Flood Mapping of Bangladesh

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Editor: Dr. Nova Ahmed

Abstract

Floods are one of the most devastating natural disasters. Bangladesh is one of the worst sufferers of flood. Every year, floods cause massive damage in Bangladesh. Flood mapping and monitoring helps provide useful information related to floods and help in flood risk management. The application of satellite image processing to prepare flood mapping and monitoring systems is of paramount interest in recent times. The necessity to develop a suitable flood mapping and monitoring system in the context of Bangladesh is increasing day by day. In this project, we explore the basics of remote sensing and flood inundation mapping with the help of Google Earth Engine (GEE), a planetary-scale data analysis and visualization tool. The region of interest of our project is Bangladesh. We also develop a flood information map based on out inundation maps and prepare statistical visualizations of flood history data collected from government sources.

Keywords: Flood Mapping, Remote Sensing, Google Earth Engine, Data Visualization

1. Introduction

Bangladesh is one of the most flood-prone countries in the world due to its location, topography, and monsoon season. Floods can cause widespread damage to property and infrastructure, and can also lead to loss of life. The people of Bangladesh have developed a number of coping mechanisms to deal with floods, but the scale and severity of recent floods has overwhelmed many of these mechanisms. Therefore, it is necessary to have access to current flood statistics, tools, and information in order to be well-prepared for future floods. In order to better prepare for floods and lessen their effects, flood maps are employed. They provide decision-makers with information on potential flood risks, aid in flood mitigation efforts, and raise flood awareness among the general population. Our goals in this project are (a) to develop detailed and accurate flood inundation maps for Bangladesh for previous few years, (b) prepare an informative flood information map, and (c) prepare statistical visualizations based on flood history data.

Remote sensing is the process of detecting and monitoring the physical characteristics of an area by measuring its reflected and emitted radiation at a distance, usually from a satellite. Remote sensing is very useful for studies related to natural disasters such as floods, droughts, wildfires, land erosion etc. Remote sensing data is complex and requires heavy computation power. Google Earth Engine (GEE) (Gorelick et al. (2017)) is a cloud computing platform for planetary-scale geospatial data analysis. GEE allows swift analysis of remote sensing data by letting users run computations on the powerful servers of Google. In our project, we have made use of remote sensing and GEE to prepare flood inundation maps of Bangladesh.

2. Related Works

Floods are one of the most dangerous natural disasters all across the globe. A recent study done by Tellman et al. (2021) utilized satellite imaging and found that the proportion of the global population that are exposed to floods is increasing. According to Kreibich et al. (2022), risk management lessens the effects of floods and droughts, but it can be challenging to lessen the effects of extraordinary events that happen at a scale never seen before. So, investigations to find more efficient risk management methods is of utmost necessity especially in context of Bangladesh given that worse hydrological events are projected due to climate change.

One of the most useful techniques as well as a current standard practice for flood detection and analysis is remote sensing, as found in the review article by Munawar et al. (2022). An early work by Islam et al. (2010) utilizes MODIS images to create flood inundation map of Bangladesh. MODIS data is readily available and cost-effective so it is a good option to monitor and assess flood inundation dynamics in Bangladesh. However, we chose to use Synthetic Aperture Radar (SAR) data for flood mapping from the Sentinel-1 satellite as it is more suitable for flood mapping. The shortcoming of using MODIS data is that it is affected by clouds, rain and fog, hence unable to provide accurate images. On the contrary, SAR data is not affected by atmospheric conditions.

The aim of our project is to prepare a flood inundation map of Bangladesh following existing flood mapping methodologies, algorithms and techniques that utilize SAR data from Sentinel-1 satellite. Uddin et al. (2019) has performed a flood mapping of Bangladesh utilizing SAR data from Sentinel-1. Singha et al. (2020) has done the same and identified the flood-affected paddy rice fields by integrating the flooding areas and remote sensing-based paddy rice planting areas. These works, including ours, also make use of Google Earth Engine (GEE) which is a a very useful tool for large-scale geospatial data analysis. However, since our project has been conducted on a much smaller scale, it ends at the flood mapping. The mentioned projects, conducted more in-depth research and analyses based on the flood mapping of Bangladesh. But we have prepared a flood information map and statistical visualizations based on flood history data, which was out of the scope of the mentioned projects.

Besides Bangladesh, SAR data from Sentinel-1 satellite has also been used for the flood mapping of other regions across the world. Tiwari et al. (2020) used SAR and GEE to develop a flood inundation map of the 2018 Kerala floods. McCormack et al. (2022) reported a methodology to calculate annual flood extent by using SAR, using Ireland as the region of interest for their study. Nghia et al. (2022) applied GEE to map and monitor floods along the Mekong river. GEE is a useful and popular tool for flood mapping as well as other environmental monitoring applications, which is why these studies also used GEE, like we did for our project. However, our project only focused on making use of GEE for the flood mapping of Bangladesh. In other relevant studies, GEE has been utilized to monitor surface water dynamics (Chen and Zhao (2022)), as well as for mapping and monitoring long-term changes of global surface water by (Pekel et al. (2016)), changes in distribution and trajectory of global tidal flats (Murray et al. (2019)), flood mapping methodologies (Vanama et al. (2020), Islam and Meng (2022)), impact of drought and flood on Southeast Asia (Venkatappa et al. (2021)) and a plethora of other applications.

Other studies make use of data from another satellite known as Landsat. A method has been introduced for near real-time flood monitoring by combining contemporary Synthetic Aperture Radar (SAR) time series data with historical Landsat data on the Google Earth Engine (GEE) by DeVries et al. (2020). It has been assessed if the heightened temporal coverage provided by the existing Landsat-8 (L8) and two Sentinel-2 (S2) satellites combined enhances our capacity to identify surface water and assess the extent of flooding when compared to relying solely on the Landsat-8 sensor (Tulbure et al. (2022)). Our project however, did not make use of Landsat data, and focused only on the use of SAR data for flood mapping.

3. Methodology

3.1 Flood Inundation Map

3.1.1 Flood Mapping Tool: Google Earth Engine

Earth Engine is a platform designed by Google to make planetary-scale remote sensing analysis easy. Its petabyte-scale data catalog co-located with a massive CPU allows for interactive data exploration. It also provides APIs that allows researchers and engineers to build custom applications using programming languages like JavaScript, R and Python as well as GIS tools such as ArcGIS and QGIS. We have used JavaScript and the Earth Engine Code Editor in our project.

3.1.2 Sentinel-1 and Synthetic Aperture Radar (SAR)

The Sentinel-1 mission consists of two polar-orbiting satellites that operate day and night and perform C-band synthetic aperture radar imaging, allowing them to acquire imagery regardless of weather. It is the first of the Copernicus Programme satellite constellation conducted by the European Space Agency (ESA).

Synthetic-aperture radar (SAR) is a type of radar used for producing two-dimensional images or three-dimensional reconstructions of objects such as natural settings. Compared to traditional stationary beam-scanning radars, SAR provides finer spatial resolution by utilizing the movement of the radar antenna over an area of interest.

Radio waves are pulsed out in succession towards a target location, and then each pulse's echo is picked up and recorded to create a SAR image. With wavelengths ranging from a meter to several millimeters, a single beam-forming antenna is used to transmit the pulses and receive the echoes. The antenna's position in relation to the target shifts over time as the SAR device on board the aircraft or spacecraft moves. Combining the recordings from these various antenna positions is made possible by signal processing of the successively recorded radar echoes. By forming the synthetic antenna aperture, this process makes it possible to produce images with greater resolution than could be achieved with a particular physical antenna.

