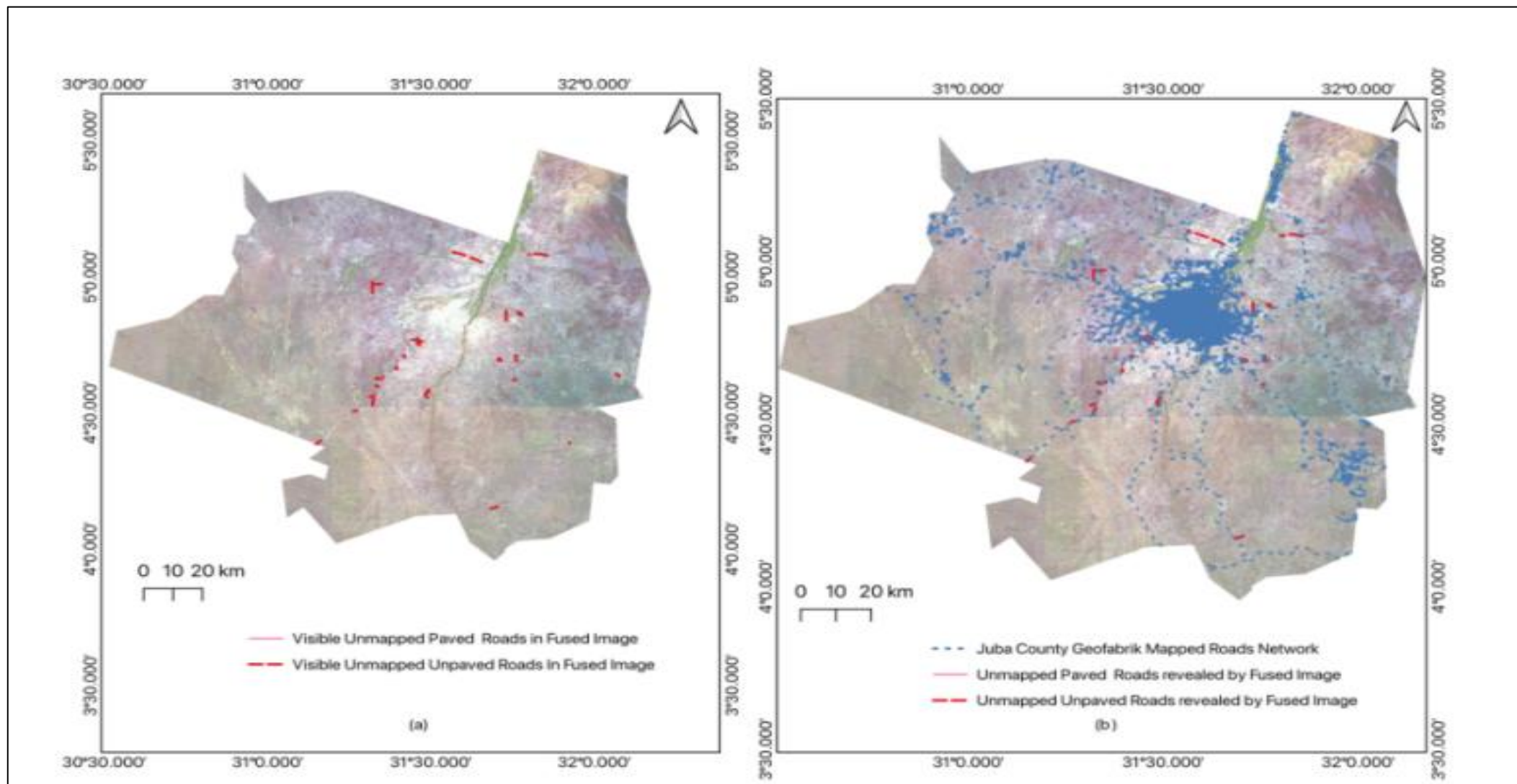
Figure 3: Digitized Unmapped Road Overlay on OSM/Geofabrik

