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WFP
World Food Programme

Technical Report

Satellite-derived Flood Mapping for Cambodia

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Acknowledgement

The United Nations World Food Programme (WFP) Cambodia is strengthening capacities of the national and sub-national disaster management committees in order to effectively coordinate preparedness and response as a strategic outcome of its Country Strategic Plan (CSP) from 2019-2023. This capacity strengthening includes utilization of innovative disaster risk management approaches, tools, and information products. In close collaboration with the National Committee for Disaster Management (NCDM), this will be accomplished through structured capacity strengthening activities, technical partnerships, and the co-development of technology solutions and strategic plans.

Given recent advances in the use and availability of Earth observation-related technologies and products, the application and utilization of remote-sensing data plays an increasingly important role in disaster risk management. The Platform for Real-time Impact and Situation Monitoring (PRISM), initiated by WFP in partnership with NCDM, integrates satellite-derived data for early warnings and monitoring of climate hazards in order to strengthen risk-informed decision making. The Asian Disaster Preparedness Center (ADPC) through the SERVIR-Mekong project provides expertise to produce actionable information related to drought and flood conditions using satellite data and integrating it with PRISM.

The data analysis and writing of this report was undertaken by ADPC as part of a collaboration with WFP to benefit NCDM. Contributions from ADPC staff include Susantha Jayasinghe, Kittiphong Phongsapan, Thannarot Kunlamai, Nyein Soe Thwal, Rishiraj Dutta, and Peeranan Towashiraporn. Additional analytical support was provided by Ate Poortinga and David Saah of Spatial Informatics Group. The report benefitted from reviews and inputs of several WFP staff including Aaron Wise, Amit Wadhwa, Andre Martinez, Benny Istanto, Chanvibol Choeur, Indira Bose, Krishna Krishnamurthy, Kurt Burja and Nithima Ducrocq. The report and the analyses contained herein would not have been possible without the support of SERVIR-Mekong, a joint initiative of USAID and NASA, and use of its geospatial tools, datasets, and specialists. This work contributes to the global partnership between WFP and SERVIR.

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1. Introduction

According to a recent United Nations Office for Disaster Risk Reduction report, floods were reported to be the most frequent of disasters, with 3,148 occurrences of flood between 1998-2017, accounting for 43.4% of the total number of disasters. Within that time period, floods were estimated to have affected 2 billion people worldwide, with impacts heavily exacerbated by increased vulnerability due to factors including rapid land cover changes and urbanization[1]. Many countries lack the resources to prevent, mitigate and adequately respond to floods, leaving them particularly vulnerable.

1 "United Nations Office for Disaster Risk Reduction (UNISDR)-UNISDR's Contribution to Science and Technology for Disaster Risk Reduction and the Role of the International Consortium on Landslides (ICL)," in WLF 2017:Advancing Culture of Living with Landslides, eds K. Sassa, M. Mikoš, and Y. Yin (Cham: Springer), 99–115. doi: 10.1007/978-3-319-59469-9_6

Cambodia is one of the most hazard-prone countries in Southeast Asia. With 13.5% of its population living below the poverty line, the country is extremely vulnerable and exposed to the impact of these shocks as well.[2] Climate change models for Cambodia generally predict that extreme flood events will increase in the future, while the country's population is also expected to nearly double over the next 40 years. In addition to the threat of climate change, rapid changes to land use increase the risk of flood events, particularly in urban and peri-urban areas.

Obtaining information in a timely manner during flood events about the flood's extent in affected areas can be difficult. Satellite remote sensing enables an aerial view over large spatial areas, which proves useful for emergency responders by giving them an overview of the flood event and potential communities affected.

Recent advances in Earth observation-related technologies and products has made data increasingly more accessible to non-experts. One such technology is cloud-based computing used for satellite data analysis which enables the development of near real-time flood monitoring applications. Earth observation data has been widely adopted and utilized in supporting disaster response. Organizations and international programs such as UNOSAT, Sentinel Asia, and the International Charter for Disasters have been providing services to their member countries to map flood inundation for over a decade.

The PRISM platform in Cambodia is integrated within the government and has been deployed across much of the country. The deployment included trainings to equip and empower national and sub-national staff with the ability to monitor the impact of hazards on the ground. The platform aggregates various sources of information on hazards and integrates real-time mobile data into its visual, interactive map-based dashboard. The PRISM platform is used by the National Committee for Disaster Management (NCDM) as a primary data collection tool for capturing hazard exposure and impact information after an event. PRISM also integrates poverty information from the Ministry of Planning (IDPoor) which enables estimates of the location and number of vulnerable populations affected in real-time.