3.1.3 Datasets

Earth Engine contains a massive repository of datasets which can be utilized for geospatial analysis. Among the datasets available, we have employed the following datasets for preparing flood maps of Bangladesh:

- FAO GAUL 500m: Global Administrative Unit Layers 2015, Country Boundaries
  This dataset provides the boundaries for each country of the world. We have used this dataset to draw the boundary of Bangladesh as a whole.
- FAO GAUL 500m: Global Administrative Unit Layers 2015, Second-Level Administrative Units
  This dataset provides second-level boundaries for each country of the world. For Bangladesh, this dataset provides boundaries of each of the 64 districts of Bangladesh. We have used this datadet to draw the boundary of each district for the district level maps.
- JRC Global Surface Water Mapping Layers, v1.4
  This dataset offers maps of the location and temporal distribution of surface water from 1984 to 2021, as well as statistics on the extent and change of those water surfaces. We used this dataset to identify which areas were water in our map.
- WWF HydroSHEDS Void-Filled DEM, 3 Arc Seconds
  A digital elevation model, or DEM, is a picture of the Earth's topographic surface that doesn't include any buildings, trees, or other surface objects. We used this data set from the WWF HydroSHEDS Void-Filled DEM to separate sloped areas from our flood map and improve our map.

3.1.4 Flood Mapping Methodology: UN-SPIDER

UN-SPIDER is a platform for disaster management and emergency response that enables the use of space-based technology i.e. remote sensing. Its recommended practices include flood mapping methodologies. We followed this methodology while preparing our flood map.

3.2 Flood Information Map

A flood information map is a visual representation or tool that provides an idea about areas prone to flooding. These maps are designed to help individuals, communities, and authorities understand the flood risk in specific areas.

After the flood inundation maps were extracted from GEE, we were able to use those maps to make a flood information map. From the flood inundation map, we were able to analyse and rank the divisions of Bangladesh in terms of severity of flooding. Darker blue represents higher severity of flooding.

We also made use of another table for the flood information map from Barua et al. (2016). From this table we found district wise flood severity information, categorising each district as "severe", "moderate", "normal", or "non-flood area". We set a value of each to each of this categories and found the division wise average for these values. We compared these values with the flood inundation map, to get a more accurate flood information map.

However, a limitation we faced during creating the flood information map was that there were no proper data sets available regarding the divisional severity of flooding in Bangladesh, hence we could not extract exact numerical values.

3.3 Flood History Statistics

For preparing statistical visualizations of the data related to floods in Bangladesh, we collected relevant data from the Bangladesh Water Development Board (BWDB). This data is essential for creating an accurate and informative chart to help us visualize and understand the trends and patterns related to flood levels and rainfall in Bangladesh.

Having gathered the data, we meticulously cleaned and formatted it to ensure accuracy and consistency. Data integrity is paramount, and we have taken steps to remove any inconsistencies or errors. With our clean and organized data, we created the chart using charting software (Microsoft Excel). We carefully selected the appropriate type of chart that aligns with the specific data we have collected. The choice of chart type is vital in conveying a message effectively, and it will enable us to visualize the relationship between flood levels, rainfall, and time accurately.

4. Results

4.1 Flood Inundation Map

Our area of interest is Bangladesh. We extracted Bangladesh region from the FAO GAUL 500m: Global Administrative Unit Layers 2015, Country Boundaries dataset, then applied the UN-SPIDER flood mapping methodology to make flood maps for the years 2022, 2021, and 2020.

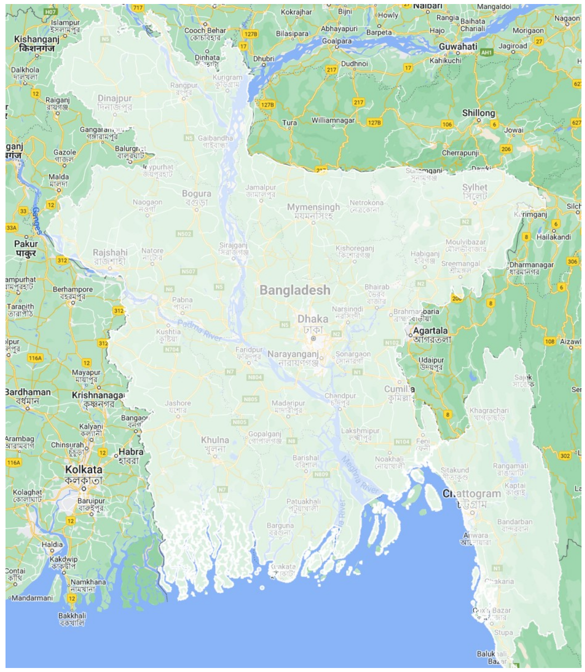
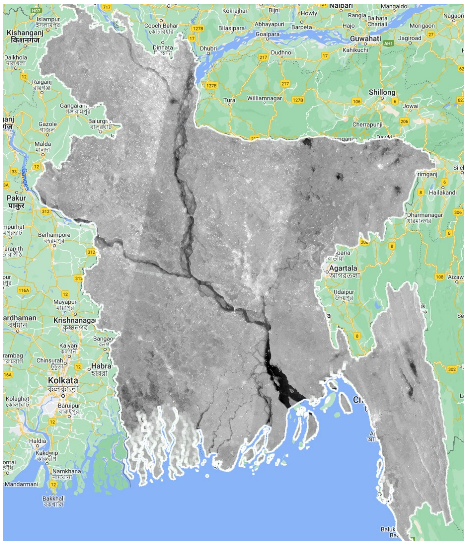


Figure 1: The map of Bangladesh extracted from GEE.

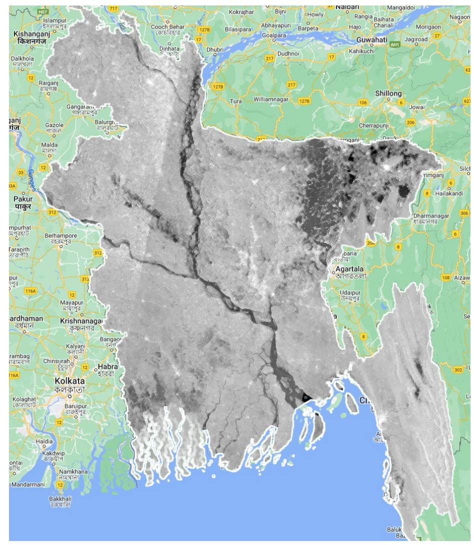
4.1.1 Flood Inundation Map of Whole Bangladesh

We created inundation maps of entire Bangladesh for the years 2022, 2021 and 2020. This map is an interactive visualization and we have uploaded our maps as web applications. This map provides qualitative information about flooding in Bangladesh for the years 2022, 2021 and 2020. By interacting with the maps, we can identify which regions were most affected by flood. For all 3 years, the area most affected by flood is Sylhet.

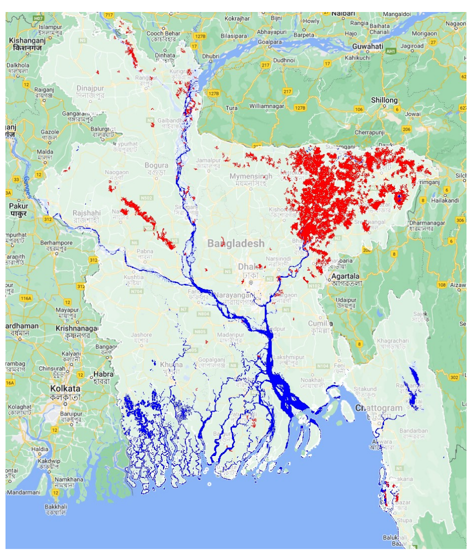
For 2022, we chose the date range 01-04-2022 to 30-04-2022 to compose the image before flood. We chose the date range 01-06-2022 to 30-06-2022 to compose the image after flood.



