

Unsupervised Mapping of Flood-prone Areas in Ghana Using Sentinel-1 Time-Series

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Abstract

Flooding is one of the most persistent natural hazards in Ghana, causing recurrent damage to infrastructure, livelihoods, and local economies. Despite its widespread impacts, most flood-related research has been concentrated on Accra, leaving many regions understudied. This paper addresses this spatial gap by integrating Earth Observation (EO) datasets to identify and characterise flood-prone areas across Ghana at a national scale. Precipitation patterns between 2015 and 2025 derived from the IMERG dataset showed a clear seasonal cycle, with major rainfall peaks from April to October, directly corresponding to observed flood events. This implies an associated annual seasonal cycle of flooding. Sentinel-1 Synthetic Aperture Radar (SAR) imagery was used for flood mapping using a change detection (ratio) approach on the backscatter coefficients. Results showed that flood is concentrated in the southern half of the country, particularly in Western, Western North and Eastern Regions, and hotspots around Kumasi in Ashanti and the Weija dam in Greater-Accra regions. Spatial patterns of the flood align closely with the national topography, with low elevation areas especially those beneath the Y-shaped mountain in the country more vulnerable. Technically, the study demonstrates the effectiveness of SAR-based change detection for flood mapping in data-sparse environments, while highlighting limitations relating to in-situ validation. The results underline the necessity of adopting engineering solutions to reduce flood impacts as a long term solution to the annual recurring flood observed in the country. From a policy perspective, the findings provide evidence to support flood risk management strategies.

1. Introduction

Flooding is a significant and (annually) recurring problem in Ghana, having widespread impacts on communities, infrastructure, and livelihoods. A flood event is defined as the presence of temporary surface water that occurs through rainfall and appears in post-event SAR imagery but is absent in pre-event conditions, after excluding permanent surface water bodies. This includes both fluvial (overflow from rivers and lakes) and pluvial (rainwater accumulation) flooding, but does not explicitly distinguish between them. While studies on floods in Ghana are centred on Accra, the capital city, and its surrounding areas such as around the Weija dam, many other communities, particularly in other parts of the southern regions, experience substantial flood impacts that go largely unstudied. This is largely due to the political and economic disparity of these areas compared to Accra. One community which has this impact is Moree township, located in the Abura Asebu Kwamankese District of Central Region of Ghana. Floods in this community which mostly occur during the rainy seasons affect students, businesses, infrastructures and even the means of livelihood of the residents in this area. Similarly, heavy rain that occurred on Friday, June 17, 2022 flooded the Surowi river which led to the collapse of the bridge and road that connects areas in the north of Central Region (such as Twifo-Praso and Jukwa) to areas in the south such as Cape Coast where most economic activities occur, for instance farmers from Twifo-Praso and Jukwa trade their farm proceeds in the Kotokuraba and Abura markets. The bridge collapse impacted transportation and economic activities for several days until repairs and reconstruction of the bridge was

completed.

Flooding in the country has been recurring for the past decades with devastating impacts and an annual pattern that follows the wet season period observed in the country. A major driver of the flood phenomena in the country has been climate (Mensah and Ahadzic, 2020, Amoako and Frimpong Boamah, 2014, Tengan and Aigbavboa, 2016) though other factors such as poor urban planning and development, poor and inadequate drainage facilities and poor environmental attitude are at play. However, the topography of the area, i.e. at the national scale, could also be a major factor. An elevation map¹ of Ghana (Figure 1 (left)) reveals lower elevation across the southern belt intermixed with mountains. In the Eastern Region is a higher mountain area and also between the Eastern and the Volta Regions is the Lake Volta (Figure 1 (right)). Interspersed with the elevation are surface water bodies such as rivers and lakes (for instance lake Bosomtwe in the Ashanti Region) that are widely distributed in the country. These topographical features play a contributing role to the annual recurring flood situation usually observed due to surface runoff from higher elevations (e.g. northern regions) towards the lower elevation regions (e.g. southern sector). The annual flood occurrence is one that requires scientific approaches to minimise its impacts as several approaches for flood risk management such as construction of drainage facilities, drainage desilting, building demolition along water-ways and relocation of residents (Laar and Mahama, 2025) have proved

¹ All maps are displayed in the Ghana National Grid (EPSG:2136) co-ordinate reference system

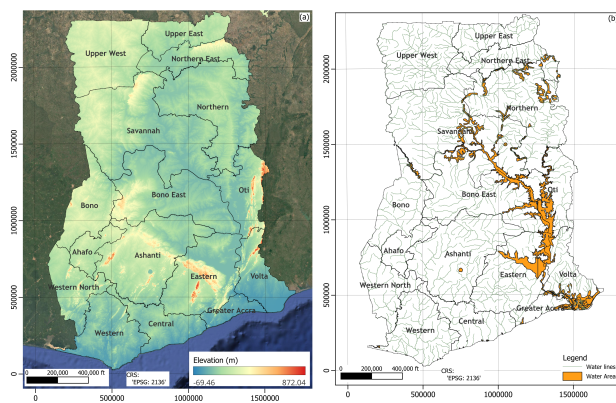


Figure 1. Elevation map (left) and surface water, i.e., water lines and areas (right), in Ghana.

