Faculty of Engineering and the Built Environment

Department of Land and Spatial Sciences

PROJECT DESCRIPTION

Comparing and analysing flood mapping approaches such as binarization, stacking and FLOOPY using sentinel 1

By

Sibungo Pride Manvwali

218101600

Supervisor

Kaleb Negussie

Course coordinator

Erich Naoseb

Introduction

Inundation is one of the most catastrophic natural disasters in the world as it poses threat to human lives to the level of causality depending on the severity of the flood. Not to mention the negative impact on the environment; infrastructure, crops and farmland etc. (Ulloa et al., 2020). Furthermore, due to climate change it is predicted that the frequency and extensiveness of floods will increase depending on region to region (Tupas et al., 2023). Considering the enormous damages caused by floods to human lives in the last decade dating from 2006 to 2015 (Domeneghetti et al., 2019), with up to 0.8 billion people affected as well as an estimated amount of $300 billion economic damage as a result(Domeneghetti et al., 2019). Yet it is discernible that simulating floods remains poor due to a lack of available measurements and subordinate data to come up with robust approaches to tackle flood dynamics (Domeneghetti et al., 2019). Subsequently, flood mapping essentially entails identifying and delineating areas that are prone to inundation, assessing the intensity and magnitude of a prospective flood. Moreover, providing accurate and precise information is the objective, that way reliable flood mapping assessments can be established as it enables entities to mitigate and facilitate flood disasters efficiently. With this information, local authorities and municipalities, as well as entities that specialize in this field, could design measures to alleviate flood damage to human lives and the environment.

Additionally, several methods can be exploited when it comes to flood mapping, namely, remote sensing techniques, hydrologic modelling, hydraulic modelling, and GIS (Geographical Information System) techniques. With hydrologic modelling, the volume of water entering a certain area during a flood is estimated using precipitation data, considering the soil type of the area, topography and many other crucial data. Meanwhile, hydraulic models estimate how water will move through a specific area, the depth and speed of the floodwaters, whereas remote sensing techniques, such as satellite imagery and aerial photography, can map floodplains by pinpointing vulnerable areas through image classification methods. Lastly, GIS techniques enable analysis and visualization capabilities to comprehend, communicate, and share the results amongst people (Saleh et al., 2020).

Background

Namibia is an eccentric country with a relatively large area in square kilometres that's about 823 290 sq. km in size (Statistical & Destatis, 2023). This country has a vast area but not all of it is inhabited by people. It is situated in the south-western part of Africa bordered with Atlantic and Namib desert, stretching across the entire western part of the country, covering an enormous area of land for example the coastline is 1500 km long (World bank, 2021). What is more, it is a neighbouring country to Angola on the north side, South Africa on the south side, Botswana on the west and Zambia on the northeast side (Herbold, 2023). Aside from being home to the second largest desert, the Namib Desert, where the desert meets the ocean, is considered a must-see on traveller's itineraries. This is also where you will find other popular landscapes like the Caprivi Strip, the Skeleton Coast, and the Kalahari region.

Namibia is comprised of hot and dry conditions in the course of the year with 92% of the country classified to be semi-arid or hyper arid (Bailey et al., 2014). In other words it entails that it is an area with low humidity as the rate of evaporation is higher than the rate of precipitation (info-namibia, 2023). Furthermore, with a general hot and arid climate, characterized by significant temperature variations between seasons (Orti & Negussie, 2019). As well as unpredictable rain patterns with variations too. It's dryness is influenced by the northward Benguela current and hot climate as a consequence rainfall is erratic and sparse (World Bank Group, 2021). Generally, rainfall varies greatly from place to place. Such that in the northeast the amount of rain ranges from 50 mm along the coast and the south-western area to 650 mm in the north eastern side annually (World Bank Group, 2021).

Subsequently, Namibia experiences a lot of floods mostly in the north to north eastern part as well as in the central plateau occasionally. From 2008 to 2009 these regions received a significant amount of rain which led to severe floods. The common floods that occur in Namibia are seasonal river floods for example the Okavango and Zambezi river is expected yearly to fill up (Mwiya, 2005). Occasional flash floods with urban floods being last in place.

What is more, heavy precipitation that occurred in neighbouring countries like Angola and Zambia significantly contributes to flooding in areas within proximity to this countries. Also, to track back, in 1982 to 2008, floods have been a critical issue in Namibia, particularly impacting the majority of the population residing in the North Central regions of Oshikoto, Omusati, Ohangwena, Oshana, as well as the North Eastern regions of Kavango and Caprivi. The floods not only caused destruction to infrastructure and crops but also hindered access to healthcare for patients and disrupted children's education (Amadhila et al., 2013).

In February 2009, a substantial amount of rainfall triggered flash floods that impacted nearly 700,000 individuals residing in the northern and north eastern regions. This catastrophic event forced 56545 people to evacuate from their homes, with a number of 105 deaths reported. About 545 00 people were likely to suffer from shortage of food in the 2009/2010 agricultural season. The emergency relief operation executed by the NRCS (National Red Cross Society) made their first objective to provide shelter, sanitation facilities, access to clean water and advocating for health and hygiene practices (Cross, 2010).

The NRCS was actively providing aid to individuals impacted by the most severe floods witnessed in decades in the northern regions of Namibia, including Oshana, Omusati, Ohangwena, Oshikoto, Kavango, and Caprivi. The number of people affected has escalated to 500,000, out of which around 60,000 have been displaced, approximately 19,000 where residing in relocation camps, and there had been reports of 65 deaths connected to the disaster since it began (Crescent, 2011).

Intense rainfall occurred between January and March 2017 in the Cuvelai River Basin in Angola, combined with local rain in Oshana, Oshikoto, Ohangwena, and Omusati, which resulted in inundation in Lishana. The term "Lishana" refers to shallow flood plains. As a result, the above mentioned regions including kavango region become flooded because of the water streaming from this river basin in Angola (International Federation of Red Cross and Red Crescent Societies, 2016).

Moreover, the water levels at the Engela station surpassed 1 meter on January 27, 2023, as reported by the Namibia Hydrological Services. As more rainfall occurs in the Cuvelai basin, the flood levels continue to rise in areas bordered to this basin such as the Kavango, Caprivi and central northern regions mentioned in this study (Outbreak & Readiness, 2023).

In light of the above, it is event the northern and north-eastern regions of Namibia have been facing great challenges concerning floods and each time these places experience an inundation, the impacts intensify. Existing methods used to compact this situation appear to be insufficient when it comes to predicting and mapping floods effectively, as the occurrence of heavy rains brings about more severe effects than events in the past. This calls for extensive flood studies to be conducted in order to improve flood prediction techniques and manage flood disasters successfully. By doing so, crucial information can be collected or made accessible to local governments as it will be readily available for use, and all they have to do is choose an area of interest and apply what has already been proven to work by many studies and analyses proven in flood studies. With this knowledge, they will have more options to do risk assessments depending on the simulated results chosen.

This project intends to do a flood mapping study using remote sensing and GIS techniques. Specifically satellite imagery (SAR data or Multi Spectral Instrument data) which entails acquiring sentinel 1 or 2 images to perform image classification processing and a statistical analysis. Synthetic Aperture Radar (SAR): Sentinel 1 sensors can take high-quality pictures of the Earth's surface, regardless of the weather, which makes them ideal for mapping extensive floods (Tupas et al., 2023). Sentinel 1 is useful for detecting water surfaces because they have low backscatter, it only means that this characteristic allows for the differentiation between water bodies and other land features.

In addition to its ability to capture images even in challenging weather conditions for continuous landscape monitoring, Sentinel-1 also has a high spatial resolution, meaning the captured images contain a high level of detail, allowing for the identification of smaller-scale floods. Furthermore, both Sentinel-1 and Sentinel-2 provide frequent revisits to specific areas, known as temporal resolution, enabling the examination of flood duration and tracking its progression over time. Notably, Sentinel-2 also has a high spatial resolution as well, it is equipped with multi-spectral capabilities, capturing imagery of the Earth's surface in 13 spectral bands, including near-infrared, visible, and shortwave infrared (Nhangumbe et al., 2023). This enables the identification and classification of vegetation, soil, and water using spectral indices such as the normalized difference vegetation index (NDVI) or normalized difference water index (NDWI) (Nhangumbe et al., 2023).

There is fairly a long list of advantages of using Sentinel-1 and Sentinel-2 data. What makes them even more useful is the fact that they have global coverage and are open source which means anyone can access it. Through the Copernicus program one can access Sentinel data easily as well as on other platforms that support this program like NASA, Google Earth Engine etc. Additionally, the integration of GIS in this datasets is a way to assign compatibility with GIS platforms, this makes them best suited for this types of studies because it gives the space to interact with other geospatial data which enhances analysis and visualization capabilities.

Nonetheless, Sentinel-1's Synthetic Aperture Radar (SAR) capabilities may result in misinterpretation, as it can sometimes mistake water for smooth surfaces like roads or buildings, and its effectiveness can be affected by noise or geometric distortions (Tarpanelli et al., 2022). On the other hand, Sentinel-2's Multispectral Instrument (MSI) is hindered by cloud cover and the inability to capture images during night time, limiting its practicality for certain flood mapping scenarios (Konapala et al., 2021).

By using Sentinel-1 or Sentinel-2 data or both, researchers can take advantage of the strengths of both sensors. In this way certain limitations that they individually possess can be addressed. This approach allows Sentinel-2 data to aid in distinguishing water from non-water surfaces that can't be detected in Sentinel-1 images, while Sentinel-1 data can compensate for cloud cover gaps in Sentinel-2 images (Nhangumbe et al., 2023). Consequently, this integration enhances the precision and effectiveness of flood mapping studies, thereby improving preparedness, response, and recovery endeavors in regions prone to flooding (Tarpanelli et al., 2022).

Project aims and objectives

This study aims to utilize two approaches for conducting a flood mapping study. Exploit the advantages of using Sentinel-1 in flood mapping. As well as compare the outcomes obtained using Sentinel-1 with the respective methods. In order to have a new opinion thereby challenging old studies, add to existing studies to make it easier for people to understand floods or compare the impacts by scrutinizing the results from different flood mapping studies available and most importantly providing accurate and precise data that could enhance in further researches in this dynamic hence closing the gap of unavailability of information to substantially deploy robust flood mapping analysis that could potentially be used in real time.

