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Using Satellite Imagery To Map The Impact Of Conflict On Rural Markets In Sudan

POLICY BRIEF

KEY FINDINGS

1. **Overall trends:** While there is variation across states and specific locations, rural markets in Sudan have not experienced a substantial decline since the conflict began. This holds true regardless of territorial control.
2. **Displacement and rural markets:** Rural market activity appears to be influenced by displacement patterns. Where displacement is primarily rural and internally displaced persons (IDPs) are hosted within the community, market activity grows in a sustained manner. This is believed to reflect market actors adapting to the increased demand and higher levels of agricultural production among IDPs.
3. **Conflict impacts:** While satellite remote sensing measures of rural market activity across Sudan have not been significantly curtailed by the conflict, specific conflict events – attacks on markets and civilians, battles – do reduce the activity of nearby markets. Where conflict is focused on urban centers, rural markets show increased activity, likely a result of traders shifting to alternative venues. With disrupted urban markets, trade also becomes more localized, and the mix of crops and goods traded shifts as demand from urban centers and across state lines declines. When conflict occurs in rural areas, nearby markets are affected but typically recover in 9 to 12 months, even after the most disruptive events like battles. However, successive conflict events can delay this recovery significantly
4. **Markets' influence on farming:** Where market activity is steady or growing, agricultural production in nearby areas increases in subsequent periods. This is likely driven by farmers' access to inputs during the planting season and confidence in finding demand for their products. However, market volatility and shrinking can have strong negative impacts on local agricultural production.
5. **Triangulation with other data is needed:** Our analysis shows trends in market size and agricultural production, but cannot untangle *who* engages with the markets and sells the crops, nor see the terms of trade. Data from other studies and Mercy Corps programming have shown alarming rises in the cost of food and agricultural inputs, so the overall functionality of markets does not contradict the acute need among the population.

SPARC
Supporting Pastoralism and Agriculture in Recurren and Protracted Crises

MERCY CORPS

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Introduction

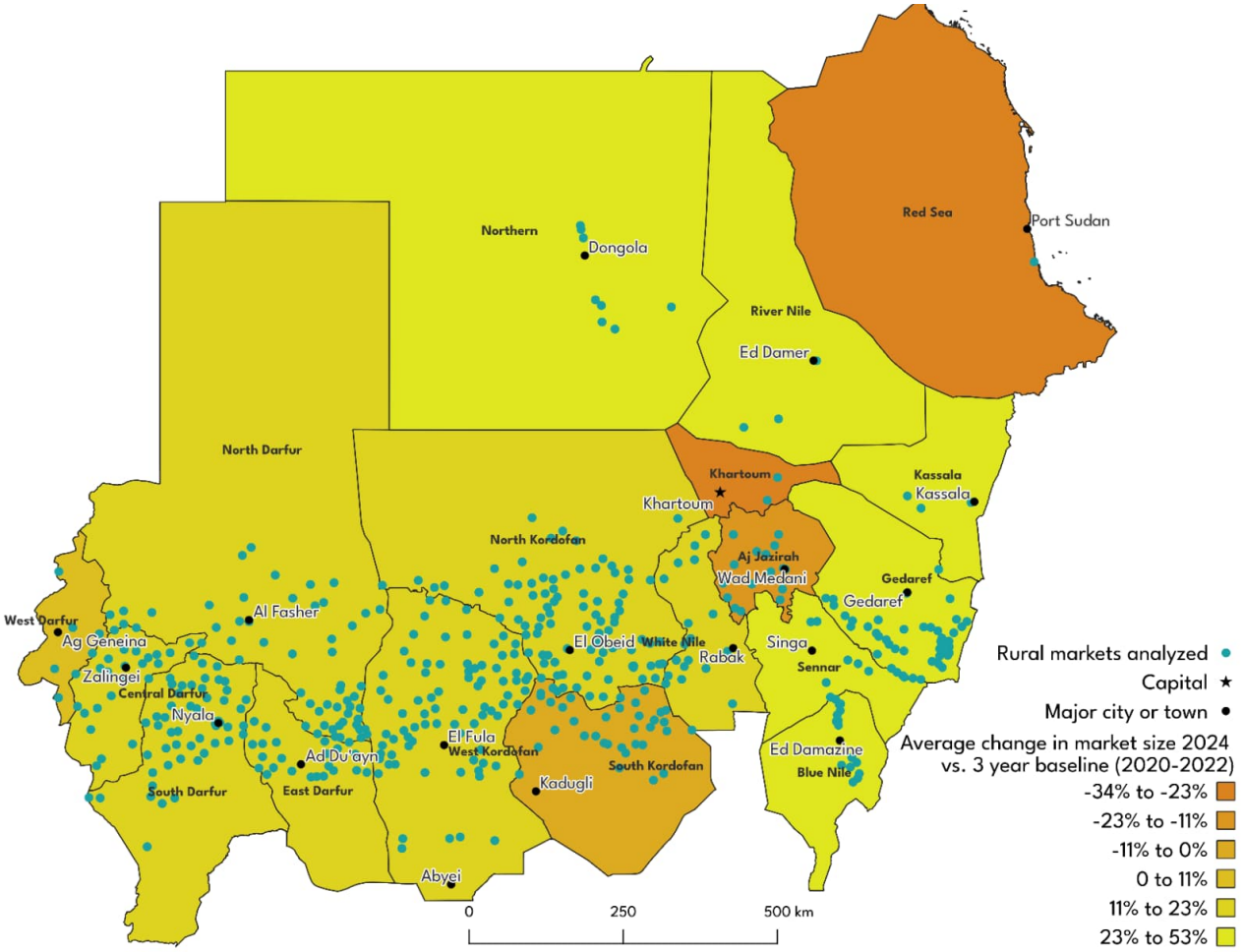
Civil war broke out between Sudanese Armed Forces and the Rapid Support Forces in April 2023. Since the start of the conflict, more than 10 million people have been displaced, while markets and trade routes have been targeted. Food basket prices in May 2025 had risen 124% compared to the previous year, and the most recent Integrated Food Security Phase Classification projected more than half the population to be at or above the IPC-3 Crisis level through the same month. 1% of the population was projected to face famine (IPC-5).

