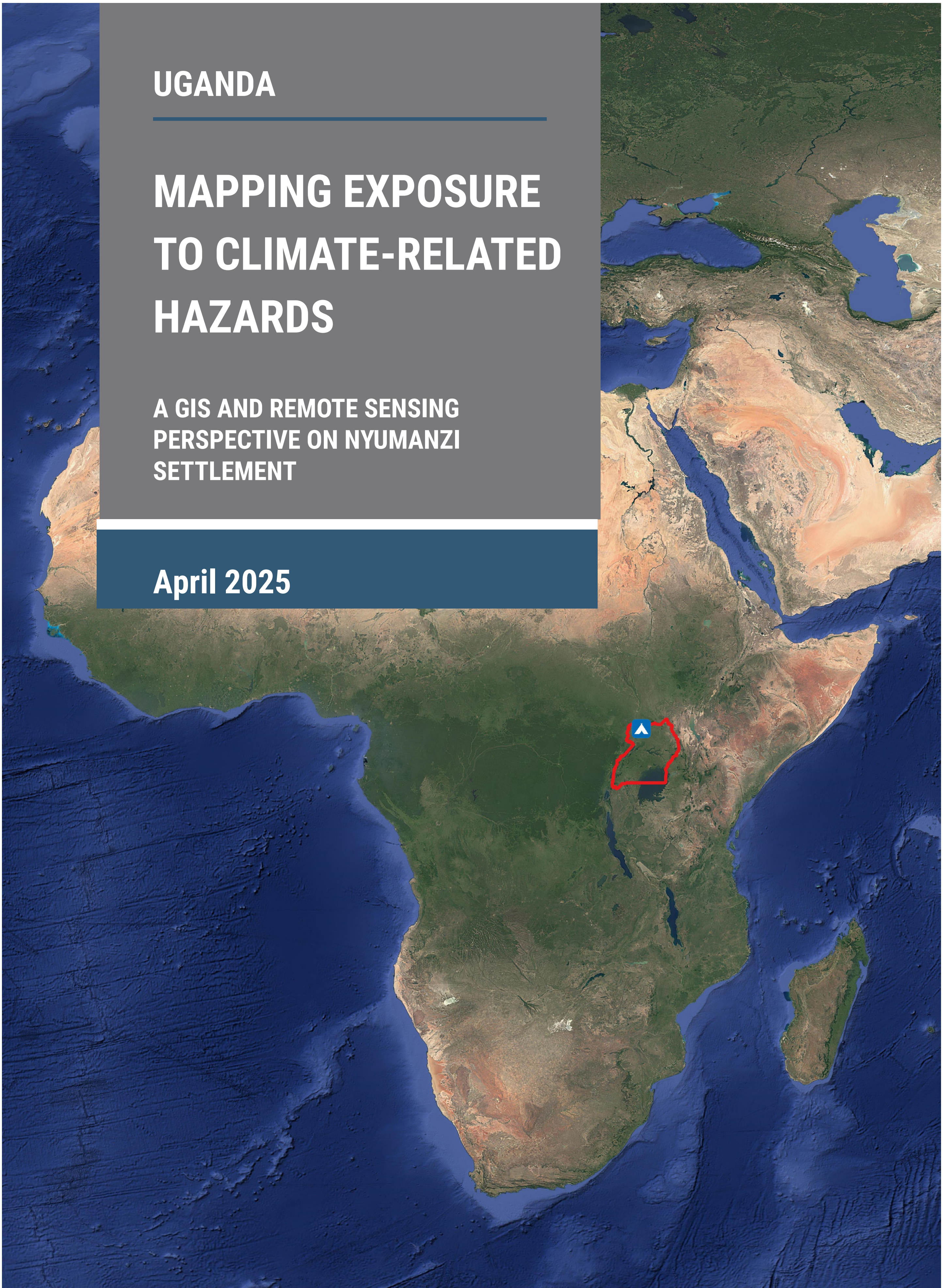
UGANDA

# MAPPING EXPOSURE TO CLIMATE-RELATED HAZARDS

## A GIS AND REMOTE SENSING PERSPECTIVE ON NYUMANZI SETTLEMENT

April 2025



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# TABLE OF CONTENTS

## Section 1.01 List of Acronyms

| | |
|---|---|
| **AI** | Artificial Intelligence |
| **BIO1** | Annual Mean Temperature (Bioclimatic Variable) |
| **BIO12** | Annual Precipitation (Bioclimatic Variable) |
| **CHIRPS** | Climate Hazards Group InfraRed Precipitation with Station Data |
| **CMIP6** | Coupled Model Intercomparison Project Phase 6 |
| **DRR** | Disaster Risk Reduction |
| **ESM** | Earth System Model |
| **GCM** | General Circulation Model |
| **GEE** | Google Earth Engine |
| **GFDL** | Geophysical Fluid Dynamics Laboratory |
| **GHG** | Greenhouse Gases |
| **GIS** | Geographic Information System |
| **HH** | Household |
| **LST** | Land Surface Temperature |
| **MODIS** | Moderate Resolution Imaging Spectroradiometer |
| **ND-GAIN** | Notre Dame Global Adaptation Initiative |
| **NDVI** | Normalized Difference Vegetation Index |
| **OPM** | Office of the Prime Minister |
| **OSM** | OpenStreetMap |
| **SAR** | Synthetic Aperture Radar |
| **SPI** | Standardized Precipitation Index |
| **SSP** | Shared Socioeconomic Pathways |
| **TCI** | Temperature Condition Index |
| **UNHCR** | United Nations High Commissioner for Refugees |
| **UN-SPIDER** | United Nations Platform for Space-based Information for Disaster Management and Emergency Response |
| **VCI** | Vegetation Condition Index |
| **VHI** | Vegetation Health Index |
| **WFP** | World Food Programme |

## Section 1.02 Geographic Classifications for Uganda

**Region** Uganda is officially divided into four regions: Northern, Central, Eastern, and Western Region. However, for practical purposes, unofficial regional distinctions are also commonly used, such as West Nile in the northwestern part of the country and Southwest near the borders with Rwanda and the DRC.

Nyumanzi Refugee Settlement is located in the Northern Region.

**District** A district is the highest local government administrative unit in Uganda. It is responsible for governance, public services, and development within its boundaries. Uganda is divided into 146 districts.

Nyumanzi is situated within the Adjumani District. The district has experienced an influx of refugees, with settlements like Nyumanzi contributing to the district's demographic landscape[1].

**County** A county is a subdivision of a district, mainly used for electoral and administrative purposes. However, counties do not function as independent administrative units—they serve as groupings of sub-counties.

Nyumanzi Refugee Settlement is located in East Moyo County.

**Sitio / Purok** Refugee settlements are not officially classified as administrative units in Uganda’s government structure. However, they function as distinct humanitarian governance units under the management of Uganda’s Office of the Prime Minister (OPM) and the United Nations High Commissioner for Refugees (UNHCR).

Although not part of Uganda’s formal administrative system, settlements are internally structured for management and service delivery. They are typically divided into zones, which are then further subdivided into blocks. These divisions are for operational purposes only and do not hold official administrative status.

Nyumanzi Settlement is divided into seven blocks, named alphabetically from Block A to Block G.

## Section 1.03 Figures, Tables and Maps

# INTRODUCTION

Uganda, a low-income country in East Africa, is home to 1.8 million refugees as of January 2025, making it the largest refugee-hosting country on the continent.[2,3] The majority of refugees originate from South Sudan (54%) and the Democratic Republic of the Congo (31%).[4] Most refugees reside in 13 refugee-hosting districts across West Nile and Southwest Uganda, where they live alongside host communities in open villages known as settlements.[5]

Nyumanzi refugee settlement, established in 2014, is densily populated and the largest of 19 individual settlements that together are commonly referred to as the Adjumani settlement in Northern Uganda.[6] Nyumanzi is located 40 kilometers from Adjumani town and 17km from the South Sudan border. As of January 2025, Nyumanzi hosts 47,342 refugees, primarily from South Sudan.[7]

Despite Africa's minimal contribution to global greenhouse gas (GHG) emissions, Uganda remains highly vulnerable to climate change.[8,9] The Notre Dame Global Adaptation Initiative (ND-GAIN) ranked Uganda as the 14th most vulnerable country and one of the least prepared (163rd out of 182) to respond to climate-related challenges.[10] Uganda's vulnerability is heightened by widespread poverty and a strong reliance on climate-sensitive sectors, including agriculture, water, fisheries, tourism, and forestry.[11]

Since the 1960s, average temperatures in Uganda have risen by 1.3°C. Daily temperature records from that period indicate an increase in the frequency of hot days, with an even more pronounced rise in the occurrence of hot nights.[12] Although defining trends in extreme rainfall conditions is challenging due to data limitations and seasonal variability, droughts in Uganda have become more frequent over the past 60 years. In particular, the western, northern, and northeastern regions have experienced increasingly frequent and prolonged drought conditions over the past two decades.[13] Flooding has become increasingly frequent, primarily driven by more intense rainfall.[14]

These climate trends have had severe localised impacts, including in refugee-hosting areas such as Nyumanzi Settlement. In September 2023, rain induced floods displaced over 4,000 refugees and host community members.[15] The following month, in October 2023, authorities in Dzaipi sub-county, where the settlement is located, urged the government to relocate the settlement due to recurring severe flooding, which had persisted for three consecutive years.[16] However, it remains unclear whether the proposed relocation was intended as a temporary measure or a permanent solution, as no official resettlement has been carried out to date.

Adjumani District, where Nyumanzi is located, experiences temperatures reaching 33°C (with anecdotal evidence pointing at 36.6°C) and is projected to face the highest category of compounded heat risk between 2080 and 2099, making it highly vulnerable to extreme heat.[17][18][19]

Prolonged dry spells and resulting water scarcity were highlighted by the population during the August 2024 scoping exercise and subsequent data collection. Projected precipitation and temperature trends, combined with existing infrastructure limitations and population growth, indicate a high likelihood of increasing water stress across much of Uganda. Forecasts suggest declines in both surface and groundwater supplies, along with reduced groundwater recharge due to decreasing precipitation.[20]

This report provides a detailed description of the methodology and key findings from various assessments conducted in Nyumanzi Settlement between 2019 and 2024 to evaluate climate-related hazards and their impacts on refugees and host communities. The report is structured into the following sections:

1. **Flood Assessment** – This section analyses flood patterns in Nyumanzi Settlement using Sentinel-1 Synthetic Aperture Radar (SAR) data and the UN-SPIDER methodology to assess flood extent and