ineffective due to high cost of mitigation measures and the inability of the people to effect change (Mensah and Ahadzic, 2020). To provide a comprehensive overview of the flood phenomena, national scale analysis will be paramount. Light Detection and Ranging data offer higher accuracy for flood monitoring (Essel, 2017), but the high cost of its setup limit its use for national scale analysis. Earth Observation has proved fruitful in providing insights on dynamics in remote areas through the provision of satellite-based data. Particularly, global coverage of SAR satellites have revolutionized flood monitoring by providing all-weather, day-and-night imaging capabilities, penetrating through clouds and in some cases tree canopies (Vaglio Laurin et al., 2016) to interact directly with the Earth's surface. SAR data have been used in multi-temporal change detection to detect water-related phenomena such as canopy water content (Pirotti et al., 2023) and temporary flooded areas at national and global scales (Misra et al., 2025).

As satellites have the limitation of providing observations in a swath region, multi-temporal satellite data with coverage over Ghana is being used in this study for the identification of flood-prone areas. The spatio-temporal criteria is being used because in an interaction with the EUMETSAT User portal (EUMETSAT, 2020) that displays data from geostationary meteorological satellite, precipitation carrying clouds were observed (between May 17 and 20, 2025 and almost all days in July 2025) to be sweeping across Africa from the East to the West, engulfing the whole of Ghana and part of the Gulf of Guinea. With the whole country experiencing heavy rain during the period gives the intuition that flood phenomena occurs not only in Accra as it's usually reported and studied but also other parts of the country, igniting this study to address the spatial gap in the study of flood phenomena in Ghana. The main objectives are to:

1. identify the spatio-temporal pattern of precipitation and flood in Ghana using EO datasets; and
2. analyse the spatial relationship between flood and the national topography.

The findings of this study will provide crucial and supportive insight for developing scientific policies and strategies to mitigate the devastating effects of floods in Ghana.

The remainder of the paper is structured as follows. Section 2 presents the area of study, section 3 presents the datasets and the methodology being used, section 4 presents the results obtained, which is discussed in section 5. Section 6 then presents the conclusion and recommendations.

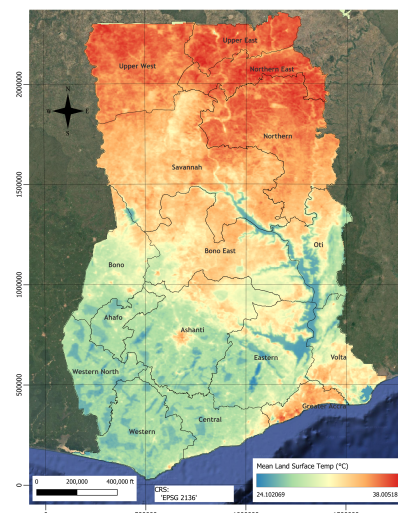


Figure 2. Average land surface temperature of Ghana between 2020 and 2024

2. Study Area

The study area is Ghana, officially known as the Republic of Ghana. It is a country located in West Africa bordered by Ivory Coast to the west, Burkina Faso to the north, Togo to the east and the Gulf of Guinea to the south. There are 16 administrative regions, with 6 Metropolitan Assemblies, 117 Municipal Assemblies and 138 District Assemblies and Accra as the capital city. The area is 239,567 km². The population of the country was 30,832,019 in 2021 (according to a report of the (Ghana Statistical Service, 2021)), which represent a population density of 129 persons per km². Ghana is a lower-middle income country, being a major exporter of gold, oil and cocoa. Located right above the equator, the country enjoys a tropical climate, with the northern sector usually hot and dry whereas the southern sector is relatively warm (Figure 2) influenced by the sea breeze though major cities such as Accra and Kumasi located in the southern half experience extreme warm temperatures due to urban heat island effect. The average temperature across the country is about 30°C and the presence of surface water bodies such as Lake Bosomtwe and Lake Volta provide a cooling effect to their immediate surroundings. Lake Volta, the largest artificial lake in the world by surface area, covers approximately 8,502 km² land surface and feeds the Akosombo dam. There are also major rivers such as Pra, Ankobra, and Densu that drain extensive catchments and discharge into the Atlantic Ocean. The topography of the country is a mix of low-lying plains and higher altitude areas. Most observed feature in the elevation map is the Y-shaped higher-altitude area located in the Eastern, Volta and Oti regions at the base of Lake Volta, with the tail end towards Greater Accra region (Figure 1 (left)). There are two major outlets at the base of the Lake that cuts through the Y-shaped mountain. On the eastern outlet is located the Akosombo dam that provides electricity for the country whereas the western outlet feeds the Densu river that drains into the ocean. The lower elevation areas are located in the southern-coastal areas and the higher altitudes are at the central and northern sectors of the country. The country experiences a dual seasonal pattern of weather with distinct dry (between November and March) and wet (between April and October) seasons. Low-lying coastal settlements and riverine communities are particularly vulnerable to flooding, especially in estuarine zones.