The intensity of the conflict has limited humanitarian access. As a result, actors have struggled not only to support the population but even to understand levels of hunger and economic activity, and strategies used by communities and markets to meet their needs. Understanding the context and the impact of the conflict is critical for channeling scarce resources to the most vulnerable areas and populations. It is also critical that aid is designed to support local responses and systems, and not undermine fragile markets where they remain functional.

Humanitarian actors have used a number of approaches to gather this information. In Sudan, the Joint Market Monitoring Initiative routinely measures the availability and cost of food and essential items, while more in-depth research funded by FCDO's Supporting Pastoralism and Agriculture in Recurrent and Protracted Crises (SPARC) has drawn on embedded researchers to understand the mindset and behavior of market actors as they cope with the conflict's changes locally and through long-distance trade. However, the humanitarian community still faces challenges in reaching the most remote and conflict-affected areas and consistently gathering information.

Satellite imagery may serve as a complementary tool to provide information at scale and regardless of conflict and on-the-ground security, complementing more detailed qualitative data. This can include measuring the health of vegetation in fields to predict harvests, and tracking changes in the level of nighttime light reflectance to assess damage, displacement, and economic vulnerability.

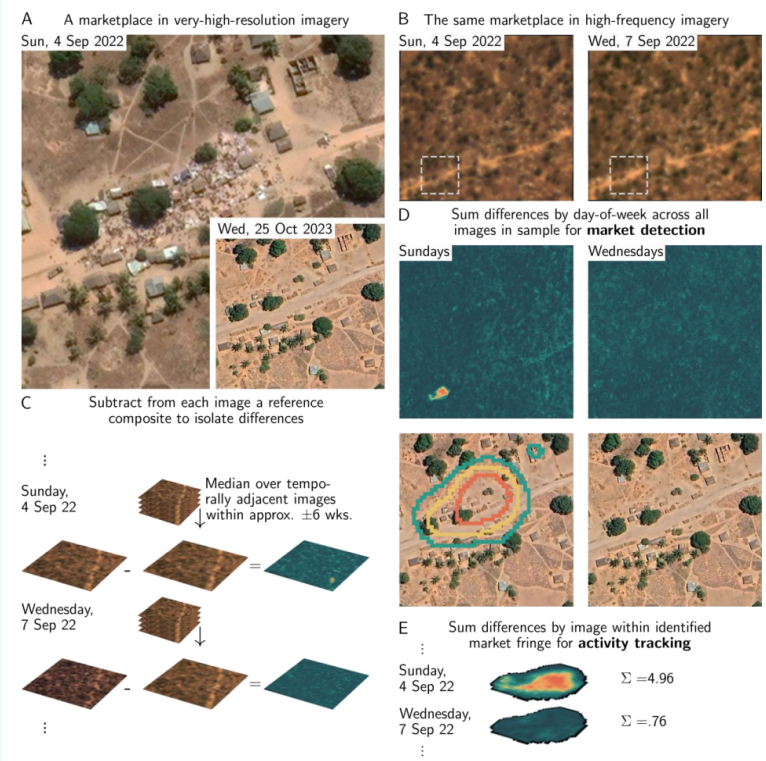
In this study Mercy Corps, with funding from SPARC, explored the use of satellite remote sensing data to understand the impacts of the conflict in Sudan on market activity and agricultural production throughout the country. This analysis was intended to identify the impacts of conflict events on rural markets and agricultural production, with an emphasis on rural and inaccessible areas that have not been previously captured in humanitarian assessments. Beyond that, it also served as an opportunity to test the feasibility and usefulness of an innovative market mapping technique, developed by Tillmann von Carnap at the University of Oslo, to understand economic activity in fragile and conflict-affected settings where in-person data collection is limited. The results of the mapping are shown below, including 484 rural marketplaces identified in Sudan and the average change in market size between 2020 – 2022 (before the conflict) and 2024. Results and analysis are discussed further in this brief.