Objectives

To assess flood mapping using the binarization method and the stacking method in snap.

To identify vulnerable flood areas in Rundu and nearby villages.

To carry out a comparative analysis of the two methods used

To test a new flood mapping library: FLOODPY

Literature review

A research conducted in Luzon , Philippines investigated four change detection models utilizing Sentinel-1 images. The models were further compared to an independent Sentinel-2 classification. The study revealed that utilizing Sentinel-1 mission is becoming a prominent way to do land monitoring studies. It demonstrated great capability in accurately mapping floods compared to single-image algorithms that only classify the present conditions. Also, to be able to do a change detection analysis effectively, the ability to identify flooded areas by examining observed differences is key (Tupas et al., 2023).

Likewise, in Beira, using Macomia district as a case study. The research paper conducted in this area investigated a fully automated technique to real-time flooding. The study made use of multi-temporal Sentinel-1 data. Furthermore, the results proved to be highly accurate at pinpointing the method's reliability to flood mapping in real-time mapping floods exploiting the combination of Sentinel-1 and Sentinel-2 (Nhangumbe et al., 2023).

According to a study conducted north-western Tunisia, flood mapping using Sentinel-1 images allowed for the extraction of information regarding the extent of hydraulic hazards and the height reached by the flood. This research showcased the effectiveness and significance of flood mapping analyses in hydrologic studies (Ezzine et al., 2020).

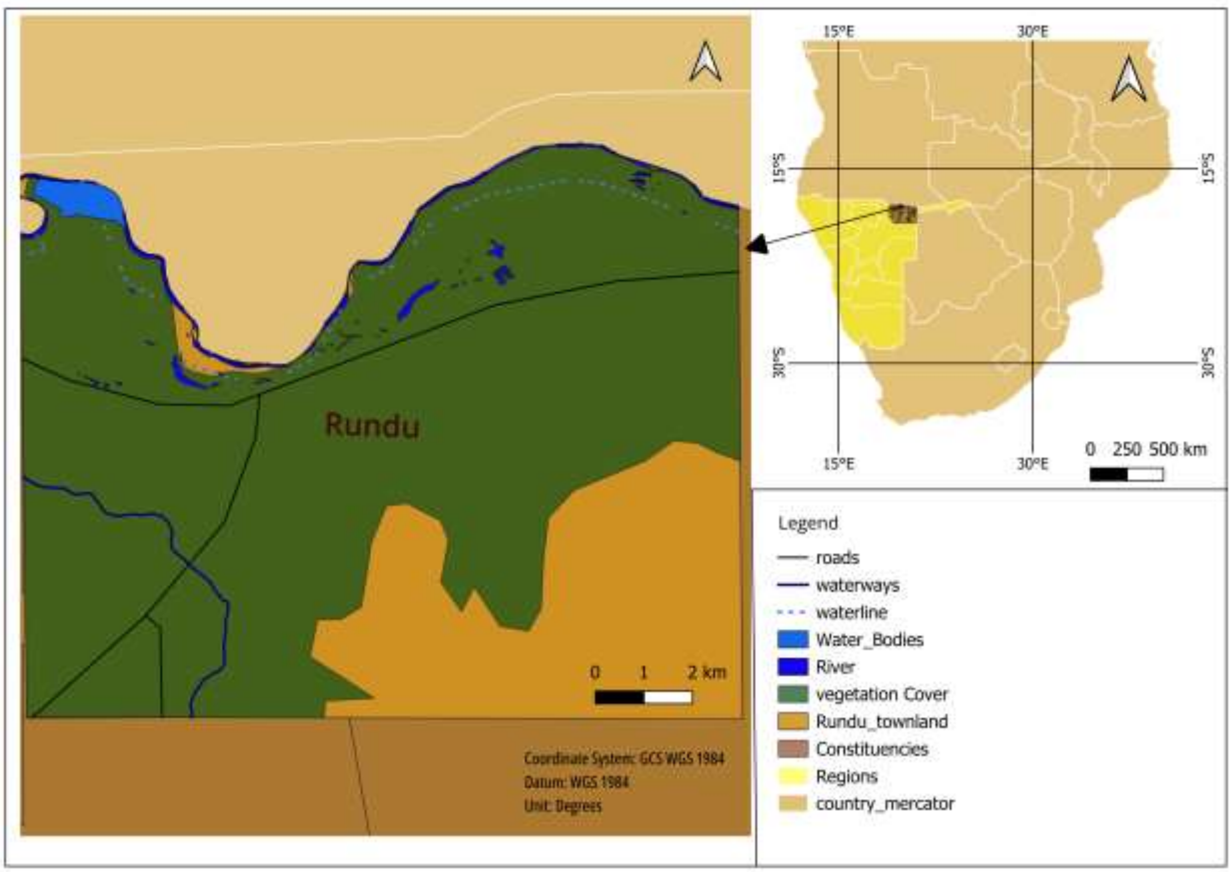
In another study in Bangladesh, had an objective to detect flood-prone areas using SAR data and facilitate flood response by using Sentinel-1. The study examined the significance of identifying areas affected by floods to enable effective response strategies. The approach resulted in an overall accuracy assessment of 96% in mapping of floods with this technique. Due to the level of precision and accuracy evident from this method in this study, the generated maps were distributed to the community to assist in hazard mitigation strategies. (Uddin et al., 2019)

Furthermore, in a study conducted in Palamas, Greece done by Karamvasis and Karathanassi (2021) introduced a new automated method to do flood mapping studies using a python library referred to FLOODPY or Floodwater mapping python (FLOMPY). This approach used both Sentinel-1 and Sentinel-2 images. In addition, FLOODPY consists of four processing steps to archive accuracy. It generates a t-score map that highlights flood changes in area. The study achieved an overall accuracy of 95% to map floods using FLOODPY. Thereafter, it slowly started to emerge accommodating other areas irrespective of their geographical location as long as flood as taken place with a threshold of 45 mm of precipitation in most cases.

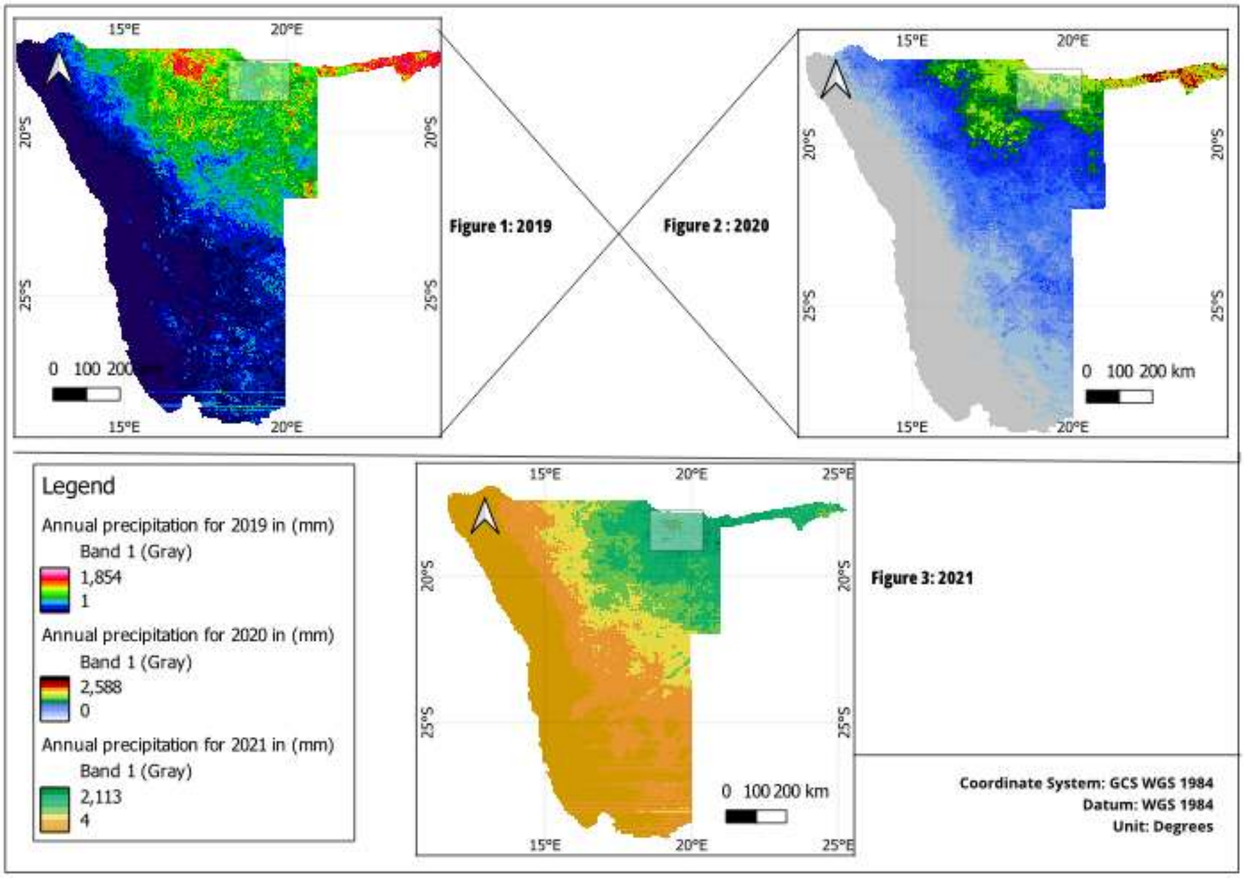
Finally, in a study done in Malaysia also proved the effectiveness of using Sentinel-1 for flood mapping analysis. This study examined and provided analysis of flood maps obtained from Sentinel-1. It was discovered that this maps revealed precise information that they used to create a flood inventory map which provide valuable information to mitigate inundation which was provided to local authorities as well as researchers to enhance their comprehension in floods (Saleh et al., 2020).