2 Ministry of Planning, Poverty Estimate in 2014 Cambodia.

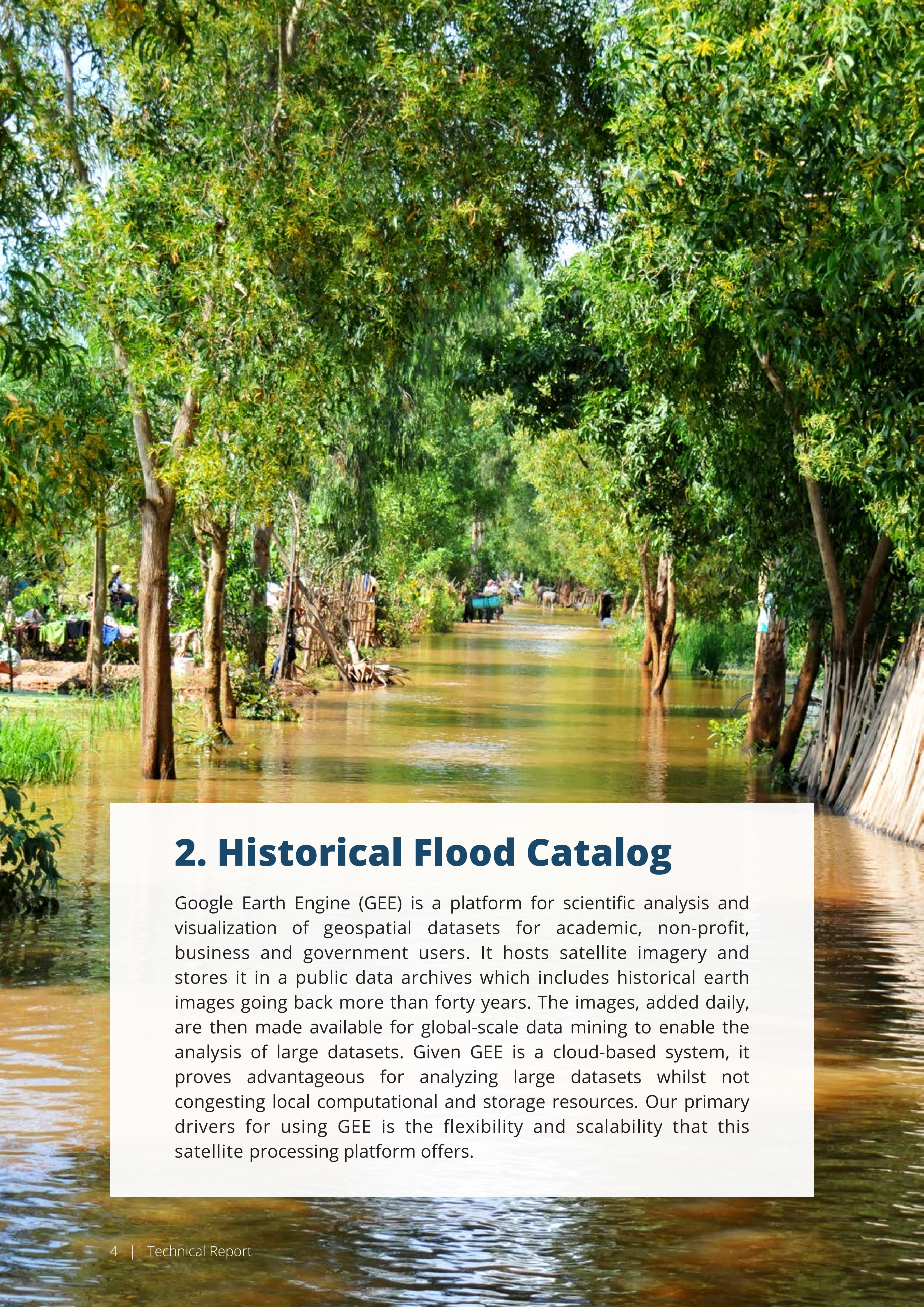
Objectives

WFP Cambodia have commissioned this report by ADPC to explore how the PRISM platform can take advantage of the advances in Earth observation technologies for flood early warning and monitoring.

To this end, the objectives of this report include:

1. Analyze historical flood events in Cambodia;
2. Produce and validate an historical flood dataset for Cambodia;
3. Produce a flood hazard index;
4. Develop and validate Near Real-Time (NRT) water maps using Synthetic Aperture Radar (SAR) data.

Sections 2, 3, and 4 of this document detail the methodologies and validations used for developing three unique datasets: Historical Flood Catalog, Flood Hazard Index, and Near Real-time Flood Mapping. Section 5 presents recommendations based on the findings.



2. Historical Flood Catalog

Google Earth Engine (GEE) is a platform for scientific analysis and visualization of geospatial datasets for academic, non-profit, business and government users. It hosts satellite imagery and stores it in a public data archives which includes historical earth images going back more than forty years. The images, added daily, are then made available for global-scale data mining to enable the analysis of large datasets. Given GEE is a cloud-based system, it proves advantageous for analyzing large datasets whilst not congesting local computational and storage resources. Our primary drivers for using GEE is the flexibility and scalability that this satellite processing platform offers.

The European Commission's Joint Research Centre (JRC) developed a water dataset in the framework of the Copernicus Programme. This dataset contains the location and temporal distribution of water surfaces over the past 30 years and provides statistics on the extent and change of those water surfaces, at a global scale. The dataset, produced from Landsat imagery, supports applications including water resource management, climate modelling, biodiversity conservation and food security. We used this derivative dataset to calculate the permanent surface water from the monthly surface water dataset which enabled time-efficient processing (vis-à-vis calculating the surface water from primary data sources). Figure 1 depicts a flowchart of the flood layer development process using the GEE platform and Surface Water dataset.

As can be seen in Figure 1, Sentinel-1 SAR and MODIS imagery was used to extract surface water information for each specific flood event (see Annex 1 for a listing of historical flood events). Permanent water was obtained from the Global Surface Water Explorer, a water dataset developed by the European Commission's Joint Research Centre (JRC) in the Copernicus Programme framework. The JRC dataset is generated using Landsat imagery starting from 1984-2018, courtesy of the U.S. Geological Survey (USGS) and NASA, and supports applications including permanent water calculation. Using these datasets allowed for surface water and flood water to be differentiated. Finally, the flood inundation layer was generated by subtracting the JRC-derived permanent water from the water extraction results for each specific flood event.