Methods

Data used

Our analysis draws on four datasets: conflict data from ACLED, displacement data from IOM, and Normalized Difference Vegetation Index (NDVI) provided by NASA, and mapping of rural markets developed by Tillmann von Carnap at the University of Oslo. The rural market mapping is a novel dataset, which uses machine learning to identify periodic markets within satellite imagery, identify market days when stalls, vehicles, and people are present, and track the change in size of the active area on market days between weeks. The full methodology is provided in von Carnap's paper, summarized visually here.



Analysis

We used several analytical methods to explore how markets and crop production have changed since the start of the conflict:

Identifying trends since the conflict began: Descriptive analysis was used to assess how rural market size and NDVI have changed from the years before the conflict (2020 – 2022) to 2024. We aggregated results at the state level due to high variability for individual markets. Since markets had also experienced intermittent shocks before large-scale conflict broke out, such as COVID-19 impacts and instances of targeted violence, we used the average of 2020 – 2022 as a baseline.

Modelling impacts of violence and the relationship between market activity and NDVI: To identify how conflict influenced market activity and NDVI, we used principal components analysis (PCA) to identify factors that had consistent impacts, including the proximity of violent events, type of event, temporal lag (i.e., how long ago the event occurred), fatalities, and recurrence.

To explore the relationship between market activity and NDVI, we used mixed-effects modeling with each of the 484 markets analyzed separately across buffer distances from 10-90km to NDVI in surrounding fields. This captured market-specific effects and provided substantial statistical power (n=620,972), but had limitations:

- Spatial autocorrelation and buffer overlap: We did not explicitly model spatial correlation between markets. With buffers extending to 90km and market locations distributed across Sudan, substantial buffer overlap exists. The same NDVI pixels may be influenced by multiple markets simultaneously, potentially leading to correlated errors and inflated significance levels, and overestimating the independence of market effects.
- Temporal autocorrelation: Monthly NDVI observations exhibit strong temporal correlation that is not explicitly modeled in our approach.

Despite these limitations, the large sample size and consistent patterns across spatial scales suggest that our core findings about scale-dependent market mechanisms are robust to these methodological concerns.

Lessons Learned

In addition to the analysis itself, we sought to test the usefulness of remote sensing to understand economic activity in the context of insecurity and extreme inaccessibility in Sudan. Satellite imagery offers a unique opportunity to see the status of markets and farms in areas most affected by conflict, identify areas of intensive need, and identify recovering areas where market-based support can achieve greater impact.