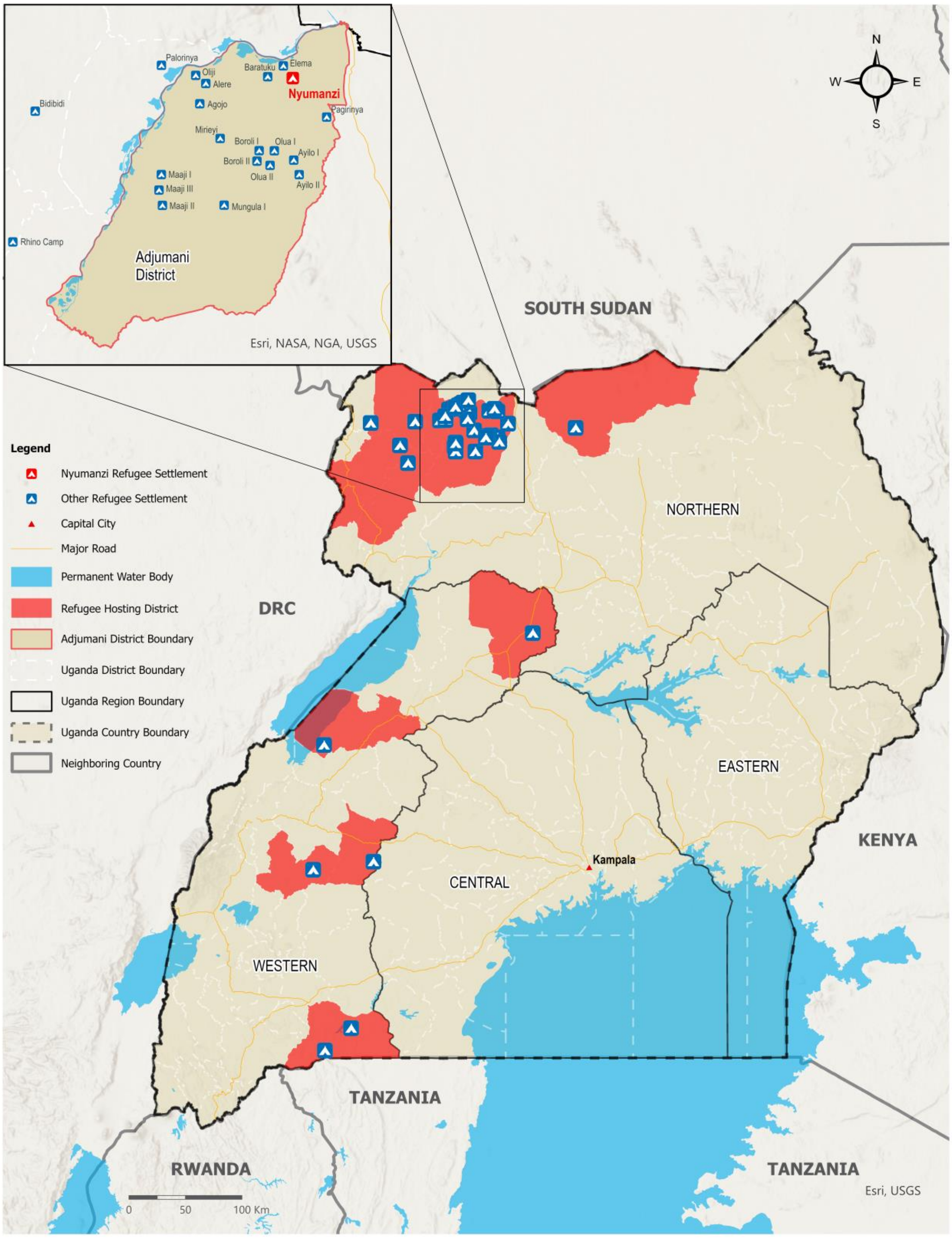
frequency from 2019 to 2023. It identifies flood-prone zones, evaluates flood impacts on settlements and agricultural lands, and estimates affected populations using geospatial analysis.

2. **Drought Assessment** – This section evaluates drought severity and vegetation stress across Nyumanzi using the Vegetation Health Index (VHI) and Vegetation Condition Index (VCI) for the driest year, 2022, identified through CHIRPS Daily Precipitation data (2014–2024). It also incorporates the Standardized Precipitation Index (SPI) to analyse precipitation deficits during the same period. The analysis provides insights into drought impacts on agriculture, water availability, and livelihoods.

3. **Land Surface Temperature (LST)** – This section examines LST variations for the hottest months during the last year (January to March 2024) using Landsat 8 data, highlighting extreme heat zones across Nyumanzi Settlement and surrounding areas. It identifies temperature hotspots in built-up areas and assesses heat stress risks affecting refugees and host communities.

4. **Climate Change Trends and Projections** – This section models historical (1970–2000) and future (2041–2060) climate trends using WorldClim data under two scenarios: SSP1-2.6 (low emissions, strong climate action) and SSP3-7.0 (high emissions, weaker climate policies). The projections indicate rising temperatures, declining precipitation, and increased climate risks such as water scarcity, agricultural stress, and extreme heat exposure.

Map 1: Study Area – Nyumanzi Refugee Settlement, Adjumani District, Uganda.



# FLOOD ASSESSMENT

## Section 2.01 Background

Recurring floods in Nyumanzi settlement have led to displacement, infrastructure damage, and public health crises, necessitating a comprehensive flood assessment to inform climate adaptation strategies and humanitarian response efforts. Flooding has been a persistent hazard, with major events affecting thousands of refugees and host community members. The most recent September 2023 flood displaced 5,000 individuals, destroyed 401 latrines, 250 houses, and 2,000 acres of crops, and caused estimated losses of UGX 70 million (USD 20,000)[21]. These floods have exacerbated food insecurity, housing instability, and the spread of waterborne diseases such as cholera, which was reported in early 2024[22].

This flood assessment is part of the Remote Sensing and GIS component of a broader study that examines climate-related hazards and community responses in Nyumanzi settlement. While the overall assessment integrates qualitative and quantitative surveys to capture community experiences and perceptions, this section specifically leverages geospatial analysis to provide an independent, data-driven perspective on flooding patterns.

## Section 2.02 Analysis Period

The selected timelines for the flood assessment were based on a combination of survey design requirements, data availability, and documented flood events in Nyumanzi Refugee Settlement. Flooding events in Adjumani District are typically reported during the rainy season from April to November[23]. Among the major causes of floods are climate change, environmental degradation, and extreme precipitation[24].

The assessment period (2019–2023) was selected to align with survey question CO.1, which asked respondents in October 2024 to recall flooding events they had experienced in the past five years in Nyumanzi or Dzaipi/Arinyapi subcounty. This five-year recall period therefore covers 2019 to 2024. This approach enables a direct comparison between reported flood events and observed flood patterns from geospatial data.

To ensure the analysis focused on periods with the highest flood risk, the wettest months within each year were identified using CHIRPS Daily,[25] a rainfall dataset that tracks historical precipitation trends. This approach helped pinpoint when flooding was most likely to occur, improving the accuracy of flood extent detection and its impact on land cover, infrastructure, and communities.

## Section 2.03 Methodology

This flood assessment examines the impact of recurring floods in Nyumanzi settlement plus a 5 Km buffer, between 2019 and 2023. To map flooded areas and assess their effects on communities and land use, the study used the UN-SPIDER methodology, [26] a recognized approach for flood detection and damage assessment.

By analysing Sentinel-1 Synthetic Aperture Radar (SAR) data in Google Earth Engine (GEE), this assessment provides a detailed view of flood patterns, even in areas where on-the-ground data is limited.

**1. Flooded Area Processing in ArcGIS Pro**

After processing the flooded area raster in GEE, the data was imported into ArcGIS Pro for further analysis. The following steps were performed:

- **Masking Flooded Areas**: The flooded raster was clipped to focus on Nyumanzi settlement with an additional 5 km buffer to account for surrounding areas that may influence flood dynamics.
- **Flood Frequency Analysis**: Using ArcGIS Pro Raster Calculator, a flood frequency map was generated for the period 2019–2023. The formula applied was:

***Flooded_Frequency = "Flooded_area_2019" + "Flooded_area_2020" + "Flooded_area_2021" + "Flooded_area_2022" + "Flooded_area_2023"***

This operation summed up binary raster layers (1 for flooded, No Data for non-flooded) across the five-year period. The final output ranged from 0 to 5, indicating the number of times each area experienced flooding.

**2. Land Use Analysis**

To assess the impact on different land cover types, further masking operations were performed:

- **Settlement Areas**: The flooded area raster was masked with OSM downloaded settlement boundaries obtained from overpass turbo[27]**.**
- **Agricultural and Rangelands**: The flooded areas were overlaid with digitized agricultural and rangeland areas (visible on high-resolution imagery available through Google Earth Pro) to quantify the extent of flooding in these regions.

**3. Estimating Affected Population**

A key objective of this study was to estimate the number of households and individuals affected by flooding. To achieve this, the OpenStreetMap (OSM) Building footprint layer was utilized. This dataset provided spatial information on building locations and distributions within Nyumanzi settlement, allowing for a more localized estimation of affected households. However, the buildings were not categorised into residential and non-residential types; all structures were assumed to be residential and occupied by a single household, which may affect the accuracy of the estimates.

**Estimating Affected Households:**

- The Summarize Within tool in ArcGIS Pro was applied to calculate the total count of buildings within each block of Nyumanzi settlement.
- The flooded area raster for each year was overlaid with the OSM building footprints to identify affected buildings.
- The number of affected households was then estimated as the total count of affected buildings.

**Estimating Affected Population:**

- Based on existing research and settlement assumptions, an average household in Nyumanzi refugee settlement is estimated to contain **10 individuals**[28].
- The total affected population was estimated as:

***Affected Population = Number of Affected Households × 10***

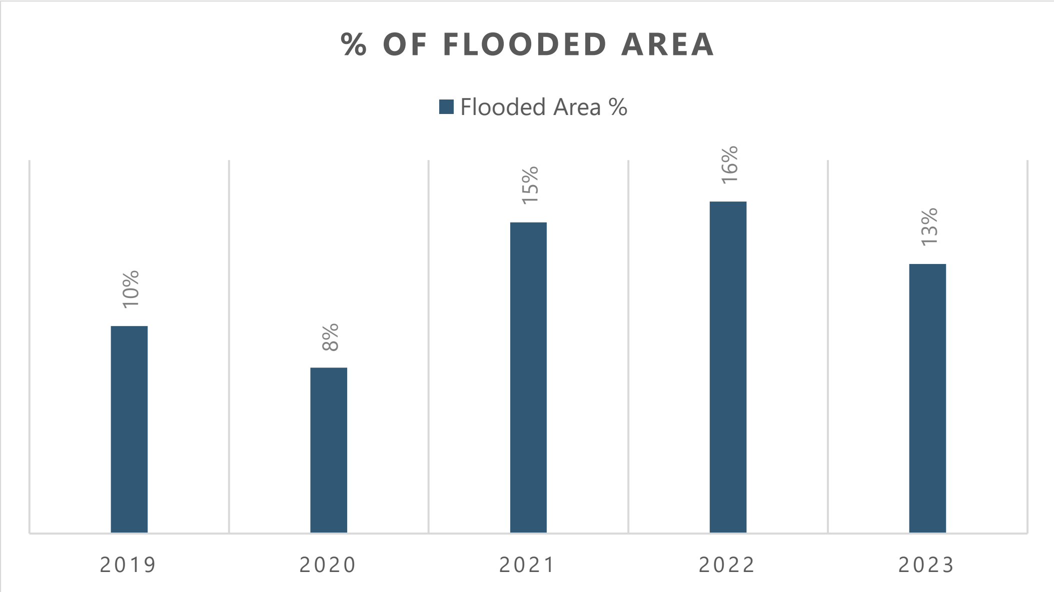
## Section 2.04 Findings

### (a) Flood Affected Agricultural/Rangeland Area

This analysis was done for Nyumanzi plus 5km buffer. For each year, the percentage of flood affected agricultural/rangeland is calculated as:

$$Percentage = \left(\frac{Affected\ Area}{Total\ Area}\right) \times 100$$

Figure 1 : Percentage of Flood Affected Agricultural/Rangeland Area

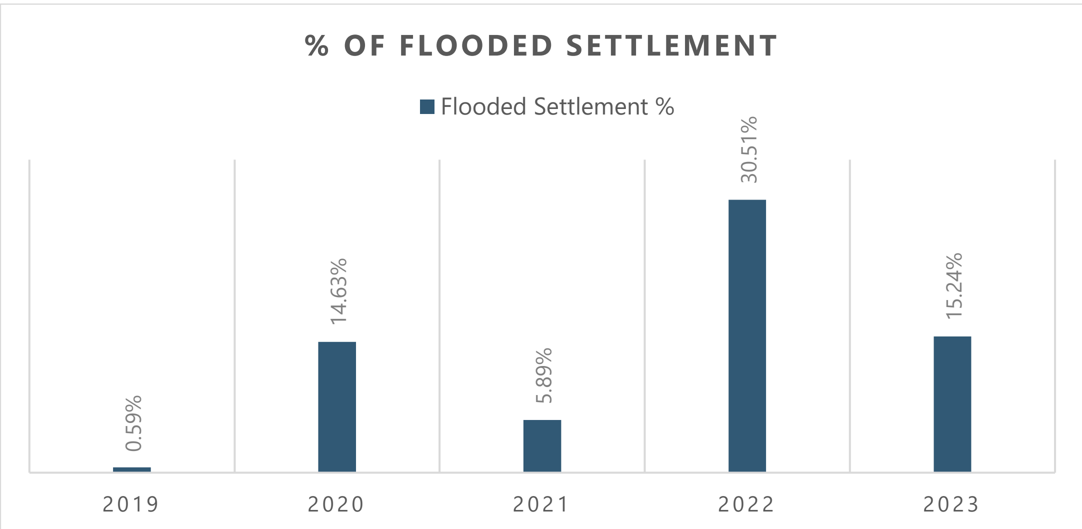



- The highest flood impact on agricultural and rangeland areas occurred in 2022 (16% of the total agricultural/rangeland).
- The lowest impact was in 2020 (8% flooded), suggesting a relatively dry year compared to the others.
- The trend shows variability in flooding, with notable peaks in 2021 and 2022.