(a) Composite image before flood



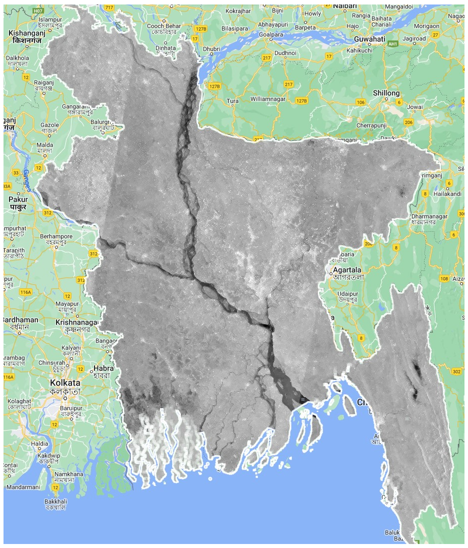
(b) Composite image after flood



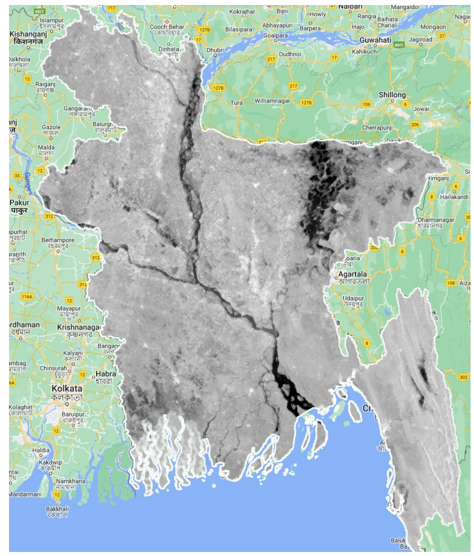
(c) Flood Inundation map. Blue: Permanent water. Red: Flood.

Figure 2: Flood inundation map of Bangladesh for the year 2022.

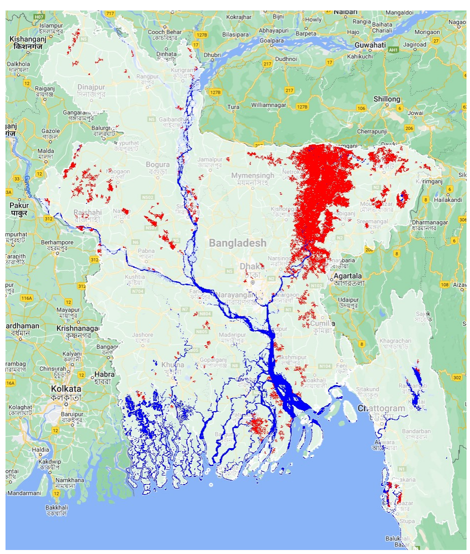
For 2021, we chose the date range 01-04-2022 to 30-04-2022 to compose the image before flood. We chose the date range 27-08-2022 to 04-09-2022 to compose the image after flood.



(a) Composite image before flood



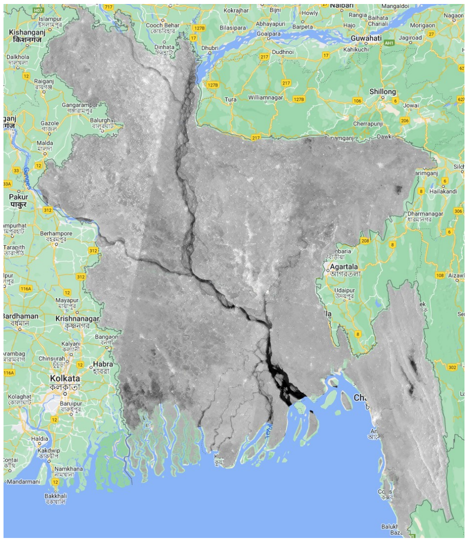
(b) Composite image after flood



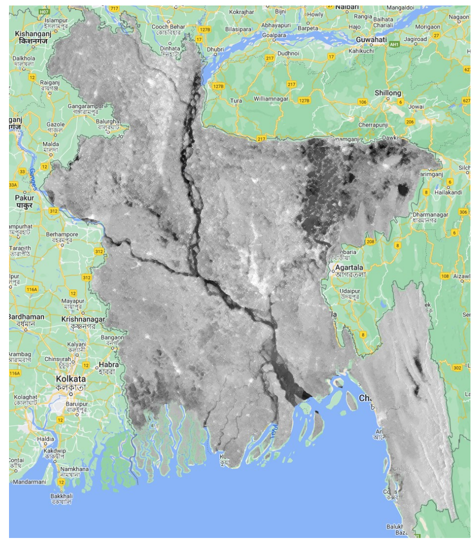
(c) Flood Inundation map. Blue: Permanent water. Red: Flood.

Figure 3: Flood inundation map of Bangladesh for the year 2021.

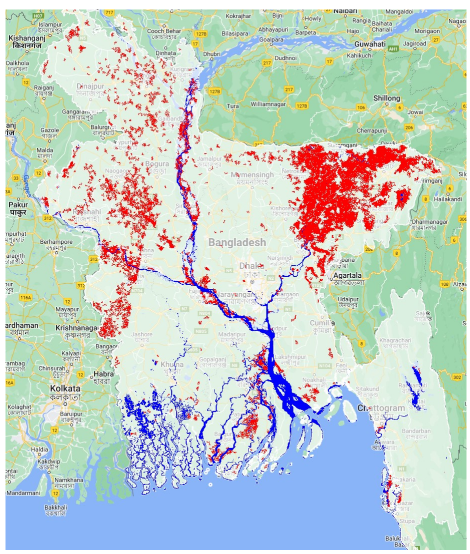
For 2020, we chose the date range 01-04-2022 to 30-04-2022 to compose the image before flood. We chose the date range 01-06-2022 to 31-07-2022 to compose the image after flood.



