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## Conflicts and climate change in South Sudan 2012-2023

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# ► Conflicts and climate change in South Sudan 2012-2023

Authors / Huanyue Hu, Matthieu Charpe





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## Abstract

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Since its independence in 2011, South Sudan has confronted persistent challenges from conflict and climate change, profoundly disrupting its economic and social stability. This study analyzes the economic impacts of conflict and climate shocks—specifically floods and droughts—on South Sudan from 2012 to 2023, employing innovative remote sensing techniques and geospatial data.

Using nighttime light intensity as a proxy for local economic activity, the study quantifies the effects of conflict fatalities and flooding on economic performance and employment. Results indicate that conflict has had a significant and enduring negative impact: areas within 10 km of five conflict fatalities experienced a 8.9 per cent decline in local employment in the first year, with cumulative losses reaching 17.8 per cent over three years. Similarly, flooding in 2021 led to a 4.9 per cent reduction in employment during the flood year and a 12.1 per cent reduction in the following year, underscoring the prolonged labour market disruptions caused by conflicts and climate shocks.

The study also examines specific events, such as the 2016 Battle of Juba and the 2021 floods, producing high-resolution maps of affected areas. By adopting a pixel-level analytical approach, this research captures localized GDP and employment effects that broader regional analyses might overlook, offering valuable insights for targeted policy interventions.

## About the authors

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**Huanyue Hu** is an international consultant and a PhD candidate in the Department of Economics at Warwick University.

**Matthieu Charpe** is a senior economist at the International Labour Organization.

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## ► Introduction

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Since its independence in 2011, there is a limited understanding of the economic and labour market situation of South Sudan given the lack of data and the limited capacities of domestic economic institutions in general. While some data collection efforts were initiated shortly after independence, the outbreak of the civil war in 2013 severely disrupted these efforts, making it increasingly difficult to obtain reliable information.<sup>1</sup> Such information gaps are particularly critical as South Sudan faces multiple challenges.

Among these, two stand out as especially pressing: conflicts and the impact of climate change. The human cost of the civil war between 2013 and 2020 reaches up to 400 000 casualties and up to 4 million displaced persons. However, the war's broader effects on livelihoods and employment opportunities remain difficult to assess due to the scarcity of reliable data.<sup>2</sup> In addition, the power-sharing deal in 2018 remains fragile and violence continues.

Beyond conflict, South Sudan is also facing severe environmental crises. These include recurring floods and drought, which exposed the vulnerability of the country's agricultural systems and exacerbated food insecurity.

The pressing crises in South Sudan calls for targeted, preferably real-time, evidence-based policy interventions. To overcome the lack of reliable census data and household data,<sup>3</sup> this work proposes to rely on GIS data and remote sensing techniques and provides a panorama of the economic situation in South Sudan, with a focus on the impact assessment of conflicts and flooding on economic activities and the labour market over the period 2012-2023.

This paper first provides a comprehensive assessment of South Sudan's economic landscape, focusing on demographics, economic structure, conflict, climate risks, and their impact on livelihoods and employment. It begins with an overview of South Sudan's demographic structure, urbanization trends, and displacement crisis, using data from Landscan/WorldPop, UNHCR, and Africapopolis. Then it depicts the spatial distribution of economic activities using nightlight luminosity. The analysis also explores the spatial distribution of agriculture and livestock which are crucial for South Sudan's economy.

This study then examines the risks posed by conflict and climate change. It analyzes the spatial and temporal patterns of political violence from 2012 to 2023 using ACLED georeferenced data on conflicts and estimates the share of the population and jobs exposed to conflict by creating 10 km buffers around conflict incidents. The analysis shows that in 2020, 3 million persons lived within 10 km of a conflict. The number of jobs in the vicinity of conflicts equaled 1 million, almost a quarter of total employment<sup>4</sup>. This publication further assesses flood and drought risks using geospatial datasets, highlighting their impact on food security.

<sup>1</sup> See for instance the World Bank High Frequency Surveys 2012-2014 and 2016-2017 as well as the World Bank Enterprise Survey 2013-2014.

<sup>2</sup> FAO (2024), South Sudan, the impact of conflict on food security and livelihoods, DIEM-Impact Report 2024

<sup>3</sup> See for instance Patrick McSharry, Joseph Mawejje, 2024, Estimating urban GDP growth using nighttime lights and machine learning techniques in data poor environments: The case of South Sudan, Technological Forecasting and Social Change, Volume 203, 123399, ISSN 0040-1625, <https://doi.org/10.1016/j.techfore.2024.123399>.

<sup>4</sup> The total population of South Sudan in 2020 is approximately 10.9 million, share of population above 15 is 57.6%, employment to population ratio is 62.7%. Multiplying these three numbers together gives us 3.9 million, which is an estimate for total employment.

To quantify the impact of conflict and climate shocks on economic activity, this work employs nighttime light intensity as a proxy for local economic performance. Nightlight data is widely used as a measure of economic activity because it is strongly correlated with GDP and is available at a fine spatial resolution of approximately 1 square kilometer or even less.<sup>5</sup> Regression analysis is used to estimate economic consequences of conflict fatalities and flooding. The findings show that conflict significantly and persistently reduces economic activity and employment opportunities. The magnitude of the effect is significant and only decline slowly over time. Three years after the conflict, negative effects continue. To illustrate the results of this quantitative exercise, a map displaying the estimated decline in GDP at pixel level following the battle of Juba in 2016 is produced. To measure the impact of floods on economic activity, this work focuses on one event, the floods taking place in October 2021. Similar to conflicts, flooding also has severe effects, particularly in the year following the event, exacerbating food insecurity and economic instability.

This work contributes to the ongoing efforts to produce information and knowledge about South Sudan. For instance, FAO (2024) mobilizes GIS data and conducted on the ground interviews with key stakeholders to assess the impact of conflict on food security.<sup>6</sup> UNHCR(2024) conducted a Forced Displacement Survey in 2023 that gathers information on internally displaced persons as well as local communities.<sup>7</sup> The World Bank (2024) proposes a panorama of poverty mobilizing the small scale 2022 Household Budget Survey combined with imputation techniques.<sup>8</sup> In the academic literature, South Sudan is particularly under-studied. McSharry and Mawejje (2024) estimates urban GDP growth in South Sudan using nightlight data and machine learning. The same authors rely on synthetic control method to estimate the impact of conflict covering the early 2010s up to 2018.<sup>9</sup> Using remote sensing Mackenhaur et al (2021) find that war in South Sudan leads to a reduction in cultivated croplands.<sup>10</sup>

The rest of the document is organized as follows. Section 1 is articulated around a panorama of South Sudan using remote sensing materials, covering population distribution, urbanization and internally displaced persons as well as economics (oil, and agriculture production) and, finally, major risks facing South Sudan (conflicts and climate change). Section 2 quantifies the economic costs associated with these risks using innovative data and quantitative methods. Section 3 concludes.

<sup>5</sup> Henderson, J. Vernon, Adam Storeygard, and David N. Weil. 2012. "Measuring Economic Growth from Outer Space." *American Economic Review* 102 (2): 994–1028.

<sup>6</sup> FAO. 2024. South Sudan: The impact of conflict on food security and livelihoods – DIEM-Impact report, January 2024. Rome.

<sup>7</sup> United Nations High Commissioner for Refugees. 2024. *Forced Displacement Survey – South Sudan 2023*. Copenhagen, Denmark: UNHCR

<sup>8</sup> World Bank. *Republic of South Sudan - Poverty and Equity Assessment (English)*. Washington, D.C.: World Bank Group. <http://documents.worldbank.org/curated/en/099120924150066342/P1799071632dc300c1b020144b4305eb7ab>

See as well World Bank. 2022. "South Sudan Economic Monitor: Towards a Jobs Agenda," 5th ed. February, Macroeconomics, Trade and Investment Global Practice, World Bank, Washington, DC.

<sup>9</sup> Mawejje, J., & McSharry, P. (2021). The economic cost of conflict: Evidence from South Sudan. *Review of Development Economics*, 25(4), 1969-1990.

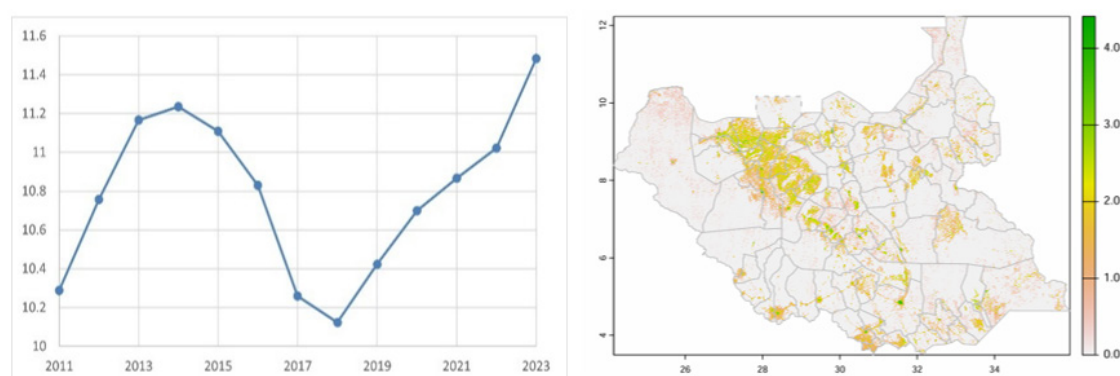
<sup>10</sup> Olsen, V.M., Fensholt, R., Olofsson, P., Bonifacio, R., Butsic, V., Druce, D., Ray, D. and Prishchepov, A.V. (2021). The impact of conflict-driven cropland abandonment on food insecurity in South Sudan revealed using satellite remote sensing. *Nature Food*, 2(12), 990-996.