In practice, remote sensing has strong potential to complement other forms of monitoring, but is limited by the high analytical demands and challenges of interpretation. NDVI and von Carnap's market mapping can both draw on extensive historical data to identify changes in trends before and after the conflict, an advantage compared to humanitarian data, which usually only begins to be collected after a crisis begins. However, there are limitations and drawbacks:

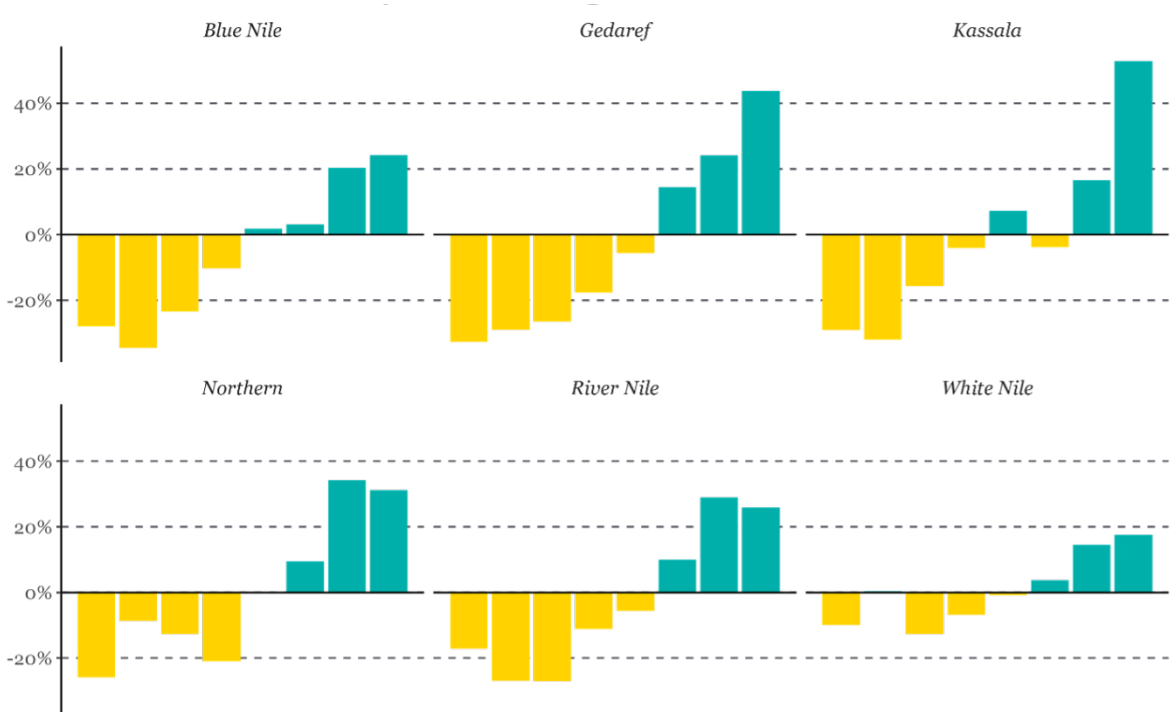
- Market data are not ground-truthed, and may not represent the entirety of rural markets in Sudan. This may stem from areas where markets are deliberately hidden from aerial view to avoid strikes, and areas where the appearance of markets could not be regularly identified by the algorithm. Interpretation of a single area, particularly below the state level, should be taken with caution.
- Market mapping captures only uncovered, intermittent markets, and thus does not reflect activity in urban hubs. Further investigation is warranted to disentangle the relationship between the two, given initial suggestions that economic activity shifted from urban to rural areas where conflict was most intense.
- Neither NDVI nor market mapping levels are directly interpretable for economic or agricultural insights – while meaningful, they do not directly measure the volume of trade or quantity of crop production. This makes them useful for identifying changing trends after conflict or policy events, and to compare between regions, while a one-time snapshot is not useful. However, both types of data are sensitive to conflict and particularly battles, reinforcing that they appear to be good proxies for economic and farming activity.
- The rural markets captured in the dataset experience their own marked seasonality, which is offset slightly from the seasonality of crop production. In states that are primarily crop producers, these

markets peak in the planting season, while in states that import crops, the markets peak after harvest. This likely reflects the use of markets as a means to access inputs in production areas and as a distribution system for food and crops in importing states.

- We tested several approaches to interpreting market data:
    - Market closures: The most straightforward lens was market closures, either for extended periods (over 3 months) or permanently, but less than 2% – 9 of 484 markets – fit this category. This is a useful finding on its own, but it makes further analysis challenging due to the infrequency.
    - Counter-seasonal status: The most complex analysis involved categorizing the size of each market's peak and lean season, and identifying which markets bucked their seasonality – booming during the lean period or shrinking when expected to be active. The results challenged easy interpretation, with a mixture of growing, shrinking, and normal markets in each state. This approach may be useful for more specific, contextually informed regional analyses.
    - Change in market size: The study ultimately settled on changes in market size compared to a three-year average from 2020 to 2022, prior to the conflict.