### (b) Flood Affected Settlement

This analysis was done for Nyumanzi settlement alone. Similarly, the percentage of flood affected settlement area is calculated:

Figure 2 : Percentage of Affected Settlement



- The highest settlement area flooding occurred in 2022, with 301% of the settlement area affected.
- The lowest settlement flooding was in 2019, with only 0.6% affected.
- 2020 and 2023 had moderate flooding impacts (14.63% and 15.24%, respectively).

### (c) Flood Impact on Settlement Blocks

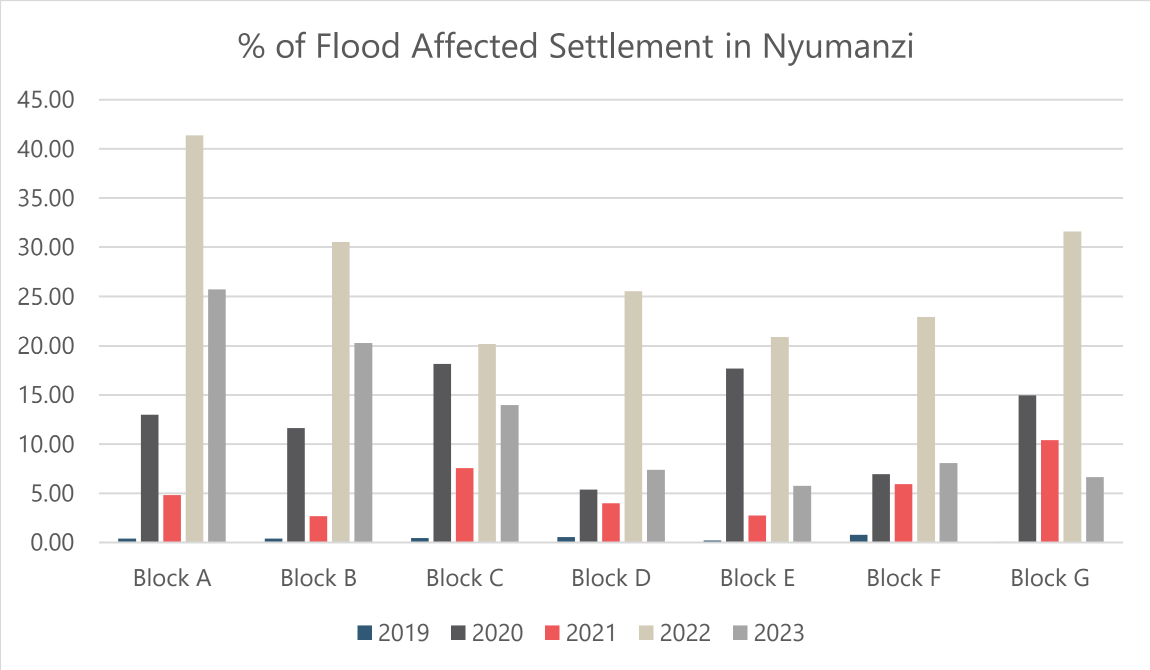
The following table represents the extent of flooding in different blocks[1] within Nyumanzi Refugee Settlement Area from 2019 to 2023.

Table 1 : Annual Flood Impact: Affected Settlement Area vs. Total Settlement Area by Block (2019-2023)

| **Year** | **2019** | **2020** | **2021** | **2022** | **2023** | |
|---|---|---|---|---|---|---|
| **Block Name** | **Affected Settlement Area (ha)** | **Affected Settlement Area (ha)** | **Affected Settlement Area (ha)** | **Affected Settlement Area (ha)** | **Affected Settlement Area (ha)** | **Total Settlement Area (ha)** |
| **Block A** | 0.010875 | 0.367855 | 0.136717 | 1.171788 | 0.728684 | 2.83 |
| **Block B** | 0.009965 | 0.284138 | 0.065757 | 0.745538 | 0.494282 | 2.44 |
| **Block C** | 0.012186 | 0.48176 | 0.200005 | 0.535262 | 0.370457 | 2.65 |
| **Block D** | 0.017515 | 0.168156 | 0.124301 | 0.797643 | 0.231302 | 3.13 |
| **Block E** | 0.008991 | 0.741973 | 0.114525 | 0.877211 | 0.242254 | 4.20 |
| **Block F** | 0.017126 | 0.149666 | 0.128153 | 0.494196 | 0.174156 | 2.16 |
| **Block G** | 0.000939 | 0.169841 | 0.11821 | 0.359137 | 0.075439 | 1.14 |

[1] "Blocks" in refugee settlements refer to small administrative units within zones, used to organise households and facilitate service delivery and governance.

Figure 3 : Flood Affected Settlement by Block




- Between 2019 and 2023, remote sensing analysis of Nyumanzi settlement revealed fluctuating levels of flood impact on buildings, highlighting spatial and temporal variations in exposure.
- **In 2019, flood impact was minimal across all blocks**, with less than 1% of building areas affected. This likely reflects a period of low flood intensity or limited flooding in built-up areas.
- **A sharp increase was observed in 2020**, with larger portions of building areas affected in most blocks. Block C (18%) and Block E (18%) showed the highest levels of exposure. This rise may indicate a major flooding event or changes in land cover and drainage conditions that increased the vulnerability of buildings.
- **In 2021, flood-affected areas decreased across most blocks**, with notable reductions in Block B (3%) and Block E (3%). **However, Block G experienced an increase in exposure** to 10%, pointing to localised variations in flood dynamics.
- **The highest flood impact occurred in 2022, with extensive building exposure in several areas.** Block A was most affected (41%), followed by Block G (31%) and Block B (30%). These figures suggest a particularly intense flood event or persistent issues possibly related to drainage or terrain.
- **In 2023, the extent of flooding declined compared to the 2022 peak but remained elevated in several areas.** Blocks A (26%), B (20%), and C (14%) continued to show high levels of building exposure. In contrast, Blocks G (7%) and E (6%) saw marked reductions, potentially reflecting the effects of improved flood management or natural drainage recovery.

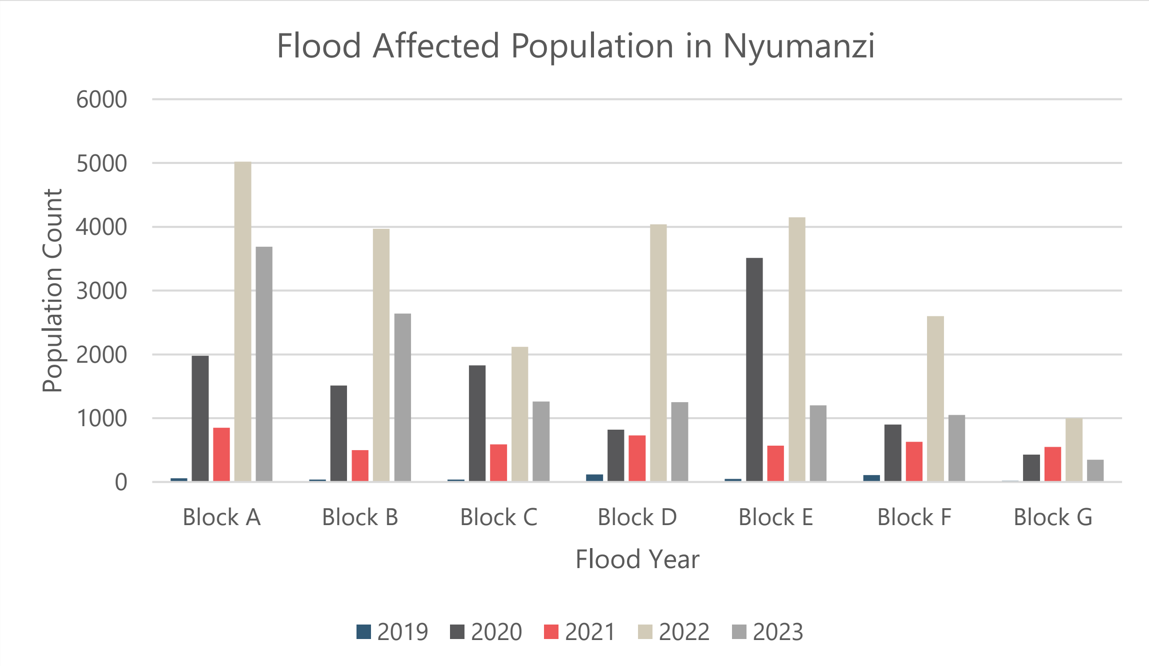
### (d) Estimated Affected Population in Settlement Blocks

The following table estimates the number of households (HH) and population affected by floods each year.

Table 2 : Estimated Annual Flood Impact: Affected vs. Total Population by Block (2019-2023)

| Block Name | 2019 HH | 2019 Pop | 2020 HH | 2020 Pop | 2021 HH | 2021 Pop | 2022 HH | 2022 Pop | 2023 HH | 2023 Pop |
|---|---|---|---|---|---|---|---|---|---|---|
| **Block A** | 6 | 60 | 198 | 1980 | 85 | 850 | 502 | 5020 | 369 | 3690 |
| **Block B** | 4 | 40 | 151 | 1510 | 50 | 500 | 397 | 3970 | 264 | 2640 |
| **Block C** | 4 | 40 | 183 | 1830 | 59 | 590 | 212 | 2120 | 126 | 1260 |
| **Block D** | 12 | 120 | 82 | 820 | 73 | 730 | 404 | 4040 | 125 | 1250 |
| **Block E** | 5 | 50 | 351 | 3510 | 57 | 570 | 415 | 4150 | 120 | 1200 |
| **Block F** | 11 | 110 | 90 | 900 | 63 | 630 | 260 | 2600 | 105 | 1050 |
| **Block G** | 2 | 20 | 43 | 430 | 55 | 550 | 100 | 1000 | 35 | 350 |
| **TOTAL** | **44** | **440** | **1098** | **10980** | **442** | **4420** | **2290** | **22900** | **1144** | **11440** |