## ► 1 Panorama of South Sudan

### 1.1 Demographics

Demographic statistics are challenging in South Sudan given that the latest census dates to pre-independence time. Hence, total population and population distribution are estimated. According to UN estimates, South Sudan's population was approximately 11.5 million (2023), with a low annual growth rate of 1.5 per cent. There was a notable population drop between 2015 and 2018, driven by conflict escalation and famine that forced millions to flee the country. The population is heavily concentrated in the central and southern regions, due to suitable conditions for subsistence farming and livestock rearing. Major cities such as Juba, Bentiu, and Malakal are among the most densely populated areas (Map 1.1.1). The population in South Sudan is very young, with a median age of 18.7 years, reflecting a high fertility rate and low life expectancy. Life expectancy is about 57.7 years, and infant mortality is high at 63.2 deaths per 1,000 live births.<sup>11</sup>

► **Map 1.1.1 Time series on total population in South Sudan (left); (Log) Population density in South Sudan in 2023 (right)**



Note: The time series on the left illustrates the population trend in South Sudan (SSD) from 2011 to 2023. The map on the right shows the log-transformed population density in South Sudan in 2023. Greener areas indicate higher population density. Boundaries shown anywhere in this paper do not imply endorsement or acceptance by the ILO. The Abyei area is represented with dashed lines.

Source: LandScan Global Population Database.

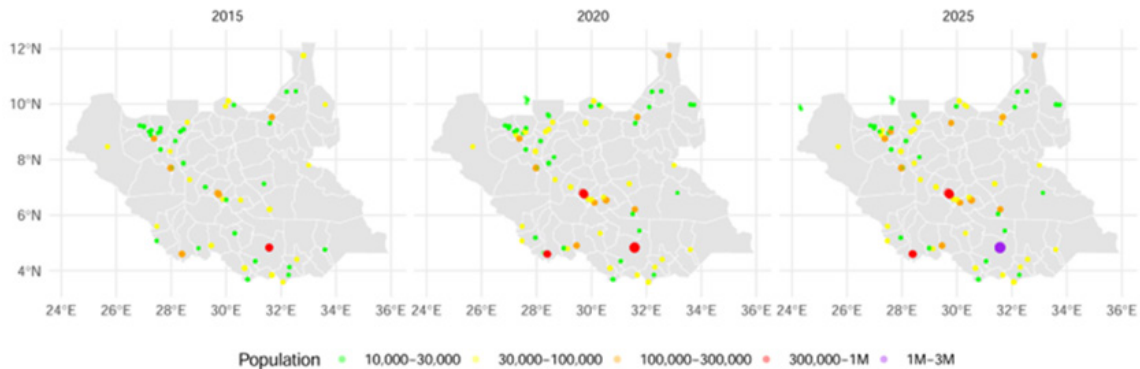
South Sudan is one of the least urbanized countries in Africa, with urban areas accounting for only 1 per cent of the total land area.<sup>12</sup> Map 1.1.2 illustrates a clear trend of increasing urbanization over the years, although most urban agglomerations remain relatively small, with populations ranging between 10,000 and 100,000 residents. By 2020, urbanization had visibly expanded, with the number of urban agglomerations exceeding 30,000 residents increasing from just one in 2015—Juba—to three by 2020, reflecting a gradual shift toward urban concentration. Projections for 2025 indicate that Juba will become the first urban agglomeration in South Sudan

<sup>11</sup> United Nations Population Division: Data Portal.

<sup>12</sup> Africapolis. *South Sudan country report*. <https://africapolis.org/en/country-report/South%20Sudan>

to surpass 1 million residents. While urbanization is progressing despite ongoing humanitarian crises, it remains limited in scale compared to other East African countries.<sup>13</sup>

► **Maps 1.1.2 Urban agglomerations in South Sudan over time**



Note: Data for 2025 is projected. Africapolis provides a standardised and geospatial database on urbanisation dynamics in Africa, which is comparable across countries and across time. The minimum population threshold used by Africapolis to consider an agglomeration as urban is 10,000 inhabitants.

Source: Africapolis.

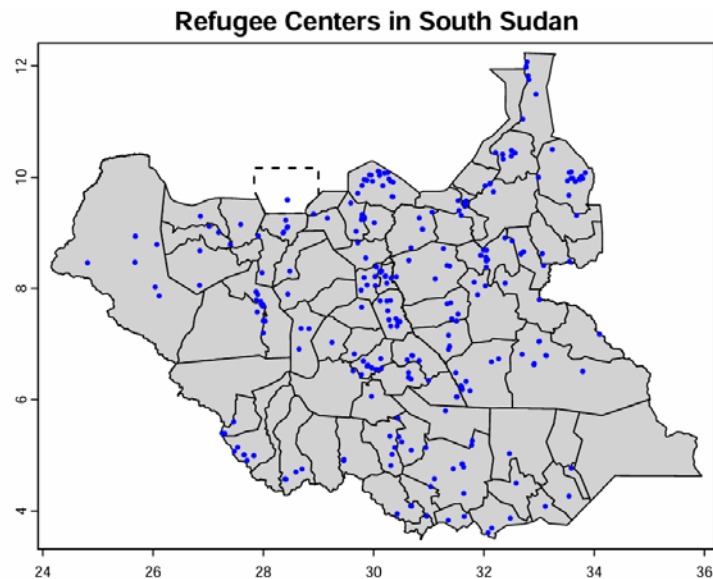
Due to the sustained periods of conflict, violence and natural disasters, approximately 2.2 million people remain displaced within the country, while roughly the same number of South Sudanese have sought refuge in neighboring countries, primarily Sudan, Uganda, Ethiopia, Kenya, and the Democratic Republic of the Congo.<sup>14</sup> This makes it the largest refugee crisis in Africa and the third-largest globally. Map 1.1.3 illustrates the widespread distribution of refugee camps across the country. Additionally, the recent conflict in Sudan has led to a sharp increase in South Sudan's refugee population, surpassing 500,000 by the end of 2024, with 150,000 more refugees expected to arrive in 2025.<sup>15</sup>

<sup>13</sup> For instance, data from Africapolis shows that as of 2020, Ethiopia had three agglomerations with more than 1 million residents, while Kenya had five.

<sup>14</sup> <https://www.unrefugees.org/news/south-sudan-refugee-crisis-explained/>

<sup>15</sup> UNHCR. South Sudan Country Refugee Response Plan 2025

► Map 1.1.3 Refugee centers in South Sudan



Source: UNHCR.

## 1.2 Economy

South Sudan is one of the least developed countries globally, with an estimated GDP per capita of approximately US\$340, according to the IMF, a sharp decline from US\$1,300 in 2015.<sup>16</sup> Estimates from the World Bank, based on the 2022 Household Budget Survey (HBS), indicate that about three-quarters of the population live below the national poverty line of SSP 358,724 annually. Moreover, over two-thirds of the population live in extreme poverty, earning less than SSP 298,478 annually, which represents the national food poverty line.<sup>17</sup> Applying the exchange rate at the end of 2022, the national poverty line amounts to 1.49 USD a day and the extreme poverty line amounts to 1.24 USD a day.

Nighttime light data suggests significant spatial disparities in economic activity across South Sudan. Only 0.1 per cent of the country's pixels register a positive nighttime light index, concentrating mainly around Juba, Bentiu and Malakal. Juba is the capital and main urban hub of South Sudan, while Bentiu and Malakal are abundant in oil resources (Map 1.2.1), which is crucial for South Sudan's economy.

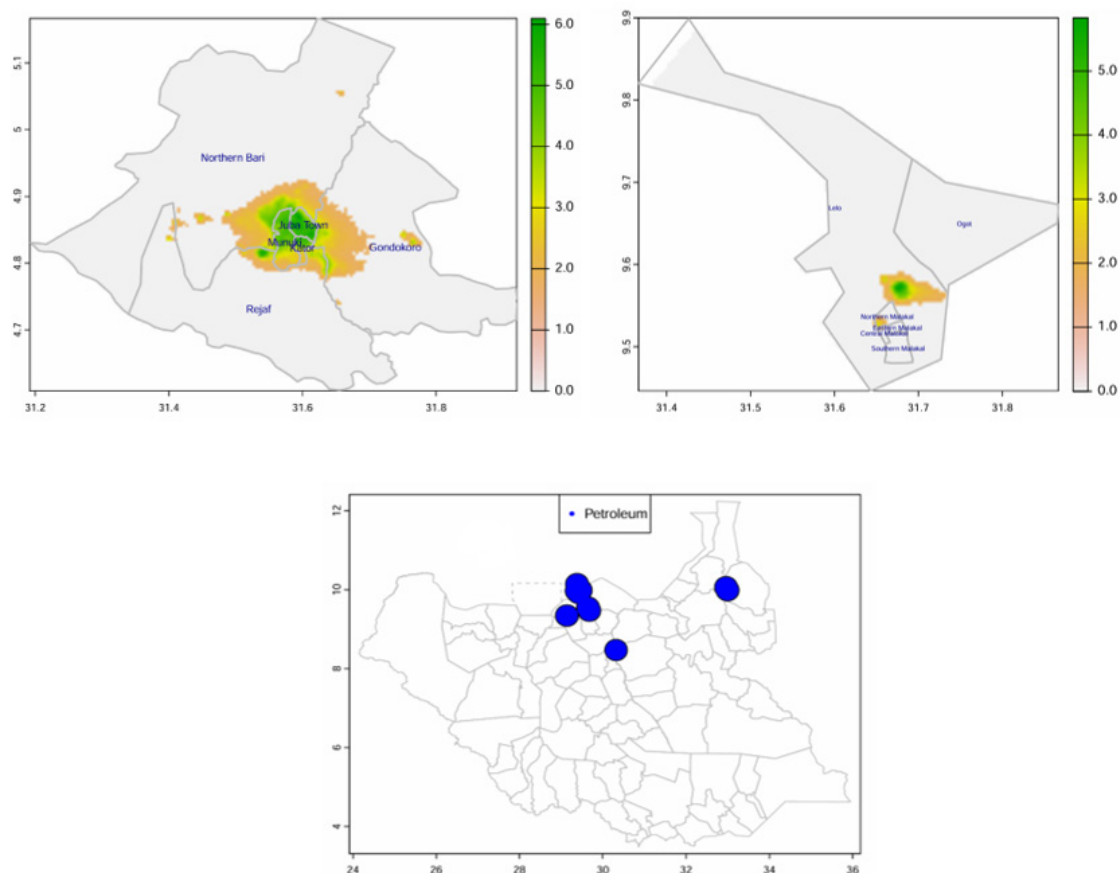
South Sudan is a heavily oil-dependent country, with oil exports accounting for more than 85 per cent of government revenue. However, the pipeline transporting oil to Sudan's Red Sea coast—its main export route—has been disrupted due to ongoing conflict in Sudan. This disruption has had devastating economic consequences, shrinking the economy by over a quarter, devaluing the local currency, and driving inflation to 120 per cent in 2024. Additionally, the disruption has also resulted in a fiscal crisis, leaving the government unable to pay civil servants and soldiers for months, weakening essential public services and fueling unrest.<sup>18</sup>