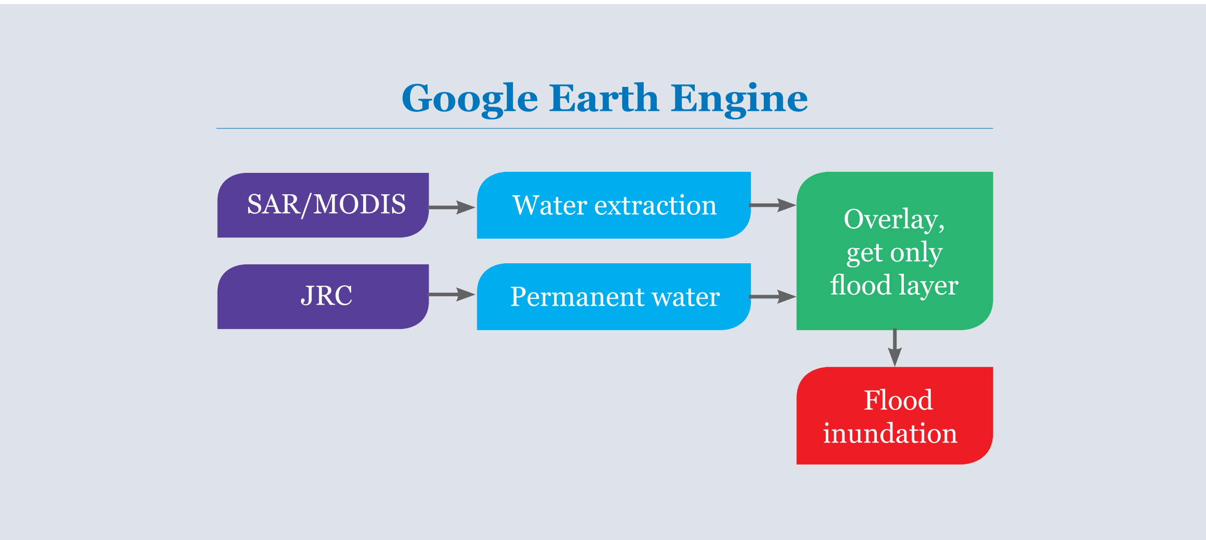


Figure 1. Workflow for development of the flood layer

2.1 Water extraction

This process uses satellite imagery from Sentinel-1 SAR (2016-2019) and MODIS (2000-2014) in the GEE platform to extract the surface water information. Subsequently, each of the satellite images is assigned a unique GEE code for extraction.

Sentinel-1 SAR is an imaging radar mission operating at C-band, which provides continuous all-weather, cloud penetration, day-and-night imagery. The Sentinel-1 SAR two satellite constellation provides high reliability, improved revisit time and extensive geographical coverage. This enables rapid data dissemination to support high priority applications such as marine monitoring, land monitoring and emergency services.

MODIS is a payload imaging sensor that was launched into Earth orbit by NASA. The instruments capture data with a frequency of 1-2 days at varying spatial resolutions (2 bands at 250m, 5 bands at 500m and 29 bands at 1km). They are designed to provide measurements of large-scale global dynamics including changes in Earth's cloud cover, radiation budget and processes occurring in the oceans, on land, and in the lower atmosphere. The MODIS data used in this study is cloud-free.[3]

Aside from floods, temporal water is often an indication of seasonal inundation. This can be both natural (wetlands) or human-induced (rice fields). Changes in location, duration and timing of seasonal inundation depends on prevailing weather conditions (including changes driven by major perturbations such as the El Niño–Southern Oscillation), erosion, sediment transport and deposition (particularly around coastlines and along river courses) as well as land-use planning and management. Changes in any of these conditions can drive transitions between permanent and seasonal classes. For example, many seasonally flooded rice paddy fields around the Sundarbans mangrove forest in Bangladesh and India have transitioned into permanently inundated fishponds.[4]

Distinguishing between permanent and temporal waters, as well as identifying floods, is not a straightforward task. Satellite imagery can only detect the presence or absence of water. Therefore, separating between temporal or seasonal and permanent water requires a clear definition to enable detailed analysis that aligns with this predetermined definition.

For example, JRC’s paper on ‘High-resolution mapping of global surface water and its long-term changes’ describes the intra-annual distribution of water, which differentiates between ‘permanent’ and ‘seasonal’ water surfaces. Permanent water is defined as surfaces which are inundated throughout the year, while seasonal water is defined as surfaces which are inundated for less than 12 months of the year.[5]

3 https://lpdaac.usgs.gov/documents/97/MCD43_ATBD.pdf

4 https://www.nature.com/articles/nature20584

5 https://www.nature.com/articles/nature20584

2.1.1 SAR water extraction

For extracting surface water from Sentinel-1 SAR, we used the 'Random Forest' machine learning algorithm for the surface water classification (see Section 4.1 for a detailed methodology of this process).

Example

For the flood event that occurred on 15.10.2016, there was no SAR imagery available for that specific day. Subsequently, the flood date range was expanded to 11.10.2016 – 20.10.2016 to obtain a holistic picture of flood extent over Cambodia. As shown in Figure 2, the first image is the unprocessed SAR image, with the temporary water clearly shown by the black areas. Figure 2 illustrates that once the Random Forest classification is applied, water can be extracted and downloaded as a GeoTIFF file.

2.1.2 MODIS water extraction

For the extraction of water bodies, the following steps were taken:

1. Develop custom code using the GEE platform.
2. The date of the flood event in the code was modified to match with the actual flood event being studied (Annex 1).
3. In the case of water bodies, there is a daily image available for the whole country and therefore, expansion of the time period was not required for this process. Modified Normalized Difference Water Index (MNDWI) was used for the surface water extraction, and can be defined as follows:

   $$MNDWI = (G-SWIR)/(G+SWIR)$$

   Where, *G* is the surface reflectance of the green band and *SWIR* is the short-wave infrared band. For the MODIS land surface reflectance dataset, *G* and *SWIR* correspond to band 4 and 6, respectively.