Study area

Rundu is the main city in Kavango East which is situated north east of Namibia, 1 100 meters above sea level. It is the second most populated city in Namibia following the capital with a population of 63 431 residents as determined by the 2011 National Census (Martin et al., 2018). This town is highly suitable to be a case study for flood analysis as it meets so many criteria. For instance, it is directly positioned at an intricate hydrological system: the Okavango River Basin and its tributaries. Its proximity to these hydrological system increases the prospect of it becoming inundated severely. The river flow varies because of the area's erratic seasonal rain patterns. As well as the streaming water from the nearby dams in Angola or heavy rains experienced in Angola within its proximity. Moreover, it is situated at the south east border of Angola which makes it even more vulnerable as it can become flooded due to heavy rains experienced in the Cubango area of Angola in proximity to this town. Generally, Rundu has a tropical climate which is typically divided into a wet and dry season. The wet season usually runs from November to April (info-namibia, 2023). However, sometimes in December heavy rains may be recorded during this time according to rainfall data records by local meteorological stations or global climate data hubs. Rundu embodies a mix of an urban and rural area, respectively composed of agricultural land, sparse grassland and natural vegetation In light of the above, this town is susceptible to floods in occurrence of heavy rain because not only does the river basin fills up due to heavy rain but running water from the neighbouring country makes the situation more dire and unpredictable. With that being said, this town is absolutely ideal for flood analysis studies.



The figure above shows a map of the study area, delineating the position of Rundu, the river and waterbodies and the extensive natural vegetation cover.



The figure above shows the general precipitation pattern of the country marking the study area to show case its rain pattern. As the figure shows the study area is part of the greenest part of the country with the highest rain received compared to other parts of the country. The values of rain in the figure is an aggregated value per year.

Methodology and data

Level 1 Detected High-Resolution-Dual polarization (VV,VH) Ground Range Detected(GRD HD) C band Sentinel 1 (SAR) data was acquired from NASA with a spatial resolution of 10m and a temporal resolution of 12 days. With the binarization method and Stacking exploited the VV polarization was. However, FLOODPY explores both polarization in determining which separates water from other features better. The SNAP tool was used to run the binarization and stacking method. While FLOODPY uses SNAP to pre-process the images and for coregistration. Google earth was used for visualization of the masked output of water and the stacked layer. QGIS was used to render maps. Lastly a classification was done to compare to the water pixels picked up as a means of validation.

Binarization was applied as done in a flood mapping tutorial (United Nations, n.d.). By examining the histogram. Basically the histogram shows high pixel values that represent land features and low pixel values that represent water. Thus, with this knowledge a threshold is chosen to mark the backscatter lower to the threshold and to assign a value of zero to other features (Prakash et al., 2021). Using a mathematical expression the above rationale can be achieved resulting in a water mask exacted from the rest of features.

Using band math the following expression can be inserted:

255*(Sigma0_VV<2.22E-2)

The following table gives a summary of the data used.

Data	Type	Source	Acquisition	Spatial Resolution	Satellite	Flood Method
SAR	(GRD-HD) VV,VH Polarization	NASA	25/11/2019	10 m	Sentinel 1	Binarization
SAR	(GRD-HD) VV,VH Polarization	NASA	19/11/2020	10 m	Sentinel 1	Binarization
SAR	(GRD-HD) VV,VH Polarization	NASA	26/11/2021	10 m	Sentinel 1	Binarization

The following table gives a summary of the data used.

Data	Type	Source	Archive Image	Crisis Image	Spatial Resolution	Satellite	Flood Method
SAR	(GRD-HD) VV,VH Polarization	NASA	12/03/2019	25/11/2019	30 m	Sentinel 1	Stacking
SAR	(GRD-HD) VV,VH Polarization	NASA	29/02/2020	19/11/2020	30 m	Sentinel 1	Stacking
SAR	(GRD-HD) VV,VH Polarization	NASA	01/04/2021	26/11/2021	30 m	Sentinel 1	Stacking

With FLOODPY one needs to gather information concerning flood events of a study area. This flood can only be as of 2014 because on the Copernicus data hub you can only acquire sentinels dating from 2014 as well as other platforms such as NASA. With that in mind, one needs to search for rain data acquired on that flood event. Now the baseline can be formed, which basically setting a configuration file to an area of interest. However, it can be a little challenging if specific information is not set because the algorithm in FLOODPY only accepts certain criteria. For instance, you could have rain data but if the flood was not intense as an urban flood or a flash flood with a threshold of 45 mm (Karamvasis & Karathanassi, 2021). This could lead to errors. Another point that could affect the feasibility of FLOODPY is the availability of sentinel tiles for the study area.

The following images shows the configuration of FLOOPY.

```
#       CONFIGURATION FILE OF FLOODPY
#|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|-|
#       A. Project Definition
#---------------------------
#A1. The name of your project withough special characters.
Projectname = Palamas1

#A2. The location that everything is going to be saved. Make sure
#    you have enough free space disk on the specific location.
projectfolder = /home/donnita/Palamas1

#A3. The location of floodpy code
src_dir = /home/donnita/projects/FLOODPY/floodpy/

#A4. SNAP ORBIT DIRECTORY
snap_dir = /home/donnita/.snap/auxdata/Orbits/Sentinel-1

#A5. SNAP GPT full path
GPTBIN_PATH = /home/donnita/snap/bin/gpt
X
#A6. WGET full path (required for windows, you can leave it empty for linux)
WGET_PATH = ""

#   B. Flood event temporal information
#--------------------------------------------------------------
# Your have to provide the datetime of your flood event. Make sure that
# a flood event took place at your provided datetime.
# Based on your knowledge you can change [before_flood_days] in order
# to create a biggest
# Sentinel-1 image that is going to be used to extract flood information
```

1. Set a file where you would like the data to be saved

```
# will be between Flood_datetime and Flood_datetime+after_flood_days
# the closest Sentinel-1 to the Flood_datetime is picked
#--------------------------------------------------------------
# B1. The datetime (time in UTC) of flood event (Format is YYYYMMDDTHHMMSS)
Flood_datetime =  20210128T030000

# B2. Days before flood event for baseline stack construction
before_flood_days = 180

# B3. Days after flood event
after_flood_days = 3

#  C. Flood event spatial information
#--------------------------------------------------------------
# You can provide AOI VECTOR FILE or AOI BBOX.
# Please ensure that your AOI BBOX has dimensions smaller than 100km x 100km
# If you provide AOI VECTOR, AOI BBOX parameters will be ommited
#-In case you provide AOI BBOX coordinates, set  AOI_File = None
#---------------------------------------------------------

# C1. AOI VECTOR FILE (if given AOI BBOX parameters can be ommited)
AOI_File = None

# C2. AOI BBOX (WGS84)
LONMIN=19.64
LATMIN=-18.06
LONMAX=19.91
LATMAX=-17.85
#  D. Precipitation information
#--------------------------------------------------------------
#  Based on your knowledge, provide information related to the
```

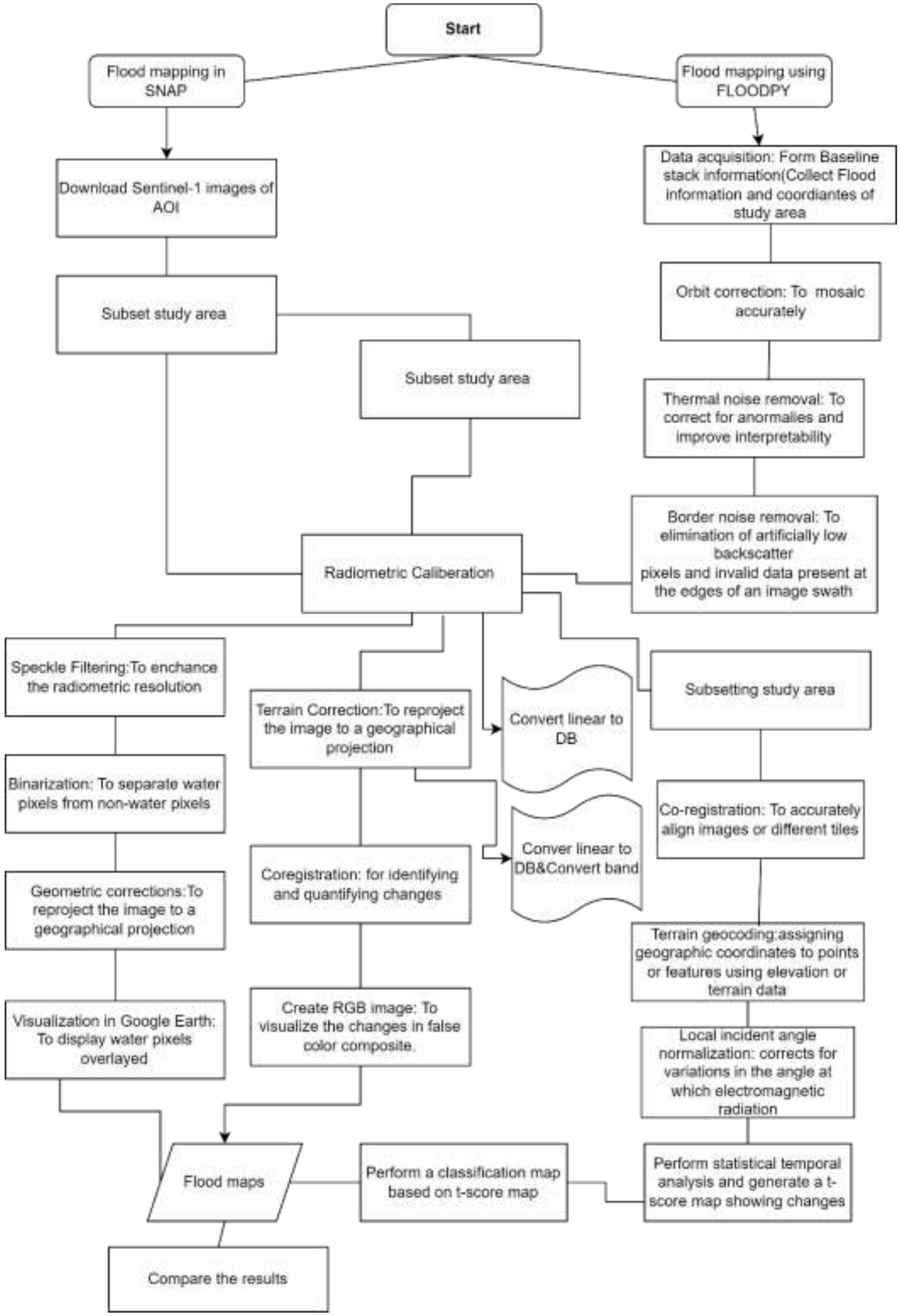
2. Set flood date, the number of images to go back to create a stack of the flooded image and another before the flood.