<sup>16</sup> <https://www.imf.org/external/datamapper/NGDPDPC@WEO/USA/DEU/SSD>

<sup>17</sup> World Bank. *Republic of South Sudan - Poverty and Equity Assessment (English)*. Washington, D.C.: World Bank Group. <http://documents.worldbank.org/curated/en/099120924150066342/P1799071632dc300c1b020144b4305eb7ab>

<sup>18</sup> <https://www.economist.com/middle-east-and-africa/2024/12/19/south-sudans-economic-crisis-threatens-its-fragile-peace>

► **Maps 1.2.1 (Log) Nighttime light in 2023 in 6 selected ADM3 regions in Juba (upper left) and in Malakal (upper right); Petroleum resources in South Sudan (down)**



Note: Greener areas indicate higher nighttime light intensity and more economic activity. Only 0.1 % of the country's pixels register a positive nighttime light index, concentrating mainly around Juba, Bentiu and Malakal. Oil abundant regions show higher nighttime light intensity.

Source: VIIRS; PETRODATA.

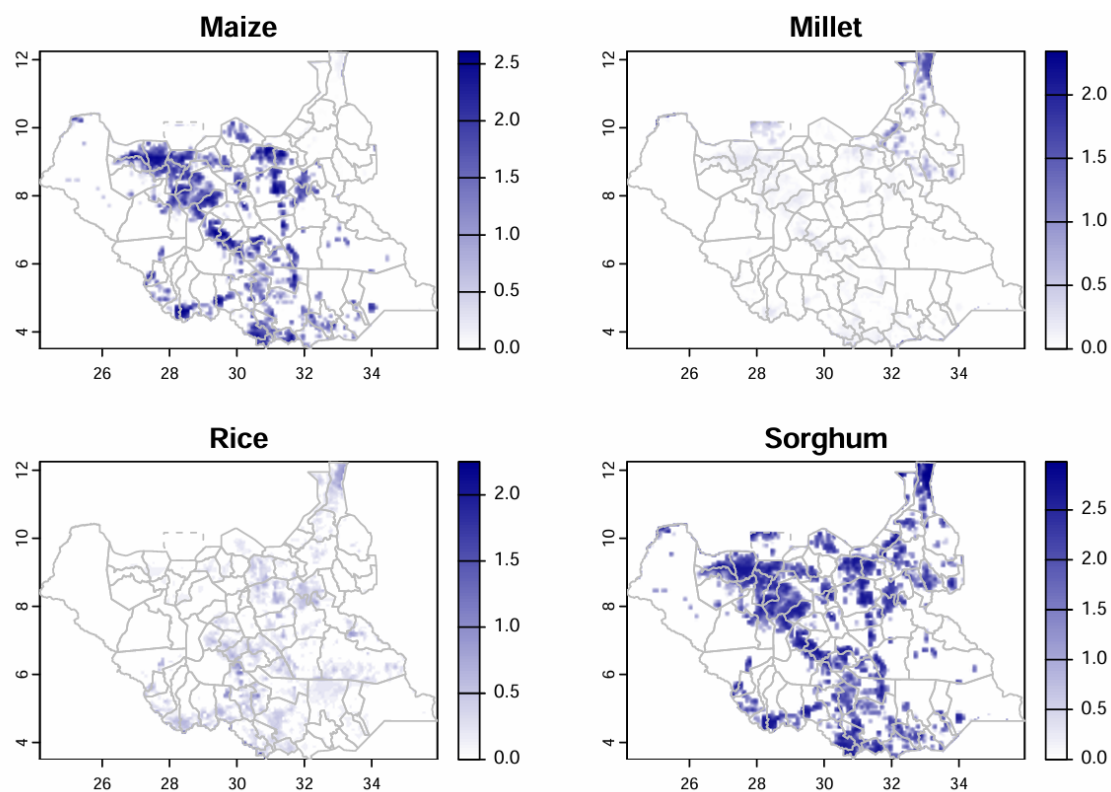
Due to the dominant role of the oil sector, agriculture and forestry contribute only about 10 per cent of the GDP.<sup>19</sup> Around 71 per cent of the population depend on agriculture as the main source of income, yet the poverty rate is highest among these households, reaching 81 per cent.<sup>20</sup> Sorghum is the most widely cultivated crop in South Sudan, contributing 76 per cent of the country's primary food supply, followed by maize, rice, and millet (Maps 1.2.2). Moreover, livestock, particularly cattle, serves as the key means of subsistence for a significant portion of households. These herds are mainly located in western Upper Nile State, along with East Equatoria, Jonglei, and the Bahr El Ghazal states (Map 1.2.3).<sup>21</sup>

<sup>19</sup> ILO (2023). Decent Work Country Programme for South Sudan 2023 - 2025

<sup>20</sup> World Bank. *Republic of South Sudan - Poverty and Equity Assessment (English)*. Washington, D.C.: World Bank Group. <http://documents.worldbank.org/curated/en/099120924150066342/P1799071632dc300c1b020144b4305eb7ab>

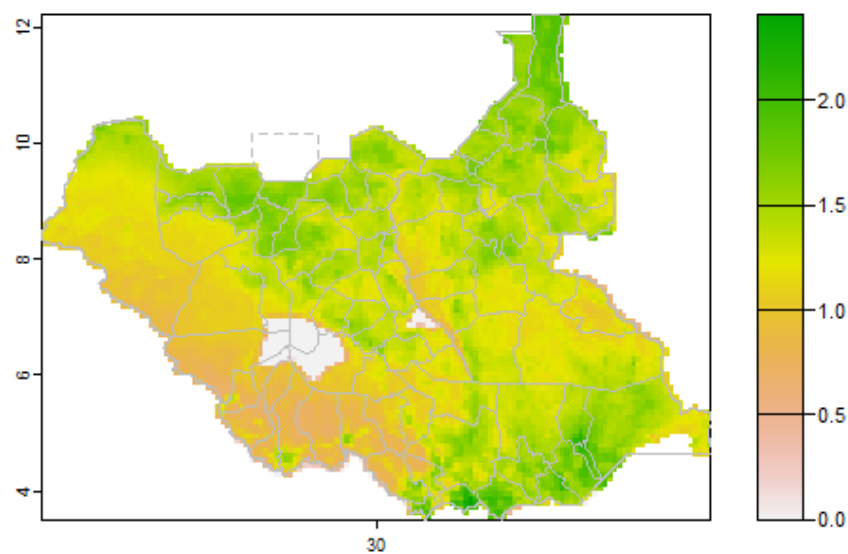
<sup>21</sup> AfDB (2013), Infrastructure Action Plan in South Sudan: A Program for Sustained Strong Economic Growth



► **Maps 1.2.2 Distribution of four major crops grown in South Sudan (Log-Transformed)**

Note: CROPGRIDS is a comprehensive global geo-referenced dataset providing area information for 173 crops for the year 2020, at a resolution of 0.05° (about 5.6 km at the equator). Variables are log-transformed. Darker blue indicates higher crop yield.

Source: CROPGRIDS.

► **Map 1.2.3 Cattle distribution 2020 (Log-Transformed)**

Note: The Gridded Livestock of the World (GLW) is a peer-reviewed spatial dataset on the global distribution and abundance of livestock species, available at global extent and 5 minutes of arc resolution (approx. 10 km at the equator). Cattle density (originally in unit head/pixel) is log-transformed. Greener regions indicate higher cattle density.