3. Materials and Methods

3.1 Data

The data used for this study, obtained from Google Earth Engine data repository, include: Sentinel-1 Ground Range Detected (GRD) scenes; Copernicus Digital Elevation Model; Integrated Multi-satellite Retrievals for Global Precipitation Measurement (IMERG); and European Space Agency (ESA) World-Cover 10m v200. The IMERG product provides global precipitation rate estimates (mm/hr) at the ground surface (Huffman et al., 2023). It is based on a multi-satellite algorithm that merges and interpolates precipitation estimates from a constellation of satellites. Its primary input is precipitation estimates from multiple Passive Microwave (PMW) sensors on Low Earth Orbiting (LEO) satellites. These are then blended and calibrated using Infrared (IR) data from geostationary satellites. The spatial coverage is global, between 60°N and 60°S, with a 30-minute temporal sampling and a spatial resolution of approximately 0.1° (11 km). Its processing algorithm applies a morphing technique to propagate precipitation information between satellite overpasses, ensuring seamless temporal coverage. The algorithm for IMERG has been upgraded to Version 07, which introduces a wide range of improvements across all components of the system, many of them implemented in response to feedback on Version 06. In this study, the Version 6 was used to provide the precipitation rate estimates between 2015 and 2023 and the version 7 between 2024 and 2025 to detect the temporal trend of precipitation of the country between 2015 and 2025. For further details on the IMERG data such as its algorithm and three latency categories: Early Run (4 hours after observation), Late Run (12 hours), and Final Run (2.5 months, gauge-adjusted with GPCC ground-based analyses), it is recommended the documentation (Huffman et al., 2023).

On the other hand, Sentinel-1 GRD dataset was used purposely to identify flood areas. The Copernicus Sentinel-1 is a radar imagery satellite that provides an all-weather day and night observed images of the Earth's surfaces. The satellite mission consists of two identical sensors (A and B) which have a 12-day revisit time each but a 6-day revisit time period when combined, operating in a dual polarisation mode and along ASCENDING and DESCENDING orbits. The sensors operate with a C-band SAR instrument at 5.405GHz and at a 10 m resolution. Also, it operates in 4 acquisition modes (European Space Agency, 2016):

- Stripmap (SM) is the basic mode which continuously images a narrow strip (80 km) of the Earth's surface at a high resolution. This is useful for high-resolution imaging of a specific, narrow area, such as a city.
- Interferometric Wide Swath (IW) mode has a wide swath width (250 km) compared to SM and maintains a good resolution. It is the most common acquisition mode over land, with VV and VH polarisations. It is normally used for interferometry to measure ground movement.
- Extra Wide Swath (EW) has a very wide swath (400 km) making it ideal for large area studies but has a lower spatial resolution compared to IW and SM. It is not ideal for detailed analysis on land.
- Wave Mode (WV) is a specialised mode for monitoring ocean waves at a low swath (20 km).

In addition, an image scene of the Sentinel-1 product contains either 1 or 2 of the following 4 possible polarisation bands:

1. VV: single co-polarisation, vertical transmit/vertical receive. It is sensitive to smooth surfaces and objects with vertical structures. It is useful in monitoring changes in water bodies and mapping surfaces like smooth water, as well as providing good contrast for identifying ships;
2. HH: single co-polarisation, horizontal transmit/horizontal receive. It is sensitive to surface roughness and horizontal features, making it the primary choice for certain types of geological mapping;
3. VV + VH: dual-band cross-polarisation, vertical transmit/horizontal receive. The VV channel provides information about surface scattering, while the VH cross-polarisation is extremely valuable for detecting volume scattering from vegetation, helping to differentiate between different crop types or forest densities. It is also used for land-use land cover classification; and
4. HH + HV: dual-band cross-polarisation, horizontal transmit/vertical receive. This is less common but can be useful in specific applications, particularly for some agricultural studies.

The dual polarisation of Sentinel-1 is useful for flood detection as the radar is sensitive to surface conditions. The SAR sensor is an active sensor that transmits microwave radiations and receive portions of the back scattered signal, measuring its intensity and phase. It is worth noting that the intensity of the backscattered signal depends on the different physical properties of the target. Smooth surfaces reflect radar energy away from the sensor, giving a low-backscatter coefficient ($\text{dB} < 0$) with the surface appearing dark in the image. However, rough surfaces scatter the energy towards the sensor ($\text{dB} > 0$), giving a higher backscatter coefficient with the surface appearing bright in the SAR image. The dB (decibel) unit represents the backscatter coefficient of the ground range scene detected by the sensor. This requires a threshold to separate the dark pixels (representing the water thus flood areas) from the brighter areas (non water areas). To perform any mathematical operation on the backscatter coefficient, the logarithmic scale (dB) of the backscatter is converted to the natural scale using the following expression:

$$\sigma_{\text{natural}} = 10^{\frac{\sigma_{\text{dB}}}{10}} \quad (1)$$

Water surfaces are typically very smooth at the C-band wavelength. As the flood represents temporary water bodies, there is a change in the backscatter intensity at the area where they occur. In areas under vegetation cover, identification of flooded areas becomes a complicated matter that requires careful handling (Amitrano et al., 2024). In terms of polarisation, VV is suitable for detecting open water surfaces especially in built-up areas and VH for detecting water under vegetation (Igarashi and Wakabayashi, 2024). In a study conducted by Zhuang et al. (Zhuang et al., 2025) using SAR data to inundate flood areas, the (VV+VH)² polarisation was found to have better performance in detecting flood areas compared to other single and dual polarisations. However, the VV polarisation is being used for this work.