Results

- Road Network Visibility Analysis (RNVA) Cases with Select–Zoomed-In Approach at 1:5000.
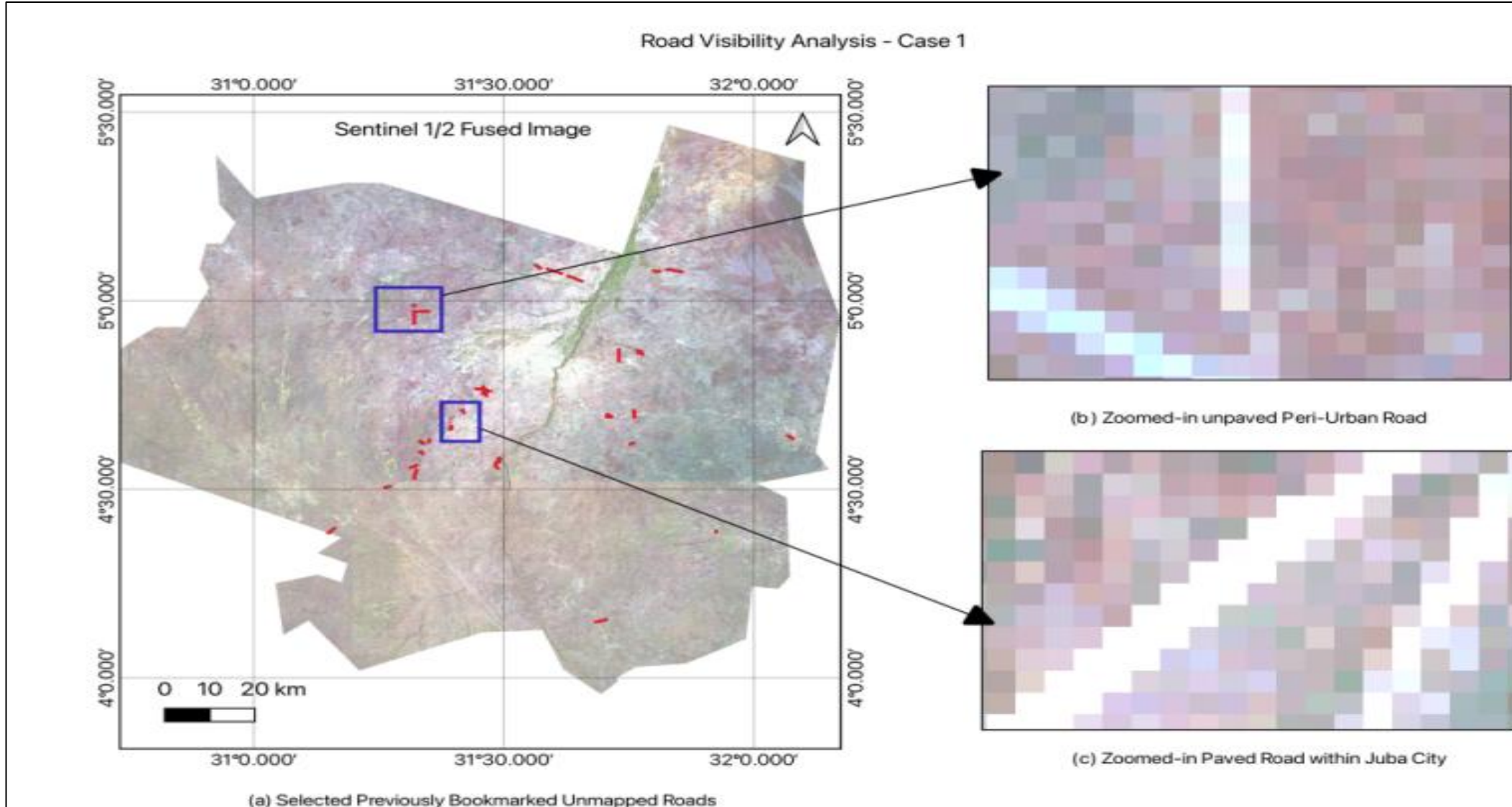
