Author: Jānis Kapenieks jun.
Contact: janis.kapenieks_1@rtu.lv
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Flood Mapping and Damage Assessment Using Sentinel-1 SAR Data

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Introduction

Global warming has led to an increase in the frequency of extreme weather events[1]. In 2024, Latvia experienced the impact of cyclone Kirsti, leading to wind and rain damage in Zemgale and western Vidzeme.

Latvia capital Riga was affected significantly with power and water supply outages and flooded streets. According to meteorologists this cyclone was the strongest summer storm in Latvia's history[2][3]. The total damage caused by this cyclone still to be estimated. By August 22nd, 2024, insurers had received 9,097 applications for compensation for damage caused by the July storm, the Latvian Association of Insurers (LAA) said.[4]
The total amount of claims is more than EUR 20 million. So far, EUR 7 million has been paid out, representing around 40% of all claims[5]

The extreme weather event caused by cyclone Kirsti affected agriculture sector significantly as the harvest period was close especially in grain farming. Rain showers and wind gusts caused significant loss of harvest in Zemgale region.

Research objectives

The aim of my research is to identify the most effective algorithms for flood detection in agricultural and low-density urban areas. My goal is to create a reliable methodology for initial damage assessment just after or during the flooding event. The primary data source utilized in this study is satellite imagery from Sentinel-1 GRD. Sentinel-1 GRD offers C-band synthetic aperture radar imaging, allowing for the acquisition of images regardless of weather conditions[6].

The objective of my research is to identify a remote sensing method for assessing damages resulting from flooding focusing on agriculture sector. The results from remote sensing data will be validated using real world assessments.

Potential users of the research results: public and private organisations providing assistance and rescue operations after extreme weather events. This includes

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[1] IPCC. (2021). "Climate Change 2021: The Physical Science Basis." Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.
[2] https://bnn-news.com/julys-storm-listed-as-the-strongest-summer-storm-observed-in-latvias-history-259447
[3] https://www.lsm.lv/raksts/zinas/latvija/02.08.2024-julija-beigas-piedzivota-vetra-bijusi-stipraka-vasaras-vetra-latvijas-noverojumu-vesture.a563642/
[4] https://eng.lsm.lv/article/society/society/23.08.2024-over-9000-insurance-claims-filed-after-july-storm-in-latvia.a566111/?utm_source=lsm&utm_medium=article-bottom&utm_campaign=article
[5] https://eng.lsm.lv/article/society/society/23.08.2024-over-9000-insurance-claims-filed-after-july-storm-in-latvia.a566111/?utm_source=lsm&utm_medium=article-bottom&utm_campaign=article
[6] https://docs.sentinel-hub.com/api/latest/data/sentinel-1-grd/

municipalities, government agencies, insurance companies. The research results will provide estimated damages caused by flooding focusing on agriculture and insurance in agriculture.

Related works

The detection and analysis of floods using SAR satellite imagery data is a critical area of research, especially with the increasing impacts of climate change. This section reviews relevant literature to provide context for the algorithms and methodologies explored so far in this study.

I have analysed several studies that have proposed various algorithms for flood detection using satellite SAR imagery data. Most studies propose multi-temporal change-detection methods as the main alghorithm.

For instance, [7] uses RST algorithm that is an automatic multi-temporal change-detection method being used and extensively tested for detecting various environmental hazards. This method is based on identification of pre-flooding SAR image and this is compared to an image during the flooding and calculating statistically significant changes.

Research by [8] provides more detailed approach that is based on two SAR images: a flood image and a reference image (before floods). This research propose flood mapping framework based in four phased approach: image pre-processing, semi- automatic thresholding, change detection, and flood map generation.

Research by [9] focuses on detecting patterns of pre-monsoon and monsoon floods in five valley districts of Manipur in India. Aperture Radar (SAR) image data of Sentinel-1 was used for this research. More specifically satellite vertically emitted and vertically received (VV) SAR images were used in the study. Three SAR images obtained in different time periods were used in mapping flooded areas as two sets of remotely sensed images, before the flood and during the flood.