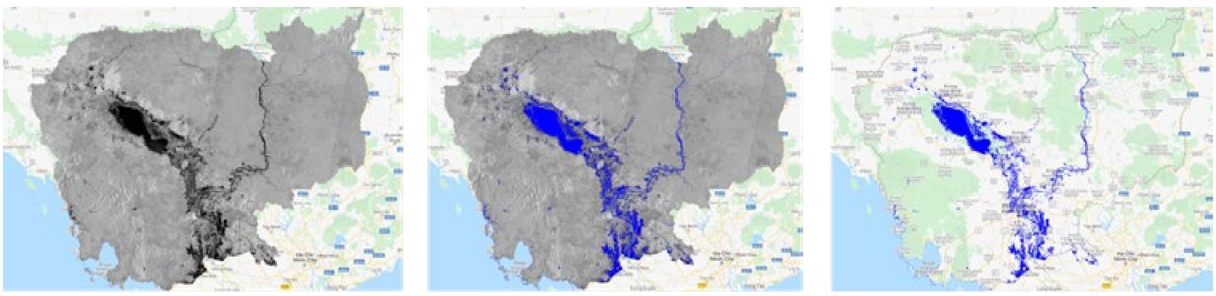


Figure 2. SAR water extraction process

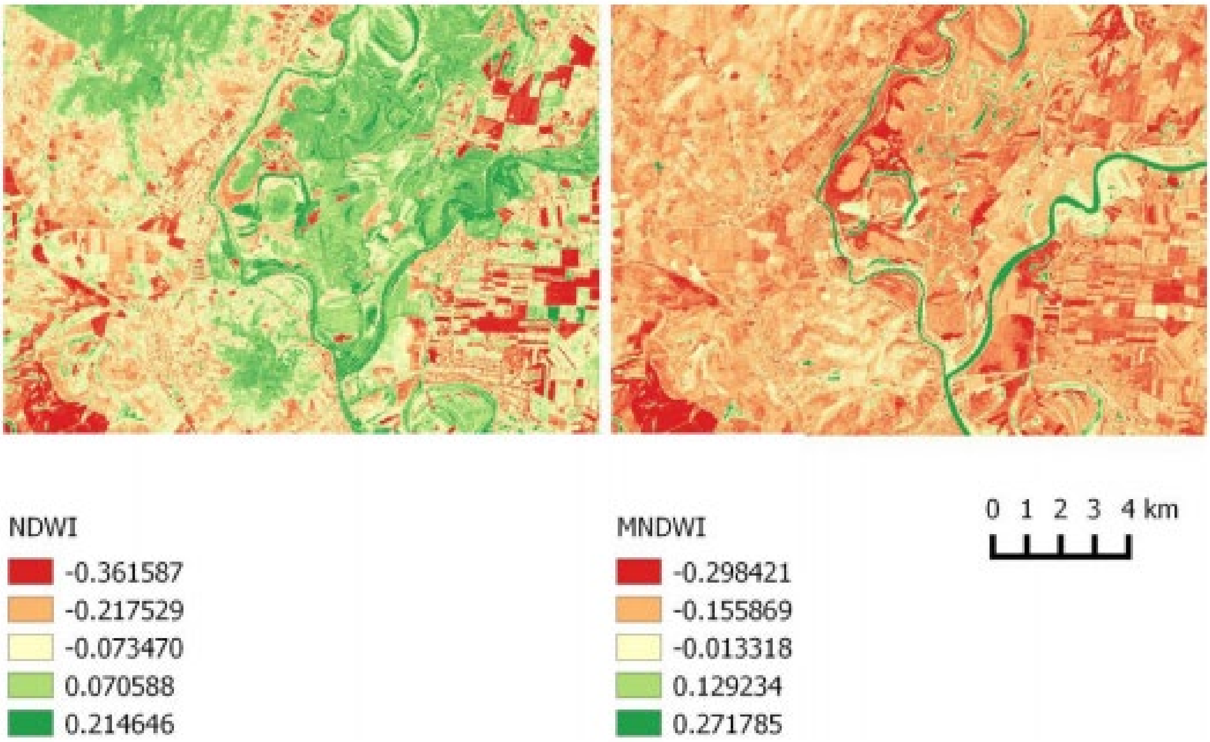


Figure 3. Comparison between NDWI and MNDWI

The MNDWI can assist in identifying open water features by suppressing and even removing built-up land, vegetation, and soil noise.[6] When using the NDWI, built-up land noise is often combined with the enhanced water information and therefore, the area of extracted water is largely overestimated. According to a comparative study between NDWI and MNDWI, it was deemed that NDWI was not an appropriate water index for enhanced water information: for example, water had the same pixel value as both forests and grassland (see Figure 3).[7] MNDWI enhanced water bodies such as rivers, oxbows, and ponds; however, all other land cover classes did not seem to be distinguished. Thus, the MNDWI is more suitable for enhancing and extracting water information especially for a water region dominated by built-up land areas.

4. The threshold values in the code were modified to separate 'water' and 'non-water' to generate a binary layer. Based on ADPC's experience and from a peer-reviewed study, the default threshold value of -0.3 was chosen.[8] Figure 4 shows the MNDWI and water extraction maps.
5. The images were then downloaded in GeoTIFF (raster) format which can be opened with any GIS software (ArcGIS, QGIS, etc.).

6 https://www.tandfonline.com/doi/abs/10.1080/01431160600589179?journalCode=tres20

7 http://landscape.geo.klte.hu/pdf/agd/2016/2016v10is3_4_13.pdf

8 Ji et al. (2009), Analysis of Dynamic Thresholds for the Normalized Difference Water Index, https://www.researchgate.net/publication/275681435_Analysis_of_Dynamic_Thresholds_for_the_Normalized_Difference_Water_Index

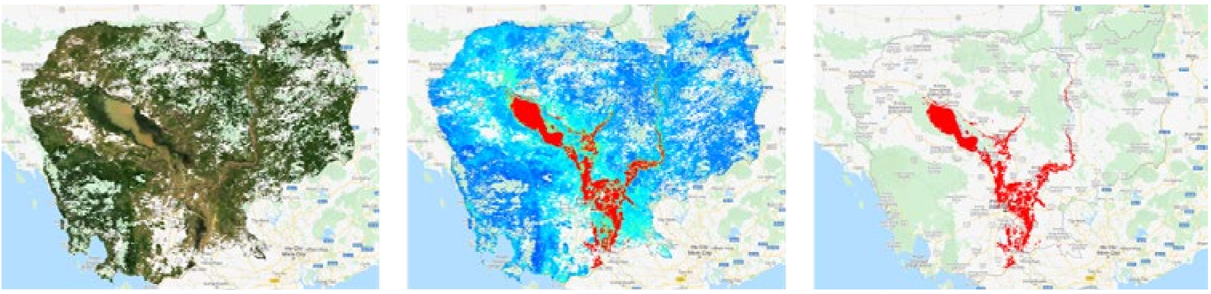


Figure 4. MODIS satellite water extraction
(Left to right: MODIS imagery, MNDWI calculation, water extracted)

2.2 Validation

The following data sources were used for comparison in the validation process:

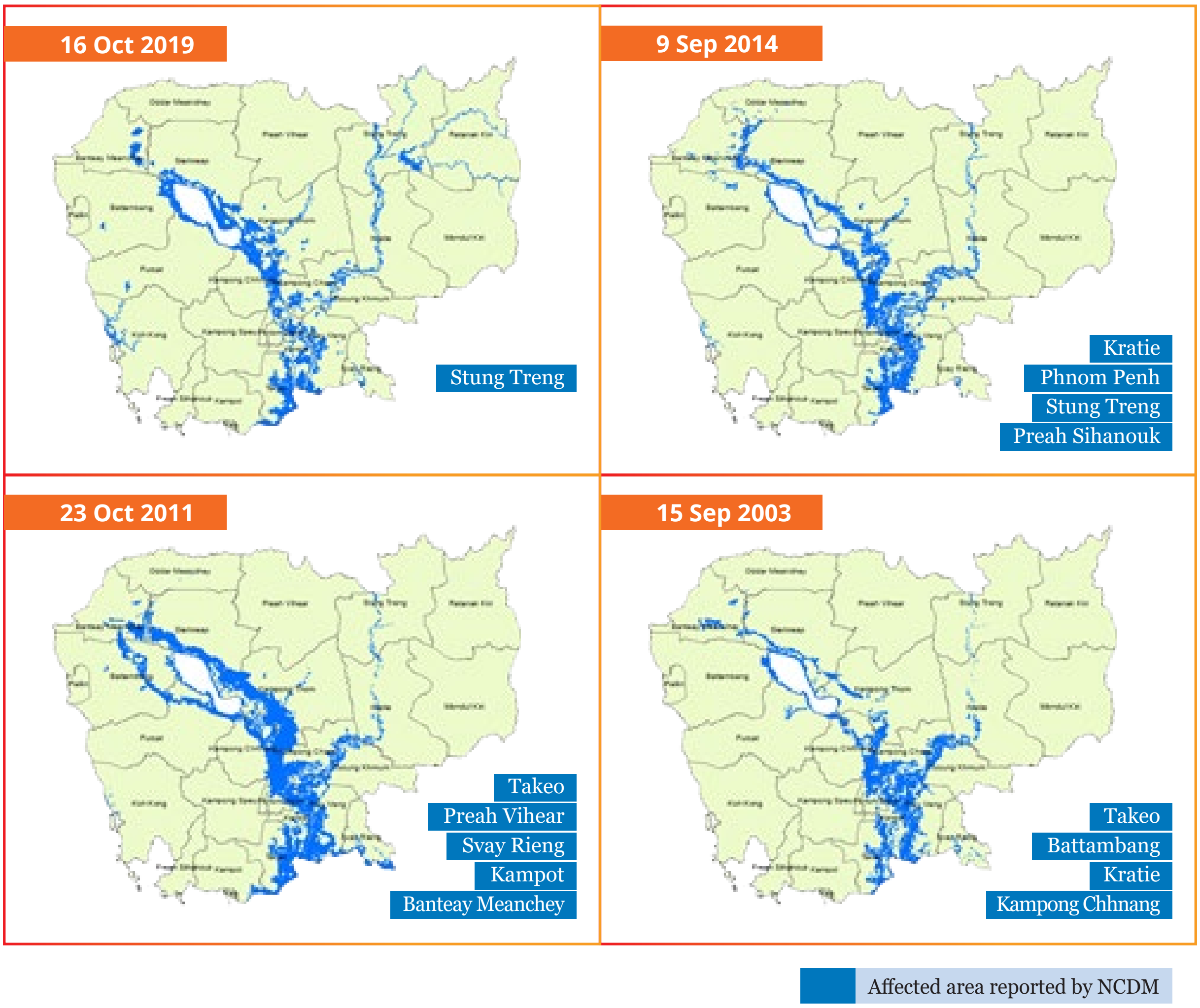
1. National Committee for Disaster Management (NCDM) disaster loss database and website
2. Flood Inundation map event developed by UNOSAT
3. High resolution satellite images

2.2.1. Validation using NCDM disaster loss database and other sources

The NCDM disaster loss database for Cambodia was used to validate the flood extraction results. Ideally, the disaster loss database would include specific information on the flood-affected area such as commune names as well as the start and finish dates for each flood event. In addition, daily recordings of how flood water is receding as well as flood depth from ground observations, would be useful information. However, the database only lists the name of each district and province affected by flood and is therefore not particularly comprehensive. This step of the validation process only uses the name of the district and province as a comparison with the flood layer. The result of this validation shows that all the extracted flood layers and their respective locations align with the affected districts and provinces mentioned in the disaster loss database.

Table 1 below shows an example of the flood affected area listed by the disaster loss database in comparison to the results obtained in our study.

Table 1: Comparison of flood affected area and result of water extraction



2.2.2. Validation using UNOSAT database

This step of the validation process involved a cross-comparison between ADPC's results and the UNOSAT database to give an indication of performance.[9] The selected period for flood event validation was 23-29 October 2013, based on the availability of UNOSAT flood data. ADPC's results of the extracted surface water layer from the same time period was compared using a visual validation method. Figure 5 shows a visual comparison between ADPC and UNOSAT flood extent layers.

However, this was not an exact comparison as there were differences in the spatiotemporal resolution of the data. A better approach involved comparisons with high-resolution data to minimize errors due to spatial and/or temporal inconsistencies. ADPC selected a sample of high-resolution satellite imagery which was used for surface water validation purposes. Before the samples were extracted and used for validation, the high-resolution image was combined with the Sentinel-1 image closest to that specific date.