3.2 Methods

There are two main stages that were used for this study, derivation of the temporal pattern of rainfall and the estimation of flood areas in the country.

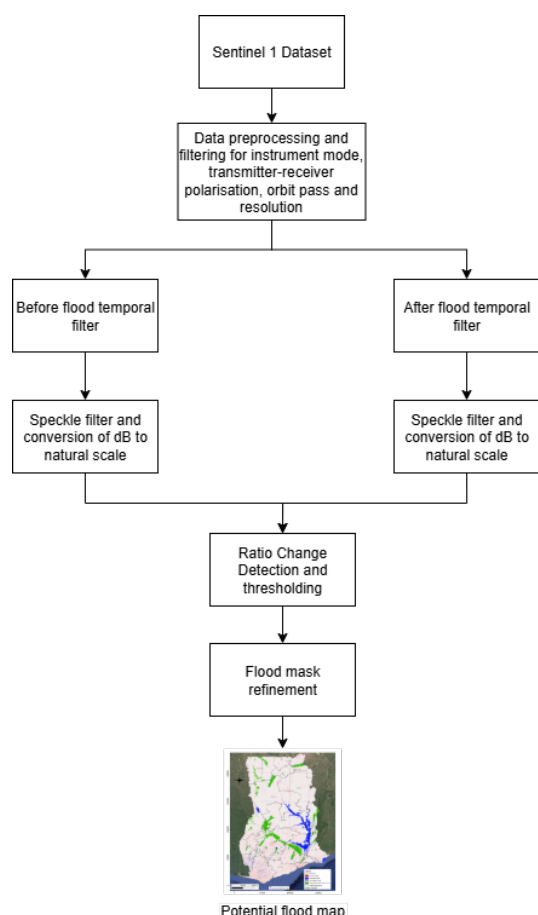


Figure 3. Summary of Data Processing Methods

3.2.1 Temporal pattern of rainfall: Generally, there are two main seasons observed in Sub-Saharan Africa, wet and dry seasons. Ghana being in the tropical space, it also experiences this seasonality. However, to demonstrate the use of Earth Observation in making a scientific proof of this seasonality, the IMERG dataset was used. The sum of all 30-minute rain rate measurements for each day between January 2015 and July 2025 was computed and used to establish the temporal pattern of the rainfall. The sum was used instead of the average as precipitation might fall in some areas and not others, thus using the average will result in cancelling out the rain rate, especially when there are low rain rates observed, leading to loss of the pattern in the dataset.

3.2.2 Flood detection: The Sentinel datasets were filtered for the following properties after clipping to the geometrical bounds of the country:

- transmitterReceiverPolarisation: [VV] (cross polarisation);
- instrumentMode: IW (Interferometric Wide Swath);
- orbitProperties.pass: ASCENDING;
- resolution_meters: 10 m.

This filtering helped to have a homogenous subset of the Sentinel datasets for the flood change detection. A temporal filtering was performed to select days for the pre and post flood events. The temporal pattern obtained from Section 3.2.1 was

used to select days (between '2024-12-13' and '2024-12-23') in which there was low precipitation as the before flood period. The total accumulated rainfall for this pre-event period, derived from the GPM IMERG dataset, was approximately 0.22 mm over Ghana. As the Sentinel-1 satellite have a limited swath region, several days were used so that each swath of the satellite covers a portion of the country. A mean of each pixel in the image was obtained, so there is the mean for the overlapping regions. To define the period for the after flood events, a spatial visualisation of the H60 data product on the EUMETSAT user-view was used as a guide to select the period in which there were precipitation carrying clouds over the country (between '2025-07-06' and '2025-07-09'). The corresponding accumulated rainfall during this post-event period was 14.12 mm from the IMERG dataset, highlighting a substantial increase compared to the pre-event conditions. Lastly, we confirmed the dates selected for the after-flood period by engagement with some residents in some affected communities, such as in Accra and Moree in the southern sector of the country. Sentinel-1 GRD imagery requires the following preprocessing steps for its applications:

- application of precise orbit information;
- border-noise removal to eliminate low-intensity noise and invalid data at scene edges;
- thermal-noise removal to reduce additive noise within sub-swaths and mitigate discontinuities between multi-swath acquisitions;
- radiometric calibration to backscatter intensity using sensor calibration parameters from the GRD metadata;
- terrain correction (orthorectification) to account for topographic distortions; and
- radiometric terrain flattening to normalise incidence-angle/topography effects on backscatter.