3. The rain data recorded the day of the flood event, and the coordinates of the AOI. Also, if your study area has negative numbers the smallest will be taken as LATMAX while the biggest negative will be your LATMIN, just like how it is shown in the image above.

4. You can choose to provide your own details or keep it the same to access the data like for FLOODPY to download the available satellites and rain data you set. If FLOOPY cannot find a tile specific to the date you set it will not carry on, or if it cannot get enough tiles to do coregistration of the flood image and the image before it will also not continue with processing. And lastly keep in mind the size of your study area as it can only accommodate the size shown in the images (400 square meters). After everything is provided FLOOPY runs everything by itself.

```
# D1. number of consequent days that precipitation will be accumulated.
#       before each Sentinel-1 acquisition datetime
days_back = 12

# D2. The threshold of acculated precipitation [mm]
accumulated_precipitation_threshold = 64

########################################
#         E.  Data access and processing    #
########################################
#E1. The number of Sentinel-1 relative orbit. The default
#       value is Auto. Auto means that the relative orbit that has
#       the Sentinel-1 image closer to the Flood_datetime is selected.
#       S1_type can be GRD or SLC.
S1_type = GRD
relOrbit = Auto

#E3. The minimum mapping unit area in square meters
minimum_mapping_unit_area_m2=4000

#E4. Computing resources to employ
CPU=8
RAM=20G

#E5. Credentials for Sentinel-1/2 downloading
scihub_username = flompy
scihub_password = rslab2022
aria_username = floodpy
aria_password = RSlab2022
```

Methodological Framework



How the Binarization method was done.

1. The acquired images were subset to a smaller size focussing mainly on Rundu urban and rural with a few villages close to it. The subset area was set to have a geometry of -18.257° S , 19.507° E, -17.641° S, 19.963° E.
2. Pre-processing was applied to the images such as Radiometric Calibration to convert raw digital numbers into meaning full reflectance of the physical properties recorded hence to be able to carry out any sort analysis on the image.
3. Speckle filtering was applied to the image to remove speckle noise hence improve the quality of the image or to have a smooth image thereby achieving a greater level of detail.
4. Using band math an expression is applied to the image that separates water pixels from other features.

   Expression: 255*(Sigma0_VV<2.22E-2)

   The expression above group pixels with a lower value to 2.22E-2(Value extracted from the histogram) and assign a value of zero to other pixels that represents other features because they have a higher value than 2.22E-2. Then the extracted water pixels will be given new values from 1 to 255 using the VV polarization converted to a sigma band through calibration. Thereafter a water mask image was rendered.

   Post processing was applied to the images through terrain correcting the image to project to a geographical projection.
5. For visualization in google earth, the colour of the watered pixels was set while the non-data was set to none and then the image was exported into a KMZ file.

How the Stacking method was done

1. As mentioned in the previous step the images were subset.

2. Then a 3 by 3 multilooking filter was applied to remove speckle noise as well as downscale the resolution to 30 meters because the flood extended quite to a large area.
3. Geometric correction was done to re-project the image.
4. The sigma_VV band was then converted to decibal for better image interpretation of the features especial to distinguish between the smooth surfaces which land features and rough surfaces which is water surfaces.
5. Coregistration was done, this was to stack the images together to assess the changes of the flood on the image before the flood also known as the archive image and the image during the flood known as the crisis image.
6. Thereon an RGB image composite was created selecting the Sigma_VV band in decibal of the archive image for band 1. Then the Sigma_VV band in decibal for the crisis image for both band 2 and 3. By doing so, the change can be quantified.
7. The results of the RGB image was then exported to a KMZ file to overlay in google earth.

How the FLOOPY method was applied

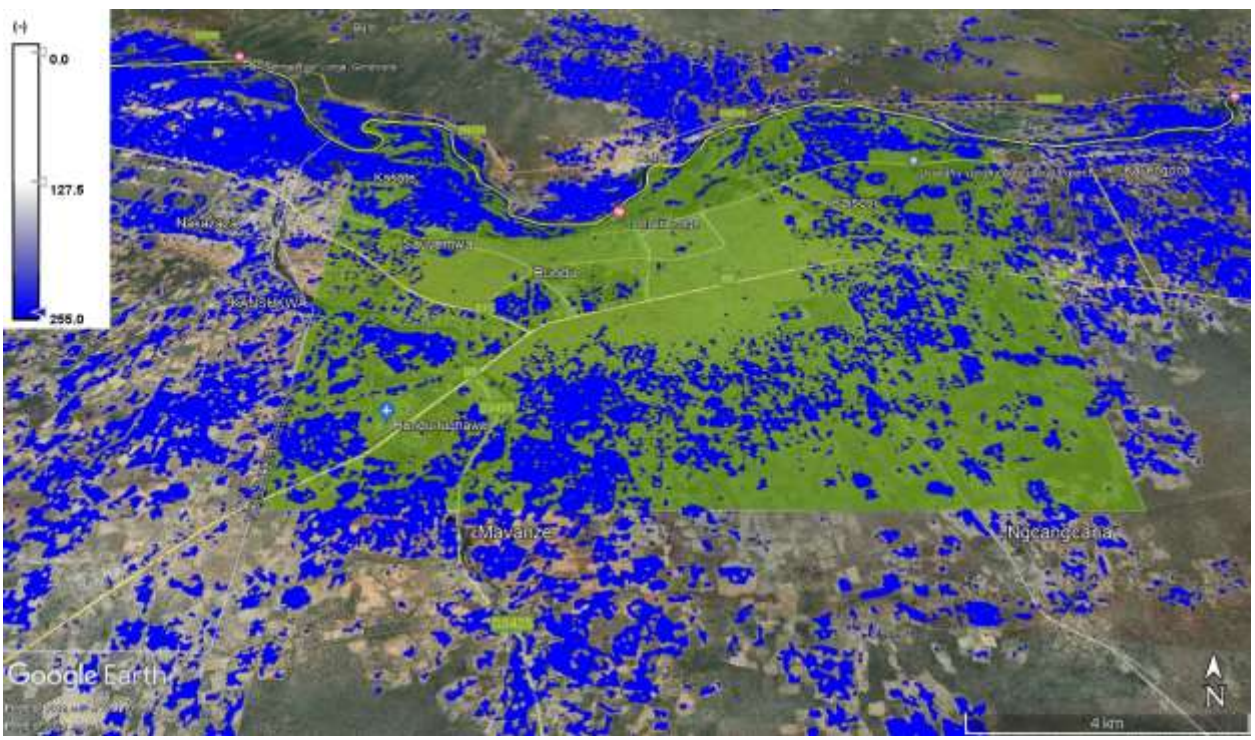
Configure your configuration file and execute the command (FLOODPYapp.py My_FLOODPYapp_template.cfg) this is to run all the steps at once. However, one could run the steps individually as explained in the documentation (https://floodpy.readthedocs.io/en/latest/).

Results

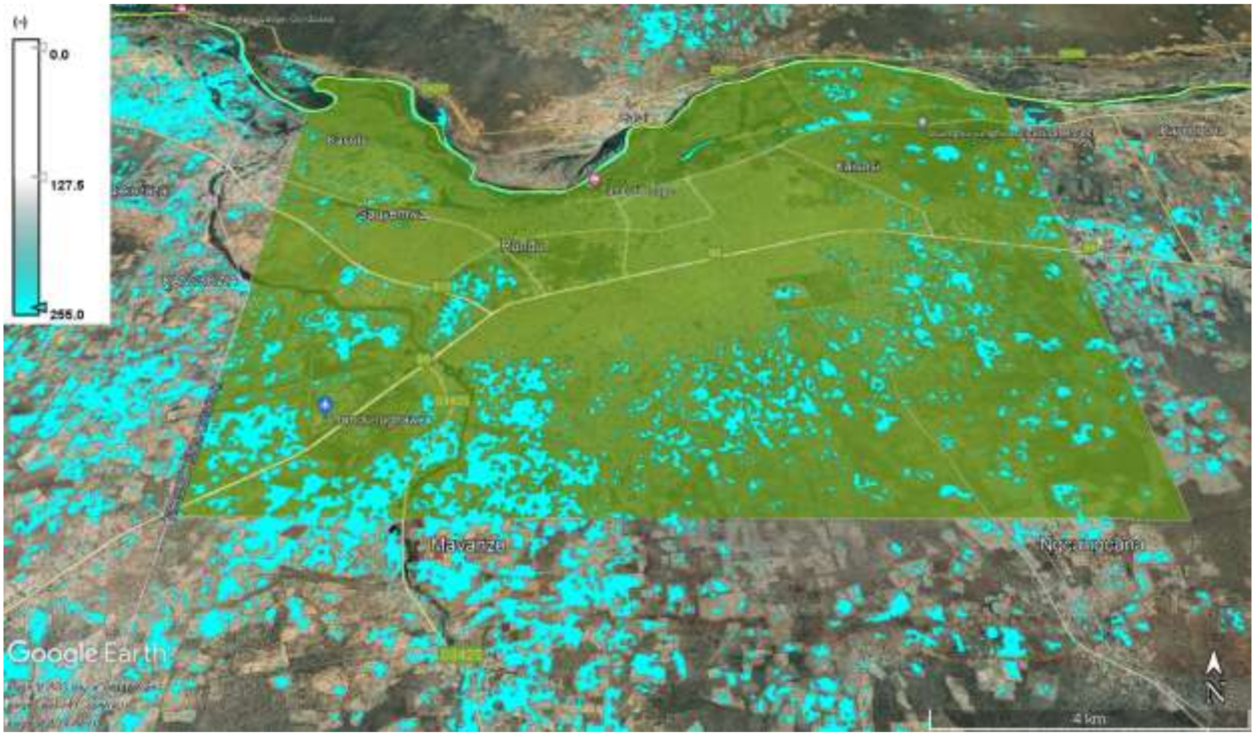
The binarization method and the Stacking method both picked up the water pixels equally in the 2019 and 2021 images. For the 2020 image it was a little difficult for the water pixels to be exacted as the backscattered reflected similar to the ones of the build-up area. Moreover, they all showed Rundu rural to be susceptible to flooding as the most water was exacted around this area followed by the area close to the river bed. FLOODPY provided useful results when it came to the 2020 image but however this cannot directly be compared because the image used by the FLOODPY method was not the same one used in the other methods. But one thing can be determined, with FLOODPY the water pixels were separated more than the others. What is more, the FLOODPY didn't generate outputs for 2019 for this study area as it could not acquire enough images to coregistrate.