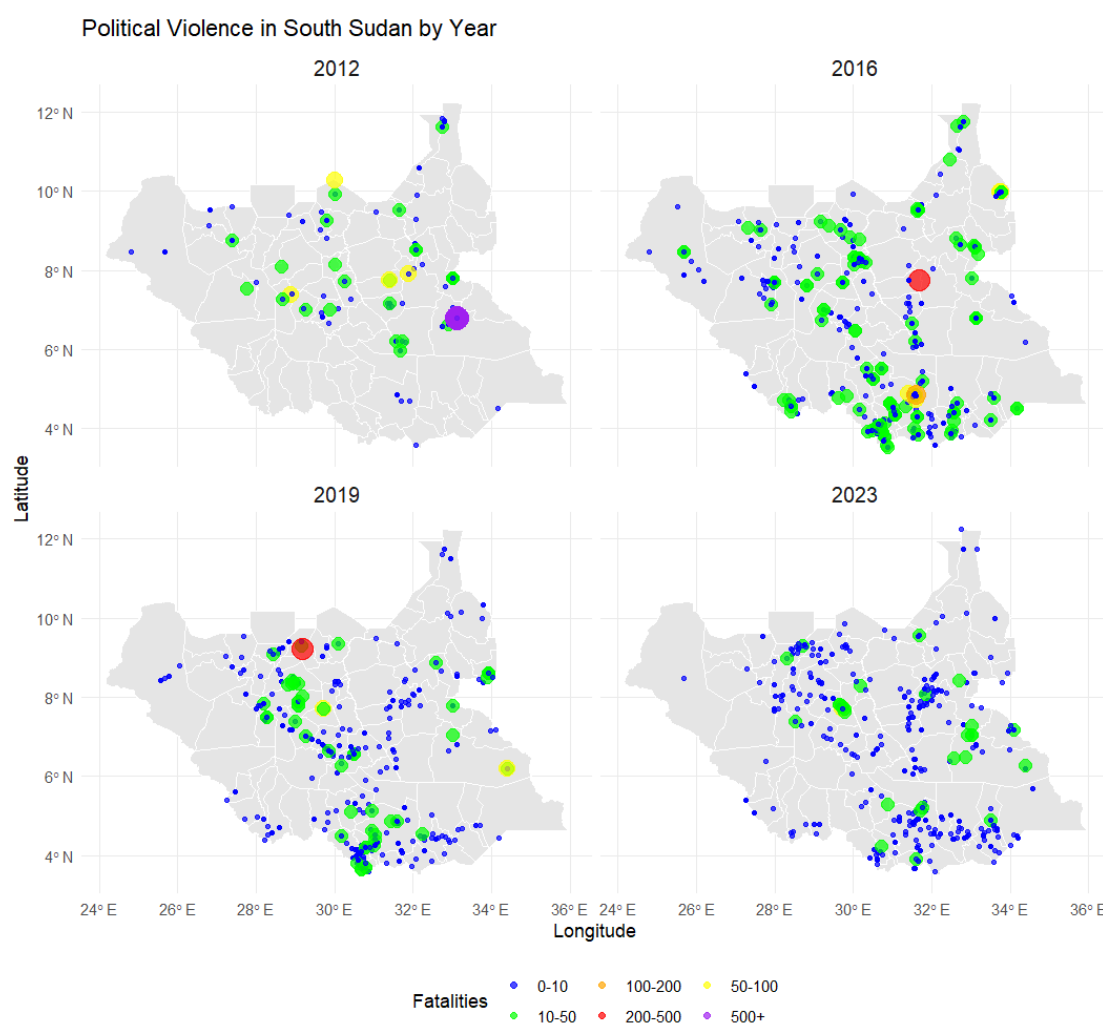
Source: FAO. GLW 4: Gridded Livestock Density (Global - 2020 - 10 km).

## 1.3 Risks

### 1.3.1 Conflicts

People's livelihoods in South Sudan have been exposed to great risks due to the ceaseless conflict and violence. Shortly after its independence, a civil war broke out in the new country between the two largest ethnic groups, resulting in widespread fatalities, displacement, hunger and economic decline. Efforts to restore peace have encountered repeated setbacks. Both the 2015 peace agreement and the 2018 revitalized peace deal failed to bring lasting peace to the country, leading to continuous sporadic violence. Maps 1.3.1 illustrates the spatial distribution and intensity of conflict-related fatalities in South Sudan from 2012 to 2023. A notable increase in the number of conflicts is observed between 2012 and 2016, with violence becoming more widespread and intense, particularly in central and southern regions. Despite the 2018 peace deal, conflict levels remain high in subsequent years, although the distribution of high-fatality incidents appears to have decreased by 2023.

► **Maps 1.3.1 Political violence in South Sudan by year and fatality**



Note: This map illustrates the distribution of political violence incidents in South Sudan from 2012 to 2023 using data from Armed Conflict Location & Event Data (ACLED). ACLED collects information on the dates, actors, locations, fatalities, and types of



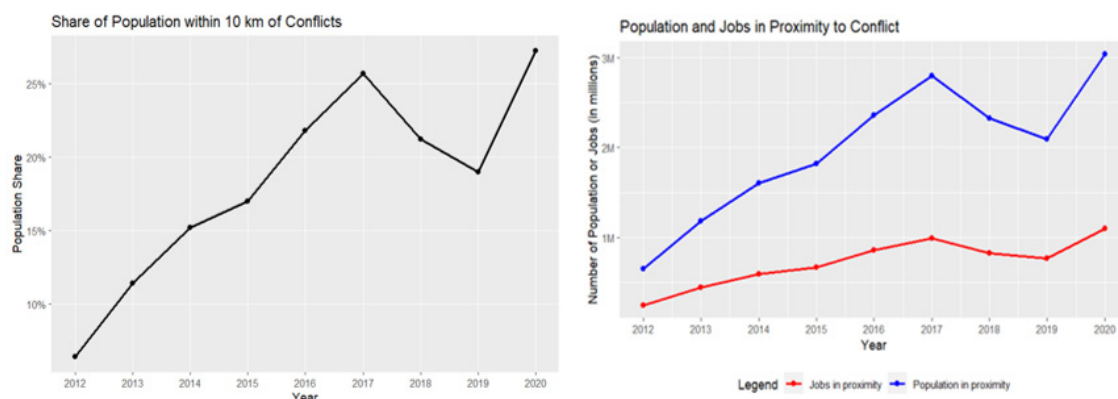
all reported political violence and protest events around the world. Each point on the maps represents a recorded incident, with larger and darker-colored circles indicating higher fatality counts.

Source: ACLED.

Conflicts put South Sudanese lives and livelihoods at severe risk, as shown by the increasing population in conflict-affected areas (Figure 1.3.1). To estimate the population exposed to conflict, we create a 10-kilometer buffer around each recorded conflict point and use high-resolution WorldPop data to calculate how many people fell within these conflict zones.<sup>22</sup> By dividing this figure by the total population for each year, we obtain the share of the population affected by conflict. The results show a steady rise in the affected population from 2012, peaking at nearly 2.8 million in 2017—about a quarter of the total population. Following the 2018 peace agreement, there was a temporary decline in 2018 and 2019, but the numbers surged again to over 3 million by 2020.

Then we estimate potential jobs at risk due to proximity to conflicts, illustrated by the red line. Using the International Labour Organization's (ILO) modeled employment-to-population ratio for South Sudan, we multiply this ratio by the total number of people (aged 15 and above) near conflict to estimate the number of jobs potentially affected. The findings reveal that more than 1 million jobs were at risk by 2020, which is approximately 4.5 times the number in 2012.<sup>23</sup> These trends highlight the growing threat of conflict to both the lives and livelihoods of South Sudanese people, emphasizing the urgent need for sustainable peace and economic resilience measures.

► **Figure 1.3.1 Estimated (share of) population and jobs living close to or potentially exposed to conflicts over time**



Note: These figures illustrate the growing exposure of South Sudan's population and jobs to conflict between 2012 and 2020. The first graph shows the increasing share of the population within 10 km of recorded conflict events, while the second graph estimates the total number of people and jobs at risk due to proximity to conflict zones. The analysis is based on high-resolution WorldPop data, conflict records from ACLED, and employment estimates from the International Labour Organization (ILO). The trends highlight a sharp increase in conflict exposure, with over 3 million people and nearly 1 million jobs at risk by 2020. Abyei region is not included in the calculation.

Source: WorldPop, ACLED, ILO modelled estimates.

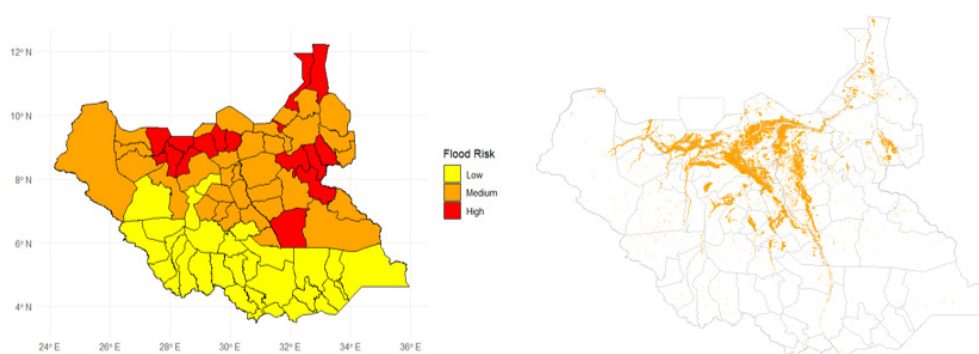
<sup>22</sup> Note that outflow of refugees is not taken into considerations in the calculations due to data limitations.

<sup>23</sup> In South Sudan, the minimum working age is 14+, (ILO convention N° 138). However, the employment to population ration is defined as 15+ according to ILO modelled estimates.

### 1.3.2 Climate change and food insecurity

Another major threat to the country's economic development and people's wellbeing is climate change in recent years. Flooding has become increasingly frequent and destructive, affecting nearly a million people annually since 2019. Excessive flooding has reduced crop yields, worsened food security, and resulted in livestock deaths, for example cattle. States such as Jonglei, Northern Bahr El Ghazal, Unity, Warrap, and Western Bahr El Ghazal are particularly vulnerable to recurrent floods (Map 1.3.2 left). In 2024, heavy rainfall and the bursting of the Nile River banks caused widespread flooding starting in May. By the end of October, approximately 870,000 people were potentially exposed to or living near flooded areas (Map 1.3.2 right).