Figure 4 : Estimate of Flood Affected Population

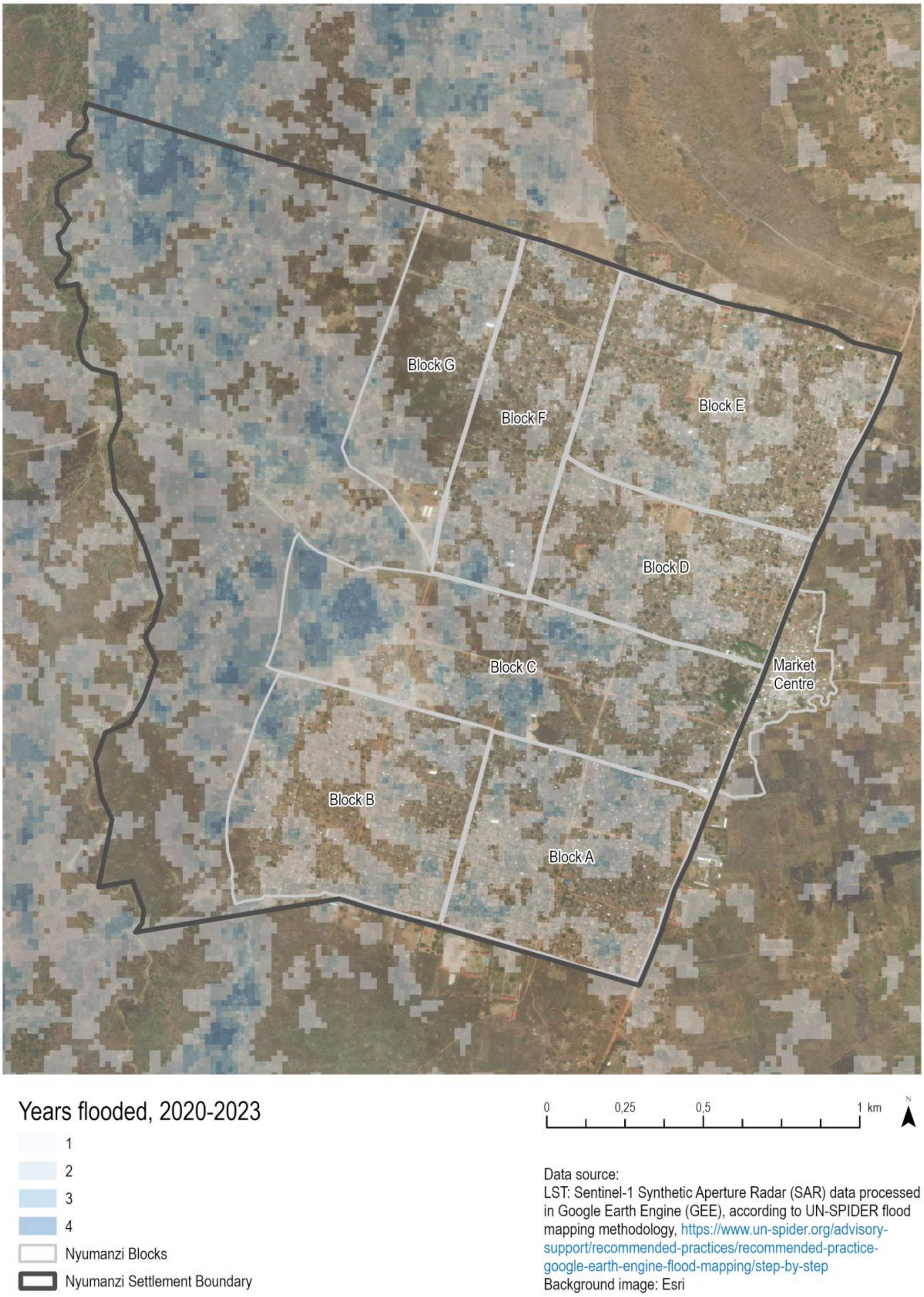



- 2022 saw the highest number of affected people, with 22,900 individuals affected by flooding.
- 2020 and 2023 also had high impacts, affecting 10,980 and 11,440 people, respectively.
- Block A had the highest impact in 2022, with 85 households (850 people) affected.
- Block G remained the least affected, with only 2350 people affected in the last 5 years (2019-2023).

## Section 2.05 Flood Frequency Map (2018–2023)

The map below provides a spatial representation of flood frequency, illustrating the likelihood of different blocks within Nyumanzi experiencing flooding.

Map 2 : Nyumanzi Flooding Frequency Map (2019–2023)




Data source:
LST: Sentinel-1 Synthetic Aperture Radar (SAR) data processed in Google Earth Engine (GEE), according to UN-SPIDER flood mapping methodology, https://www.un-spider.org/advisory-support/recommended-practices/recommended-practice-google-earth-engine-flood-mapping/step-by-step
Background image: Esri

## Section 2.06 Key Takeaways: Flooding Trends and Impacts (2019 – 2023)

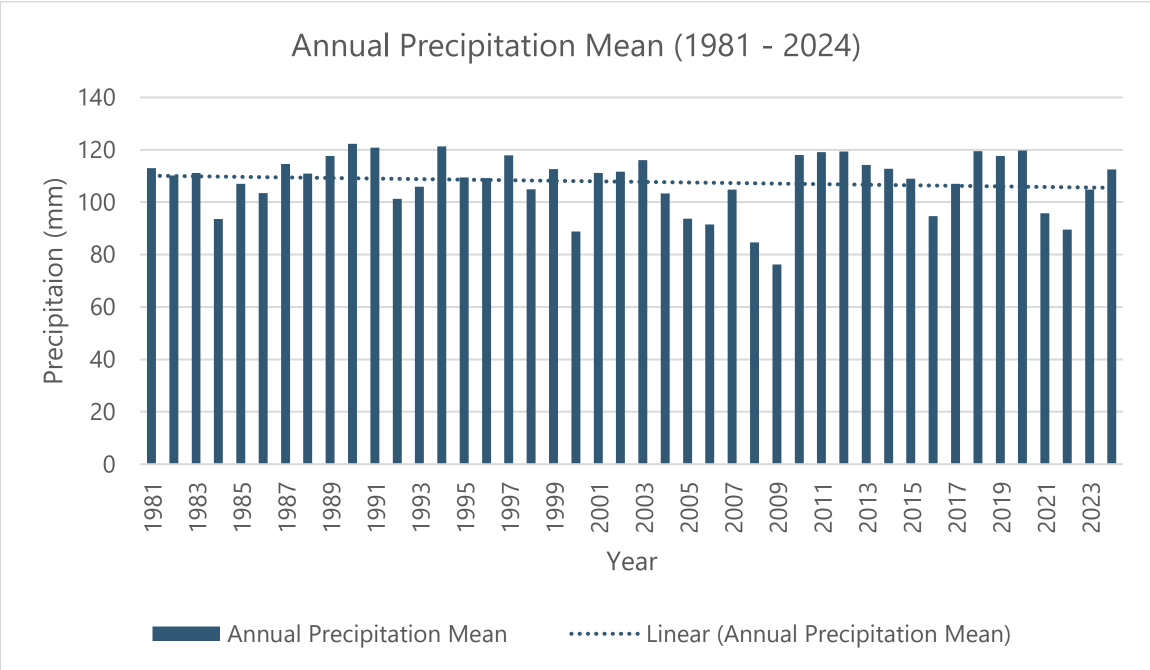
1. Overall Flooding Trends
   - Flooding in Nyumanzi Settlement varied considerably across the five-year period. The most severe year was **2022**, during which approximately **23% of the settlement's land area** was affected, with an estimated **19,520 individuals** impacted. Moderate flood impacts were recorded in both **2020** and **2023**, each affecting about **15%** of the total land area. In contrast, **2019** had the lowest recorded impact, with just **0.59%** of the area inundated (equivalent to **1.15 hectares**), indicating a relatively dry year.
2. Impact on Agricultural and Rangeland Areas
   - Flooding also had notable effects on farmland within a 5 km buffer zone surrounding the settlement. The most extensive agricultural impact occurred in **2022**, when **16% of farmland**—approximately **10 hectares**—was inundated. Conversely, **2020** saw the lowest level of agricultural flooding, with just **8%** of farmland affected, reflecting drier conditions during that year.
3. Impact on Settlements & Infrastructure
   - Several settlement blocks experienced considerable flooding in 2022. The worst-affected areas included:
     - **Block A**: 13.39 hectares flooded, covering **31%** of the block's area
     - **Block B**: 9.66 hectares flooded (**21%**)
     - **Block D**: 6.83 hectares flooded (**22%**)
   - The **market centre** remained largely unaffected throughout the period, with the exception of **2022**, when about **6%** of its total area was inundated.
4. Estimated Population Impact
   - The estimated number of individuals affected by flooding peaked in **2022**, with over **22,900 individuals** impacted across the settlement. Among them, **Block A** had the highest exposure, with an estimated **502 households**, or approximately **5,020 individuals**, affected. In contrast, **Block G** remained the least affected area throughout the five years, with an estimated cumulative impact of **2,350 individuals** between 2019 and 2023.
5. Flood Frequency Patterns & Risk Zones
   - Recurring flood hotspots were identified through longitudinal analysis. **Block A, Block B, and Block D** experienced flood events in at least **four out of five years**, highlighting persistent risk in these zones. While **Blocks G and E** were also affected, both showed reduced flood coverage in **2023**, possibly reflecting improvements in drainage or natural recovery.
   - The most extensive block-level impacts occurred in **2022**, with:
     - **Block A**: 17.94 hectares flooded (**41.37%** of block area)
     - **Block G**: 6.24 hectares flooded (**31.6%**)
     - **Block B**: 14.69 hectares flooded (**30.52%**)
   - Additionally, **agricultural and rangeland areas** near **Mudjopele** and **Origo villages** were severely impacted in 2022. This reduced the availability of cultivable land and pasture, further straining food production and livestock grazing.

# DROUGHT ASSESSMENT

## Section 3.01 Background

According to an article by Oxfam, climate change impacts small-scale farmers in the West Nile sub-region of Uganda, including Adjumani district, which hosts the Nyumanzi settlement29. This region faces unpredictable droughts and floods that result in reduced agricultural yields and food insecurity. This climatic stress necessitates a focused analysis of Vegetation Indices to monitor the health and productivity of crops.

Figure 5 : Adjumani District Annual Precipitation Mean (1981 - 2024)




Drought impacts can be understood through two critical perspectives: meteorological drought, which results from prolonged reductions in precipitation, and vegetation drought, which manifests as stress on crops and pasturelands. This study integrates the Standardized Precipitation Index (SPI) to analyse rainfall variability and Vegetation Health Index (VHI) and Vegetation Condition Index (VCI) to assess vegetation stress. By combining these indicators, the study provides a comprehensive view of drought conditions in Nyumanzi and Adjumani District, offering insights into how extreme weather events impact food security and water availability.

Vegetation indices (VIs) are mathematical combinations of two or more spectral bands that highlight vegetation characteristics, enabling consistent spatial and temporal comparisons of photosynthetic activity and canopy structure[30].

Complementing vegetation indices, the Standardized Precipitation Index (SPI) is a widely used metric for assessing wet and dry conditions based on precipitation data. It quantifies precipitation anomalies by comparing observed rainfall to historical averages, identifying meteorological drought across various time scales. SPI is expressed in terms of standard deviations from the mean precipitation, providing an objective measure of precipitation deficits or excesses.

In recent years, Adjumani and Nyumanzi have experienced severe droughts in recent years, notably in July 2022, when a prolonged dry spell resulted in food shortages and humanitarian crises[31]. Over 200 people reportedly died from hunger that month alone due to the prolonged drought and ongoing insecurity in the area[32][33]. This dire situation left more than half a million residents vulnerable to starvation, according to local officials and charity workers. In August 2014, The Lutheran World Federation (LWF) partnered with UNICEF to address the pressing issue of water shortage by implementing motorized water systems in Nyumanzi, along with Ayilo 2 and Elema refugee settlements[34]. This initiative was critical due to the poor underground water potential and the overwhelming demand from the large refugee population, resulting in long queues at water points. The situation worsened during dry spells when boreholes either dried up or their yields decreased.

## Section 3.02 Analysis Period

The analysis of the VCI, VHI and SPI was conducted for June 2022, a period identified as the driest within Nyumanzi settlement and its surrounding areas between 2014 and 2024. This period was selected based on CHIRPS Daily Precipitation data[35], which highlighted June 2022 as a critical time for assessing drought conditions.

## Section 3.03 Methodology

### (a) VHI/VCI Methodology

The VHI and VCI analysis was conducted following the UN-Spider Agriculture Drought Monitoring and Hazard Assessment methodology using Google Earth Engine (GEE) [36]. The analysis focused on Nyumanzi settlement and a 5km buffer, incorporating surrounding agricultural and rangeland areas. To enhance accuracy, these land cover types were manually digitized in Google Earth Pro.