Displacement, Safe States, and Rural Markets

Annual rural market day activity in Sudan relative to the three-year average



Rural markets in Sudan have shown incredible resilience to the impacts of the conflict, with market activity growing significantly across most states and localities. This trend is most pronounced in 'safe' states that have seen large influxes of IDPs. Most notably, Kassala, Gedaref, Northern and River Nile states have

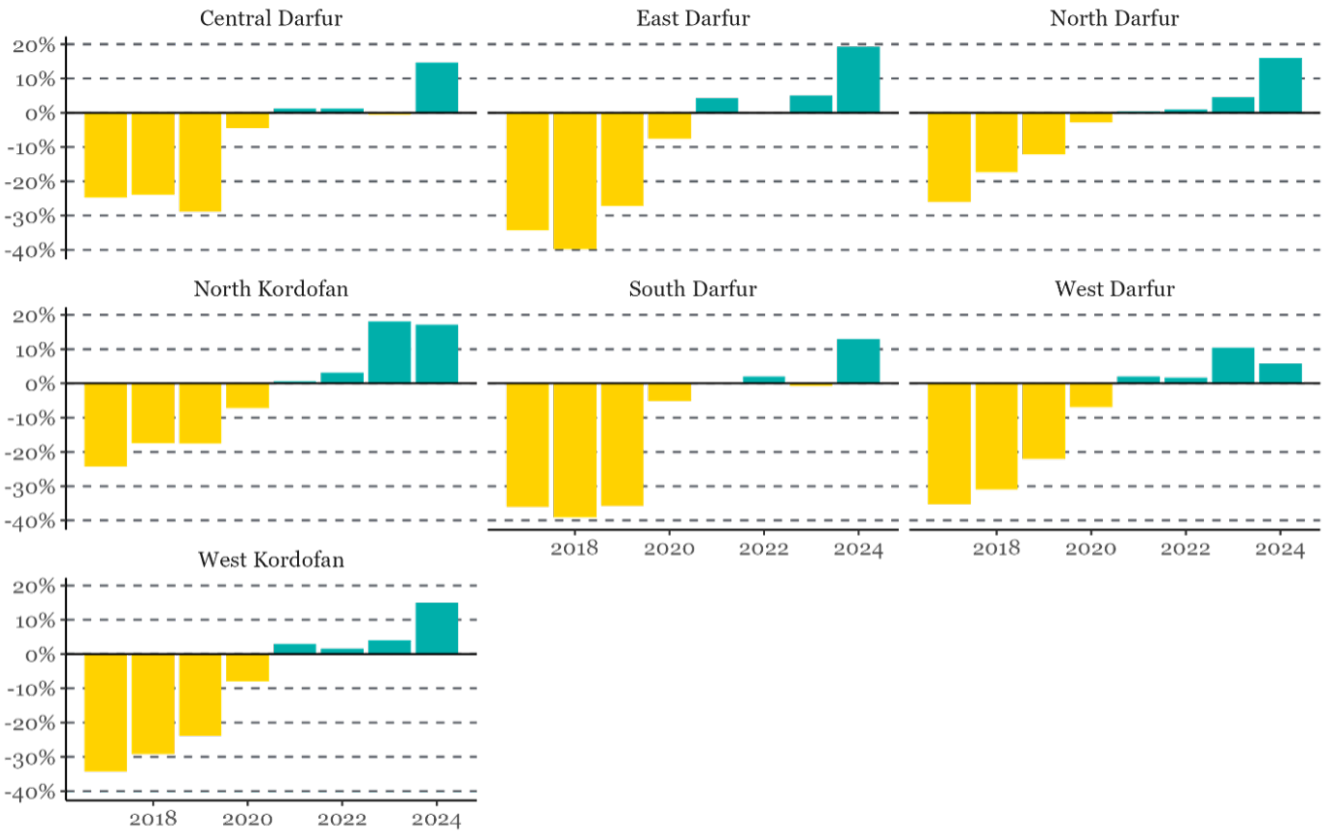
seen little to no conflict and large influxes of IDPs, as compared to Blue Nile and White Nile, where active conflict has occurred within geographically limited locations.

Many IDPs in these states are living within host communities, leading to population growth in rural areas and likely linked to increased market activity there. For example, 89% of IDPs in Gedaref are staying within the host community as opposed to rented accommodation or public buildings, 40% of whom are staying in rural areas.