(a) Composite image before flood



(b) Composite image after flood

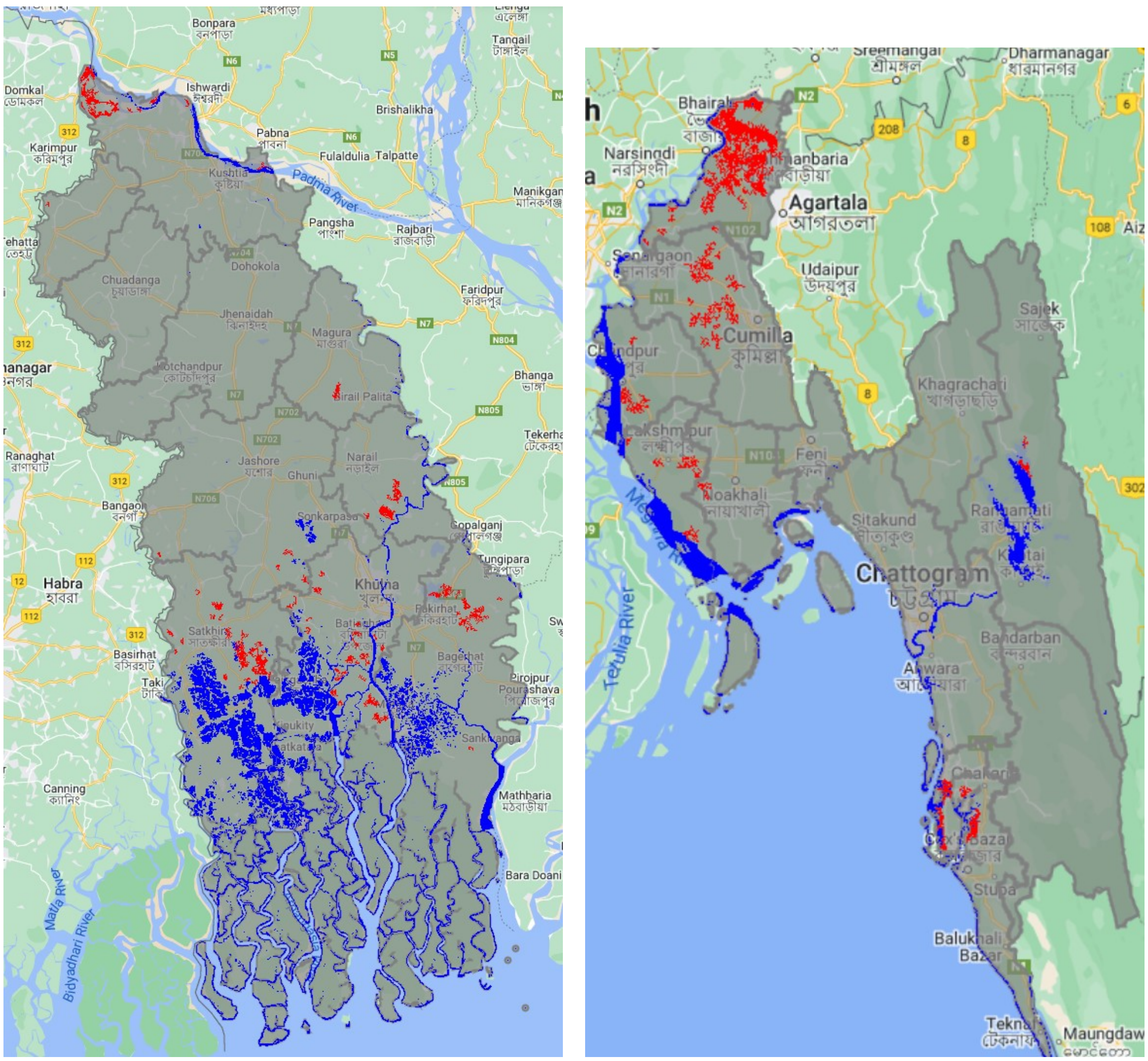


(c) Flood Inundation map. Blue: Permanent water. Red: Flood.

Figure 4: Flood inundation map of Bangladesh for the year 2020.

4.1.2 District Level Maps of Each Division of Bangladesh

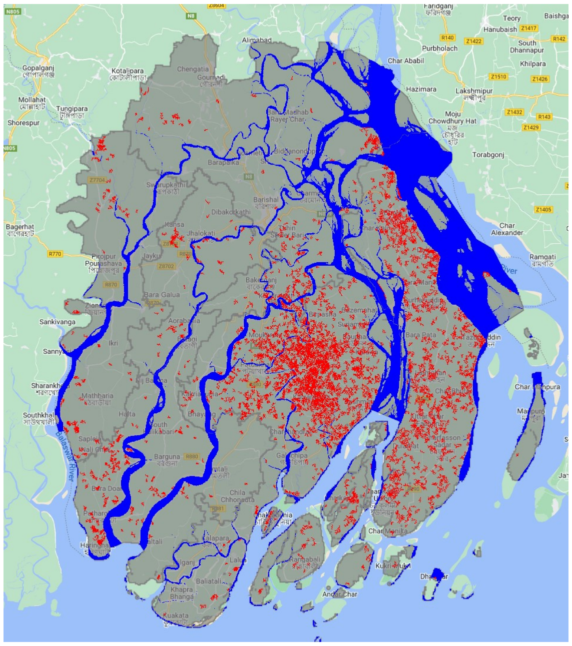
Although the maps shown in the previous section are good for visualization and qualitative understanding, they do not provide any quantitative information about flood. We faced a problem when we tried to perform numerical computations to calculate flood extent on the map of entire Bangladesh. The area of Bangladesh is too large to calculate the flood extent. So, we divided the map by division into 7 maps. We created 64 individual maps of each division, arranged them by division and compiled them in the same script to create division level maps of Bangladesh. As this task was time consuming, we did it only for the year 2021. Moreover, the calculation of flood extent requires heavy computation so we only generated the permanent water layer and flooded layer on the map.



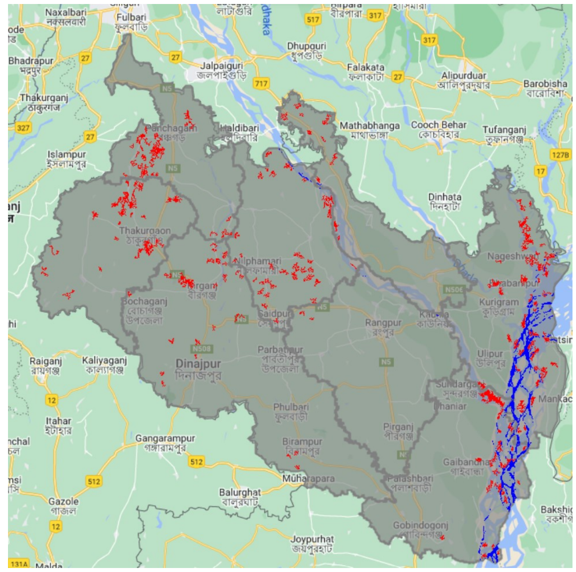
(a) Flood Inundation Map of Khulna.

(b) Flood Inundation Map of Chittagong.

Figure 5: Flood inundation map of Khulna and Chittagong.

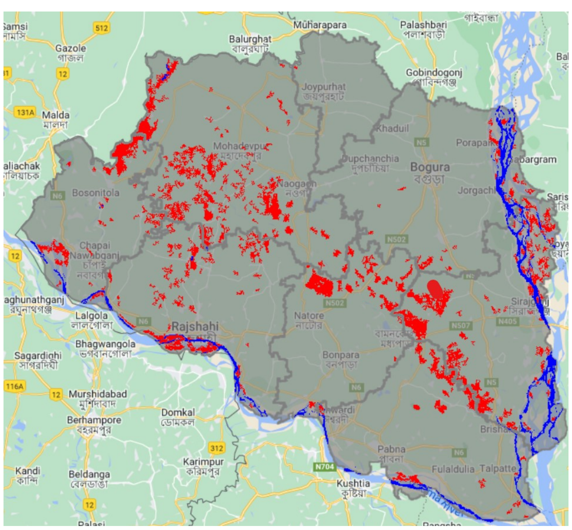


(a) Flood Inundation Map of Barisal.

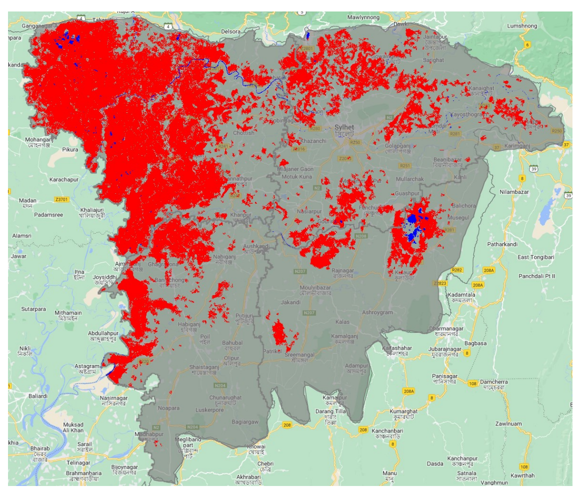


(b) Flood Inundation Map of Rangpur.