The VCI and VHI were generated to assess drought severity. VCI measures vegetation health based on NDVI variations, while VHI integrates VCI and Temperature Condition Index (TCI) to account for both vegetation stress and thermal conditions. These indices were used to derive a Drought Index, classifying drought severity into categories ranging from mild to extreme.

The processed VCI/VHI raster datasets were exported to ArcGIS Pro for further spatial analysis and mapping. This allowed for detailed visualization of drought severity across Nyumanzi, offering insights into agricultural productivity, pasture conditions, and food security for both refugee and host communities.

The classification schemes used for VHI and VCI followed the established thresholds by Kogan (1995) [37], ensuring standardized drought assessment.

Table 3 : VHI Drought Classification Scheme (from Kogan, 1995)[38]

| VHI Range | Drought Classification | Interpretation |
|---|---|---|
| < 0.1 | Extreme Drought | Very high vegetation stress, potential crop failure, severe impact on agriculture |
| 0.1 - 0.2 | Severe Drought | Significant vegetation stress, low productivity, potential food shortages |
| 0.2 - 0.3 | Moderate Drought | Noticeable vegetation stress, reduced growth, early warning signs for agriculture |
| 0.3 - 0.4 | Mild Drought | Slight vegetation stress, some impact on crops but manageable |
| > 0.4 | No Drought | Healthy vegetation, good growing conditions |

The Vegetation Condition Index (VCI) is a remote sensing-based drought monitoring index that measures how close the current month's Normalized Difference Vegetation Index (NDVI) is to its historical minimum and maximum values[39]. It helps assess vegetation health and drought severity.

Table 4 : Drought Grades Defined by Vegetation Condition Index (VCI)

| VCI Range | Drought Classification | Interpretation |
|---|---|---|
| < 0.10 | Extreme Drought | Severe vegetation stress, high likelihood of crop failure |
| 0.10 - 0.20 | Severe Drought | Significant vegetation stress, reduced agricultural productivity |
| 0.20 - 0.30 | Moderate Drought | Noticeable vegetation decline, affecting some crops and pastures |
| 0.30 - 0.40 | Mild Drought | Slight reduction in vegetation health, but not critical |
| 0.40 - 0.50 | Near Normal Conditions | Vegetation is close to historical averages |
| 0.50 - 1.00 | No Drought (Optimal Conditions) | Healthy vegetation, normal or above-average conditions |

### (b) SPI Methodology

The SPI analysis was conducted using the UN-Spider Drought Monitoring methodology within GEE[40]. Daily precipitation data from the CHIRPS dataset (2014–2024) was used to calculate SPI values at a monthly interval. This analysis focused on Adjumani district.

SPI was calculated by fitting the long-term precipitation record to a probability distribution, which is then transformed into a normal distribution so that the mean SPI value for the location and period is zero[41]. Positive SPI values indicate greater than median precipitation, while negative values indicate less than median precipitation. The SPI can be computed for different timescales, reflecting the impact of drought on various water resources.

The SPI values are typically classified into categories that describe the severity of wet and dry conditions. According to the World Meteorological Organization's Standardized Precipitation Index User Guide, [42] the classification is as follows:

Table 5: SPI Classification Table

| SPI Value Range | Classification |
|---|---|
| 2.0 and above | Extremely wet |
| 1.5 to 1.99 | Very wet |
| 1.0 to 1.49 | Moderately wet |
| -0.99 to 0.99 | Near normal |
| -1.0 to -1.49 | Moderately dry |
| -1.5 to -1.99 | Severely dry |
| -2.0 and below | Extremely dry |

## Section 3.04 Findings

### (a) VHI Findings

- The VHI Drought Index Map (June 2022, Before Harvest) indicates that large areas within and around Nyumanzi settlement experienced moderate to extreme drought conditions.
- Mudjopele, Origo, and Paoko to the west of Nyumanzi were among the most severely affected areas, showing extreme drought, which suggests severe vegetation stress and a high risk of crop failure.
- Ege and Mbere, located just outside the settlement, were also impacted by moderate to severe drought, indicating water stress on crops and pasture.
- Some parts of Lire, Ovuvu, and Iloho, to the north and northeast, showed mild drought conditions, suggesting slightly better vegetation health compared to the western and central areas.
- The southern villages of Pasia, Maiaicko, and Makolombgili experienced a mix of mild to moderate drought, indicating noticeable but less severe vegetation stress.

### (b) VCI Findings

- The VCI Drought Index Map reflects a similar pattern, with Mudjopele, Origo, and Paoko continuing to experience extreme drought conditions, confirming severe vegetation loss.
- Nyumanzi settlement and its immediate surroundings, including Ege and Mbere, exhibited moderate to severe drought, which likely impacted local agricultural productivity and food security.
- Lire, Ovuvu, and Iloho to the north had mild drought conditions, suggesting some level of resilience in vegetation health.
- Angwarapi and Adjugopi, located on the southwestern edge of the mapped area, also showed moderate drought, indicating reduced pasture availability for livestock.

### (c) SPI Findings

#### (i) Severely Dry Conditions:

- The most affected areas experiencing severe drought are spread across different parts of Adjumani District.
- Notably, Nyumanzi Settlement and its immediate surroundings are among the regions facing severe drought conditions, which could have an implications for agriculture, water availability, and livelihoods.
- Other towns such as Ofongi and parts of Rhino Camp are also experiencing severely dry conditions, indicating a widespread drought impact.

#### (ii) Moderately Dry Conditions:

- Some parts of the region, including areas near Laropi, Adjumani town, and Nimule, are classified as moderately dry rather than experiencing extreme drought.
- While these areas are still affected by dryness, the conditions are comparatively less severe than those in Nyumanzi and Ofongi.
- The moderate drought conditions could still affect crop yields and pasture availability but may not lead to immediate crisis levels.

## Section 3.05 Implications of Findings

The analysis of VHI, VCI, and SPI indices reveals drought impacts on vegetation, water resources, and livelihoods in Nyumanzi Refugee Settlement and Adjumani District. These findings highlight the urgent need for interventions to mitigate the effects of drought on both refugee and host communities.

**1. Vegetation Stress and Crop Failure Risk**

The severe drought conditions in Mudjopele, Origo, and Paoko pose a high risk of crop failure due to extreme vegetation stress. Ege and Mbere also face moderate to severe drought, contributing to water stress on both crops and pastures. This threatens local food security, particularly in areas with agricultural dependence. These regions need immediate support for agricultural resilience, including drought-resistant crops and water management strategies.

**2. Livestock and Pasture Availability**

In areas like Ege, Mbere, and Adjugopi, drought has reduced pasture availability, threatening livestock productivity. As these regions face moderate drought, pastoralist communities reliant on grazing are at heightened risk.

**3. Water Availability and Community Wellbeing**

The severe drought in Nyumanzi and surrounding regions, as indicated by the SPI findings, is putting pressure on water resources.

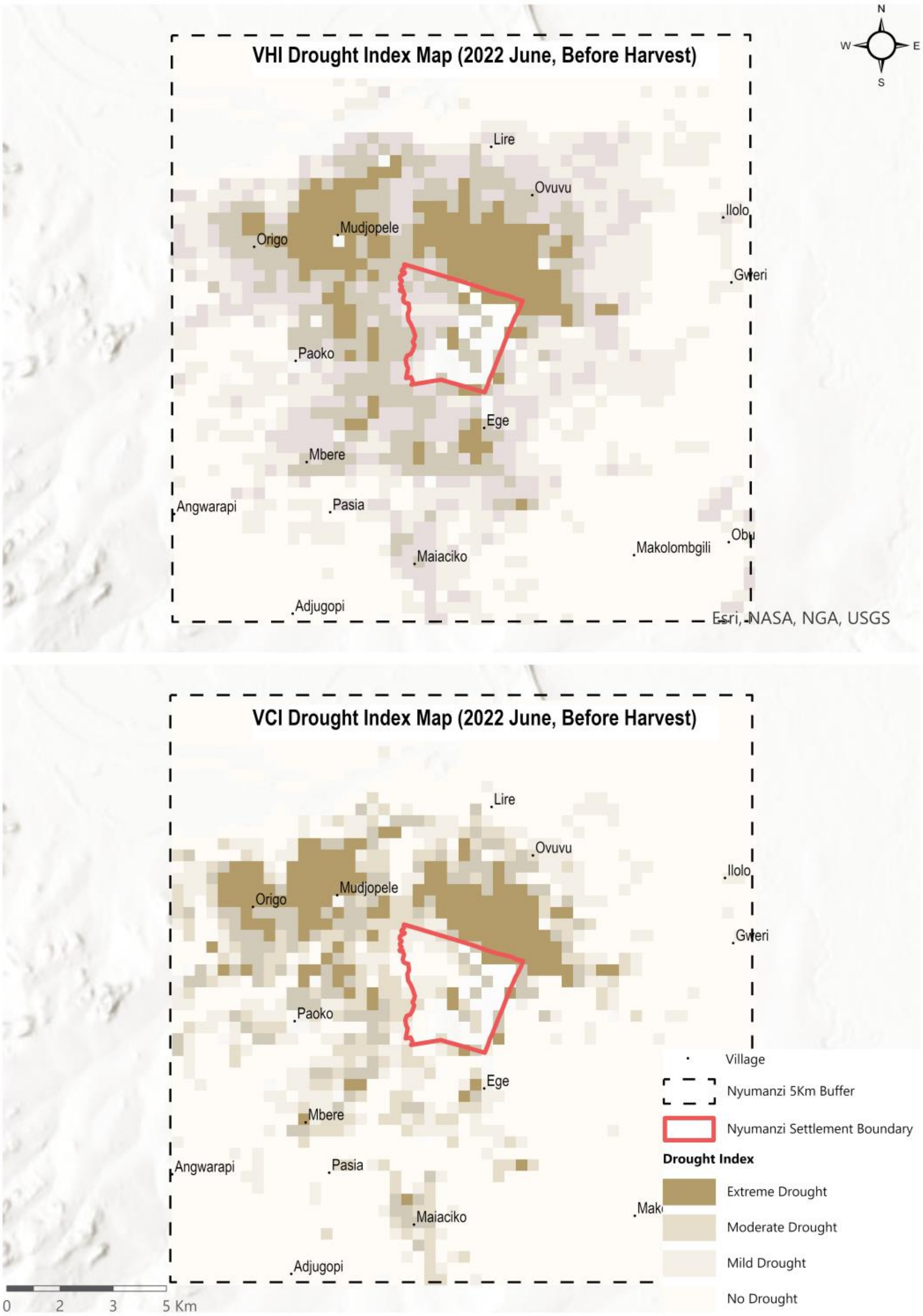
**4. Regional Drought Impacts**

The SPI results also show severe dryness in other areas such as Ofongi and parts of Rhino Camp, broadening the scope of the drought in Adjumani District. While areas like Lire, Ovuvu, and Iloho show milder drought conditions, these regions can serve as potential support areas for the more affected regions.

## Section 3.06 Maps

### (a) VHI/VCI Map

Map 3 : VHI/VCI Drought Index Map




## Section 3.07 Key Takeaways: Drought Trends and Impacts (June 2022)

1. Overall Drought Severity

- June 2022 was identified as the driest period between 2014 and 2024, with extreme drought conditions affecting Nyumanzi Refugee Settlement and surrounding host community villages.
- The drought was confirmed using Vegetation Health Index (VHI), Vegetation Condition Index (VCI), and Standardized Precipitation Index (SPI) analysis.
- Meteorological drought (precipitation deficits) and vegetation drought (crop and pasture stress) were observed across multiple locations, leading to food shortages and severe water scarcity.