Similarly, Northern and River Nile have also seen large influxes of IDPs to rural areas (395 thousand and 437 thousand IDPs respectively) and have seen sustained large increases in rural market activity.

Urban Conflict and Rural Markets

Annual rural market day activity in Sudan relative to the three-year average



Similar patterns occur across the Darfur region: in Central, East, and South Darfur, where conflict between the SAF and the RSF alongside intercommunal conflict has played out around multiple towns, there was a slight negative impact on rural market activity in 2023. In 2024, we saw rural markets rebound in those states after the end of active conflict, recovering and, in many cases, showing increased market activity.

This trend is likely driven by a number of factors: The closure of trade routes has limited the opportunity for export, as trade is forced to become largely localized over short distances. The cultivation of cash crops has been severely impacted by the conflict , with farmers replacing cash crops with food crops in response to the scarcity of food and the high prices in the market. This reduces the incentive for farmers,

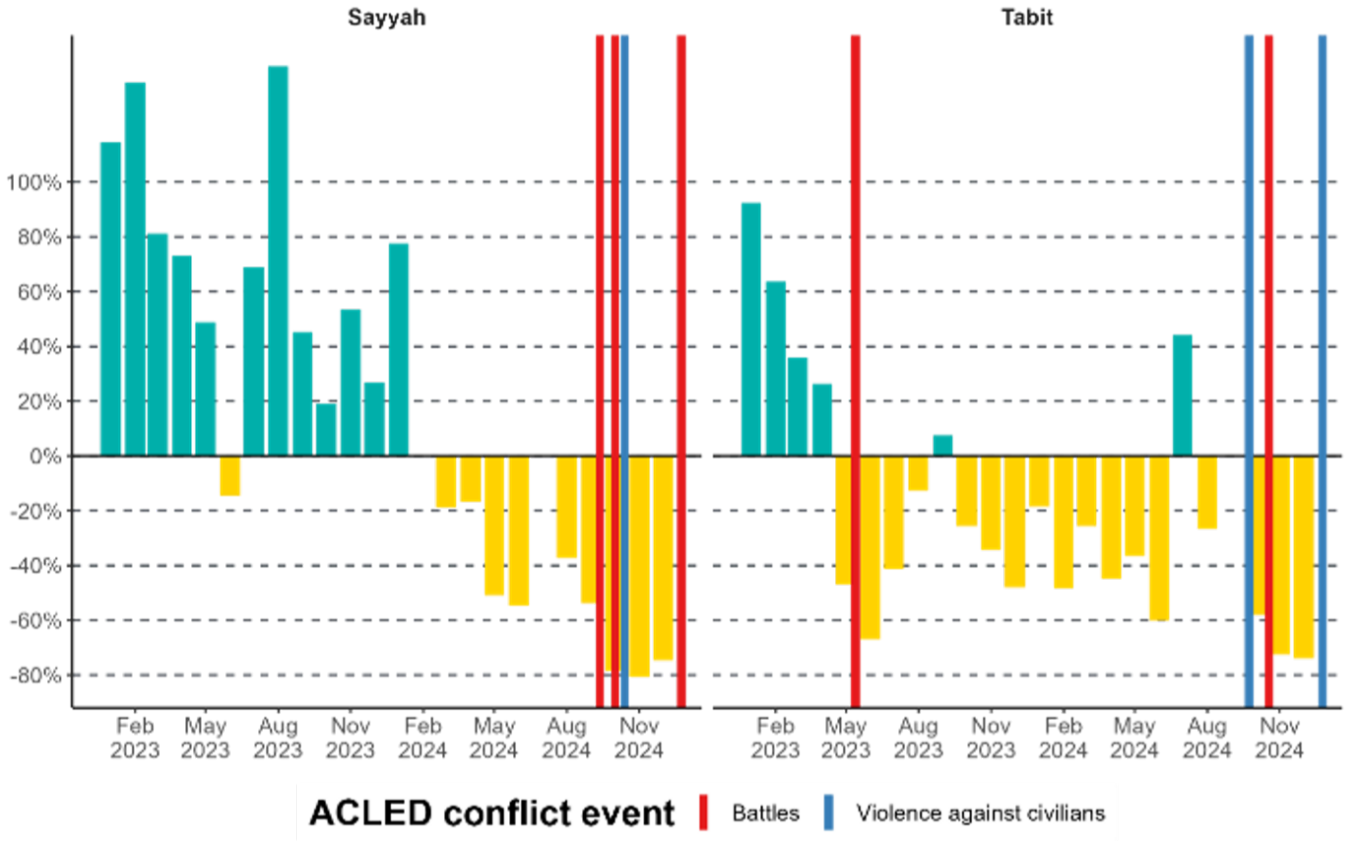
transporters, and traders to go to primary markets due to the reduced profit margins. The highly urbanized nature of the conflict, the targeting of markets and insecurity along roadways have pushed trade from primary markets in urban and peri-urban locations and towards smaller rural markets due to security concerns.