► **Map 1.3.2 Flood risks (left); Flooded areas in October 2024 (right)**



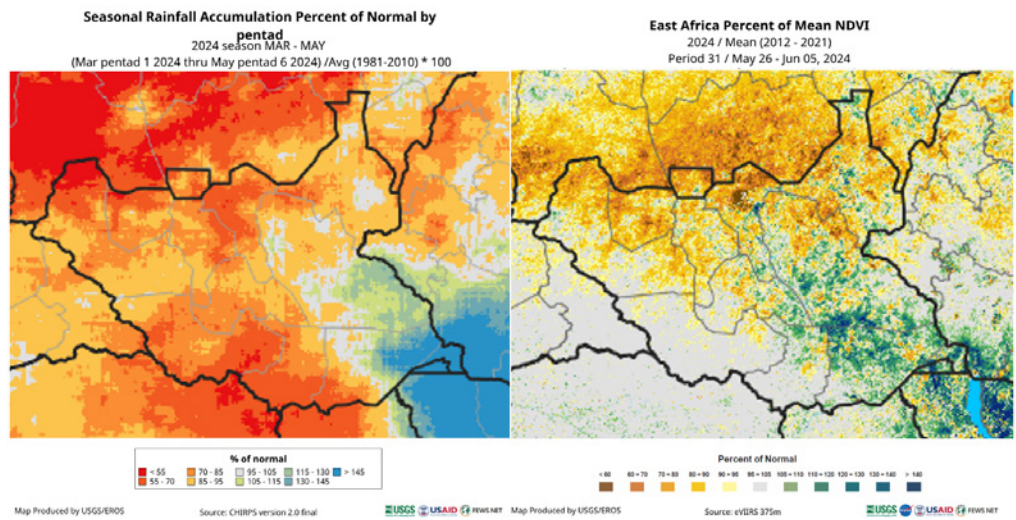
Note: The map on the left illustrates flood risk levels across South Sudan, categorized into low, medium, and high-risk areas based on data from the 2011 Flood Risk dataset. Regions in darker shades indicate a higher likelihood of flooding, particularly in central and northern parts of the country.

Source: Left: ICA (Integrated Context Analysis) South Sudan, 2016: Flood Risk, 2011 (dataset), Humanitarian Data Exchange, United Nations Office for the Coordination of Humanitarian Affairs, New York, [https://data.humdata.org/dataset/wfp\\_ica\\_ssd\\_2016](https://data.humdata.org/dataset/wfp_ica_ssd_2016). Right: UNOSAT Dashboard: Satellite detected water extents between 26 and 30 October 2024 over South Sudan, version 01 Nov, 2024, United Nations Institute for Training and Research, Geneva, <https://unosat.org/products/4016>.

In addition to floods, South Sudan also faces recurring droughts approximately every five years. Over the period from 2009 to 2022, three major droughts were recorded. The droughts of 2009 and 2021 affected millions, with 4.4 million and 7.7 million people impacted, respectively, leading to food shortages. The 2016 drought had even more devastating consequences and led to widespread famine, with the severity likely exacerbated by the challenges of responding amidst ongoing conflict.<sup>24</sup> Map 1.3.3 highlights the potential link between drought conditions in 2024 and below-average crop yields. Drought-like situations are anticipated to escalate in 2025 due to the lingering effects of El Niño and lead to more displacement of people, increased crop failures and livestock deaths.

<sup>24</sup> World Bank. *Republic of South Sudan - Poverty and Equity Assessment (English)*. Washington, D.C.: World Bank Group. <http://documents.worldbank.org/curated/en/099120924150066342/P1799071632dc300c1b020144b4305eb7ab>

Map 1.3.3 Drought in South Sudan poses threat on food security

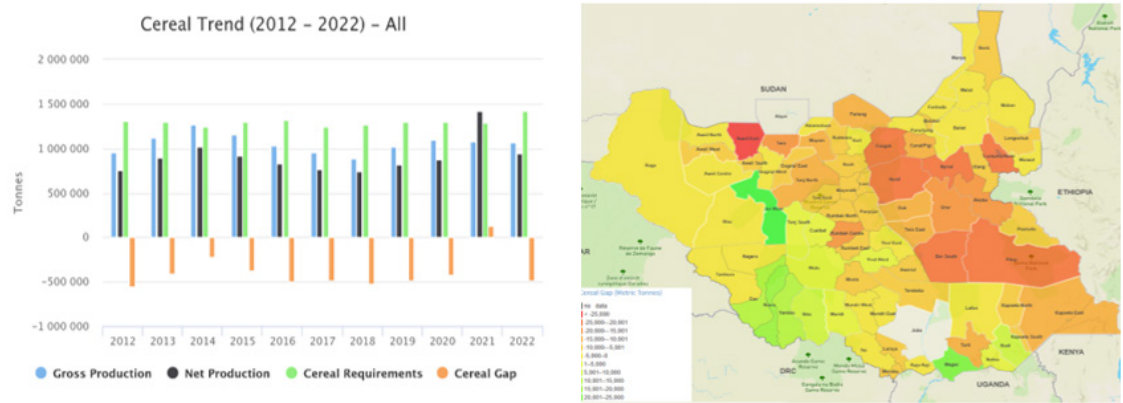


Note: This map illustrates the drought conditions and their impact on food security in South Sudan in 2024. The left panel depicts seasonal rainfall anomalies for March–May 2024, comparing accumulated rainfall per centages with the 1981–2020 average. Areas shaded in red and orange indicate regions experiencing below-normal rainfall, signaling potential drought conditions. The right panel presents the Normalized Difference Vegetation Index (NDVI) for May 26 – June 5, 2024, comparing vegetation health to the 2012–2021 average. Lower NDVI values, particularly in northern regions, suggest poor vegetation growth, indicating reduced crop yields and deteriorating pasture conditions.

Source: USGS Famine Early Warning System<sup>25</sup>

As a result of these extreme climate shocks, cereal production (both gross and net) has consistently fallen short of meeting the country’s cereal requirements, leading to a persistent cereal gap of nearly 500,000 tonnes (Figure 1.3.2). The severity of these shortages varies across the country, with acute deficits particularly concentrated in the northern and eastern regions (Map 1.3.4).

Figure 1.3.2 Cereal trend; Map 1.3.4 Spatial distribution of cereal gap



Note: Figure 1.3.2 illustrates the cereal production trend in South Sudan from 2012 to 2022. The cereal gap is represented by the orange bars, indicating the shortfall in cereal availability each year. Map 1.3.4 provides a spatial distribution of the cereal gap across South Sudan, highlighting regions with acute cereal deficits. The northern and eastern regions are particularly affected, as shown in darker shades of red and orange, while some southern and western areas experience relatively lower shortages.

Source: Crop data, CLiMIS.

<sup>25</sup> I followed the figure in <https://www.ft.com/content/fd64c53f-6a00-4df2-bb73-3a9a9be58661> and updated it to 2024.

## ► 2 Impact of climate change and conflict on economic activity and employment a quantitative exercise

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Assessing the economic impact of conflicts and floods in South Sudan is challenging due to data limitations. In the absence of household panel data and/or local measure of GDP, it is not possible to constitute a baseline against which to measure the impact of conflict and climate change. To address this, we leverage remote sensing data to estimate effects at the pixel level.

In this analysis, we use annual nighttime light satellite imagery at a spatial resolution of 15-arc seconds as a proxy for local economic activity. Chen and Nordhaus (2011) as well as Henderson et al. (2012) develop a statistical framework that integrates satellite-based nighttime light data with official income growth measures to improve growth estimates, particularly in countries with weak national income accounts, and demonstrate how this approach enables subnational and supranational analyses of economic activity.<sup>26</sup> Since then, nightlight luminosity has been increasingly used by researchers to measure economic growth.

For the period 2012-2023, we use VIIRS data<sup>27</sup> obtained from blackmarble,<sup>28</sup> specifically the snow-free radiance from all angles. The annual frequency data is corrected for sunlight, glare, moonlight, cloud cover, and lightning from the aurora. The data is measured in radiance, and pixels with a value of 65,535 are excluded from the analysis. We also remove pixels marked with a low-quality flag.

Nighttime light data has gained popularity in economics due to its abundance in terms of frequency, geographic detail, and accessibility. One main advantage is that radiance is measured via a calibrated sensor that produces a comparable measure of light intensity through the globe. In contrast, national account statistics are subject to large revisions and micro data are subject to bias. However, the main disadvantage is that light intensity is an indirect measure of economic activity and that socio-economic attributes are not directly observed. In low-income countries, the radiometric properties of the satellite are such that the sensors may not capture low light. Economic activities in very poor areas with non-zero population but zero-light may lead to measurement errors as highlighted by Huber and Mayoral (2024).<sup>29</sup>

As South Sudan is largely a rural country, the question arises whether light intensity is an accurate proxy of agriculture production as agriculture might generate less lights than manufacturing or services. Our main take on this question is that while nightlight performs less at reflecting agriculture production than other sectors, the agriculture production to light elasticity remains positive as agriculture production remains a main determinant of final consumption. In the specific case of South Sudan, given the large share of the agriculture sector and pastoralism in particular,

<sup>26</sup> Henderson, J. Vernon, Adam Storeygard, and David N. Weil. 2012. "Measuring Economic Growth from Outer Space". *American Economic Review* 102 (2): 994–1028.

X. Chen, & W.D. Nordhaus, Using luminosity data as a proxy for economic statistics, *Proc. Natl. Acad. Sci. U.S.A.* 108 (21) 8589-8594, <https://doi.org/10.1073/pnas.1017031108> (2011).

<sup>27</sup> Visible Infrared Imaging Radiometer Suite

<sup>28</sup> <https://blackmarble.gsfc.nasa.gov/>

<sup>29</sup> John D. Huber & Laura Mayoral, 2024. "Economic Development in Pixels: The Limitations of Nightlights and New Spatially Disaggregated Measures of Consumption and Poverty," Working Papers 1433, Barcelona School of Economics.

the quantitative exercise presented below should be seen as reflecting mostly the impact in urban areas. We explored several alternatives, including the use of an existing crop database (Map 1.2.2), to improve coverage of rural areas. In our regression analysis, we found no significant impact of conflicts on crop production. One possible reason for this is that we relied on an existing global crop database. While creating a custom crop production measure, as sometimes done in the literature, might have been an option, it would have required a separate paper and is outside the scope of this study. Additionally, we considered the FAO global cattle database to capture pastoralism (see Map 1.2.3). Although the database contains data points from 2010, 2015, and 2020, methodological changes over time complicate its use as a panel.