2. Vegetation Stress and Agricultural Impacts
   - Extreme drought conditions were observed in the host community villages of Mudjopele, Origo, and Paoko, with VHI values below 0.1, indicating a high risk of crop failure.
   - Moderate to severe drought was recorded in the host community villages of Ege and Mbere, leading to water stress on agriculture and rangelands.
   - Lire, Ovuvu, and Iloho, also host community villages, experienced mild drought conditions, suggesting slightly better vegetation health but still facing dryness.
   - The host community villages of Pasia, Maiaicko, and Makolombgili had mild to moderate drought stress, affecting crop productivity and grazing areas.
3. Impacts on Livestock and Pasture Availability
   - Drought conditions reduced pasture availability in the host community villages of Ege, Mbere, and Adjugopi, posing risks to livestock productivity and food security for pastoralist communities.
   - Severe vegetation loss in Mudjopele, Origo, and Paoko further worsened grazing conditions, leading to increased competition for resources.
4. Water Availability and Community Well-being
   - Water scarcity reached critical levels in Nyumanzi Refugee Settlement and its surrounding host community villages, with SPI analysis confirming a severely dry classification (-1.5 to -1.99 SPI values) in June 2022.
5. Regional Drought Patterns & Risk Zones
   - Nyumanzi Refugee Settlement, along with the host community villages of Ofongi and parts of Rhino Camp, were the most severely affected by drought, with SPI values falling below -2.0, indicating extreme dryness.
   - Moderate drought conditions were observed in Laropi, Adjumani town, and Nimule, where rainfall deficits were less severe but still impacted agriculture.
   - Lire, Ovuvu, and Iloho, host community villages with milder drought conditions, could serve as potential support zones for surrounding drought-affected areas.
6. Implications for Drought Mitigation
   - Emergency interventions are needed to support food security, water management, and agricultural resilience, particularly in Mudjopele, Origo, Paoko, Ege, and Mbere (host community villages).
   - Drought-resistant crop varieties and improved irrigation infrastructure should be prioritized to mitigate future agricultural losses.
   - Water resource planning and alternative supply strategies are required to ensure long-term water availability for both Nyumanzi Refugee Settlement and surrounding host communities.

- Pastoralist communities in affected host villages require support for livestock adaptation strategies, including livestock feed programs and improved grazing management.

# LAND SURFACE TEMPERATURE (LST)

## Section 4.01 Background

Extreme temperature events worldwide are becoming more frequent, lasting longer, and growing in intensity. From 2000 to 2016, approximately 125 million more people experienced exposure to heatwaves[43]. Uganda's temperatures have been increasing since the 1950s, with an observed warming of 0.78°C since the 1990s.[44]

Northern Uganda's climate is naturally variable and has historically experienced droughts with socio-economic impacts. However, human-induced climate change is expected to drive a rise in average temperatures, increasing the risk of heatwaves and heats stress in the region. While rainfall patterns may become more erratic, with intense and unevenly distributed events, rising temperatures will have profound effects on water availability, food security, natural resource management, human health, and infrastructure[45].

The increasing frequency and intensity of extreme heat events pose risks to vulnerable communities. While air temperature (measured at 2 meters above the ground) is commonly used for climate assessments, it does not fully capture the actual heat exposure experienced by people, buildings, and the environment. This study analysed LST trends in Nyumanzi settlement because LST provides a more accurate representation of ground-level heat conditions, particularly in areas with metal-roofed shelters, compacted soil, and limited vegetation, where surface temperatures can far exceed air temperatures. By assessing historical and current LST variations, this research provides insights into heat stress exposure, itself posing potential risks to human health, infrastructure and livelihoods.

## Section 4.02 Analysis Period

The analysis focused on Land Surface Temperature (LST) trends in Nyumanzi settlement and its surrounding 5 km buffer during the period of January to March 2024. This timeframe was selected to reflect the most recent LST conditions, providing an up-to-date assessment of heat exposure in the region. Given the increasing impact of extreme heat events due to climate change, analysing LST in early 2024 helps identify areas most affected by high temperatures. These insights are crucial for understanding current heat stress risks and informing adaptive measures for both refugees and host communities.

## Section 4.03 Methodology

The LST analysis was conducted for Nyumanzi Settlement and a surrounding 5 km buffer zone using Google Earth Engine (GEE). Unlike previous studies that relied on MODIS data, this analysis utilized Landsat 8 Collection 2 Level 2 Surface Reflectance data for improved spatial resolution. The study focused on the period from January to March 2024, aligning with peak temperature months to assess the most recent heat stress conditions.

A detailed breakdown of the methodology, including the Google Earth Engine script used for data processing[46].

## Section 4.04 Findings

The temperature distribution across Nyumanzi Settlement and the surrounding 5 km buffer shows a clear contrast between hotter villages in the south and cooler areas in the north.

The findings based on the 2024 (January – March) can be summarized as below:

1. Hottest Villages (South & Central)
   - Paoko, Mbere, Pasia, Maiaciko, and Ege record the highest LST values, reaching up to 65.84°C.
   - These areas are likely covered with bare soil, compacted surfaces, and built-up areas with metal roofing, which absorb and retain heat, making them potential hotspots for heat stress.
2. Moderately Warm Villages (Transition Zone)
   - Mudjopele and Origo exhibit mid-range temperatures, suggesting a mix of vegetation and built-up areas.
   - The Nyumanzi Settlement boundary lies within this transition, where surface temperatures fluctuate due to varying land cover.
3. Coolest Villages (North)
   - Lire, Ovuvo, Ilolo, and Gweri experience the lowest LST values, around 30.12°C.
   - These regions are marked by denser vegetation and potential water bodies, helping to reduce surface heat through evapotranspiration and shading effects.

## Section 4.05 LST Map

The LST Variation Map provides a closer look at specific locations within Nyumanzi Settlement, highlighting key sites with distinct temperature readings. The analysis reveals the following mean temperatures:

**1. Nyumanzi Refugee Settlement & WFP Relief Food Center (60°C)**

These locations exhibit some of the highest LST values, likely due to high-density metal-roofed structures and compacted ground surfaces, which retain and amplify heat.

**2. Market Center (54°C)**

This area shows slightly lower temperatures than the refugee settlement but remains hot. The temperature difference could be due to variations in surface materials and activity levels within the market.

**3. WFP Warehouse (58°C)**

This area also experiences high heat exposure, suggesting similar surface characteristics to the relief food centre.

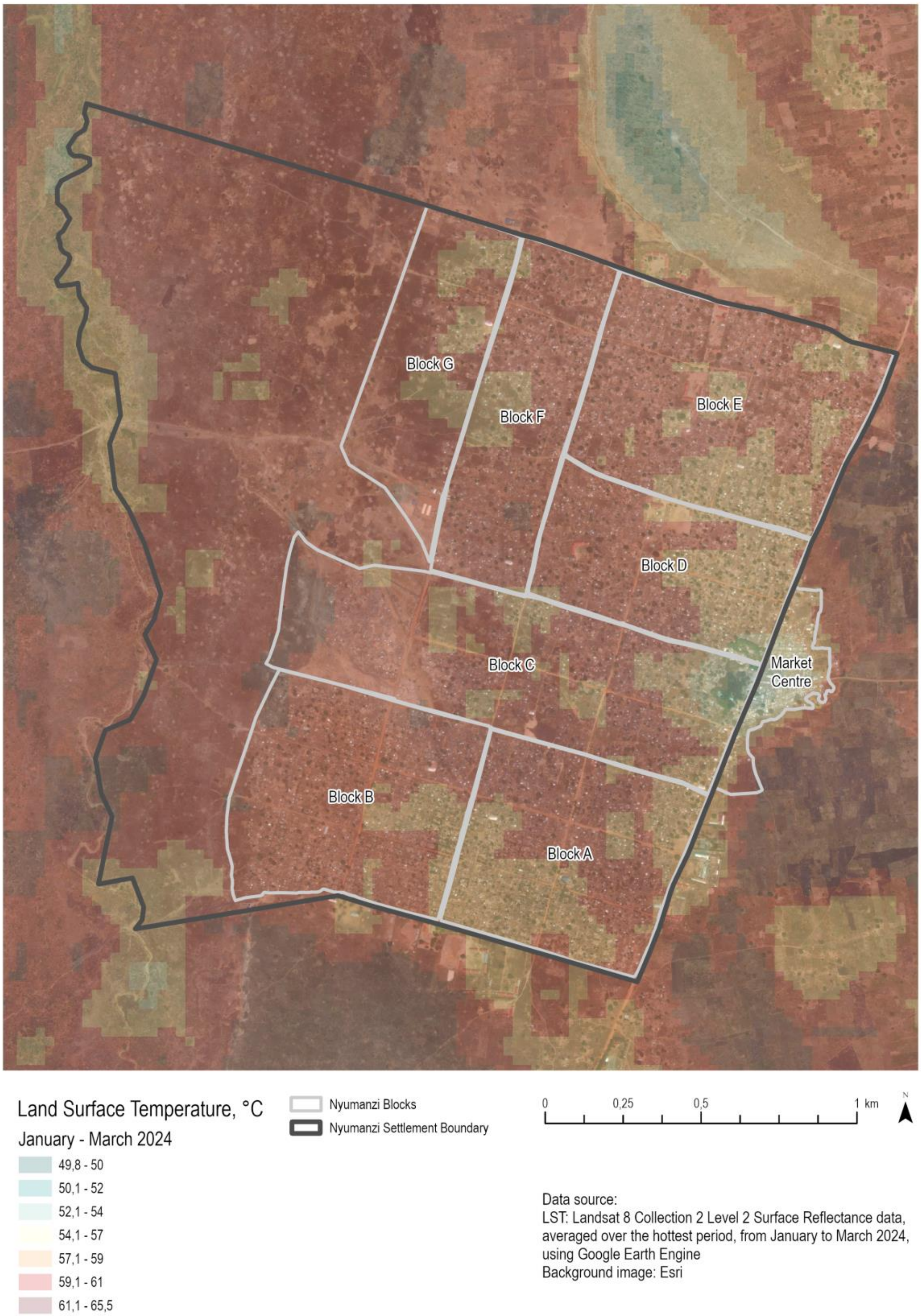
**4. Agricultural Land (60°C)**

Notably, agricultural areas reach temperatures similar to built-up regions. This could be due to bare, dry soil in certain parts, which absorbs and radiates heat more efficiently than vegetated fields, as well as the post-harvesting period.

**5. Swamp Area (55°C)**

While still hot, the swamp records the lowest temperature among identified locations. This may be due to higher moisture levels providing some cooling effect, although it remains relatively warm, possibly due to seasonal drying or sparse vegetation.

Map 4 : LST Hotspots and Land Cover Influence in Nyumanzi Settlement



## Section 4.06 Key Takeaways: Land Surface Temperature (LST) Trends and Impacts (January – March 2024)

1. **Extreme Heat as a Growing Climate Risk**
   - Nyumanzi Refugee Settlement and host community villages are experiencing dangerously high land surface temperatures (LST), with recorded values reaching up to 65.84°C.
   - Rising temperatures increase risks of heat stress, food insecurity, and infrastructure damage, particularly in exposed settlements and agricultural areas.
   - LST analysis provides a more accurate picture of heat exposure than air temperature alone, reinforcing the urgent need for climate adaptation.
2. **Land Cover Strongly Influences Heat Distribution**
   - Areas with bare soil, compacted ground, and metal-roofed structures (such as Nyumanzi Refugee Settlement and its market centres) recorded the highest LST values (60–65.84°C).
   - In contrast, villages with more vegetation and water bodies (Lire, Ovuvo, Ilolo, Gweri) had the lowest LST (30.12°C), proving that green spaces act as natural cooling zones.
   - Even agricultural land showed extreme heat retention (60°C), emphasizing the need for sustainable farming practices that protect soil moisture and reduce heat absorption.
3. **High-Risk Zones for Heat Stress**
   - Nyumanzi Refugee Settlement, WFP Relief Food Center, and the Market Center emerged as key heat hotspots, where infrastructure and lack of shade worsen exposure risks.
   - The southern host community villages (Paoko, Mbere, Pasia, Maiaciko, Ege) recorded the highest temperatures, making them priority areas for climate adaptation measures.
4. **Urgent Need for Heat Adaptation Measures**
   - Shade infrastructure, tree planting, and reflective roofing materials can reduce heat stress in refugee settlements and market areas.
   - Water management strategies, including irrigation and agroforestry, are necessary to protect agriculture from extreme heat impacts.
   - Public health interventions (such as cooling stations and heat warnings) will be essential to prevent heat-related illnesses among vulnerable populations.