Where violence is heavily centered around the state capital or other urban centers, we see rural market activity grow significantly. This was true in North Darfur that avoided the worst of the conflict in 2023 and its related disruptions. Violence in the state started in earnest in 2024 and focused on the state capital of El Fasher. During that year the highly urban El Fasher locality held the majority of IDPs, but we still saw large increases in rural market activity across the state.

While it is too early to draw conclusions, we also saw a decrease in rural market activity in West Darfur in 2024. The first of the Darfuri states to see large-scale battles followed by near total control by the RSF, violence in urban centers such as Ag Geneina ended at an earlier stage than in other states. As a result, the decrease may be a sign of recovery of markets in urban centers or a reflection of other dynamics and warrants further investigation.

Local Dynamics and Recovery

Monthly rural market day activity in select markets in North Darfur relative to the three-year average



The impact of conflict manifests more clearly when conflict events occur in or around specific markets. Activity in those markets shows drastic decreases of over 60% after conflict events, highlighting how

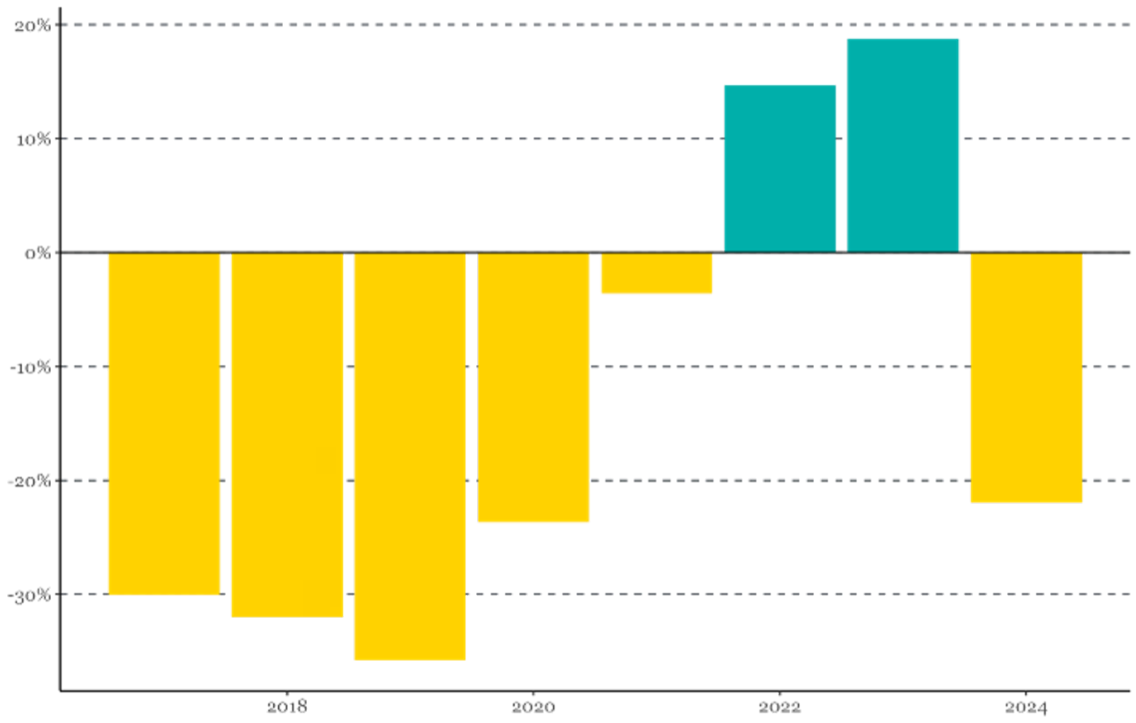
patterns at the state or locality level can obscure the impacts of the conflict at the local level. Successive conflict events can delay recovery, with battles having the most significant impact on market activity.