Figure 6: Flood inundation map of Barisal and Rangpur.



(b) Flood Inundation Map of Rajshahi.



(b) Flood Inundation Map of Sylhet.

Figure 7: Flood inundation map of Rajshahi and Sylhet.

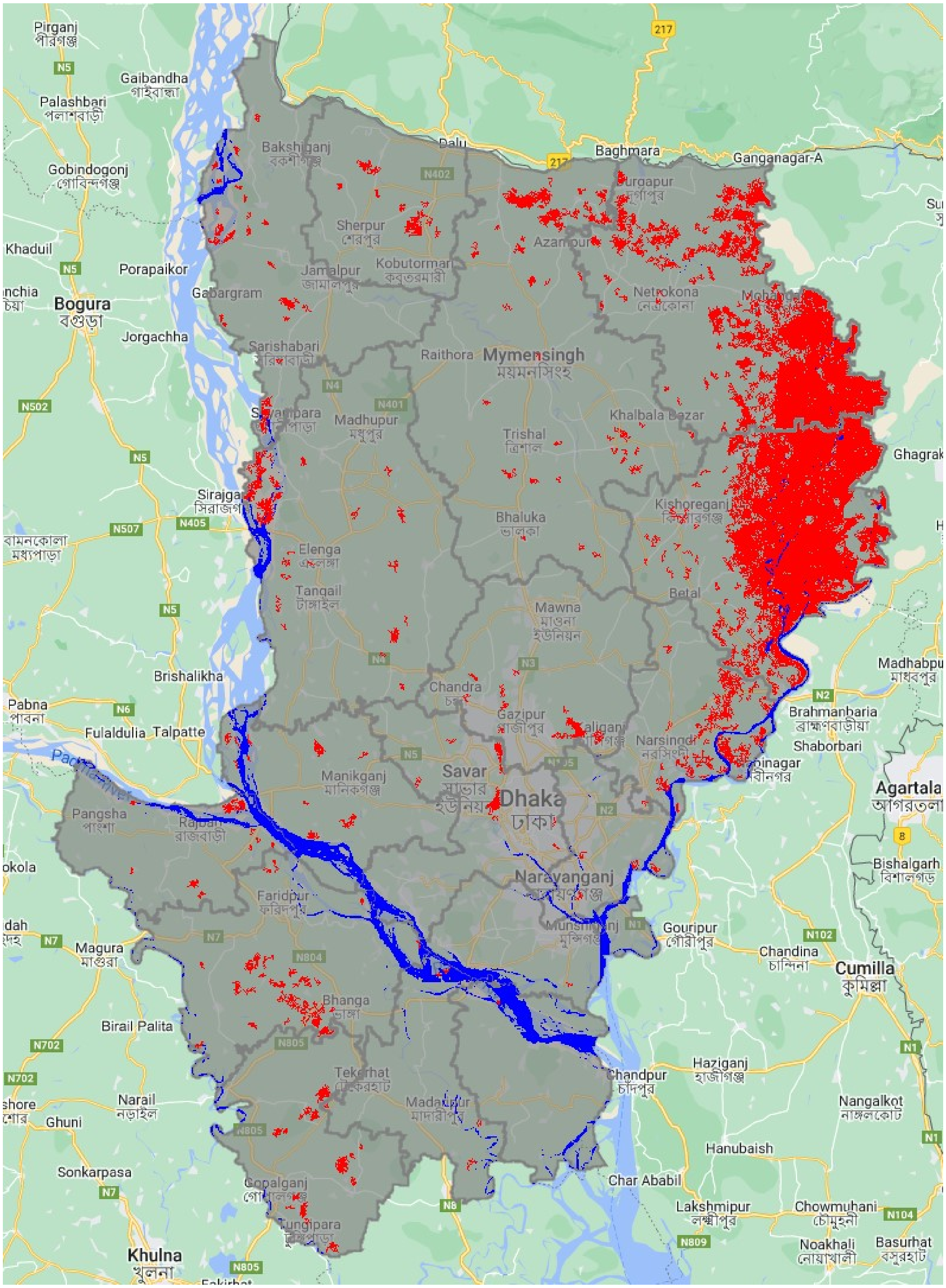


Figure 8: Flood inundation map of Dhaka.

4.1.3 Flood Extent Calculation

The maps of whole Bangladesh we created are good for visualization purpose, but in order to carry out numerical computations on created maps, it is required to work on small areas of interest as computation is expensive and it is not possible to compute different values for a massive area such as Bangladesh.

So, we broke down our map into districts and created 7 maps, one for each division of Bangladesh, each further divided into the districts that fall under that division. Next, we applied the flood extent calculation methodology according to the UN-SPIDER process that we followed and extracted flood extent of all divisions of Bangladesh. Finally, we added the flood extent of all divisions to calculate total flood extent of Bangladesh for the time period we selected

We found the total area affected by flood was 25437.95 square kilometers, which is 18.14% of the total area of Bangladesh Two important points to note are, the methodology we selected for our project (UN-SPIDER) is a good methodology for visualization. But it may not be the best for calculating numerical values as there is no "apple-to-apple" comparison method available for validating the calculation done by this process. In our literature review, we found more advanced methodologies that make use of other types of data to calculate and validate the map accuracy.

We compared our calculation to the data we collected from BWDB. According to BWDB, total inundation in 2021 was 33%, but we found it to be 18.14%. It is not a proper comparison, but the only one that we found for our methodology.

4.2 Flood Information Map

We prepared a divisional flood information map based on the maps produced by GEE and another data source, as mentioned in section 3.2. Here, darker blue means the region is more prone to flood. According to the flood information map, the divisions most susceptible to flood is Sylhet and the division least susceptible to flood is Khulna. This is verified by the data we found from our map as well as relevant information sources such as BWDB.

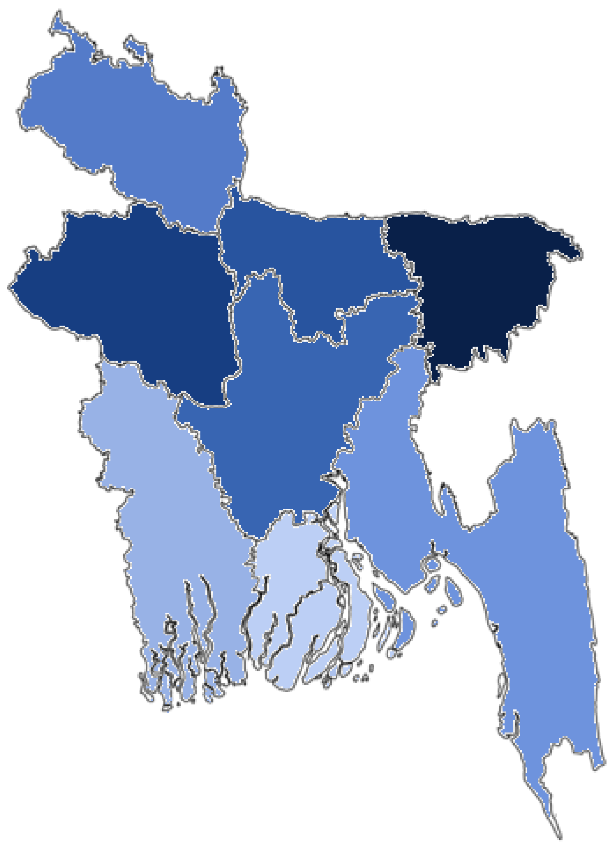


Figure 9: Bangladesh Divisional Flood Information Map.

4.3 Flood History Statistics

We collected data from flood reports provided by Bangladesh Water Development Board (BWDB) and created statistical visualization to understand the trends of the rivers of Bangladesh.