Research papers listed above highlights the advantages of using Sentinel-1 GRD data for flood monitoring. Their findings indicate that C-band synthetic aperture radar imagery can effectively capture flood extents despite cloud cover, a critical factor for continuous monitoring. Regarding satellite image processing in their research methods they use change detection algorithms comparing two images: an image taken before and during the flooding event.

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[7] Lahsaini, M.; Albano, F.; Albano, R.; Mazzariello, A.; Lacava, T. A Synthetic Aperture Radar-Based Robust Satellite Technique (RST) for Timely Mapping of Floods. *Remote Sens.* **2024**, *16*, 2193. https://doi.org/10.3390/rs16122193

[8] Lang, F.; Zhu, Y.; Zhao, J.; Hu, X.; Shi, H.; Zheng, N.; Zha, J. Flood Mapping of Synthetic Aperture Radar (SAR) Imagery Based on Semi-Automatic Thresholding and Change Detection. *Remote Sens.* **2024**, *16*, 2763. https://doi.org/10.3390/rs16152763

[9] Manglem, Abujam. (2022). Flood Mapping in Valley Districts of Manipur Using Satellite-based Synthetic Aperture Radar (SAR) Images. Ecology, Environment and Conservation. 28. S480-S487. 10.53550/EEC.2022.v28i07s.079.

While existing studies provide valuable insights and methods used, few have addressed the integration of real-time data collection and analysis in agriculture and low-density urban settings. This presents an opportunity for further research and development of more robust detection algorithms focusing on agriculture sector in order to access damages caused by extensive flooding.

In summary, while significant advancements have been made in flood detection using satellite imagery, critical gaps remain in methodology. This research aims to build upon these foundational studies by exploring novel algorithms that address these limitations.

Research methods

The main data source for this research is image data available form online satellite imaging services. These services provide several types of image data, based on different sensor technology:

- Multispectral imagery: one of the most common types of satellite data based on capturing reflected sunlight. It allows for the collection of data in multiple parts of the electromagnetic spectrum, extending beyond what the human eye can perceive. These bands can encompass visible, infrared, and thermal wavelengths, and each band serves a specific purpose in remote sensing and data analysis.
- Hyperspectral imagery: captures multiple narrow bands of the electromagnetic spectrum, with each band capturing data in a very specific wavelength range. This allows to differentiate among different objects as each material, such as minerals, vegetation, water bodies, or man-made structures, has a unique spectral signature.
- SAR Data (Synthetic Aperture Radar). SAR technology uses radar waves to illuminate the Earth's surface and capture the backscattered signals. The captured signal is processed to create radar images. SAR technology advantage is the system can penetrate clouds, see beneath trees, and work in all weather conditions.

For detecting open water bodies and flooded areas mostly satellite multispectral and SAR imagery are used. [references] [10][11][12]. This is related to data availability:

- Satellites with multispectral and SAR sensors have been collecting imagery data for more than ten years.
- Multispectral and SAR satellite data archives are available for free of charge for limited use (Sentinel Hub, LANDSAT).

Sentinel API is accessible from Sentinel Hub providing a number of RESTful API endpoints that provide access to various satellite imagery archives. These archives are available

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[10] Zhou Y, Dong J, Xiao X, Xiao T, Yang Z, Zhao G, Zou Z, Qin Y. Open Surface Water Mapping Algorithms: A Comparison of Water-Related Spectral Indices and Sensors. *Water*. 2017; 9(4):256. https://doi.org/10.3390/w9040256

[11] Zhang W, Hu B, Brown GS. Automatic Surface Water Mapping Using Polarimetric SAR Data for Long-Term Change Detection. *Water*. 2020; 12(3):872. https://doi.org/10.3390/w12030872

[12] Estanqueiro, Marta & Mathew, Sojan. (2021). SURFACE WATER MAPPING AND EXTRACTION METHODS USING REMOTE SENSING DATA: A COMPARATIVE STUDY IN VOJVODINA (NORTHERN SERBIA).

free of charge if used withing specified limits. These limits are specified on monthly basis and they are more than enough for small and medium sized operations.