The Binarization method: The highlighted colours represents the flooded areas.

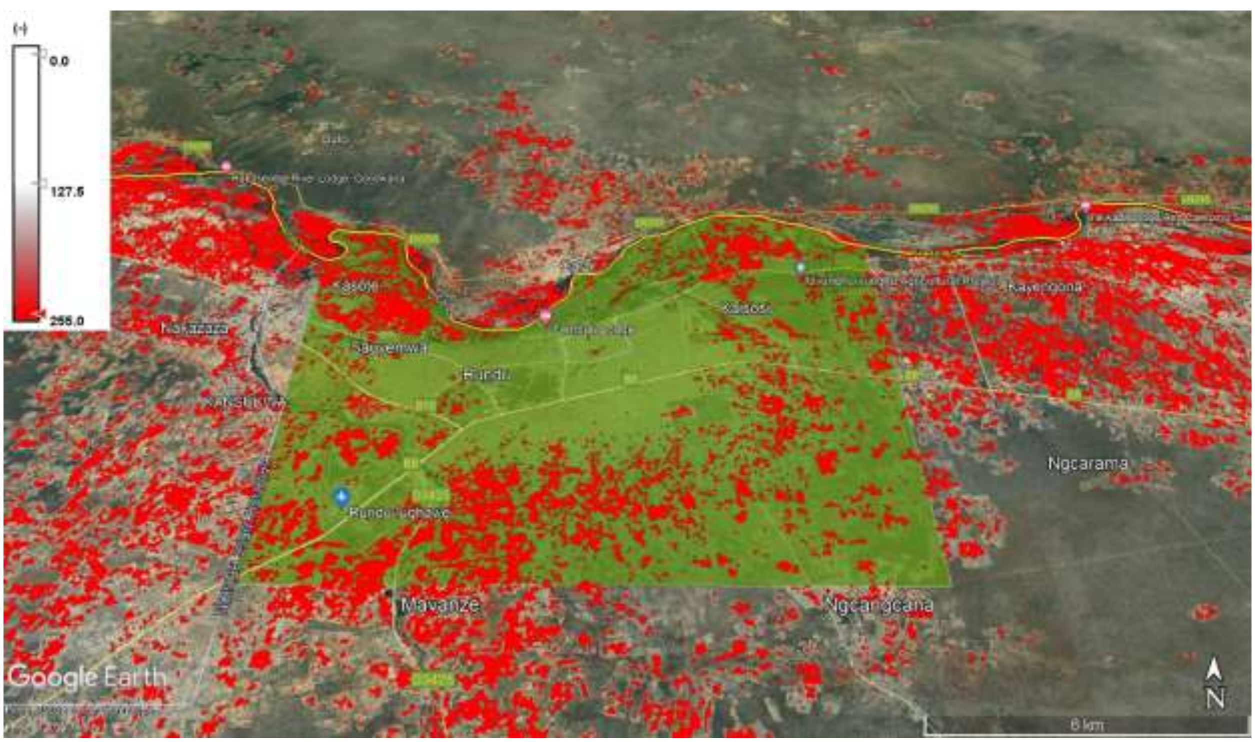
The following image shows the result of 2019.



The following image shows the result of 2020.