All the steps but radiometric terrain flattening have been applied on the Sentinel-1 GRD datasets in Google Earth Engine. In this work, only speckle filtering was applied. Speckle noise is a major issue that degrades the quality of SAR imagery, making it difficult to be analysed, requiring an applicable technique for its removal. Common filters for removing the speckle noise usually take the pixel values of the original image and alter them according to the neighbouring pixel values. Example filters are the box filter and the adaptive filters which is more advanced than the box filters. Adaptive filters change the way it operates based on the local statistics of the pixel it is considering so that different land cover features are treated differently. An example of such filter is the Lee filter which for instance reduces speckle noise near edges without blurring it. Following the mean images for the pre and post events, the simple Lee filtering algorithm was employed due to its ease of implementation. However, other techniques such as the Enhanced Lee Filter which better handles heterogeneous areas in SAR imagery where the standard Lee filter struggles can be used. The algorithm was applied with a 7x7 sliding window (Lee et al., 1991). In the speckle filtering algorithm, the required equivalent number of looks was set at 4.4 as specified for the IW GRD product of Sentinel 1 (European Space Agency, 2016). The speckle filtered images have the backscatter intensity measured in dB units. For performing further mathematical analysis, they

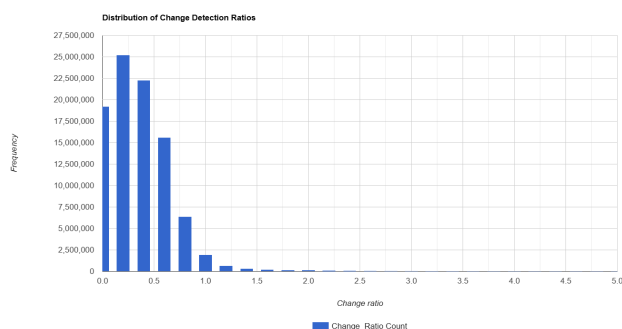


Figure 4. Distribution of the Change ratio between the post and pre-flood events.

were converted to the natural scale. To perform the change detection between the pre and post event images, there are difference, ratio or other techniques available. Since the SAR image is gamma distributed, the ratio option was considered (Rignot and van Zyl, 1993) using the expression:

$$change = \frac{post_event}{pre_event}, \begin{cases} \text{No Flood if } change > threshold \\ \text{Flood if } change \leq threshold \end{cases} \quad (2)$$

Also, since different land cover features give different backscatter coefficients, using the ratio will be more appropriate to have a relative change detection algorithm so a common threshold can be applied to classify into flooded and non-flooded areas. The ratio technique implies that if the ratio between the post event and the pre-event is 1, it indicates no change in the backscatter intensity for the pixel (Singh, 1989). If the post event value is larger than the pre-event value, that is positive ratio, it means an increase in the intensity of the backscatter signal, thus not a flood area. If the ratio is less than 1, with the pre event larger in intensity than the post event for the pixel, it gives indication of reduction of the backscatter intensity of the signal and the pixel will appear dark, thus flood. This is because water surfaces give lower backscatter values. To cater for minute changes and natural changes in surface conditions, a hypothetical threshold of 0.75 was applied instead of 1 to detect water areas, made up of flood and permanent surface water areas. All pixels with ratio less than 0.75 are considered as water pixels in the image. The threshold was obtained from a plot of distribution of the change ratios as a vast majority of the ratios are clustered towards the left, primarily between 0.0 and 1.0 (Figure 4).

3.2.3 Refinement of the flood mask: Following the classification of the ratio imagery into water and non-water areas, filtering operations were performed to improve the accuracy of the flooded areas and to remove noise such as permanent water bodies and steep slopes. Areas classified as permanent water in the ESA World Cover dataset were excluded from the flood mask. As flood occur in flat areas, hypothetical slope range of 5° and 10° were used for sensitivity analysis by visual inspection on the number of flood areas detected and slope of 10° gave good detection of flood areas especially in areas that were reported to have flood. All pixels with slope beyond 10° threshold were removed from the flood mask. In addition, since mountain tops could have flat surfaces and its rare for flood to occur at the mountain tops, a hypothetical threshold of 330 m above mean sea level was set to filter the flood mask. All elevations that are greater than this threshold were also excluded. The empirical

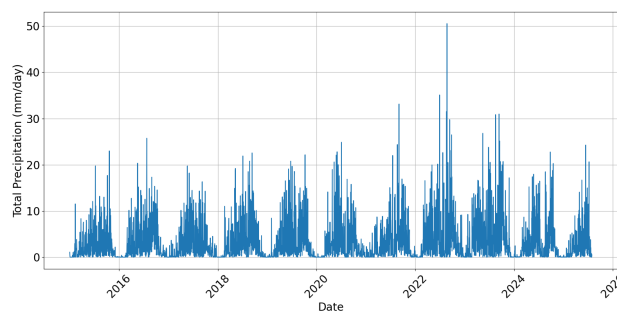


Figure 5. Temporal pattern of total rainfall in Ghana between January 2015 and July 2025.

threshold was chosen as it gave a good representation of the mountain areas by visual inspection on the map. Last, to avoid counting instances of isolated pixels as flood areas (i.e. unlikely to be real flood areas), small clusters of connected pixels (less than or equal to 6 connected pixels) that have been classified as water areas were removed to give the final potential flood areas. A summary of all the procedures are given in Figure 3.

4. Results

The following sections detail the temporal trends of precipitation and the resulting spatial distribution of potential flood areas identified during the July 2025 rainfall.