At smaller distances (10km-40km), the impact of conflict on local markets is most pronounced, with battles having the most negative impacts. Over larger distances (80km-90km), the impact of conflict on market activity becomes more complicated, and we may in fact see increased market activity representing shifting trade and market dynamics as conflict may drive market actors towards safer markets.

While recent conflict suppresses market activity, nearly all markets tend to recover or even rebound 9-12 months after major conflict events. Different conflict types show different transition points, with battles representing the longest recovery periods, followed by violence against civilians, where markets transition to recovery after five to six months, and finally, markets transition to recovery three to four months after incidents of remote violence.

The Impact of Contextual Developments on Markets

Annual rural market day activity in Al Jazirah relative to the three-year average



Aj Jazirah provides a clear case of how large contextual developments can drive market activity. Originally a state of refuge, as of November 2023, Aj Jazirah was hosting over 445,000 IDPs, of whom 64% were staying with host communities. During that time, we saw a modest increase in rural market activity at a time when the majority of IDPs were in urban areas, particularly in and around Wad Madani.

Photo credit: New York Times/ Maxar Technologies

In December of 2023, the RSF took control of the state, with widespread violence in rural and agricultural areas throughout 2024. The widespread and sustained violence led to massive displacement out of the state and has had a severe impact on rural market activity in 2024. With the SAF takeover of Jazirah and Khartoum in 2025, we are seeing accelerating returns to the state that may drive recovery in rural markets.

Agriculture and Market Activity

At local scales (10 to 30 km), the ability of markets to operate on a sustained and non-volatile pattern seems to directly impact agriculture, with analysis of NDVI data showing an eight-fold increase in the vegetation index in hotspots with sustained market activity and limited volatility. Likely driven by farmers' confidence in their ability to access purchasers, including for cash crops as well as the inputs needed for the planting season.

At the 40-50km range, sustained market activity still shows a strong positive relationship with NDVI, but more importantly, market volatility no longer has a strong negative impact, implying that regional market infrastructure creates vegetation benefits that persist even when direct market mechanisms fail. The natural integration of regional market systems gives farmers the ability to access multiple markets, making agricultural production more resilient and making it a potentially optimal scale in which market responses can operate.

The nature of market-vegetation relationships provides a framework for designing agricultural development strategies that work with the natural spatial structure of market-agricultural systems.

Recommendations for Market-Based Interventions in Sudan

1 **While impacted by conflict, rural market activity continues even in the most conflict-affected states, and some traders displaced from urban areas may be turning to those rural markets to operate.**

Humanitarian actors should avoid undermining local markets and proactively support their adaptive capacities by assessing existing trade and production before launching interventions. This will ensure

aid does not displace local traders or disincentivize producers from selling on the market. Cash-based assistance may help populations meet their needs while enabling market actors to continue operating, where markets are functional and cash is accessible.

2 **Rural markets and crop production both recover after conflict events, and appear to displace to avoid conflict – reflecting the deliberate adaptations communities, farmers, and traders are making.**

Humanitarian programs should analyze these adaptations, including changes in crop choices and trade routes, and look for areas to support positive adaptations. Where possible, this should also include engaging host communities and displaced persons to understand their evolving preferences, needs, and access constraints.

3 **The status of food security, market activity, and agriculture may change quickly as the conflict evolves, and they are not uniform across Sudan or even within a region.**

Using multiple methods to understand these changing dynamics and to complement each approach's strengths and limitations will help humanitarian actors respond appropriately. This may include integration of satellite imagery into monitoring activities like the JMMI, or a commitment to routine updates of analyses based on market mapping and conflict data.

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About Mercy Corps
Mercy Corps is a leading global organization powered by the belief that a better world is possible. In disaster, in hardship, in more than 40 countries around the world, we partner to put bold solutions into action — helping people triumph over adversity and build stronger communities from within. Now, and for the future.

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Supporting Pastoralism and Agriculture in Recurrent and Protracted Crises (SPARC) aims to generate evidence and address knowledge gaps to build the resilience of millions of pastoralists, agro-pastoralists and farmers in these communities in sub-Saharan Africa and the Middle East. We strive to create impact by using research and evidence to develop knowledge that improves how the UK Foreign, Commonwealth & Development Office (FCDO), donors, non-governmental organisations, local and national governments, and civil society can empower these communities in the context of climate change.

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