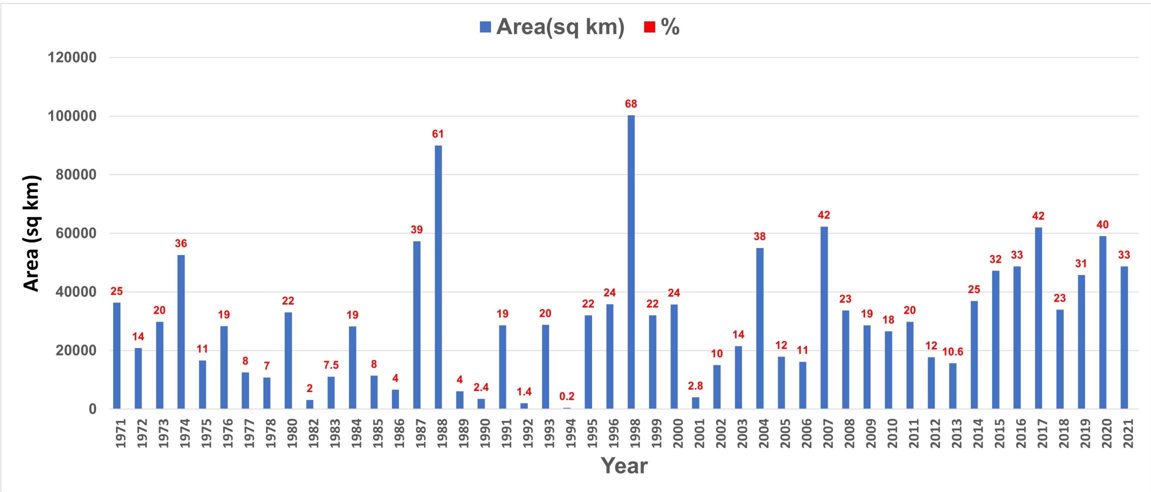


Figure 10: Year wise flood in Bangladesh, from 1971 to 2021.

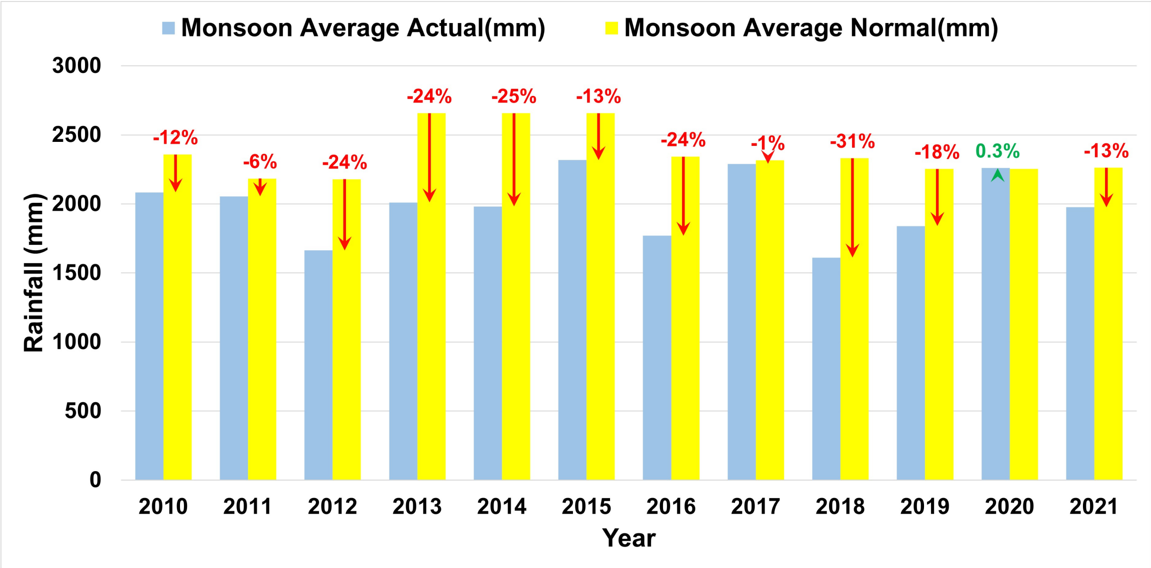


Figure 11: Monsoon rainfall (in mm) in Bangladesh, by year from 2010 to 2021.

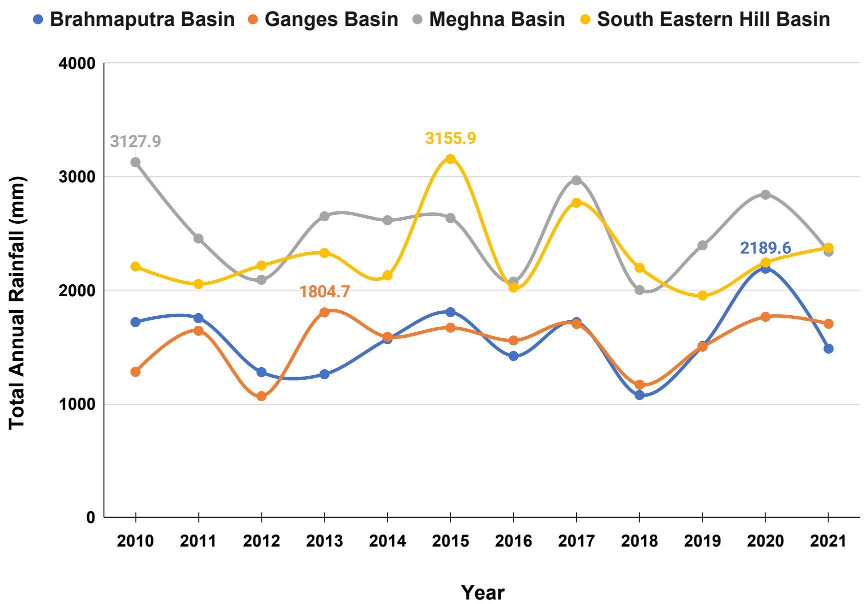


Figure 12: Total annual rainfall (in mm) among the four basins, by year from 2010 to 2021.

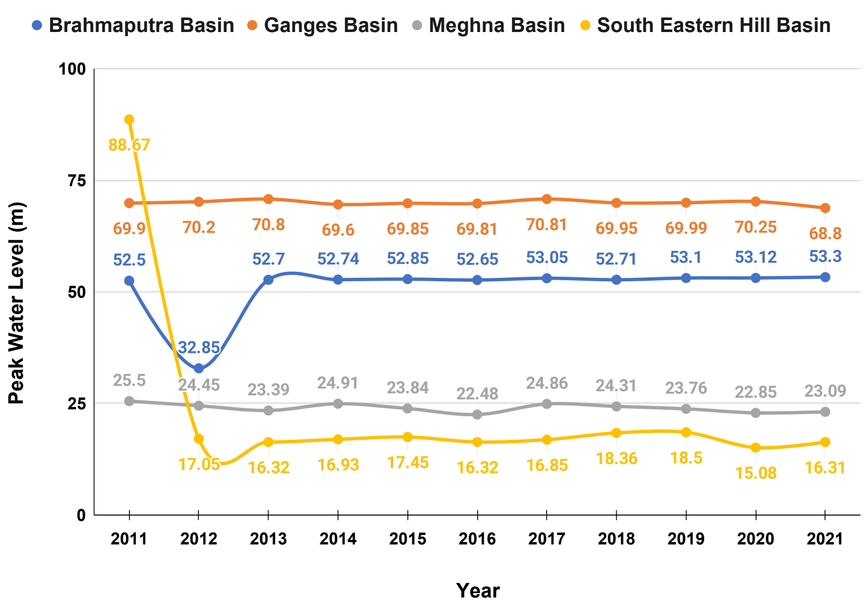


Figure 13: Peak water level (in m) among the four basins, by year from 2010 to 2021.