# CLIMATE CHANGE TRENDS AND PROJECTIONS

## Section 5.01 Background

Uganda has a generally moderate climate but has been experiencing more frequent and severe extreme weather events in recent decades. Erratic rainfall has led to river flooding, mudslides, and landslides, particularly affecting mountainous communities, while lowland areas face recurrent floods. Prolonged dry seasons have also become common, causing crop and livestock losses. Between 1900 and 2018, Uganda experienced 20 floods, 40 epidemics, 9 droughts, and 5 landslides, resulting in over 200,000 deaths and economic losses exceeding $80 million[47].

With climate-induced disasters becoming more frequent and severe in Northern Uganda, including in refugee-hosting areas like Adjumani district, understanding both historical climate trends and future projections is critical for humanitarian planning and resilience-building. This analysis leverages historical climate data (1970–2000) and future projections (2041–2060) from the WorldClim dataset to assess long-term shifts in temperature and precipitation.

For humanitarian and development actors, these insights are essential for climate adaptation, disaster preparedness, and sustainable development in Nyumanzi Refugee Settlement and the wider Adjumani District. By identifying warming trends, changes in rainfall patterns, and potential increases in extreme weather events, this study will help inform:

- Water security and resource planning in a region prone to both seasonal droughts and flooding.
- Food security strategies, ensuring that agricultural interventions align with changing rainfall and temperature patterns.
- Infrastructure and settlement planning, helping to design shelters and facilities that can withstand future climate stresses.
- Disaster risk reduction (DRR) measures, enabling proactive responses to heat stress, extreme weather, and water scarcity.

## Section 5.02 Analysis Period

To assess climate change trends in Adjumani district, this study analysed both historical and future climate data. The analysis is divided into two components: historical climate data from WorldClim version 2.1 and future climate projections based on CMIP6 downscaled datasets.

### (a) Historical Climate Data (1970–2000)

The historical climate assessment utilized WorldClim version 2.1, which provides high-resolution climate data for the period 1970–2000. This dataset, released in January 2020, offers interpolated climate surfaces derived from global weather station records.

Examining this period is crucial because it represents the baseline climate conditions before the intensification of anthropogenic climate change impacts in the 21st century. By understanding past temperature and precipitation patterns, we can establish trends and detect deviations from historical norms, providing context for evaluating future changes.

### (b) Future Climate Data (2041–2060)

For future climate projections, this study utilized downscaled datasets from the Coupled Model Intercomparison Project Phase 6 (CMIP6). The available data includes 20-year averaged projections for four periods: 2021–2040, 2041–2060, 2061–2080, and 2081–2100. This study focuses on the 2041–2060 period.

This period was selected because it represents a mid-century timeframe that aligns with policy planning horizons for climate adaptation and sustainable development.

## Section 5.03 Methodology

To assess the climate change trends in Adjumani District, we conducted a comprehensive analysis using both historical and future climate data. The methodology is structured into two main components: Historical Climate Data and Future Climate Data.

### (a) Historical Climate Data (1970–2000) - Methodology

***Data Acquisition and Processing:***
We utilized the WorldClim version 2.1 dataset, released in January 2020, which provides high-resolution (30 arc-seconds, approximately 1 $km^2$) interpolated climate surfaces derived from global weather station records for the period 1970–2000. This dataset includes 19 bioclimatic variables that represent annual trends, seasonality, and extreme or limiting environmental factors.

Bioclimatic variables are essential in climate change analysis as they offer a comprehensive understanding of the climatic constraints on ecosystems and species distributions. They are widely used in ecological modelling and climate impact studies to assess how species and habitats respond to climate variability and change[48].

***Data Processing Steps:***

1. **Selection of Variables:** From the 19 available bioclimatic variables, we focused on BIO1 (Annual Mean Temperature) and BIO12 (Annual Precipitation) due to their direct relevance in assessing general climate trends and their impact on ecological and agricultural systems.
2. **Data Extraction:** The dataset was clipped to the Area of Interest (AOI), Adjumani District, to ensure spatial relevance.
3. **Spatial Analysis:** We employed spatial analysis tools to extract raster data by attribute, focusing on BIO1 and BIO12.
4. **Visualization and Statistical Analysis:** Maps were developed to visualize spatial patterns of temperature and precipitation. Zonal statistics were performed to summarize the data within the district boundaries, providing mean values and identifying spatial variability.

### (b) Future Climate Data (2041–2060) - Methodology

***Data Acquisition and Processing:***
For future climate projections, we utilized downscaled datasets from the Coupled Model Intercomparison Project Phase 6 (CMIP6), focusing on the period 2041–2060 to align with mid-century policy planning horizons. The selected General Circulation Model (GCM) was GFDL-ESM4, developed by the Geophysical Fluid Dynamics Laboratory (GFDL).

The GFDL-ESM4 model has been recognized for its performance in simulating climate variables over Africa, including Uganda. Studies have indicated that it effectively captures historical climate patterns and provides reliable future projections, making it suitable for regional climate impact assessments[49].

***Shared Socioeconomic Pathways (SSPs):***
We selected two scenarios for future projections:

- **SSP1-2.6:** Represents a sustainable pathway with low greenhouse gas emissions.
- **SSP3-7.0:** Depicts a pathway with high challenges to mitigation and adaptation, leading to higher emissions.

***Data Processing Steps:***

1. **Selection of Variables:** Similar to the historical data analysis, we focused on BIO1 (Annual Mean Temperature) and BIO12 (Annual Precipitation) to assess future climate trends.
2. **Data Extraction:** The future climate datasets were clipped to the AOI, Adjumani District.
3. **Spatial Analysis:** Spatial analysis tools were used to extract raster data by attribute for the selected bioclimatic variables.
4. **Visualization and Statistical Analysis:** Maps were created to visualize projected spatial patterns of temperature and precipitation under both SSP scenarios. Zonal statistics were performed to summarize projected changes within the district.

## Section 5.04 Findings

This section presents the analysis of climate data for Adjumani District, divided into two subtopics: Historical Climate Data (1970–2000) and Future Climate Data (2041–2060). The findings are based on the statistical summaries provided and are interpreted in the context of broader regional climate trends.

### (a) Historical Climate Data (1970–2000) - Findings

Table 6 : Adjumani District Climate Profile. Historical (1970–2000) vs. Projected (2041–2060) - Annual Precipitation (mm)

| **Statistic** | **Historical (1970–2000)** | **SSP1-2.6 (2041–2060)** | **SSP3-7.0 (2041–2060)** |
|---|---|---|---|
| **Minimum** | 989 | 927 | 922 |
| **Maximum** | 1332 | 1261 | 1262 |
| **Range** | 343 | 334 | 340 |
| **Mean** | 1193 | 1135.53 | 1131.09 |
| **Standard Deviation** | 74 | 76.24 | 79.98 |
| **Median** | 1206 | 1148 | 1145 |
| **90th Percentile** | 1275 | 1216 | 1218 |

Table 7 : Adjumani District Climate Profile. Historical (1970–2000) vs. Projected (2041–2060) - Annual Mean Temperature (°C)

| Statistic | Historical (1970–2000) | SSP1-2.6 (2041–2060) | SSP3-7.0 (2041–2060) |
|---|---|---|---|
| **Minimum** | 23.13 | 24.7 | 25.3 |
| **Maximum** | 26.38 | 27.9 | 28.5 |
| **Range** | 3.25 | 3.2 | 3.2 |
| **Mean** | 25.03 | 26.56 | 27.21 |
| **Standard Deviation** | 0.85 | 0.85 | 0.85 |
| **Median** | 25.23 | 26.8 | 27.4 |
| **90th Percentile** | 26.09 | 27.6 | 28.3 |

The historical data indicates that Adjumani District experienced a relatively stable climate between 1970 and 2000, with an average annual precipitation of approximately 1193 mm and a mean annual temperature of about 25.03°C. The standard deviations for both precipitation (74 mm) and temperature (0.85°C) suggest moderate variability during this period.

### (b) Future Climate Data (2041–2060) -Findings

Projections were analysed under two scenarios: SSP1-2.6 (low emissions) and SSP3-7.0 (high emissions).

The projections for 2041–2060 indicate an increase in mean annual temperatures for Adjumani District under both scenarios. Compared to the historical mean of 25.03°C (1970 – 2000), the SSP1-2.6 scenario projects an increase to 26.56°C (a rise of approximately 1.53°C) (2041 – 2060), while the SSP3-7.0 scenario projects an increase to 27.21°C (a rise of approximately 2.18°C) (2041 – 2060). These findings align with broader regional projections, which indicate that mean temperatures and hot extremes have emerged above natural variability across Africa, with the rate of surface temperature increase generally being more rapid than the global average, primarily driven by human-induced climate change[50].

In terms of precipitation, both scenarios project a decrease in mean annual precipitation compared to the historical average of 1193 mm (1970 – 2000). The SSP1-2.6 scenario projects a mean of 1135.53 mm (a decrease of approximately 57.47 mm), and the SSP3-7.0 scenario projects a mean of 1131.09 mm (a decrease of approximately 61.91 mm). These projected changes in precipitation are consistent with regional studies suggesting that East Africa may experience altered rainfall patterns, with potential increases in extreme weather events such as droughts and floods[51].

The projected increases in temperature and changes in precipitation patterns may further intensify existing challenges related to water resources, agriculture, and human health in Adjumani District. Rising temperatures can lead to increased evapotranspiration, reducing soil moisture and affecting crop yields. Altered precipitation patterns can result in more frequent and severe droughts or floods, impacting food security and livelihoods. These projections underscore the need for proactive climate adaptation strategies to mitigate adverse impacts on the community and environment.

Table 8 : Projected Climate Changes in Adjumani District (1970–2000 vs 2041–2060)

**Temperature Changes (1970–2000 vs 2041–2060)**

| | **SSP1-2.6 Scenario** | **SSP3-7.0 Scenario** |
|---|---|---|
| ***Annual Mean Temperature Increase*** | + 1.53 $^{0}$C | + 2.18 $^{0}$C |

**Precipitation Changes (1970–2000 vs 2041–2060)**

| | **SSP1-2.6 Scenario** | **SSP3-7.0 Scenario** |
|---|---|---|
| ***Annual Precipitation Change*** | -57.47 mm | -61.91 mm |
| ***Precipitation in the Driest Quarter (January -March)*** | -9 mm | -3 mm |

## Section 5.05 Key Takeaways: Climate Trends and Projection Maps

### (a) Historical Climate Data Map (1970 – 2000)

To better understand historical climate trends in Adjumani District, we developed two maps:

#### (i) Historical Annual Precipitation Map (1970–2000)

- This map visualizes the spatial distribution of annual precipitation across Adjumani District during the baseline period (1970–2000).
- The precipitation levels are represented using a colour gradient, with lower precipitation areas depicted in lighter shades and higher precipitation areas in darker shades.
- The corresponding zonal statistics table summarizes key precipitation metrics, including minimum, maximum, mean, and standard deviation values, providing insights into variability within the district.

#### (ii) Historical Annual Mean Temperature Map (1970–2000)

- This map illustrates the spatial distribution of annual mean temperature across Adjumani District for the period 1970–2000.
- The temperature variations are displayed using a colour gradient, where cooler regions appear in lighter shades and warmer regions in darker shades.
- The accompanying zonal statistics table presents summary statistics, including the minimum, maximum, mean, and standard deviation of temperature values, helping to contextualize historical climate conditions.