Figure 4: RNVA Case 1- Enhanced Visibility of Paved & Unpaved Roads in Urban and Peri-Urban Areas in Juba County (City)
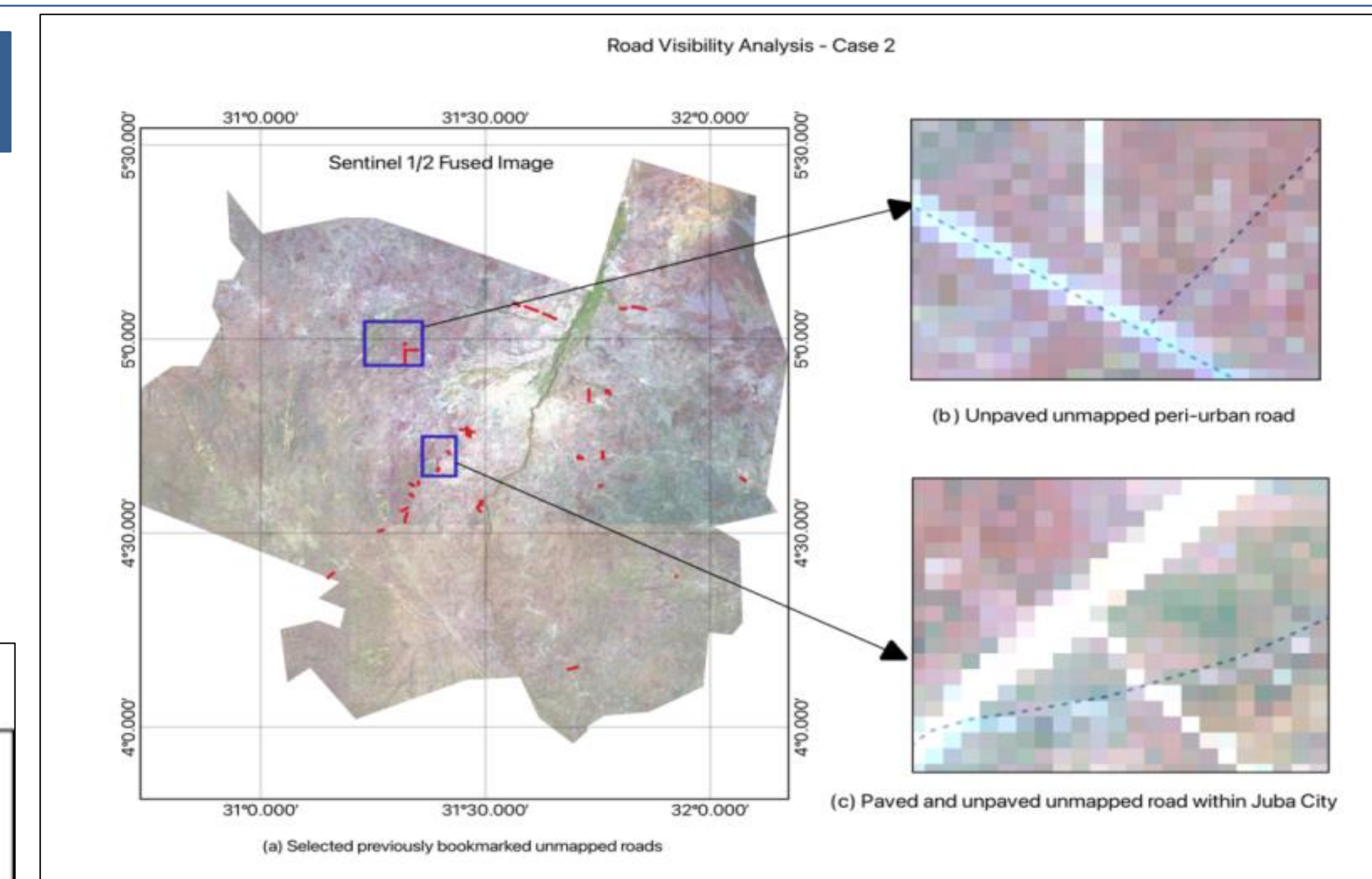
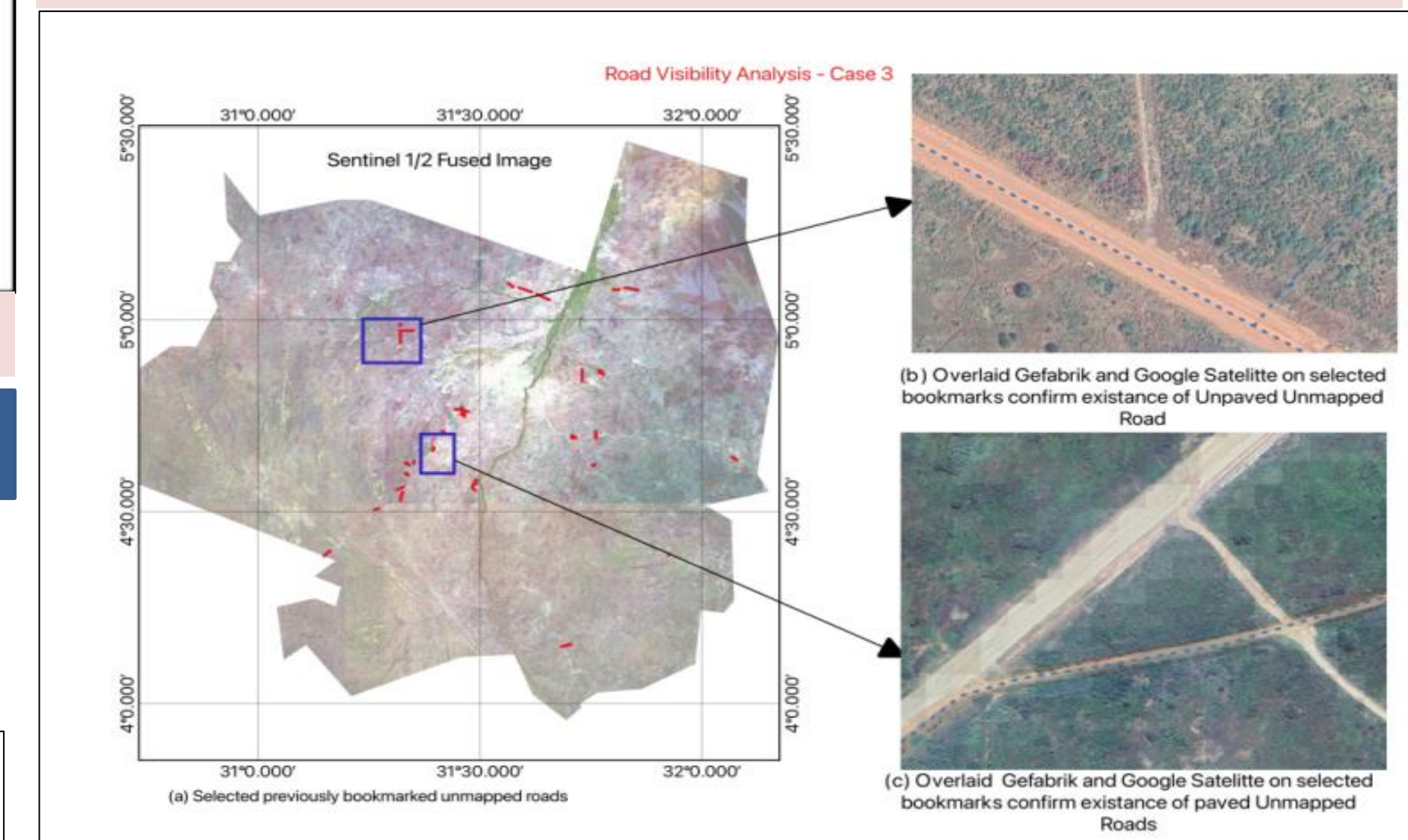Figure 5. RNVA Case 2 Unmapped Roads Revealed by OSM / Geofabrik Overlay