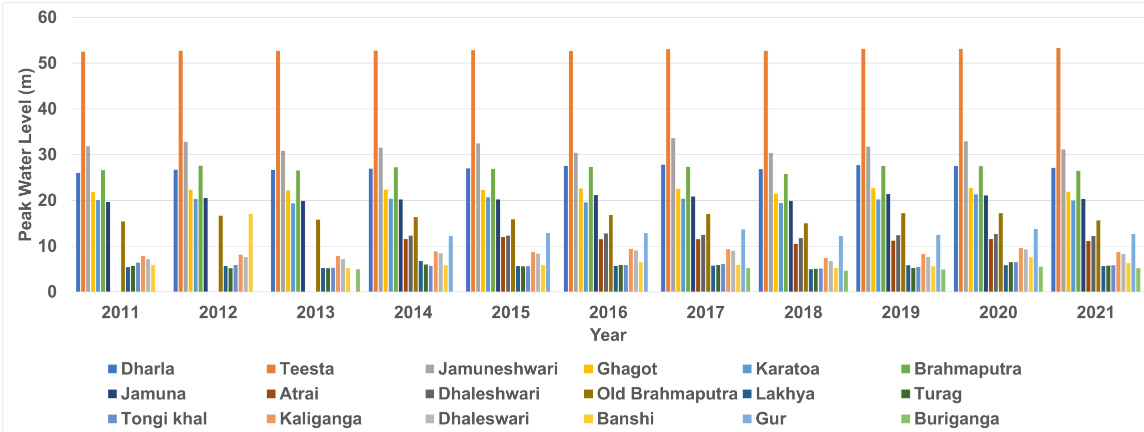


Figure 14: Peak water level of rivers of the Brahmaputra Basin from 2011 to 2021.

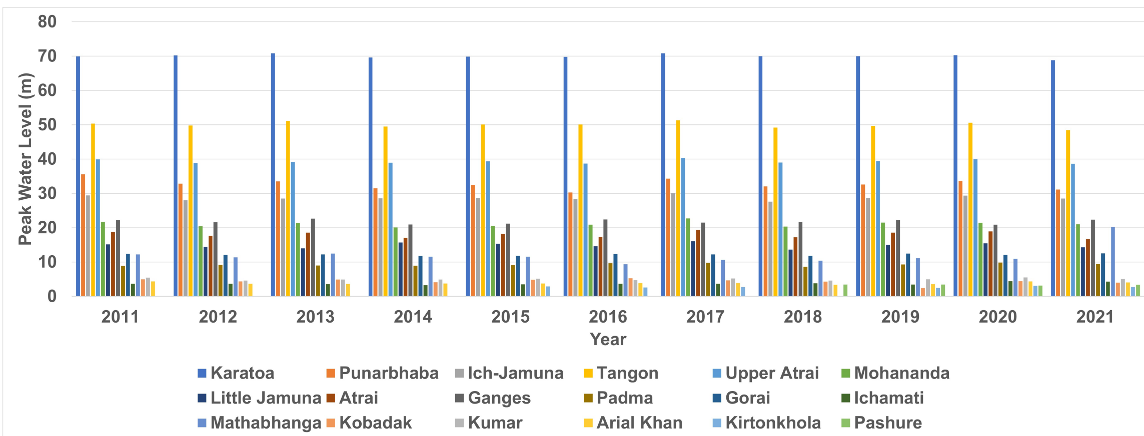


Figure 15: Peak water level of rivers of the Ganges Basin from 2011 to 2021.

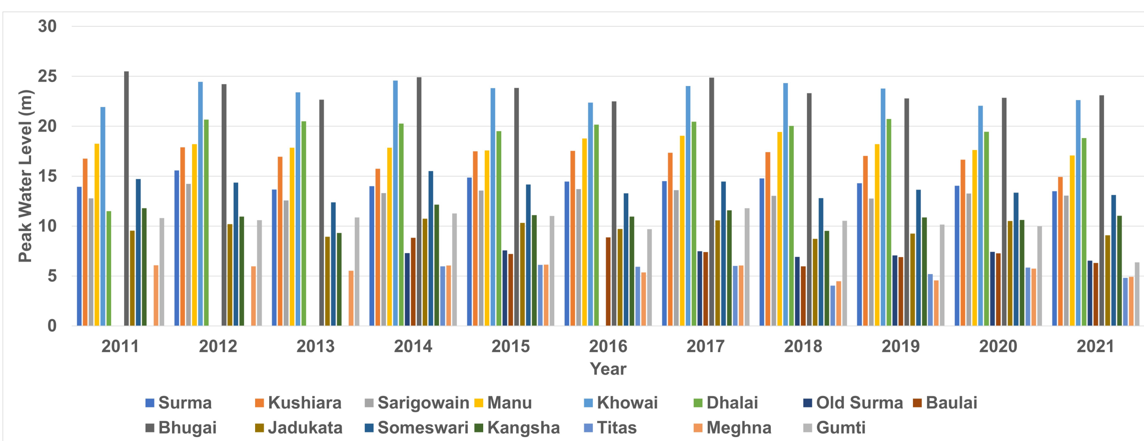


Figure 16: Peak water level of rivers of the Meghna Basin from 2011 to 2021.

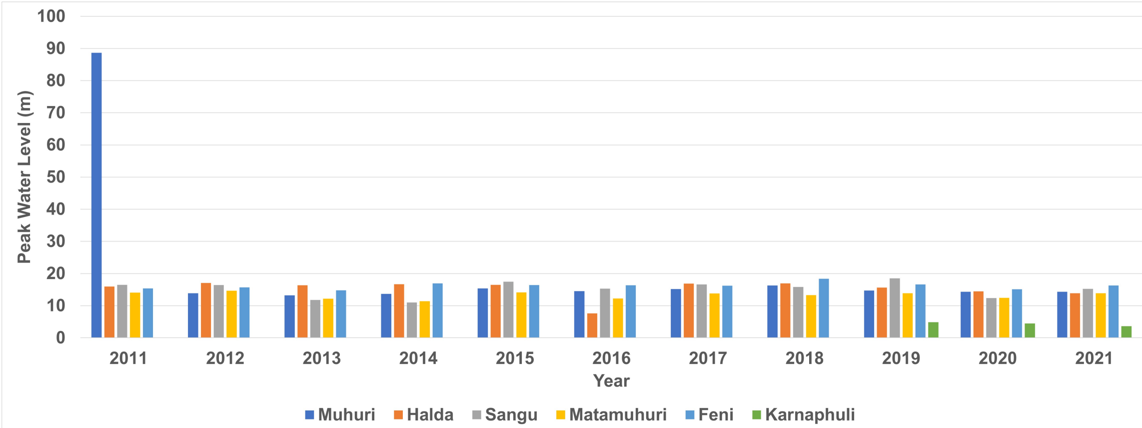


Figure 17: Peak water level of rivers of the South East Hill Basin from 2011 to 2021.

In Figure 10, we have shown the visual representation of the year-wise flood-affected area in Bangladesh. We arranged the data from 1971 to 2021 to implement the visualization. We have included the percentage of the flood-affected regions corresponding to the years. From the data, it is visible that in 1998, floods affected most of the regions compared to others. To be more precise, it covered 1,00,250 sq km, which is 68% of the total land area of Bangladesh.