We construct an annual panel dataset of nighttime light intensity and conflict events in South Sudan from 2012 to 2023 at the pixel level.<sup>30</sup> The analysis focuses on pixels with a positive nighttime light index in at least one year, resulting in a sample of 5,033 pixels. We estimate the relationship between nighttime light growth and conflict by regressing log nighttime light index  $\log(ntl)_t$  on the log of fatalities  $\log(fatality)_t$  within a 10 km radius, while controlling for pixel and year fixed effects.<sup>31</sup> To capture the persistent effects of conflict, we sequentially introduce lagged fatality variables up to three years. The estimation is a standard panel regression with pixel and year fixed effects.

This approach shares similarity with IMF (2019)<sup>32</sup> but with differences. Our dependent variable is expressed in level and not in growth rate. The main reason is that measuring growth rate of light at pixel level would generate a lot of noise that may impact the quality of the estimation. Empirical papers looking at the relationship between GDP and light tend to favor variables in level rather than in growth rate for similar reasons (see Chen and Nordhaus, 2019).<sup>33</sup> In addition, a dependent variable specified as a growth rate would resemble a growth convergence type of quantitative estimation. However, the convergence literature adopts a mid-term perspective over five years or 10 years rather than an annual frequency as with the present exercise. Lastly, the innovative aspect of our approach is to perform pixel level estimation rather than provincial or district level estimation. The advantage is that a small granular level fully captures the local effects of conflicts that may be lost when larger administrative entities are considered. Additionally, another specificity of our approach is to fully capture neighbouring effects as all conflicts within a 10 km radius of a pixel are accounted for.

Table 2.1 presents the results, showing a statistically and economically significant negative impact of conflict on nighttime light intensity. The effect persists for at least two additional years, with the magnitude declining over time. The coefficient for fatalities lagged by three years becomes negligible in magnitude and statistically insignificant (column 4). Therefore, our preferred regression is in column 3, where the coefficient for current-year fatalities  $\log(fatality)_t$  is -0.071, decreasing to -0.012 for fatalities two years prior ( $\log(fatality)_{t-2}$ ).

To put these estimates into perspective, for pixels within 10 km of five fatalities, current-year conflict fatalities lead to a 12.7 per cent decline in nighttime light growth, which is equivalent to

<sup>30</sup> While detection change can be done using daily satellite images, the time coverage between 2012 and 2023 justifies the use of annual data. For daily nighttime light detection, see Tian Li, Zhe Zhu, Zhuosen Wang, Miguel O. Román, Virginia L. Kalb, Yongquan Zhao, Continuous monitoring of nighttime light changes based on daily NASA's Black Marble product suite, Remote Sensing of Environment, Volume 282, 2022, 113269, ISSN 0034-4257. <https://doi.org/10.1016/j.rse.2022.113269>

<sup>31</sup> Both variables are transformed as  $\log(1+x)$  to account for observations with zero light or zero fatalities at one point in time.

<sup>32</sup> IMF (2019). Regional economic outlook. Sub-Saharan Africa: recovery amid elevated uncertainty.

<sup>33</sup> Chen, Xi and William D. Nordhaus. 2019. "VIIRS Nighttime Lights in the Estimation of Cross-Sectional and Time-Series GDP". Remote Sensing 11 (9).



a 10.2 per cent drop in local GDP and an 8.9 per cent reduction in employment.<sup>34</sup> In the second year, nighttime light growth decreases by 10.6 per cent, corresponding to an 8.5 per cent decline in GDP and a 7.4 per cent reduction in employment. In the third year, the impact further diminishes, with a 2.1 per cent reduction in nighttime light growth, translating to a 1.7 per cent decline in GDP and a 1.5 per cent decrease in employment. Cumulatively, over three years, the total GDP loss due to five fatalities within 10 km amounts to approximately 20.4 per cent, which translates to a total employment loss of approximately 17.8 per cent.<sup>35</sup> By the fourth year, the impact becomes negligible.

The estimated economic effects of conflict fatalities in this study are broadly in line with, but somewhat larger than, that found in the IMF (2019).<sup>36</sup> IMF (2019) estimates that a conflict resulting in 100 fatalities is associated with a 17-percentage point decline in nighttime light growth at the state level in Sub-Saharan Africa, which translates to approximately a 7 per cent reduction in local real GDP.<sup>37</sup> By comparison, our results suggest that within a 10 km radius of just five fatalities, local GDP declines by 10.2 per cent in the first year, with cumulative losses reaching 20.4 per cent over three years. This suggests that our estimates, based on a more granular, pixel-level approach, capture localized economic disruptions that may be more severe than regional averages.<sup>38</sup>

► **Table 2.1 Impact of Conflict Fatalities on Nighttime Lights**

	(1)	(2)	(3)	(4)
Log Fatality (t)	-0.0842*** (0.0036)	-0.0865*** (0.0034)	-0.0708*** (0.0036)	-0.0754*** (0.0040)
Log Fatality (t-1)		-0.0492*** (0.0029)	-0.0592*** (0.0029)	-0.0582*** (0.0032)
Log Fatality (t-2)			-0.0119*** (0.0025)	-0.0186*** (0.0026)
Log Fatality (t-3)				-0.0011 (0.0026)
Num. Obs.	60 396	55 363	50 330	45 297
R <sup>2</sup>	0.762	0.784	0.798	0.806

Note: Standard errors are clustered at the pixel level. P < 0.1, \* p < 0.05, \*\* p < 0.01, \*\*\* p < 0.001

Table 2.1 estimates the impact of conflicts over the period considered 2012-2023. To graphically illustrate the coefficients estimated in Table 2.1, we discuss below one important event, the battle of Juba taking place in 2016. In addition, a country level illustration can be found in the appendix for the year 2016.

<sup>34</sup> For a conflict that results in five deaths,  $\hat{\beta}_{Log.Fatality} = -0.071 \times \log(1+5) = -0.127$ . The elasticity between nighttime light and GDP is about 0.8 and the elasticity between nighttime light and employment is about 0.7 based on an annual panel regression between light and GDP and light and employment. On average, the number of fatalities of the conflict events over the period considered is 4.8.

<sup>35</sup> To fix ideas, we assume a total population of 10.5 million, with 57 per cent aged above 15 and an employment rate of 64 per cent. Using these assumptions, the estimated job loss caused by five conflict fatalities in proximity is calculated as:  $10.5 * 0.55 * 0.61 * 0.178$  is approximately 0.6 million jobs lost.

<sup>36</sup> IMF (2019). Regional economic outlook. Sub-Saharan Africa: recovery amid elevated uncertainty.

<sup>37</sup> See Annex Table 2.11.

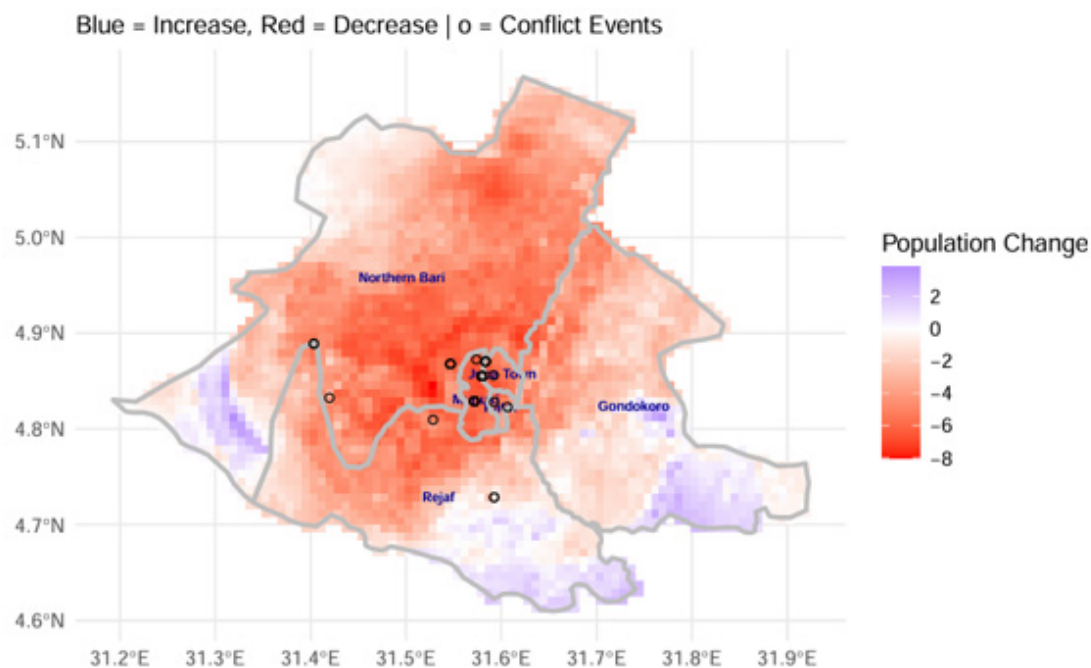
<sup>38</sup> In a related study, Mawejje & McSharry (2020) finds that the South Sudanese economy experienced a cumulative per capita GDP loss of 69.6% between 2012 and 2018, translating to an aggregate GDP loss of \$81.1 billion. While this study focuses on macro-level economic losses, our findings provide a complementary perspective by illustrating how conflict disrupts economic activity at a granular level. Additionally, our estimation of employment loss highlights the severe labor market consequences of conflict.

The Battle of Juba (2016) resulted in more than 300 deaths and constitutes an important event in terms of the intensity of violence. The conflict also led to significant population displacement, as illustrated in Map 2.1, which shows the absolute population change between 2015 and 2017 in six ADM3 regions in Juba: Juba Town, Gondokoro, Kator, Munuki, Rejaf, and Northern Bari. The results reveal a widespread population decline, particularly in central and northern part of the selected region, where the intensity of the conflict was highest (conflicts are represented by small circles on the map). The total net population decline across these areas is estimated at approximately 32,241 people, representing an 8.2 per cent decrease from the 2015 population of 393,309. However, it is important to note that this population decline mapped in 2.1 does not isolate the impact of the conflict but is a general variation between two points in time. It means that it factors in other effects such as the positive trends in urbanization and fertility. It is important to emphasize that the decline in population at pixel level in Juba illustrates the strong impact of the conflict.