4.1 Temporal Pattern of rainfall

A plot of the daily sum of rates of precipitation from the IMERG precipitation estimates shows strong seasonal cycle with periods of high precipitation followed by periods of very low or zero precipitation each year (Figure 5). Precipitation is highly variable on a daily scale, with frequent spikes and drops. Each year shows distinct peaks, representing days with very high precipitation. The magnitude of these peaks varies from year to year. For instance, some years (e.g. 2021 and 2022) show much higher extreme precipitation events, with one particularly large peak value of 50.55 mm/day around late 2022. Other notable high-precipitation events are visible in late 2021 and early 2023, where peaks regularly exceed 30.00 mm/day. However, the peaks in 2016 and 2017 are relatively modest, generally not exceeding 23.08 mm/day. Each year also shows distinct dry periods, typically between the two rainy seasons, identifiable at the end of the year and beginning of the subsequent year. The high peak usually occurs between April and October months, with the intensity around June-July months. Conversely, the driest period (where there is little to no rain) is observed from November to March coinciding with the Harmattan season of the region in which precipitation is minimal. This temporal pattern aligns with the climatology of West Africa. The peak periods underpins the timing of when flood events occur. For instance, the 'after flood period for this study, in July, corresponds directly to this major rainy season. Conversely, the 'before' flood period in December aligns with the driest season of the year, the Harmattan, providing a stable baseline for comparison. This temporal pattern of natural and seasonal cycle of rainfall highlights the need for adequate scientific measures and preparedness to mitigate the impact of heavy rainfall.

4.2 Potential Flood Areas

A spatial plot of the flooded areas revealed that the flood event was not uniformly distributed across Ghana (Figure 6). There

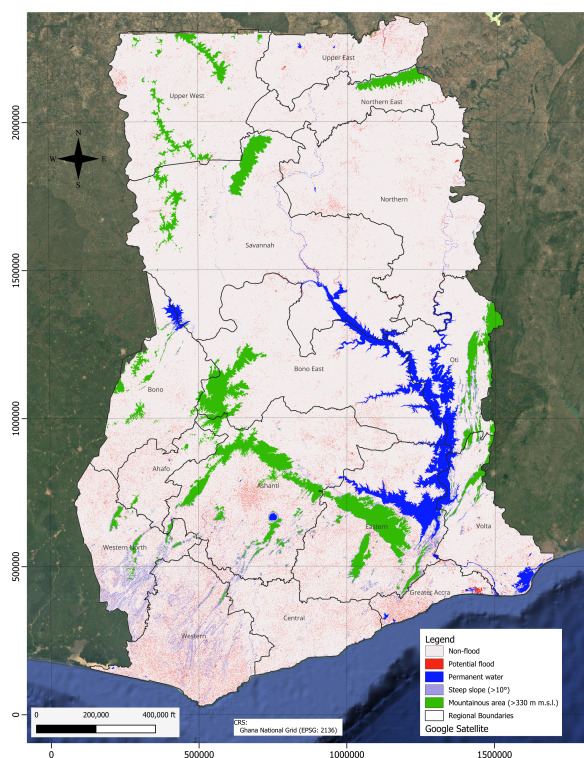


Figure 6. Potential flood areas in the rain that occurred between July 06 and July 09, 2025.

are few floods in the Northern half of the country, with major flood in Tamale, eastern part of Upper East region and Lawra, Dapola and Babile communities towards the western part of Upper West regions, areas identified in the study by (Laar and Mahama, 2025). The Upper East region experience occasional flood from spillage of the Bagre Dam on the White Volta-Nakambe river line located near Bagré Village in Burkina Faso. The southern half, beneath Bono, Bono East and Oti regions, showed significant flood compared to the northern sector. In this southern sector, Kumasi in Ashanti Region most notably shows extensive concentrated potential flood pixels (consistent with the study by (Essel, 2017)), with further spatially dispersed flood pixels in other areas of the Ashanti region. Western and Western North regions exhibit flood extents that are much spatially dispersed compared to that of Kumasi where the pixels are concentrated. The north-west sector of Central Region containing communities between Dunkwa and Diaso showed significant flood than other parts of this region so less flooded areas in the Central Region compared to its neighbouring regions. The part of Eastern region beneath the lake Volta also showed significant flood areas similar to that of Western region. In the Greater Accra regions, the flood was dominant in the Western part in the areas around the Weija dam, consistent with historical flood reports. The Lake Volta cuts through the Y shaped mountainous region beneath it. There are two main outlets of the lake, the Akosombo dam located on the eastern outlet and the western outlet connects to the Densu river that feeds the Weija dam. Table 1 summarises the total flood area for each region and Figure 9 shows the comparison of the flood areas by region. Western Region has the largest flood extent at 1121.50 km², followed by Ashanti (875.95 km²) and Eastern (604.22 km²) regions. Several regions, including Greater Accra (297.02 km²), Northern (302.25 km²), and Volta (243.9 km²), have moderate flood areas. The smallest flood-prone areas are