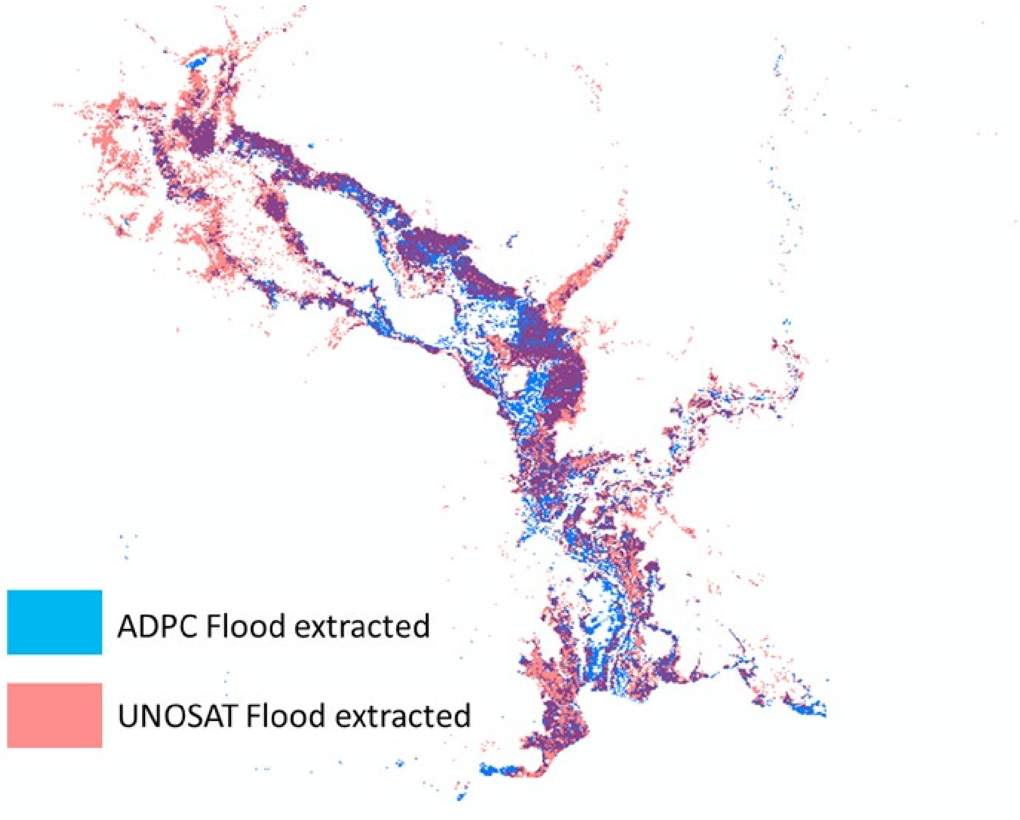


Figure 5. Data validation using existing shapefile from UNOSAT

9 https://unitar.org/maps/countries/16

2.2.3. Validation using high resolution imagery

High resolution imagery, obtained from Planet Labs, Inc. during December 2017 to April 2018, was also used for the validation process. This data have a spatial resolution of 3.125 meters and 4 bands (red, green, blue and near infrared). Initially, the imagery was used to calculate the water index enabling the water layer to be extracted. Subsequently, the water layer output was compared to the MODIS-generated water layer by creating random points to validate the accuracy. Figure 6 illustrates a flowchart of the high-resolution imagery validation process.

The high-resolution data imagery from Planet Labs was used to calculate the water index, NDWI. The equation below describes the NDWI calculation used:

$$NDWI = (G-NIR)/(G+NIR)$$

Where, G is the surface reflectance of the green band and NIR is the near infrared band. Figure 7 shows the geographical location of the high-resolution imagery used for the validation process and the NDWI calculation result, respectively.

A thresholding method for separating NDWI values into two (2) classes, water, and non-water, was applied. Finally, a water extracted layer was carried out using Planet TOA (top of atmosphere) imagery, with the water represented by the black areas.