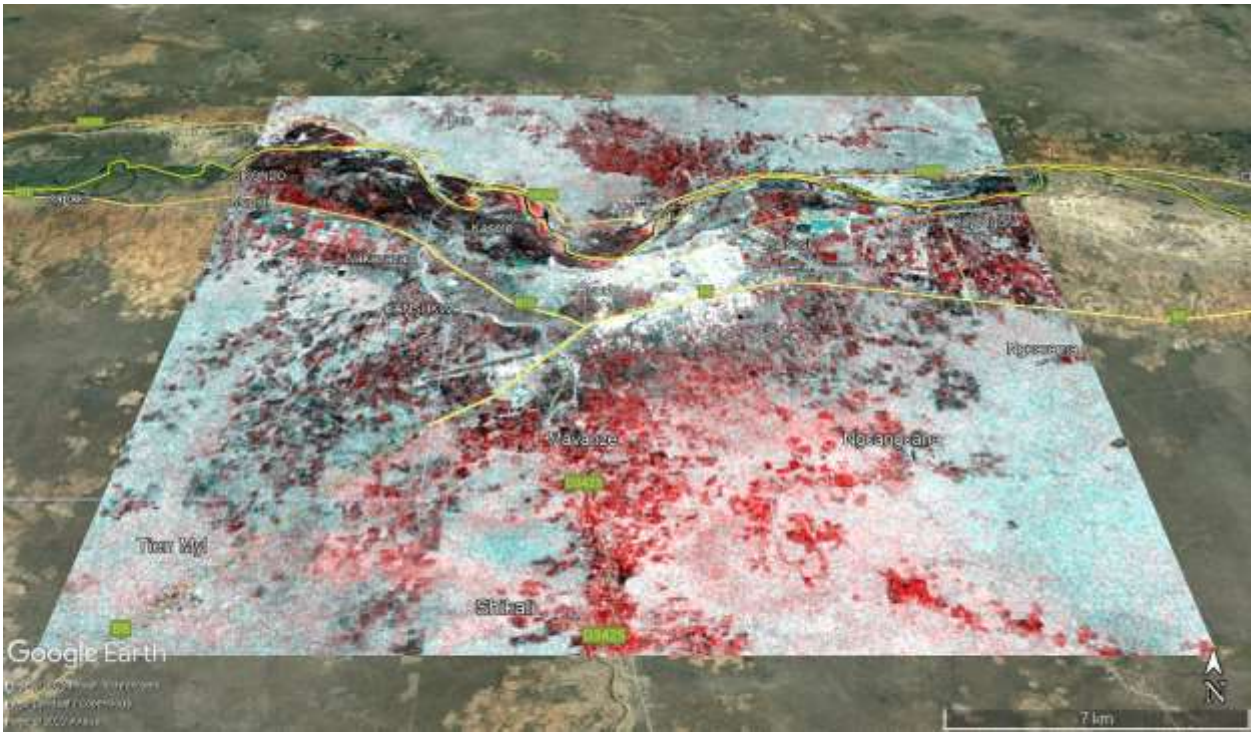


The following image shows the result of 2021

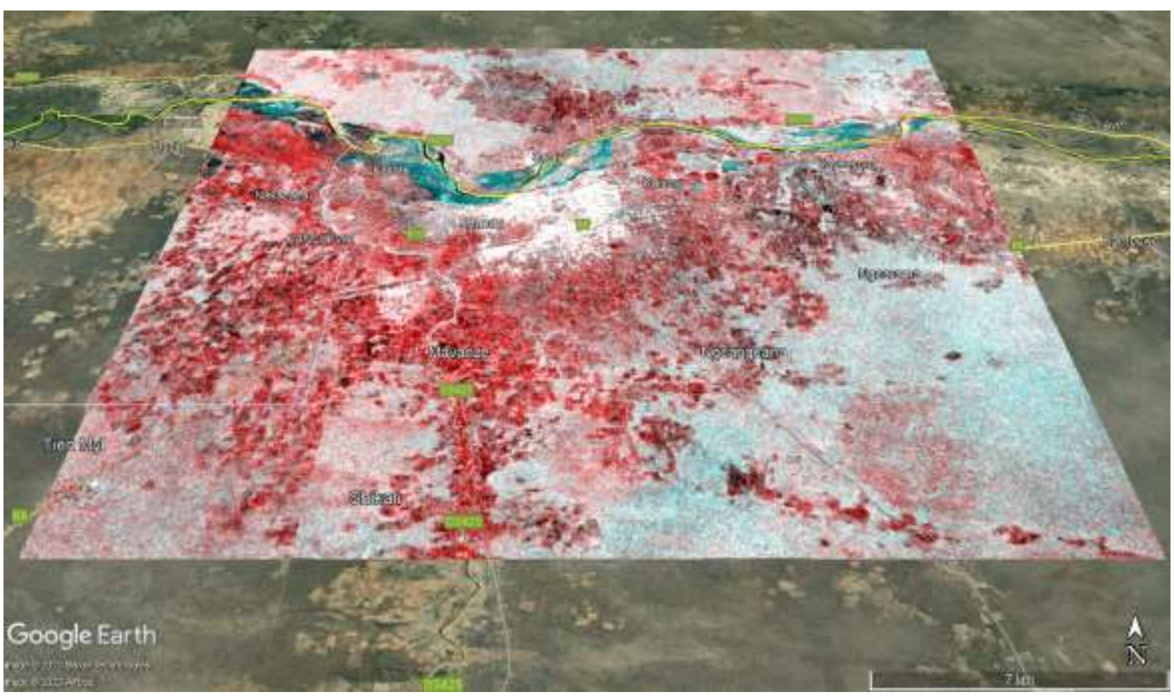


The Stacking method: The red areas shows water outside the permanent waterbodies

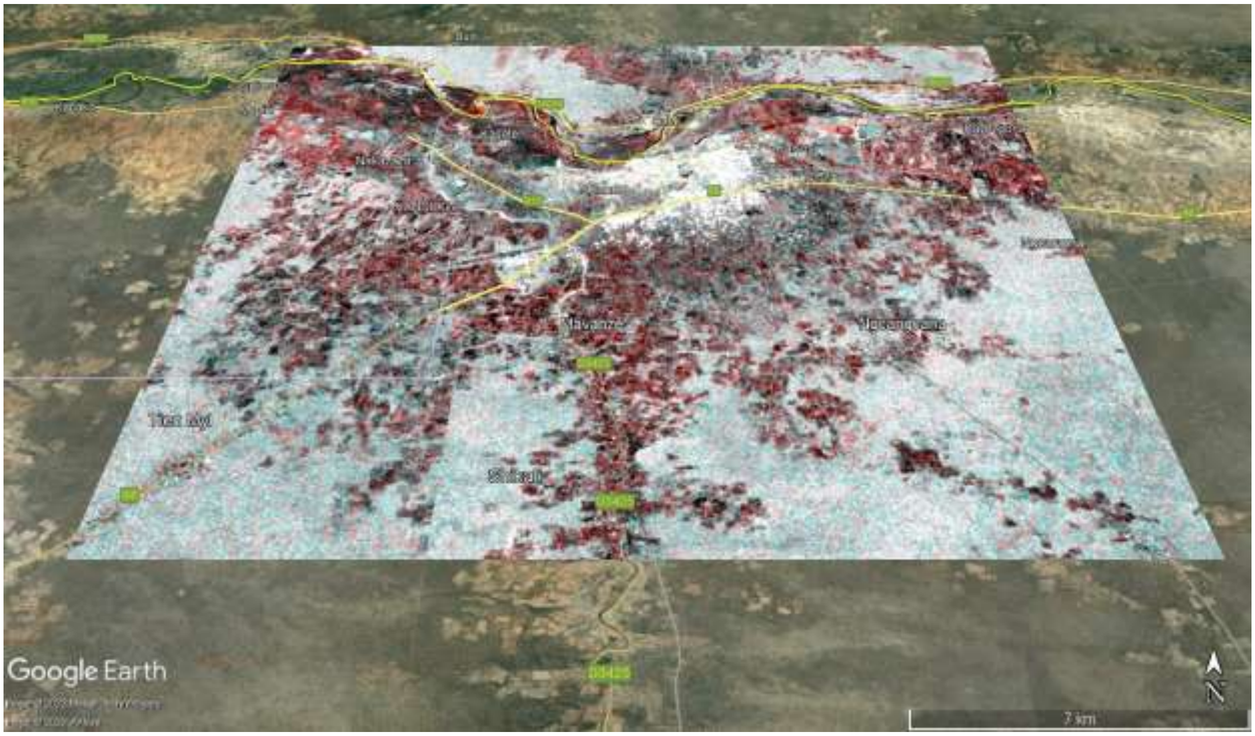
The following image shows the result of 2019.



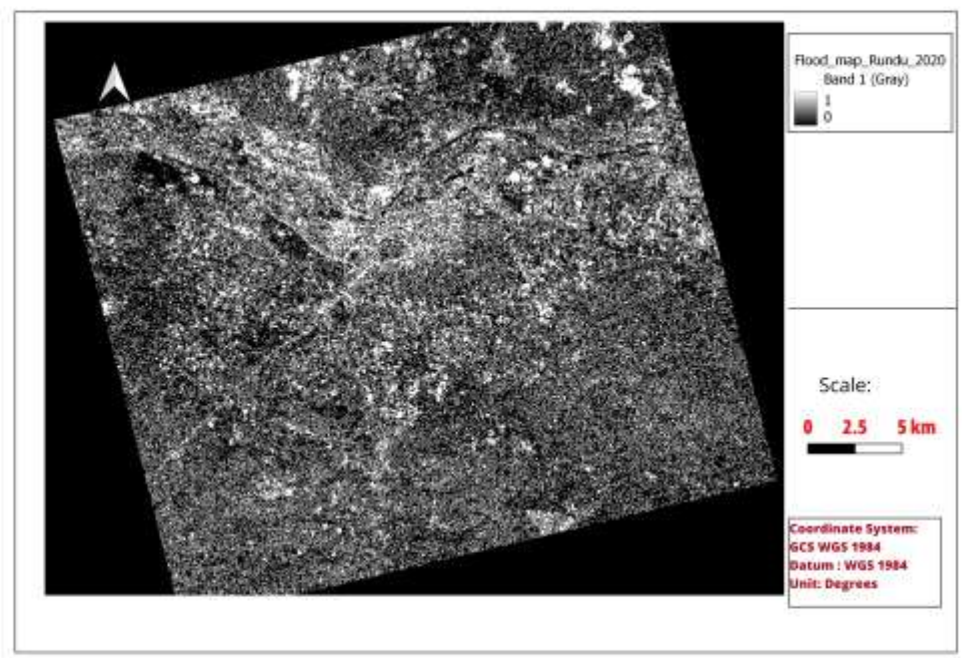
The following image shows the result of 2020.



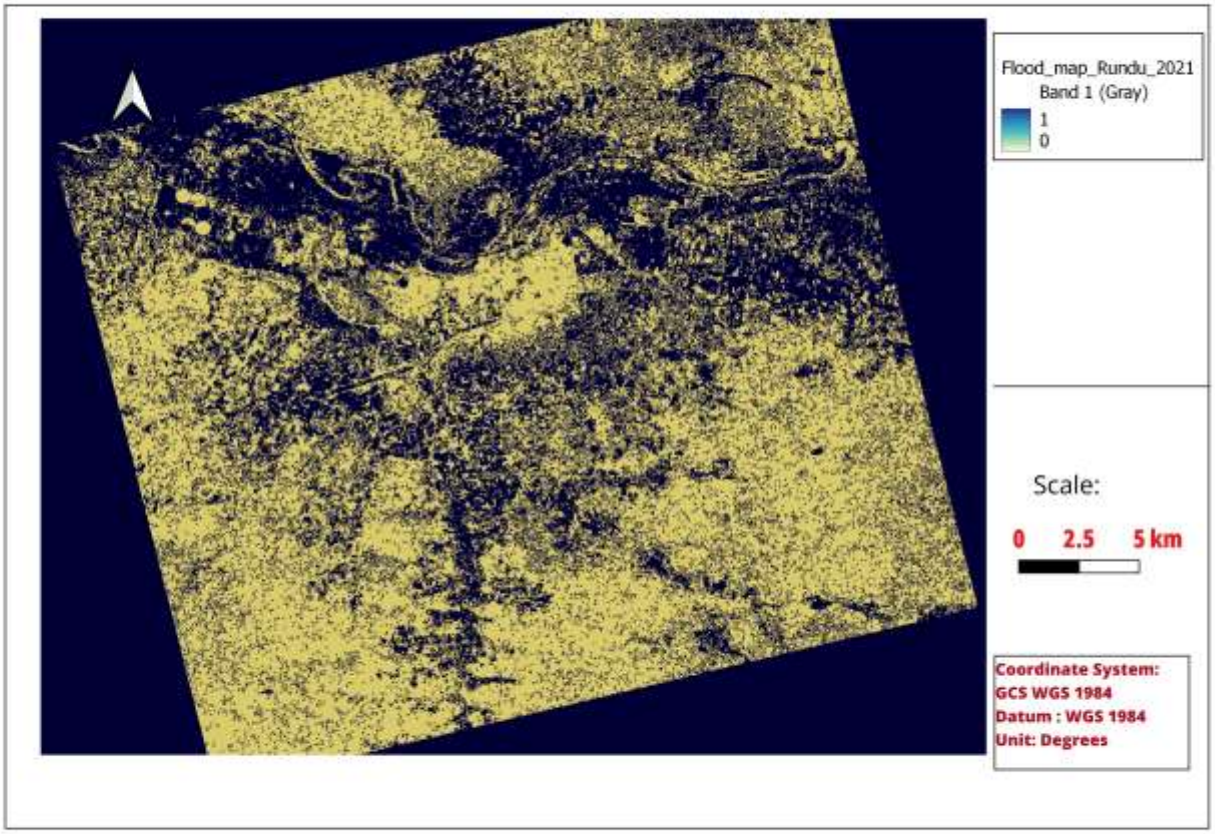
The following image shows the result of 2021.



FLOOPY flood map 2020: The darker parts shows the vulnerable areas.



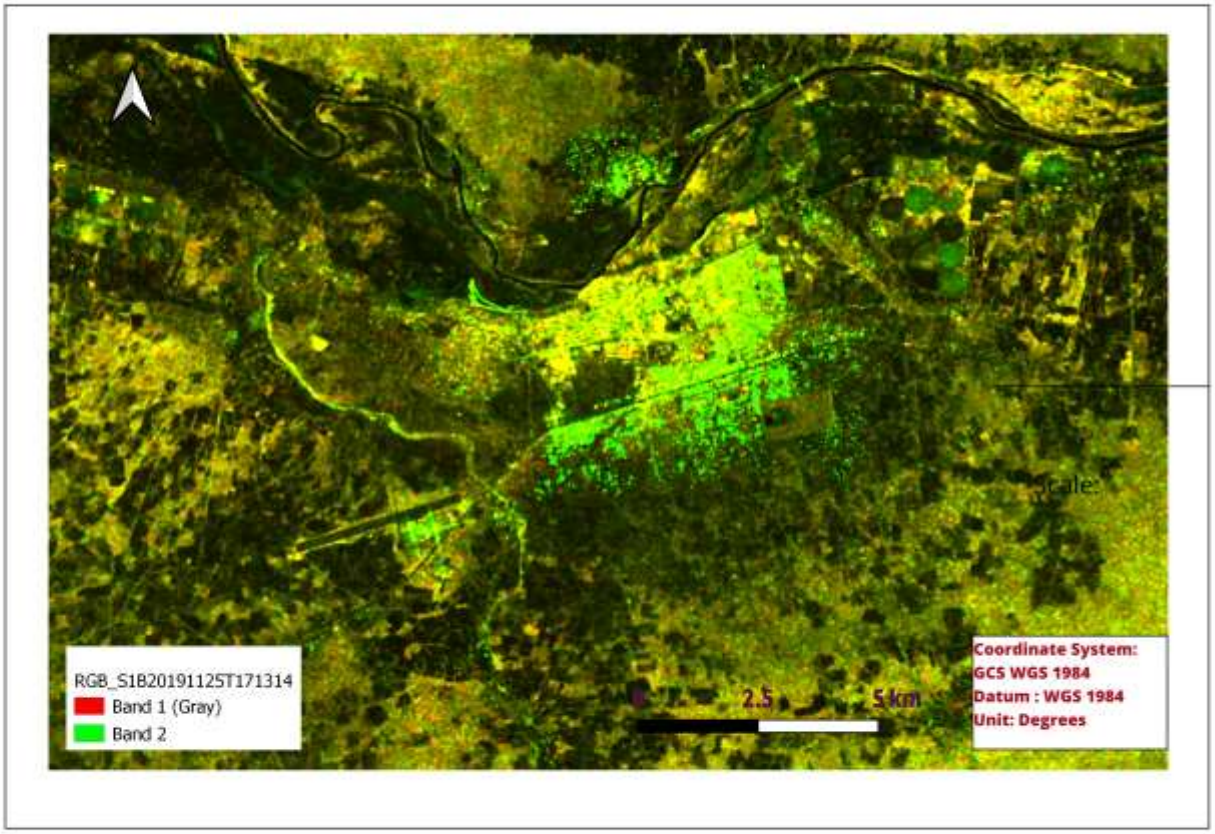
FLOODPY flood map 2021: The darker parts shows the flood vulnerable areas.