Map 2.2 presents the estimated contemporaneous economic impact of fatalities during the Battle of Juba (2016) on local GDP growth. Areas in darker shades indicate greater economic contraction following the conflict. The economic damage from the conflict is not only immediate (contemporaneous effect) but also persists over time, as indicated by similar magnitudes of total lagged effects in the following two years.

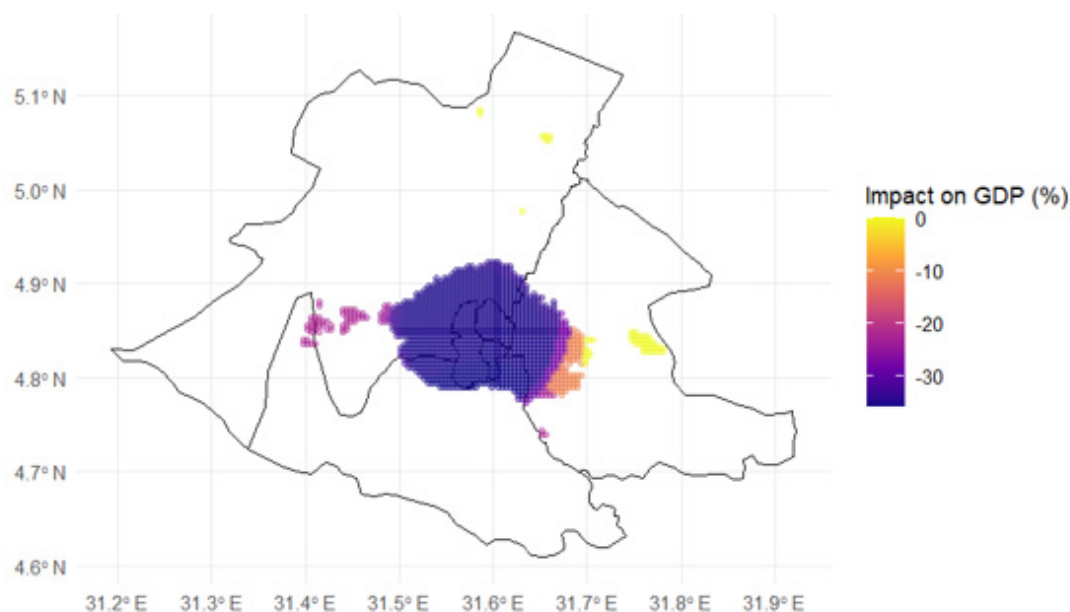
We further estimate the employment loss caused by this conflict in the selected region. By multiplying the estimated percentage change in GDP by the nightlight-to-employment elasticity, and then applying this to the estimated number of employed people aged 15 and above in the region, we find that the Battle of Juba led to job losses amounting to 25 per cent. Map 2.3 visualizes the spatial distribution of this estimated employment loss.<sup>39</sup> The light to employment elasticity is estimated using an international panel of the extensive margin of employment rather than the intensive margin of employment due to data availability. This means that the impact of conflict should be seen as employment rather than hours worked or full-time equivalent employment. In addition, the regression exercise indicates that 25 per cent of employment positions are missing due to the conflict. In other words, this does not imply that employment is lower in absolute terms. It simply means that employment would have been higher if no conflict had occurred.

<sup>39</sup> In the Appendix, we conduct the same exercise for the entirety of South Sudan in 2016. We provide two maps illustrating the impact of conflict fatalities on (i) GDP growth and (ii) absolute employment loss.

► **Map 2.1 Absolute population change from 2015 to 2017 at pixel level**

Note: This map illustrates the absolute population change in Juba between 2015 and 2017 at pixel level, highlighting the potential demographic impact of the 2016 Battle of Juba. Areas in red indicate population decline, while blue represents population increases. Circles represent conflict events in 2016.

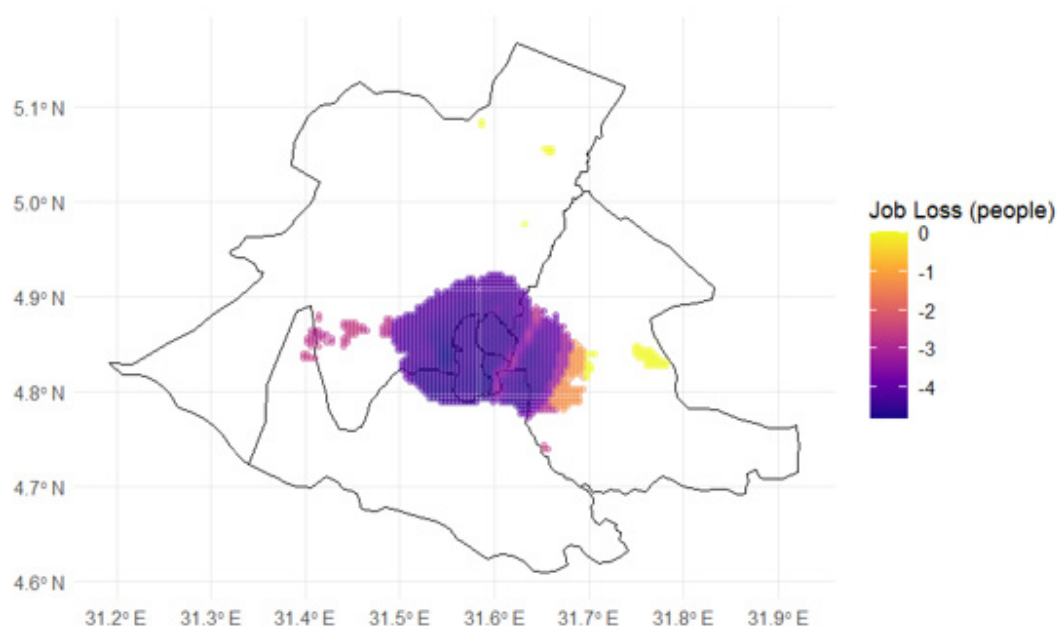
Source: WorldPop.

► **Map 2.2 Estimated contemporaneous impact of conflict fatalities on GDP growth. Battle of Juba 2016 (percentage change)**

Note: This map illustrates the estimated contemporaneous effect of fatalities during the Battle of Juba (2016) on local GDP growth across six selected ADM3 regions in Juba (Juba Town, Gondokoro, Kator, Munuki, Rejaf, and Northern Bari). The effect is calculated using the coefficient estimate of  $[(\log(\text{fatality}))_t]$  from Column 3 in Table 2.1, multiplied by  $[(\log(\text{fatality}))_t]$  and the nighttime-light-to-GDP elasticity of 0.8. The combined one-year and two-year lagged effects are of a similar magnitude to the contemporaneous effect. Only pixels with a positive nighttime light index are included in the calculation and map visualization.



► **Map 2.3 Estimated contemporaneous effect of conflict fatalities on employment loss at pixel level: Battle of Juba 2016 (absolute number of people)**

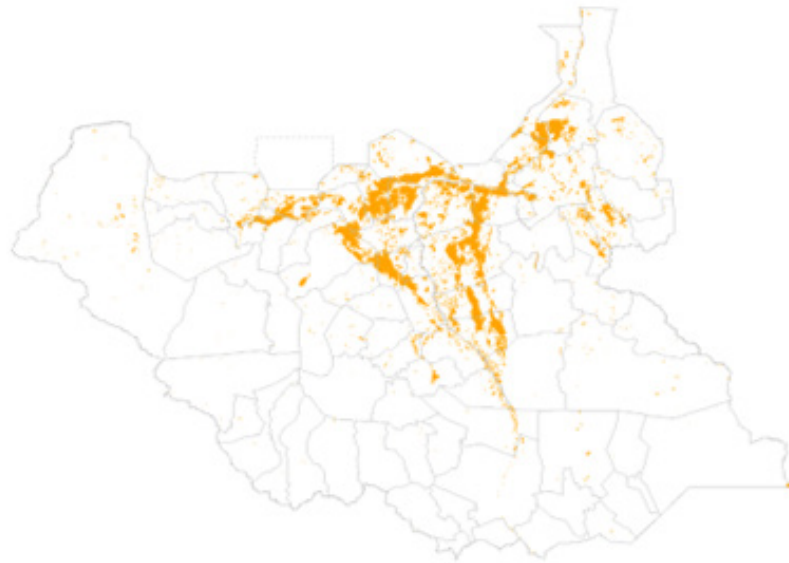


Note: This map illustrates the estimated contemporaneous employment loss caused by fatalities during the Battle of Juba (2016) across six selected ADM3 regions in Juba (Juba Town, Gondokoro, Kator, Munuki, Rejaf, and Northern Bari) at pixel level. The employment loss is calculated by combining the estimated percentage decline in local GDP (proxied by nighttime light data) with an assumed nighttime light-to-employment elasticity of 0.7, multiplied by the estimated number of employed people above 15 years old per pixel. Only pixels with a positive nighttime light index are included in the calculation and visualization. In total, we estimate that the Battle of Juba led to approximately a loss of jobs by 25 per cent.

Secondly, we estimate the impact of floods in May–October 2021 on economic activity, again using nighttime light intensity as a proxy. We leverage satellite data on water extents from 9 to 13 October 2021 over South Sudan (Map 2.2) provided by the United Nations Satellite Centre (UNOSAT).<sup>40</sup>

<sup>40</sup> <https://unosat.org/products/3169>

► Map 2.2 Satellite detected water extents between 9 and 13 October 2021 over South Sudan



Source: United Nations Satellite Centre (UNOSAT).