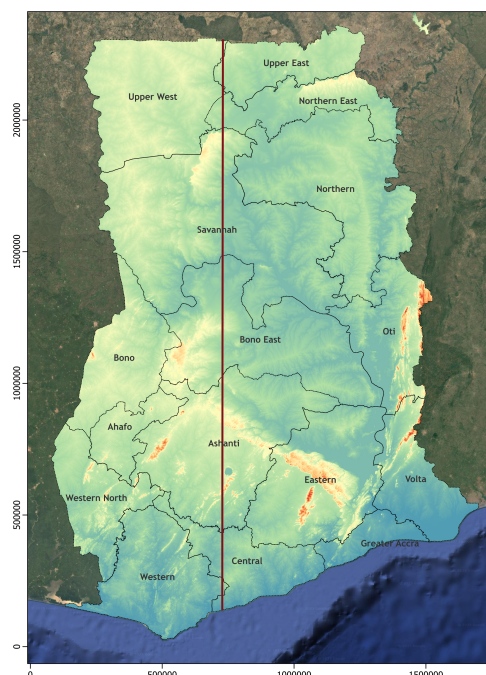


Figure 7. Vertical cross-sectional cut through the terrain of Ghana. The cut passes through Komenda (Central Region), Kumasi (Ashanti Region) and Wuru (Upper West Region).

observed in Oti (56.27 km²) and Northern East (82.92 km²), whereas the remaining regions range between 166 and 398 km².

Table 1. Summary of Flood Areas by Region in Ghana

Region	Flood Area (km ²)	Total Area (km ²)	Normalized Area (% of Region)
Ahafo	166.24	5194.96	3.20
Ashanti	875.95	24379.38	3.59
Bono	205.05	11646.88	1.76
Bono East	237.40	23256.38	1.02
Central	397.84	9663.52	4.12
Eastern	604.22	18965.83	3.19
Greater Accra	297.02	3699.32	8.03
Northern	302.25	24849.31	1.22
Northern East	82.92	9074.62	0.91
Oti	56.27	11065.96	0.51
Savannah	293.98	35862.98	0.82
Upper East	210.96	8622.27	2.45
Upper West	218.24	19033.45	1.15
Volta	243.85	9825.08	2.48
Western	1121.50	14258.32	7.87
Western North	370.96	10074.81	3.68

5. Discussion

For the past decades, there have been annual flood occurrence in Ghana causing devastating impacts to lives and society. These floods usually occur during the wet season observed in the country (usually between April-October). The seasonal cycle of precipitation obtained in Section 3.2.1 implies that flood which usually occur in the high peak periods of rainfall (around June-July) will follow similar pattern.

5.1 Spatial Relationship with Topographical Features

Whereas studies on flood are mostly concentrated on major economical areas such as Accra and Kumasi, the insight from the

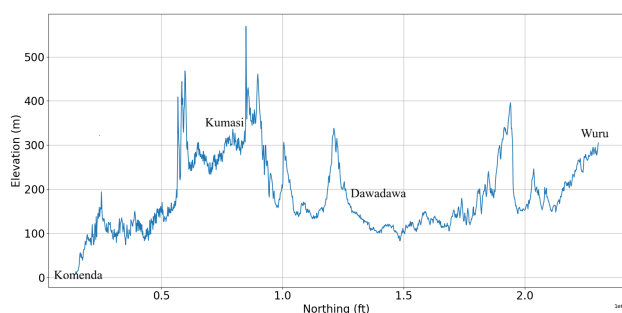


Figure 8. The associated elevation profile (at Easting coordinate 727745.68') for the cut in Figure 7, showing the location of some intersected communities.

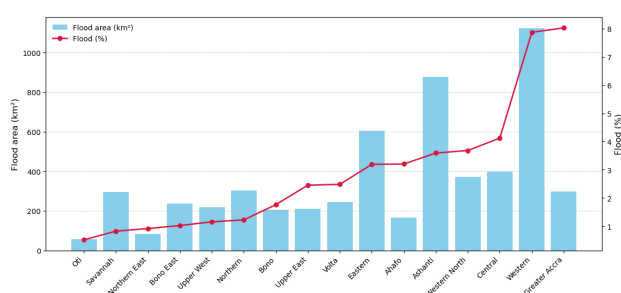


Figure 9. Comparison of the flood affected areas by the 16 regions in Ghana. The bar chart (skyblue) shows the flooded areas and the line (red) shows the flooded areas normalised with respect to the surface area of the respective region

EUMETSAT User portal revealed flood likely occur in other areas as well. The results obtained in Section 4.2 confirms this. Basically, the southern half of the country experiences more flood than the northern half. This is primarily due to the higher elevation above mean sea level of the northern half compared to the southern sectors visible from the cross sectional view of the elevation of the country (a vertical cut from Komenda in the south through Kumasi to Wuru in the North, Figures 7 and 8). Also, surface run-off from the northern regions are intercepted by mountains and redirected into the Lake Volta, which gives a hint on the less flooded areas observed in the Northern half of the country.