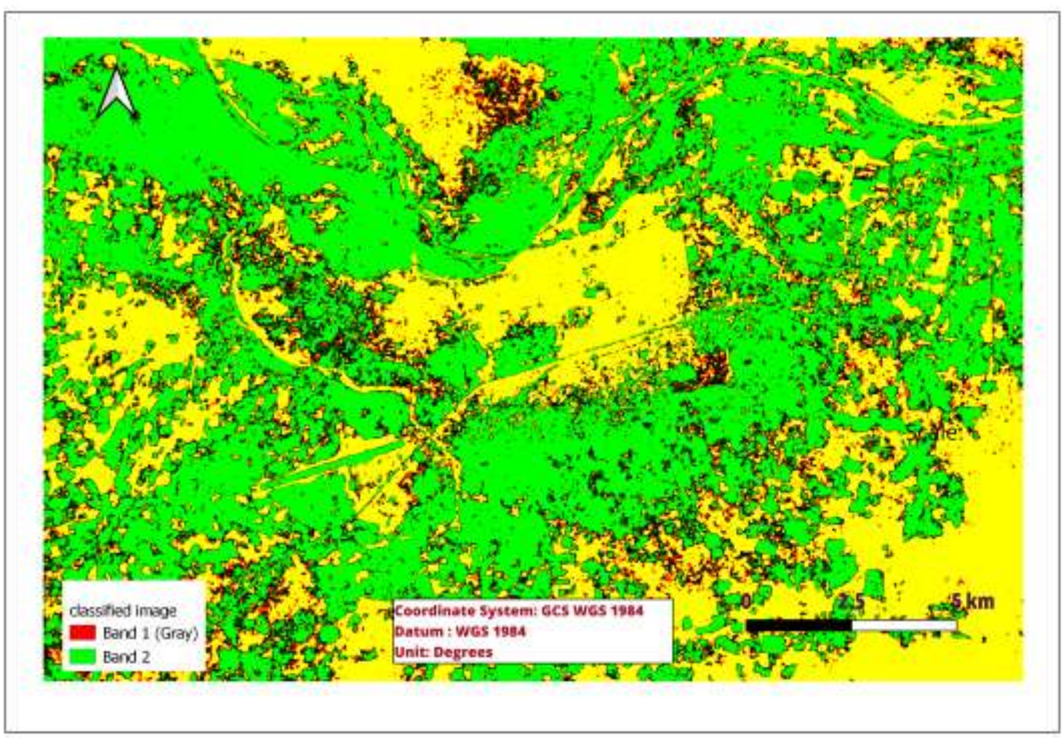


Validation

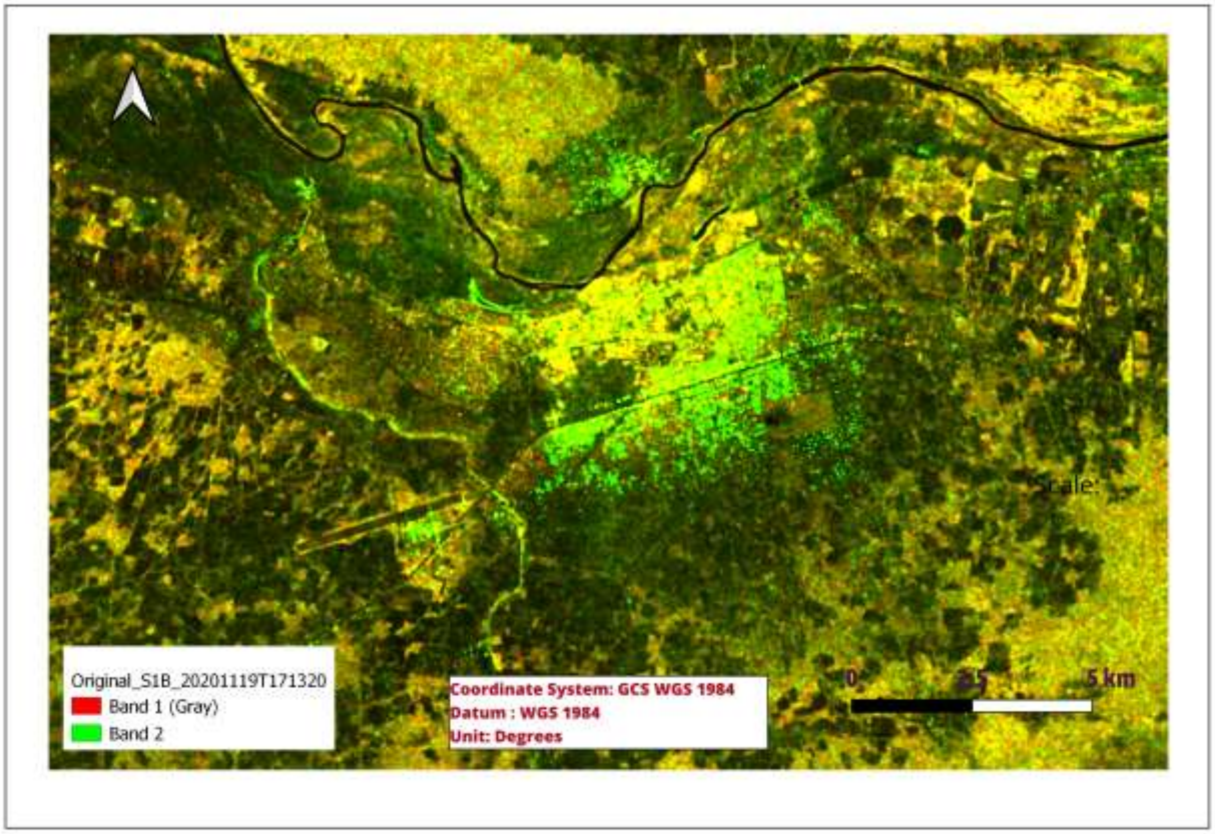
A classification was carried out to compare with the water pixels exacted from binarization and the stacking method.

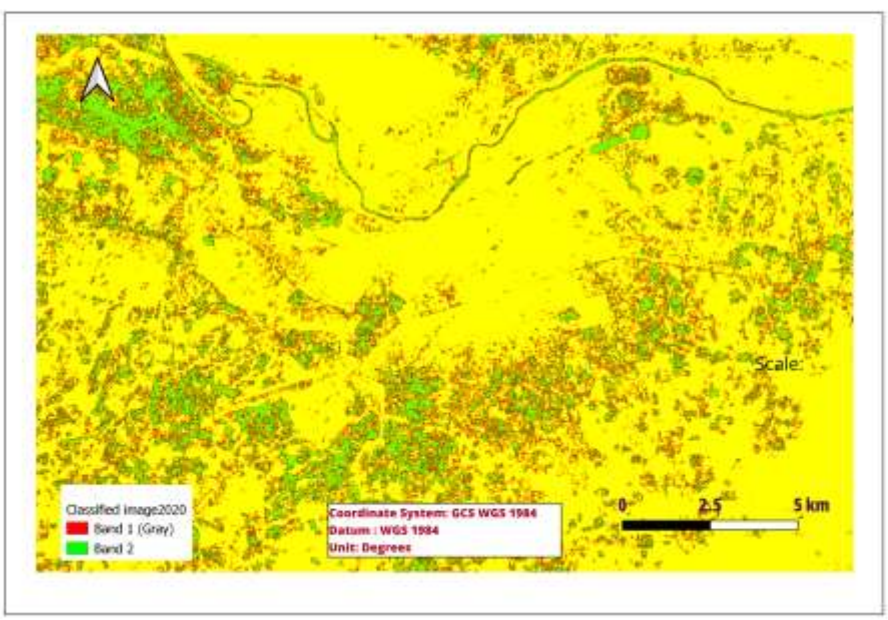
The following images shows the 2019 images


Scale:
RGB_S1B20191125T171314
Band 1 (Gray)
Band 2
0
2.5
5 km
Coordinate System:
GCS WGS 1984
Datum : WGS 1984
Unit: Degrees