Methodology:
For this research I will use Sentinel-1 SAR satellite imagery data available from Sentinel API from Sentinel Hub (part of the Copernicus program).

SAR images do not represent the color and shape of objects; they only contain backscatter signals. However, with certain adjustments, SAR images can be transformed into more intuitive terrain maps that are easier for humans to interpret. In most cases, though, SAR data is processed through algorithms and machine learning models to extract information, often without any need to look at the visual image data.

For this research I'm using services hosted on Sentinel Hub[13]. These services allows you to access raw satellite data, rendered images, statistical analysis, and other features such as satellite image pre-processing.

Workflow
For this research imagery data is processed in the following steps:

1) Selection of area of interest (coordinates of a polygon edges are specified). Two images will be downloaded:
    a. Before the flooding event,
    b. After the flooding event.
2) Image is downloaded and pre-processed using the following filters (provided by Sentinel Hub):
    a. Calibration to the chosen backscatter coefficient and thermal noise removal applied,
    b. Speckle filtering,
    c. Radiometric terrain correction using area integration,
    d. Orthorectification using Range-Doppler terrain correction using the Mapzen or Copernicus DEM.

3) Both images (before and after flooding) are merged.
3) Result image is obtained and change detection algorithm applied.
4) Flood mask extraction and result analysis.
5) Satellite data validation using data obtained from Rural Support Service in Riga, Latvia.

[13] https://www.sentinel-hub.com/

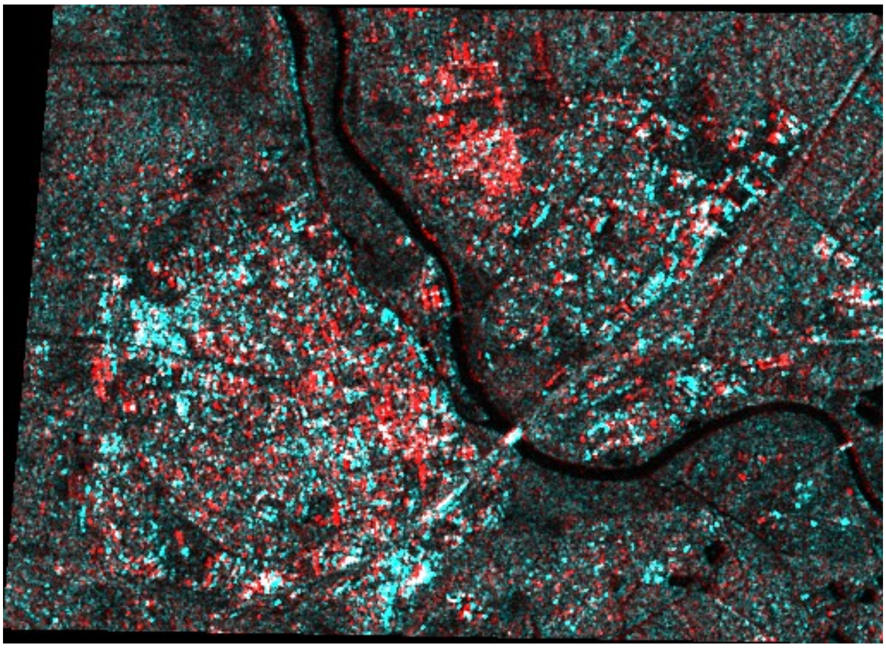

Figure 1. Merged SAR image displaying flooded areas (red color) in Jelgava (Latvia) during cyclon Kristi activity (29th of July, 2024)

Research results