Regions that sit underneath and on the left side of the Y-shaped mountain (comprising of Eastern, Ahafo, Ashanti, Western North, Central, Western and Greater Accra) experienced more flood, whereas Volta region, though in the southern half, experienced less flood. From Figure 1, the mountains on which side these regions are located are more pronounced and connected. Thus, water flow from these mountains impact more the areas, especially the urban, that sit underneath them. Generally, the concentrated flood pixels correspond to urban areas such as Tamale in the Northern region, Kumasi in the Ashanti region and Accra in the Greater-Accra region consistent with other studies such as (Essel, 2017). Whereas the study of (Essel, 2017) was limited to Kumasi, their results indicated that the city center and the northern part of the city which has higher proximity to the Y-shaped mountain are at higher risk of flooding. On the other hand, the flood that usually occur in Accra concentrated around the Weija dam is due to the overflow from the western outlet of the Lake Volta where it intersects the Y-shaped mountain and drain water from its bounds. The Eastern outlet feeds the Akosombo dam where flooding is controlled

when the dam overflows its threshold. The western outlet of the Lake Volta connects to the Densu river which intersects the Weija dam before releasing its contents into the Densu estuary located between Bortianor and Mpoase on the western part of Greater Accra region. The Weija dam has a surface area of about 33.59 km² and five spillway gates for occasional spilling when water level rises beyond 47 ft. The dam sources the water treatment plant of the Ghana Water Company Limited for provision of drinkable water to Greater-Accra and its environs. Excess water from the Lake Volta which overflow the banks of the Densu river and the Weija dam likely contribute to the flood situation observed on the western part of Greater-Accra and its immediate vicinities.

Also, Kumasi, the capital town of the Ashanti region, sits in between 2 major mountains so naturally, surface run-off from these mountain tops have immediate contact with its terrain. Together with the urban development of the city, this accounts for the concentrated flood areas identified in the city in Ashanti region.

Currently, measures use to manage flood events include flood-awareness campaigns, relocation of settles, demolition of infrastructures along the water ways, provision of relief items to affected victims of flood and desilting of drainages. Whereas these measures help manage the flood situation, the annual cycle of precipitation pattern obtained in this study implies that these measures are not a long-term sustainable solution as they do not address the inherent nature of the topography. In this perspective, advanced engineering solutions will have to be explored as a long-term sustainable solution to the flood menace in Ghana.

5.2 Limitation of the study

This study addresses the spatial gap in flood research in Ghana by employing Earth Observation data, which provides repeat coverage across large areas that are often inaccessible for field surveys. However, while EO helps overcome the challenge of sparse ground-based monitoring, the lack of quantitative in-situ validation data remains a limitation, and this study relies primarily on remote sensing-derived information. Nevertheless, some flooded areas such as Moree, Kumasi and parts of the Upper East region were confirmed based on local's experiences, which suggests that other flood-identified areas may reflect actual flooding. Future works might consider using higher spatial resolution data to improve on the accuracy of the work. While the approach shows promising results, the lack of quantitative validation and challenges such as rooftop detection highlight the need for further work to fully validate and operationalise this method. Future work could consider integrating higher-resolution imagery or optical satellite data for partial validation. Also, sensitivity analyses on classification thresholds, as well as the integration of hydrological models, could be considered in further studies to enhance the operational utility of the methodology.

6. Conclusions

The integration of multi-temporal Sentinel-1 SAR imagery and IMERG precipitation data successfully enabled a national-scale characterization of flooding across Ghana taking into account the nature of the topography. The methodology was built on the premise that a significant difference in backscatter between two temporal periods indicates a change on the ground surface. By using a dry-season baseline, the methodology effectively isolated temporary flood events from permanent water bodies and

other natural surface changes. It is acknowledged that not all backscatter changes are flood-related; variations in land cover, soil moisture, topography, or sensor acquisition geometry may also influence the signal. We hope that for instance the use of slope and elevation thresholds (10° and 330 m, respectively) in the flood mask refinement process will be useful to cater for this limitation. Nevertheless, the method was able to isolate flood areas. Also, the temporal findings revealed an annual recurrence of rainfall, aligning with previous reports that Ghana's flood risk is heightened during the major rainy season and that both urban centres and rural communities and river basins are vulnerable. The results of the flood map indicate that flood event in Ghana is not uniformly distributed but heavily concentrated in the southern half of the country, specifically in the Western, Ashanti and Greater Accra regions. From the topographical analysis, the recurrent floods near the Weija dam in Accra is due to run-off from the Lake Volta into the Densu river beneath the Y-shaped mountain. This highlight the need for infrastructural and hydrological controls as well as advanced engineering solutions to better manage the flood situation on a long term. In this perspective, policymakers and urban planners can take insight from the flood control systems implemented in countries such as Netherlands, Japan and Italy. Netherlands sits beneath the mean sea level and is at a higher risk of flood. Its government implemented the Delta works project made up of a system of barriers, dikes etc. to mitigate the impact of flood on a long term. Japan also at risk of flood implemented the G-Cans Project in which surface water from flood is redirected through underground tunnels before the water is released into lower surface elevation terminals/exits. Similarly, the government of Italy introduced the MOSE project in Venice to protect the city against incidence of flood resulting from high tides. These are sustainable projects that have been implemented to protect communities. The current approach of flood preparedness and management practiced in Ghana is not enough and also not sufficient to mitigate the natural occurrence of the flood event on a long term. Though predictive models might help to raise awareness on the likely occurrence of flood event, an engineering solution will better manage flood incidence on a long term. Also, the current measures of relocation of informal settlers from urban areas and after flood relief measures are likely to face challenges as they don't take into account the nature of the terrain. For the mean time, flood preparedness is an annual necessity.

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