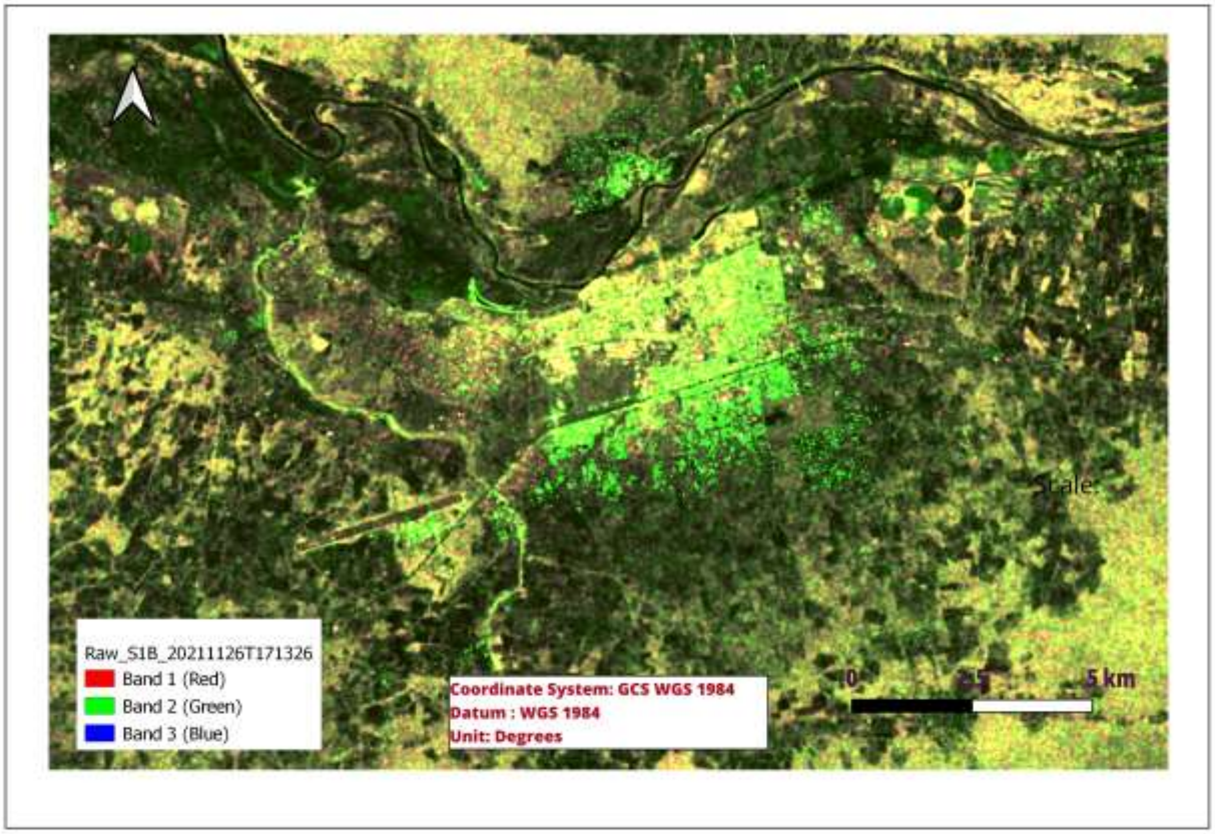

classified image
Band 1 (Gray)
Band 2
Coordinate System: GCS WGS 1984
Datum : WGS 1984
Unit: Degrees
0
2.5
5 km

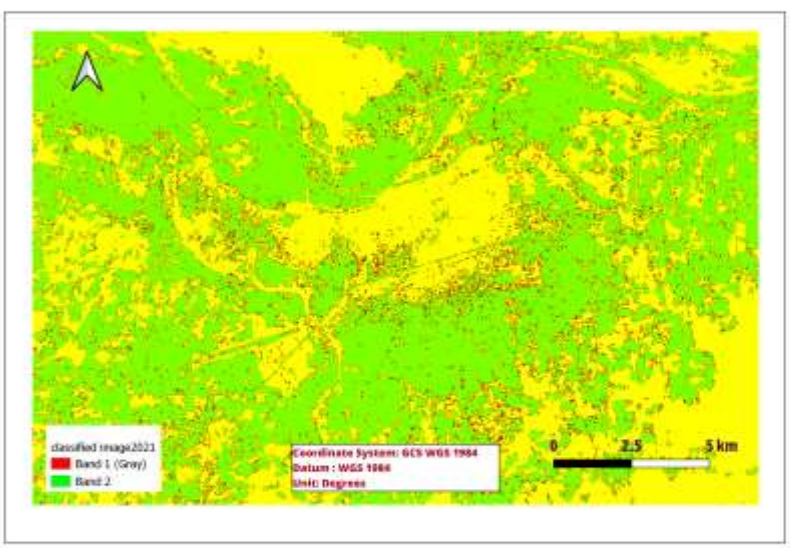
The following images shows the 2020 images



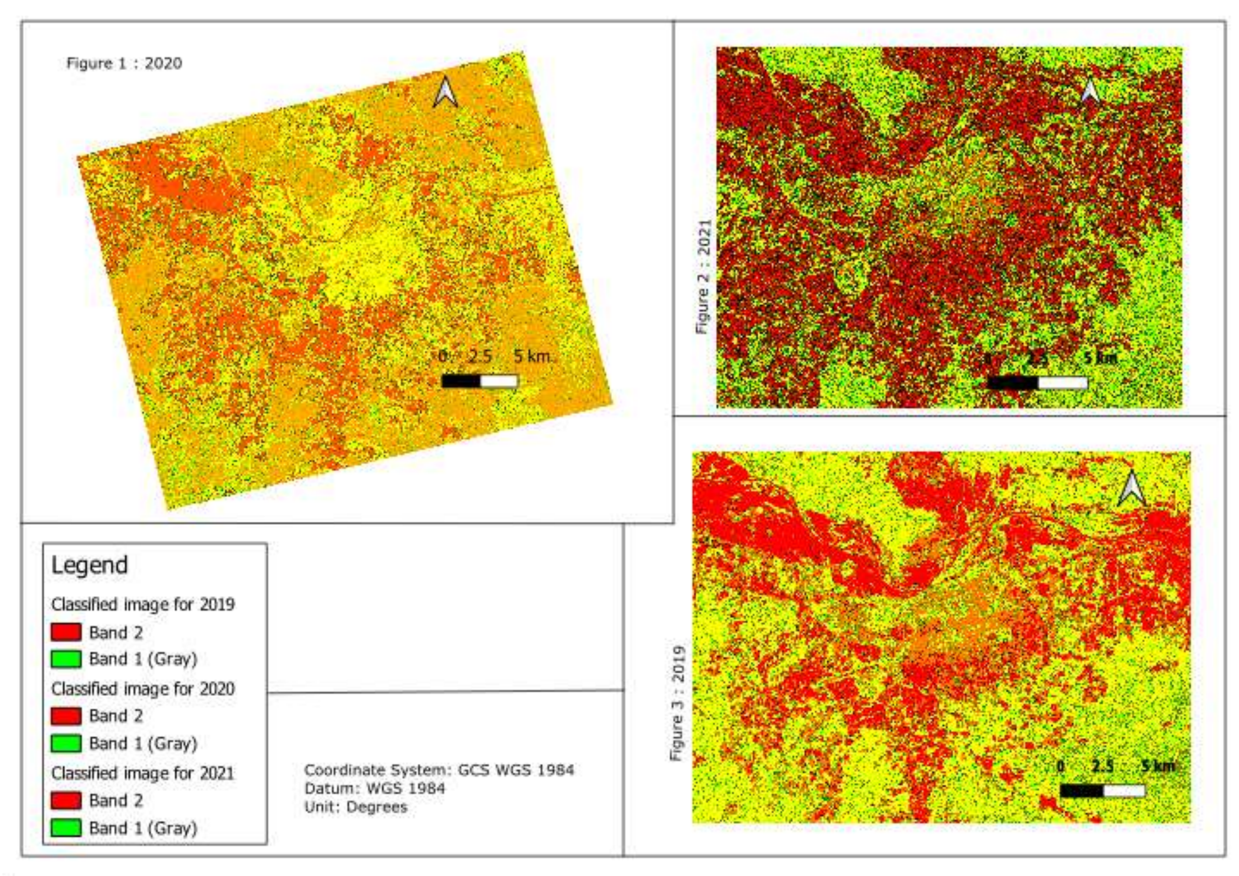


The following images shows the results of the classification of the 2021 image.





The compared classification



Accuracy assessment

Using the following formula from the data of the classification the following accuracy was determined.

Accuracy = (TP + TN) / (TP + TN + FP + FN)

Producer's Accuracy (Sensitivity) = TP / (TP + FN)

2019 image

Producer’s Accuracy	100%
User’s Accuracy	100%
Error of Commission	0%
Error of Omission	0%
Overall accuracy	100%

2020 image

Producer’s Accuracy	100%
User’s Accuracy	100%
Error of Commission	12%
Error of Omission	88%
Overall accuracy	89%

2021 image

Producer’s Accuracy	100%
User’s Accuracy	100%
Error of Commission	0%
Error of Omission	0%
Overall accuracy	100%

Conclusion

This study focussed on exploiting three different methods to do a flood mapping study in which all provided reliable results. Also, this study confirms the advantages of using Sentinel 1 as it can exact water pixels very well. Moreover, with the findings discovered in this paper, it can be examined more to really understand floods and continue to build on some literature to create robust methods to deal with floods especially places similar to this study area that is comprised of villages and an urban area. Practically this can be applied by local authorities and other organizations that specialize in this field to do more extensive research based on the findings in this paper hence set up practical and fast risk assessment plans.

References

Bailey, M., Advisor, S. T., Cross, R., Crescent, R., Centre, C., Heinrich, D., Advisor, T., Cross, R., Crescent, R., & Centre, C. (2014). *Climate Profiles of Countries in Southern Africa : Malawi*. *2021*, 1–5. https://www.climatecentre.org/wp-content/uploads/Climate-Profiles-of-Countries-in-Southern-Africa-Malawi.pdf

Karamvasis, K., & Karathanassi, V. (2021). FLOMPY: An open-source toolbox for floodwater mapping using sentinel-1 intensity time series. *Water (Switzerland)*, *13*(21). https://doi.org/10.3390/w13212943

Martin, M., Milner, S., Clarinda, K., & Frieda, A. (2018). *Economy Profile for Rundu*. *3*, 13. http://firstcapitalnam.com/cms/upload/Economy Profile of Rundu.pdf

Mwiya, S. (2005). *Floods : Flowing Water Driven Natural Hazard Risk-Based Solutions Resources*.

Prakash, G., Gupta, P. K., Rao, G. V., & Pratap, D. (2021). Flood Inundation Mapping and Depth Modelling using Machine Learning algorithms and Microwave data. *Journal of Geomatics*, *15*(2), 221–229.

Statistical, F., & Destatis, G. (2023). *Statistical Country Profile Namibia* (Issue June). Federal Statistical Office of Germany (Destatis). https://www.destatis.de/EN/Themes/Countries-Regions/International-Statistics/Country-Profiles/Namibia.pdf

World Bank Group. (2021). Climate Risk Country Profile: Uganda. *The World Bank Group*, 36. www.worldbank.org

The World Bank (2023, March 29). The World Bank in Namibia. WorldBank. Retrieved July 29, 2023, from https://www.worldbank.org/en/country/namibia/overview

Green, R. Herbold (2023, June 9). Namibia. Encyclopedia Britannica. https://www.britannica.com/place/Namibia