In Figure 11, we have visualized monsoon rainfall statistics for the last decade. We collected the data from 2010 to 2021. In this visualization, we have illustrated the comparison of actual and expected rainfall in mm for monsoons. The graph shows that the monsoon rainfall was only higher than expected in 2020. It was 0.3% more than the average rainfall and was recorded at 2260.2 mm, whereas the average rainfall was expected to be 2253 mm.

In Figure 12, we have created a comparison chart to compare the rainfall over the four main basins of Bangladesh. In this visualization, we made a trend to learn about the highest rainfall over those basins. The chart shows that South Eastern Hill Basin had the highest rainfall in 2015, 3155.9 mm. Meghna Basin recorded the highest rainfall in 2010, 3127.9 mm. In 2020, the Brahmaputra Basin recorded 2189 mm of rain; in 2013, the Ganges Basin recorded 1804.7 mm.

In Figure 13, we show that the recorded peak water level in all four basins has increased over the past decade. The peak water level of Ganges Basin and Meghna Basin did not fluctuate much in the last decade. The peak water level of Brahmaputra basin came down by 20m in 2012, but in other years it was more or less constant. The peak water level of South Eastern Hill Basin was maximum in the year 2011, then it dropped massively in 2012 and continued to be consistent from then on.

In Figure 14 to Figure 17, we visualise the peak water level of all the rivers in each of the four basins of Bangladesh.

5. Conclusion and Future Work

In this project, we have explored the usage of remote sensing to map flood inundated areas of Bangladesh in recent years. We have only explored the basics of this task. For example, we have only employed the change detection algorithm and the UN-SPIDER methodology for flood mapping. Also, we have only relied on SAR data from Sentinel-1 satellite. But there are many other standard algorithms and methodologies as well as other types of data that remain to be investigated in the context of Bangladesh. Our next project has a larger scope. We intend to develop a near real-time and accurate flood mapping and monitoring methodology in the context of Bangladesh. For that purpose, we have to make use of other types of data such as Landsat and MODIS alongside SAR which we explored in this project. We also plan to apply cutting edge technologies such as machine learning and deep learning to automate and improve the flood mapping process (Bentivoglio et al. (2022)). The literature review we conducted and the tools we learned as part of this project will serve as the foundation of the upcoming project.

Acknowledgments

We are grateful to our supervisor Dr. Nova Ahmed for encouraging and guiding us during the course of this project.

References

Uttama Barua, Musa Akther, and Mehedi Ansary. District-wise multi-hazard zoning of bangladesh. *Natural Hazards*, 82, 07 2016. doi: 10.1007/s11069-016-2276-2.

Roberto Bentivoglio, Elvin Isufi, Sebastian Nicolaas Jonkman, and Riccardo Taormina. Deep learning methods for flood mapping: a review of existing applications and future research directions. *Hydrology and Earth System Sciences*, 26(16):4345–4378, 2022.

Zhiheng Chen and Shuhe Zhao. Automatic monitoring of surface water dynamics using sentinel-1 and sentinel-2 data with google earth engine. *International Journal of Applied Earth Observation and Geoinformation*, 113:103010, 2022.

Ben DeVries, Chengquan Huang, John Armston, Wenli Huang, John W Jones, and Megan W Lang. Rapid and robust monitoring of flood events using sentinel-1 and landsat data on the google earth engine. *Remote Sensing of Environment*, 240:111664, 2020.

Noel Gorelick, Matt Hancher, Mike Dixon, Simon Ilyushchenko, David Thau, and Rebecca Moore. Google earth engine: Planetary-scale geospatial analysis for everyone. *Remote sensing of Environment*, 202:18–27, 2017.

AS Islam, SK Bala, and MA Haque. Flood inundation map of bangladesh using modis time-series images. *Journal of Flood Risk Management*, 3(3):210–222, 2010.

Md Tazmul Islam and Qingmin Meng. An exploratory study of sentinel-1 sar for rapid urban flood mapping on google earth engine. *International Journal of Applied Earth Observation and Geoinformation*, 113:103002, 2022.

Heidi Kreibich, Anne F Van Loon, Kai Schröter, Philip J Ward, Maurizio Mazzoleni, Nivedita Sairam, Guta Wakbulcho Abeshu, Svetlana Agafonova, Amir AghaKouchak, Hafzullah Aksoy, et al. The challenge of unprecedented floods and droughts in risk management. *Nature*, 608(7921):80–86, 2022.

T McCormack, J Campanyà, and O Naughton. A methodology for mapping annual flood extent using multi-temporal sentinel-1 imagery. *Remote Sensing of Environment*, 282: 113273, 2022.

Hafiz Suliman Munawar, Ahmed WA Hammad, and S Travis Waller. Remote sensing methods for flood prediction: A review. *Sensors*, 22(3):960, 2022.

Nicholas J Murray, Stuart R Phinn, Michael DeWitt, Renata Ferrari, Renee Johnston, Mitchell B Lyons, Nicholas Clinton, David Thau, and Richard A Fuller. The global distribution and trajectory of tidal flats. *Nature*, 565(7738):222–225, 2019.

Bui Phan Quoc Nghia, Indrajit Pal, Nuwong Chollacoop, and Anirban Mukhopadhyay. Applying google earth engine for flood mapping and monitoring in the downstream provinces of mekong river. *Progress in Disaster Science*, 14:100235, 2022.

Jean-François Pekel, Andrew Cottam, Noel Gorelick, and Alan S Belward. High-resolution mapping of global surface water and its long-term changes. *Nature*, 540(7633):418–422, 2016.

Mrinal Singha, Jinwei Dong, Sangeeta Sarmah, Nanshan You, Yan Zhou, Geli Zhang, Russell Doughty, and Xiangming Xiao. Identifying floods and flood-affected paddy rice fields in bangladesh based on sentinel-1 imagery and google earth engine. *ISPRS Journal of Photogrammetry and Remote Sensing*, 166:278–293, 2020.

Beth Tellman, Jonathan A Sullivan, Catherine Kuhn, Albert J Kettner, Colin S Doyle, G Robert Brakenridge, Tyler A Erickson, and Daniel A Slayback. Satellite imaging reveals increased proportion of population exposed to floods. *Nature*, 596(7870):80–86, 2021.

Varun Tiwari, Vinay Kumar, Mir Abdul Matin, Amrit Thapa, Walter Lee Ellenburg, Nishikant Gupta, and Sunil Thapa. Flood inundation mapping-kerala 2018; harnessing the power of sar, automatic threshold detection method and google earth engine. *PLoS One*, 15(8):e0237324, 2020.

Mirela G Tulbure, Mark Broich, Vinicius Perin, Mollie Gaines, Junchang Ju, Stephen V Stehman, Tamlin Pavelsky, Jeffrey G Masek, Simon Yin, Joachim Mai, et al. Can we detect more ephemeral floods with higher density harmonized landsat sentinel 2 data compared to landsat 8 alone? *ISPRS Journal of Photogrammetry and Remote Sensing*, 185:232–246, 2022.

Kabir Uddin, Mir A Matin, and Franz J Meyer. Operational flood mapping using multitemporal sentinel-1 sar images: A case study from bangladesh. *Remote Sensing*, 11(13): 1581, 2019.

Venkata Sai Krishna Vanama, Dipankar Mandal, and Yalamanchili Subrahmanyeswara Rao. Gee4flood: rapid mapping of flood areas using temporal sentinel-1 sar images with google earth engine cloud platform. *Journal of Applied Remote Sensing*, 14(3):034505–034505, 2020.

Manjunatha Venkatappa, Nophea Sasaki, Phoumin Han, and Issei Abe. Impacts of droughts and floods on croplands and crop production in southeast asia–an application of google earth engine. *Science of the Total Environment*, 795:148829, 2021.