### (b) Future Climate Data Map (2041 – 2060)

Future climate projections were mapped under two Shared Socioeconomic Pathway (SSP) scenarios, SSP1-2.6 (low emissions) and SSP3-7.0 (high emissions). One map with four layouts were produced to visualize projected changes in precipitation and temperature.

#### (i) Annual Precipitation Maps (2041–2060)

Two maps were developed to compare projected annual precipitation levels under different emissions scenarios:

- SSP1-2.6 Scenario: This map displays projected precipitation patterns assuming a sustainable emissions pathway with lower greenhouse gas concentrations. Areas of lower precipitation are indicated with lighter shades, while higher precipitation regions are depicted in darker shades.
- SSP3-7.0 Scenario: This map represents projected precipitation changes under a high-emissions scenario. It highlights potential reductions in precipitation across the district, with darker shades indicating areas projected to receive more rainfall and lighter shades showing reduced rainfall levels.

The zonal statistics table summarizes key precipitation indicators for both scenarios, offering insights into potential future rainfall variability.

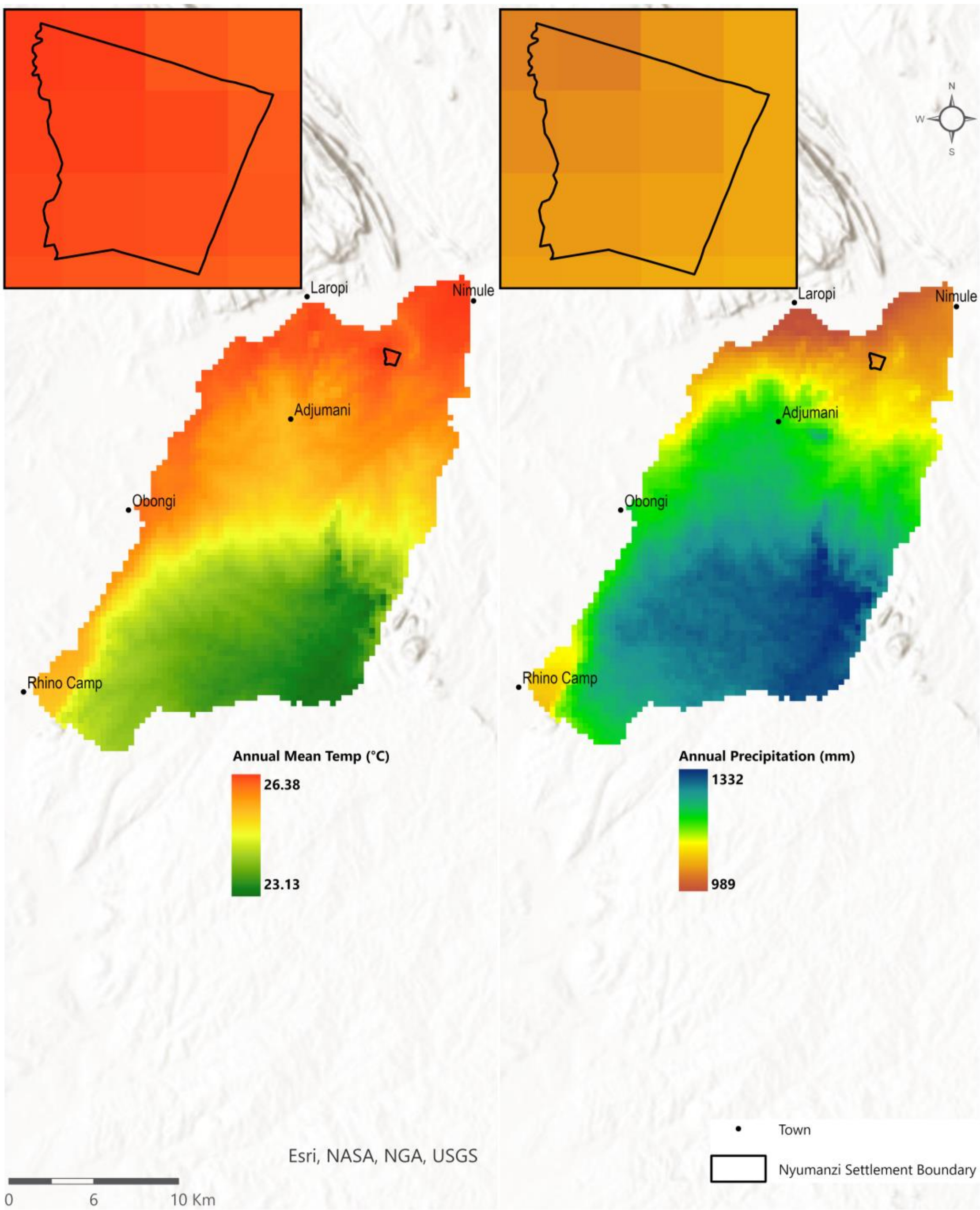
### (ii) Annual Mean Temperature Maps (2041–2060)

Two maps were generated to illustrate projected temperature changes under different emission scenarios:

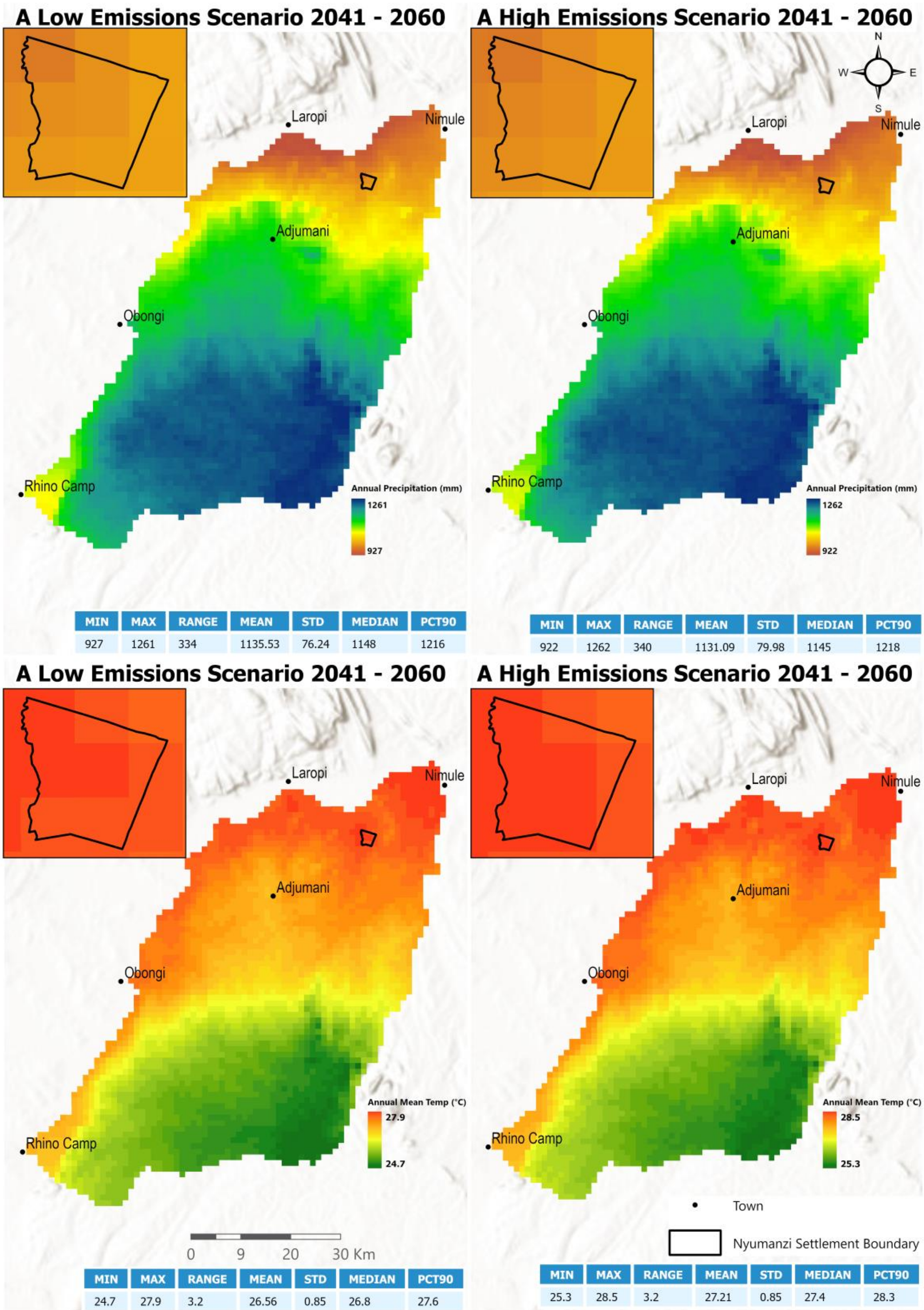
- *SSP1-2.6 Scenario:* This map visualizes projected mean temperature levels assuming a lower emissions trajectory. Warmer areas are represented using darker shades, while relatively cooler areas appear in lighter shades.
- *SSP3-7.0 Scenario:* This map portrays temperature projections under a high-emissions scenario, where warming trends are expected. Darker shades indicate higher temperature increases across the district.

The zonal statistics table presents temperature-related metrics, including minimum, maximum, mean, and standard deviation values, providing a comparative analysis of projected changes under both scenarios.

Map 7: Adjumani District Prehistoric Temperature (left) and Precipitation (right) Map (1970 - 2000)



Map 8: Adjumani District Future Climate Projections (2041 - 2060)



The findings of this geospatial analysis underscore the profound impact of climate-related hazards on the refugee and host communities in Nyumanzi Settlement. Over the assessment period (2019–2023), recurrent flooding and prolonged drought conditions have been identified as the primary climate risks, with far-reaching consequences for agriculture, infrastructure, and human well-being.

## Section 6.01 Key Takeaways

1. **Flooding (2019–2023)**

- The most severe flooding event occurred in 2022, affecting 22.51% of Nyumanzi Settlement and impacting 19,520 individuals.
- Block A was the worst-hit, with 502 households (5,020 individuals) affected.
- Flood-prone areas included Block B and Block D, where water levels remained for extended periods, leading to property damage and loss of food stocks.
- The market centre was partially flooded in 2022, disrupting trade and causing economic losses.
- Flooding affected 10 hectares of cropland within a 5 km buffer zone, reducing agricultural output.

2. **Drought (June 2022 Analysis)**

- June 2022 was identified as the driest period in the past decade, causing widespread vegetation stress and food shortages.
- The host communities in Mudjopele, Origo, and Paoko experienced extreme drought conditions, with high risks of crop failure.
- Pasture availability declined in Ege, Mbere, and Adjugopi, affecting livestock productivity and increasing reliance on external food aid.
- Water scarcity reached critical levels, leading to long queues at boreholes and forcing some residents to rely on distant, unsafe water sources.

3. **Heat Stress (January - March 2024 LST Analysis)**

- The hottest locations included Paoko, Mbere, Pasia, Maiaciko, and Ege, where land surface temperatures peaked at 65.84°C.
- Nyumanzi Refugee Settlement recorded 60°C, with metal-roofed structures and compacted soil intensifying heat exposure.
- The market centre and WFP Relief Food Center also recorded high temperatures, affecting food storage and increasing the risk of dehydration-related illnesses.
- Lire, Ovuvo, and Ilolo remained relatively cooler (30.12°C), benefiting from better vegetation cover.

4. **Future Climate Projections (2041–2060)**

- Mean temperatures are expected to rise by 1.53°C under SSP1-2.6 and 2.18°C under SSP3-7.0.
- Annual precipitation is projected to decline by 57.47 mm to 61.91 mm, increasing the likelihood of prolonged dry spells and reduced groundwater recharge.
- Nyumanzi and Adjumani District could experience more frequent extreme weather events, making proactive adaptation strategies crucial.

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