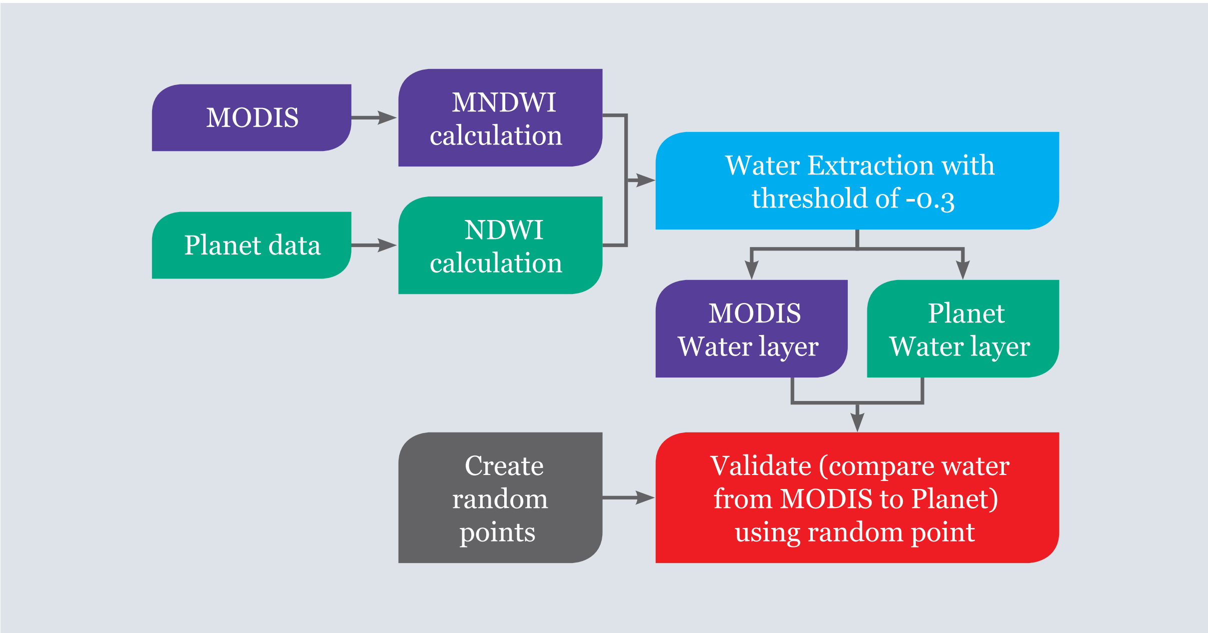


Figure 6. Validation process using high-resolution imagery

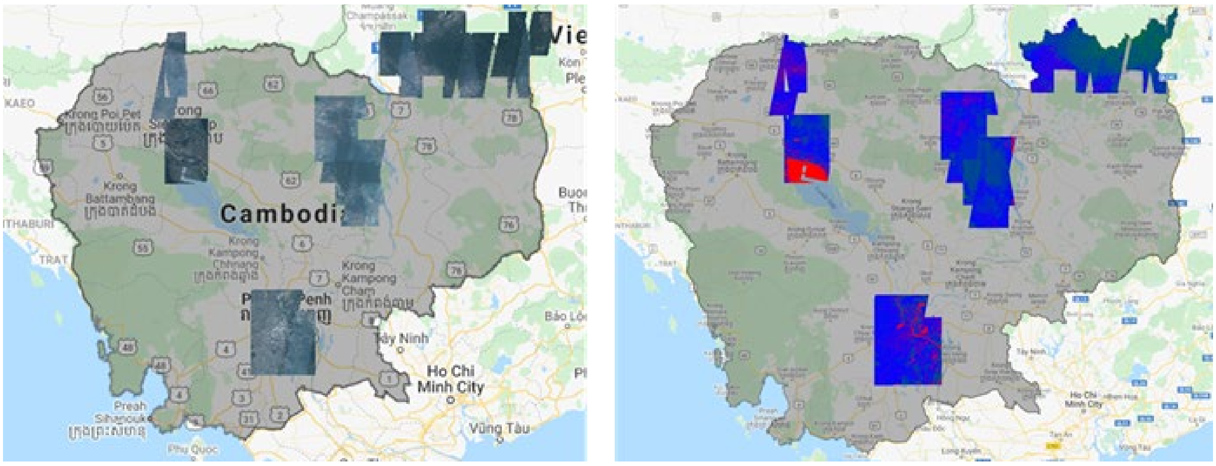


Figure 7. Planet Labs, Inc. data imagery (RGB and NDWI)

Figure 8. Water extracted layer

From the water extracted Planet image, 156 sampling points were generated for validation purposes. These data points were generated from the random stratified sampling method. Locations were dependent on data availability. MODIS and Planet data have different spatial resolutions. With Planet data, ADPC could generate very fine resolution flood maps that have high accuracy. A MODIS pixel contains spectral information of a plethora of land cover classes. Therefore it is useful to compare and validate these different information sources.

Using the sampling points, water values were obtained from the MODIS water extracted layer to see if they matched. The results indicated that 149 points were identified as water which aligned with both the layers and was calculated with 95.5% accuracy.

2.3 Surface water to flood extent

The Global Surface Water Dataset (1984-2018), developed by the Joint Research Centre (JRC), was used for calculating the permanent water layer. Flood water was calculated by subtracting the extracted water from the permanent water.

The JRC Monthly Water History (V1.1) from the JRC Global Water Dataset was used in this study to generate flood frequency maps by calculating water pixels present in Landsat satellite imagery across Cambodia, according to the JRC-developed methodology. The imagery processing steps include the detection of water whilst accounting for false positives that may result from shadowing effects.

The dataset contains monthly layers of the location and temporal distribution of surface water; July to October, 2000-2018. The data contains three types of information – no data, non-water, and water. The flood frequency for any given period is calculated by dividing the number of water occurrence pixels by the total number of pixels, excluding any 'no data' information. An example flood frequency calculation is shown in Figure 11.