Using a panel dataset of nighttime light and exposure to 2021 flood at the pixel level from 2020 to 2023, we follow the previous specification and estimate the relationship between nighttime light growth and 2021 flood exposure by regressing the (log) nighttime light index  $\log(ntl)_t$  on flood exposure  $flood_t$  and its lag  $flood_{t-1}$  within a 10 km radius, while controlling for pixels and years fixed effects. Column 1 in Table 2.2 shows that the impact of floods in the current year  $flood_t$  is a 11.1 per cent reduction in local GDP,<sup>41</sup> while floods from the previous year  $flood_{t-1}$  have an even larger effect, reducing nighttime light by 26.7 per cent.<sup>42</sup> This suggests that the economic disruptions from flooding persist well beyond the initial event, possibly due to prolonged damage to infrastructure, displacement, and disruptions in agricultural and trade activities.

Finally, column 2 includes controls for conflict fatalities and their lags to account for the compounding effects of conflict and flooding. While the effect of flooding remains significant, it is substantially reduced, showing a 5.5 per cent decline in GDP in the year when the flood occurred and a 13.8 per cent decline in GDP in the year following the flood. In terms of employment impact, based on an estimated elasticity of 0.7 between nighttime lights and employment, this corresponds to a 4.9 per cent and 12.1 per cent decline in employment, respectively.

These findings demonstrate that both conflict and climate-related disasters have long-lasting negative impacts. The substantial persistence of conflict and flood effects suggests that recovery efforts need to go beyond immediate relief, focusing on long-term livelihood restoration and disaster preparedness.

<sup>41</sup> This is calculated by  $0.1392 * 0.8 = 0.11136$ .

<sup>42</sup> As a robustness check, we implement a standard difference-in-differences (DiD) regression with pixel and year fixed effects. Our results show that, on average, nighttime light intensity in flood-affected areas declined by 11.3 per cent in the post-flood period compared to non-flooded areas, equivalent to a reduction of about 9.5 per cent in local real GDP.

► Table 2.2 Impact of floods 2021 and conflict fatalities on nighttime lights

	(1)	(2)
Flood (t)	-0.1392*** (0.0217)	-0.0693** (0.0222)
Flood (t-1)	-0.3340*** (0.0336)	-0.1723*** (0.0348)
Log Fatality (t)		0.0907*** (0.0080)
Log Fatality (t-1)		-0.1088*** (0.0089)
Num. Obs.	15 099	15 099
R <sup>2</sup>	0.900	0.902

Note: Standard errors are clustered at the pixel level. P < 0.1, \* p < 0.05, \*\* p < 0.01, \*\*\* p < 0.001

## ► 3 Conclusion

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This report provides an empirical analysis of the economic impact of conflict and climate shocks in South Sudan using remote sensing techniques. By leveraging nightlight luminosity as a proxy for economic activity, we estimate the effects of conflict fatalities and flooding on local economic performance from 2012 to 2023.

Our findings reveal that both conflict and climate-related disasters have severe and persistent economic consequences:

The findings highlight severe and persistent economic consequences of conflicts. The population living within conflict-affected areas has steadily increased over time, peaking at nearly 2.8 million in 2017—about a quarter of the total population. Following the 2018 peace agreement, exposure temporarily declined but surged again to over 3 million people by 2020. The number of jobs potentially affected followed a similar pattern, reaching approximately 1 million in 2020—4.5 times higher than in 2012.

Looking at impact assessment, conflict fatalities significantly reduce economic activity, as indicated by declines in nighttime light intensity. In areas with 5 fatalities, local GDP is estimated to have declined by 10.2 per cent in the first year, followed by a 8.5 per cent decline in the second year and a 1.7 per cent decline in the third year.

Beyond the GDP impact, conflicts are also detrimental to job creation. In terms of employment, this corresponds to an 8.9 per cent decline in employment in the first year, followed by 7.4 per cent in the second year and 1.5 per cent in the third year. As a case study, we estimate that the Battle of Juba (2016) led to approximately 25 per cent job losses in central Juba.

Flooding has also had a substantial economic impact. The 2021 floods led to a 5.5 per cent reduction in GDP in the year of flooding and a 13.8 per cent reduction in the following year (when controlling for conflict). In terms of employment, the flood-related economic contraction translates to a 4.9 per cent decline in jobs in the first year and a 12.1 per cent decline in the second year, respectively.

By adopting remote sensing techniques, this study provides a new methodological approach to studying economic trends in data-scarce environments. The findings underscore the urgent need for conflict resolution, improved disaster preparedness, and long-term economic resilience strategies to support sustainable development in South Sudan.

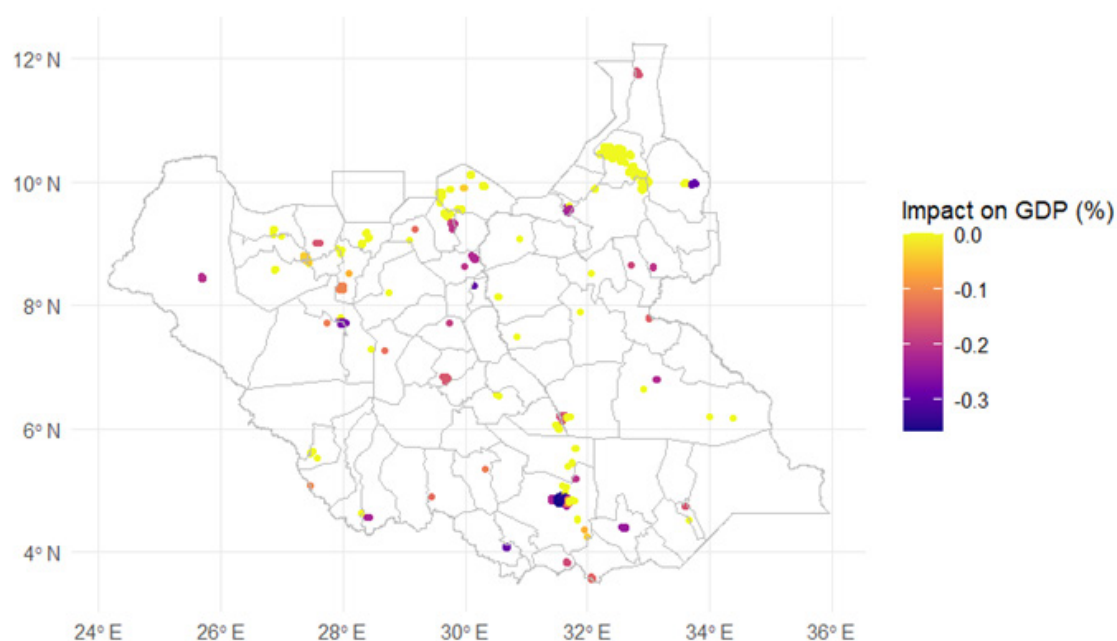
## Appendix

► Table A1 Impact on floods 2021 on nighttime lights: DiD regression result

	(1)
Post Flood	-0.1131***
	(0.0315)
Num. Obs.	15 099
R2	0.307

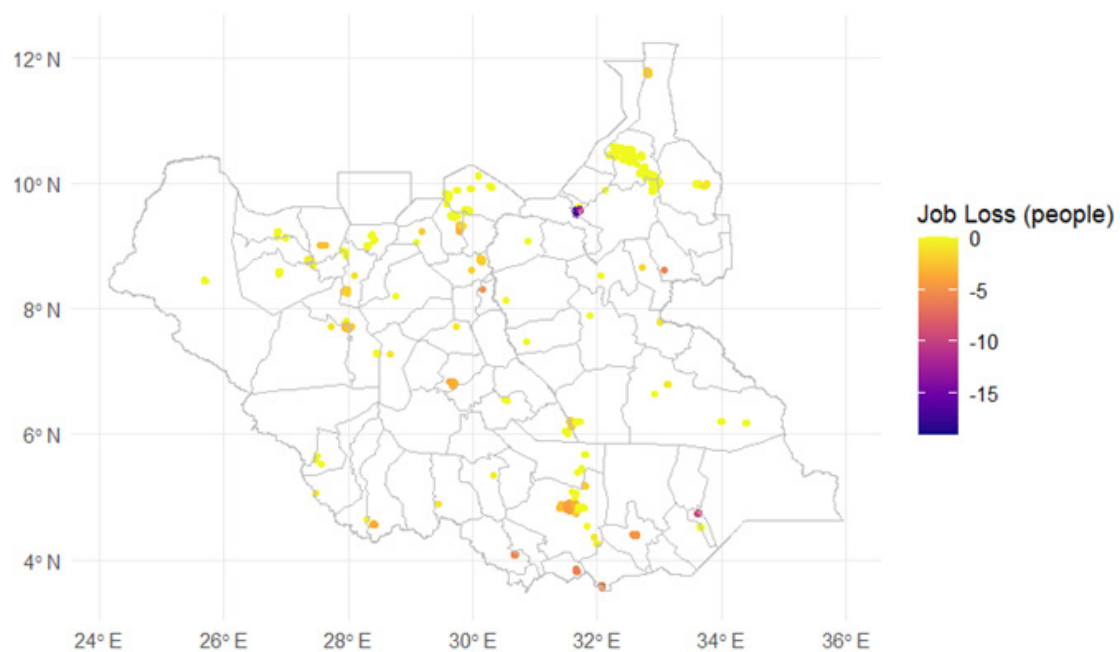
Note: Standard errors are clustered at the pixel level.  $p < 0.1$ , \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

► Map A1 Estimated contemporaneous impact of conflict fatalities on GDP growth in 2016



Note: This map illustrates the estimated contemporaneous effect of fatalities in 2016 on local GDP growth in South Sudan. The effect is calculated using the coefficient estimate of  $\log(fatality)_i$  from Column 3 in Table 2.1, multiplied by  $\log(fatality)_i$  and the nighttime-light-to-GDP elasticity of 0.8. The combined one-year and two-year lagged effects are of a similar magnitude to the contemporaneous effect. Only pixels with a positive nighttime light index are included in the calculation and map visualization.

► Map A2 Estimated contemporaneous impact of conflict fatalities on employment loss in 2026 (absolute number of people)



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