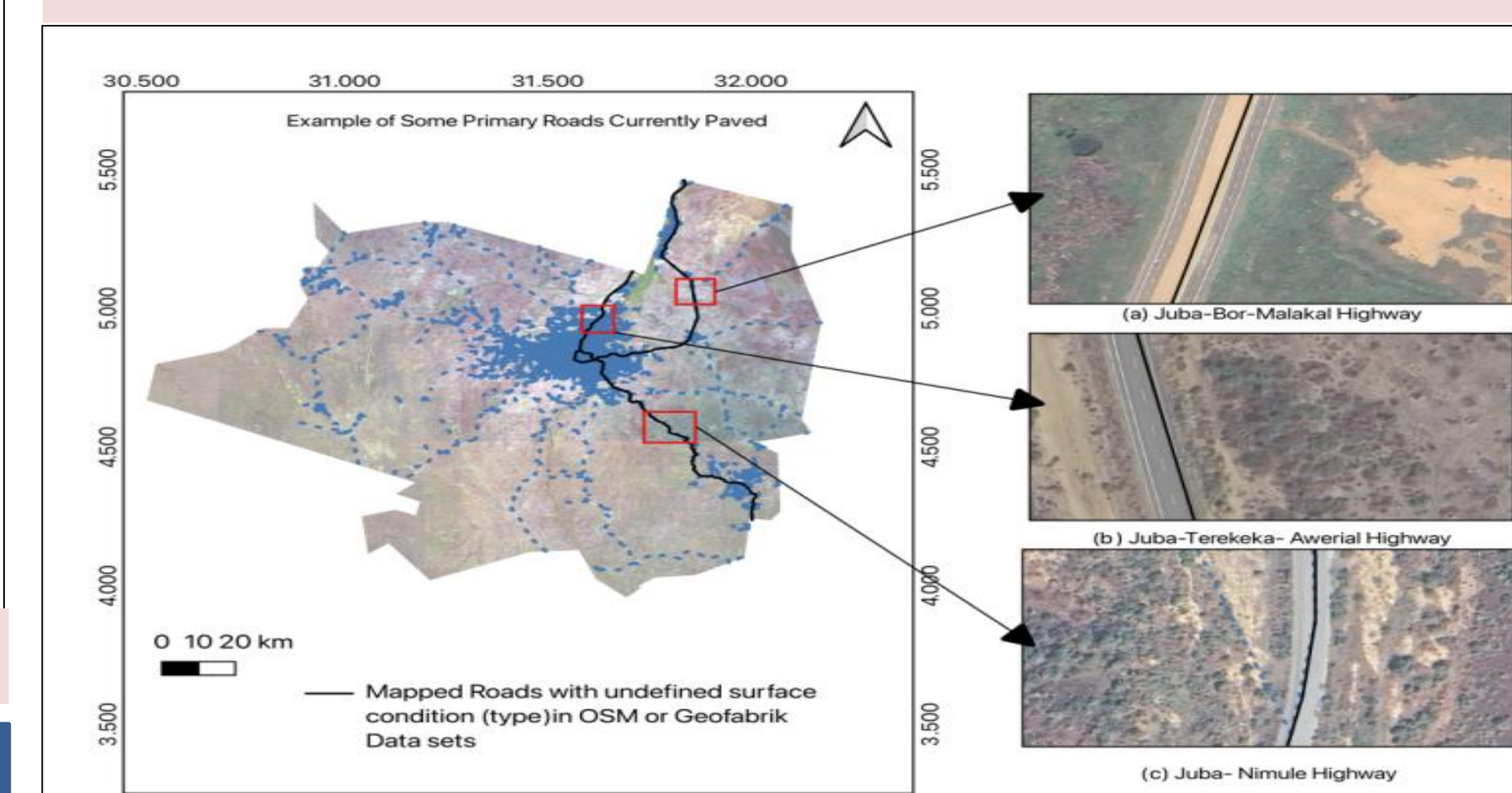Figure 6a: RNVA Case 3- Google Satellite Validation of Missing or Unmapped Roads

Figure 6 b: RNVA Case 3- Correction of Outdated Road Classification

Discussion

- Sentinel Fusion demonstrated **a practical, cloud-resilient first-ever approach** for road infrastructure mapping in Juba County, South Sudan
- IVGI integration **contributes contextual accuracy** often lacking in automated mapping

Conclusion

- The workflow **enhances road visibility**, **identifies unmapped segments**, and **corrects outdated classifications** in existing datasets
- Adaptable to **other fragile or under-mapped regions** where **conventional surveys** and **authoritative datasets** are unavailable.
- The outputs provide **a GeoAI-ready baseline for future work on automated road classification** and **surface type detection**.

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