Figure 9. Location and spatial distribution of points

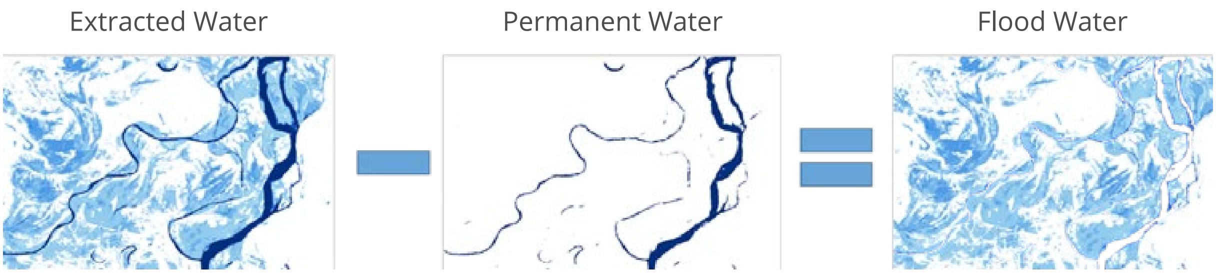


Figure 10. Methodology for removing permanent water from surface water

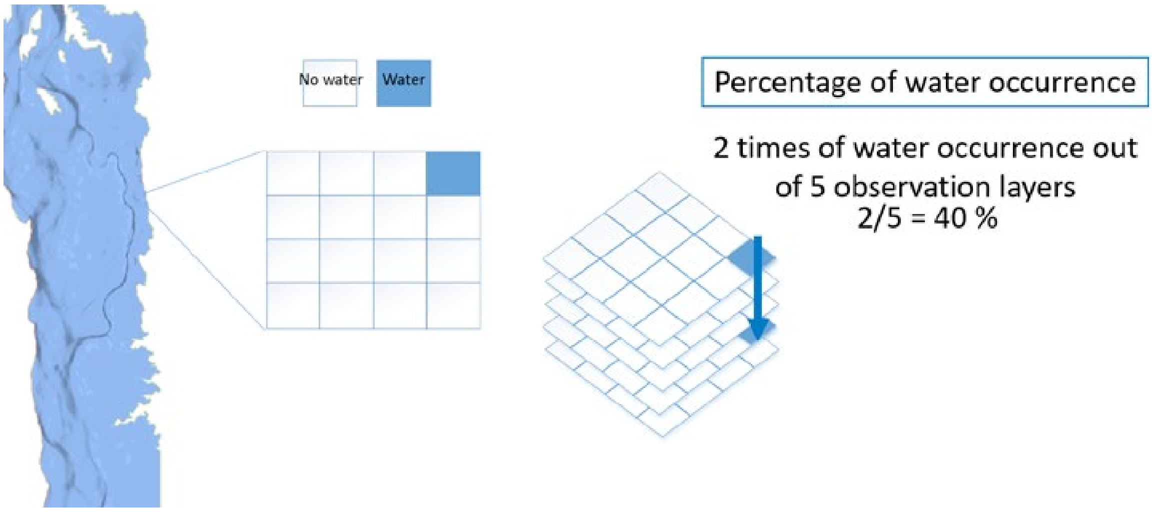


Figure 11. Example calculation for frequency of water occurrence

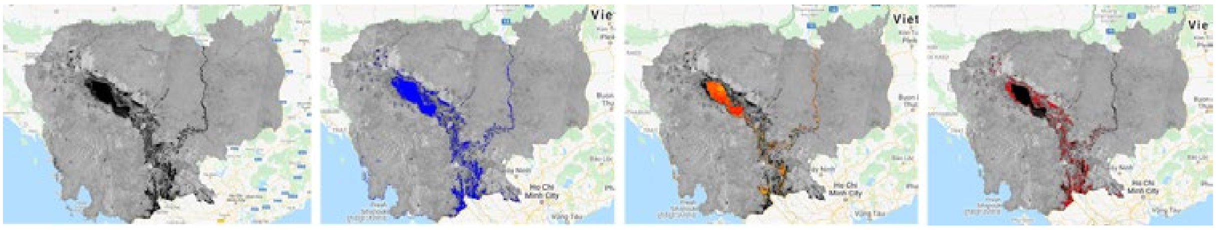


Figure 12. Processing for flood extraction
(Left to right: Satellite Imagery, surface water, permanent water, flood water)

Since historical data provides valuable information on the probability of flood occurrence, all available Landsat data was utilized in the JRC tool. As the data-series contains monthly layers, different timescales such as months or even seasons could also be investigated.

Permanent water bodies were removed from the data so that only flood events were included. The United Nations Institute for Training and Research (UNITAR) provides data on natural disasters through the Operational Satellite Applications Programme (UNOSAT) which includes flood maps. The UNOSAT flood map is a well-recognized data source and was used to distinguish between permanent and temporary water, specifically the 2015 data for comparison purposes. Figure 12 shows both the water occurrence map generated by ADPC and the UNOSAT permanent water map. Pixels with high water occurrence values are marked as permanent water in the UNOSAT data. By cross-walking the data, ADPC found 82% to be a suitable threshold to distinguish permanent from temporary water in our study area.[10] Subsequently, permanent water was masked out to distinguish them from the flooded areas. Finally, the extracted surface water (SAR/MODIS) is subtracted from the permanent water to obtain flood extent, as mentioned previously.

10 https://www.frontiersin.org/articles/10.3389/fenvs.2019.00191/full

3. Flood Hazard Indices

Flood hazard indices indicate the frequency and severity of floods aggregated to an administrative boundary, which contributes to flood-related preparedness decisions and priorities.

3.1 Datasets used

1. JRC Monthly Water History V1.1 within GEE platform[11]
2. Administrative Boundary Level 2 (District)

11 https://storage.googleapis.com/global-surface-water/downloads_ancillary/DataUsersGuidev2.pdf

3.2 Methodology

Figure 13 summarizes the methodology for Flood Hazard Index calculation.

In Cambodia, ground-based field data often has poor spatial coverage and can be difficult to obtain. Therefore, to estimate flood hazard we used remote sensing-derived historical data from the JRC Monthly Water History (V1.1). Initial flood frequency maps for Cambodia were generated using the JRC Global Water dataset and associated methodology developed by the JRC team. The methodology sequence for processing the flood frequency maps involved detecting and counting water present pixels whilst accounting for false positives that may result from shadowing effects.[12]

Figure 14 illustrates flood inundation, calculated using the same methodology applied in Figures 9 and 10.

For this study, the flood hazard index was zoned according to the district-level administrative boundaries. The flood index was calculated by the total sum of all flood frequency pixel values in the district and then divided by the total district area. An example calculation is outlined in Figure 15.

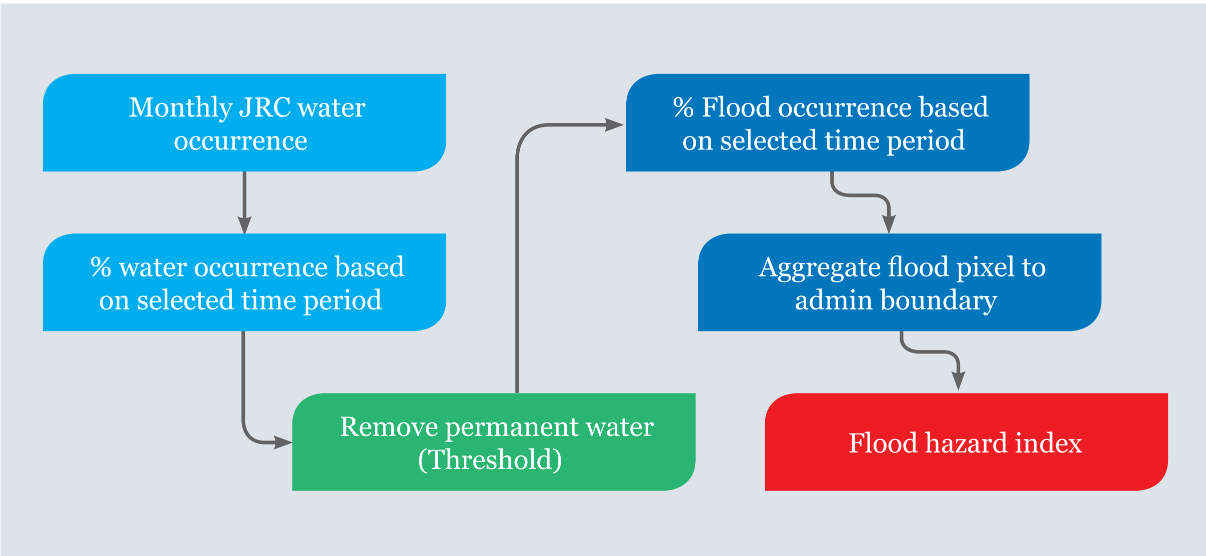


Figure 13. Methodology for Flood Hazard Index calculation

12 https://www.frontiersin.org/articles/10.3389/fenvs.2019.00191/full

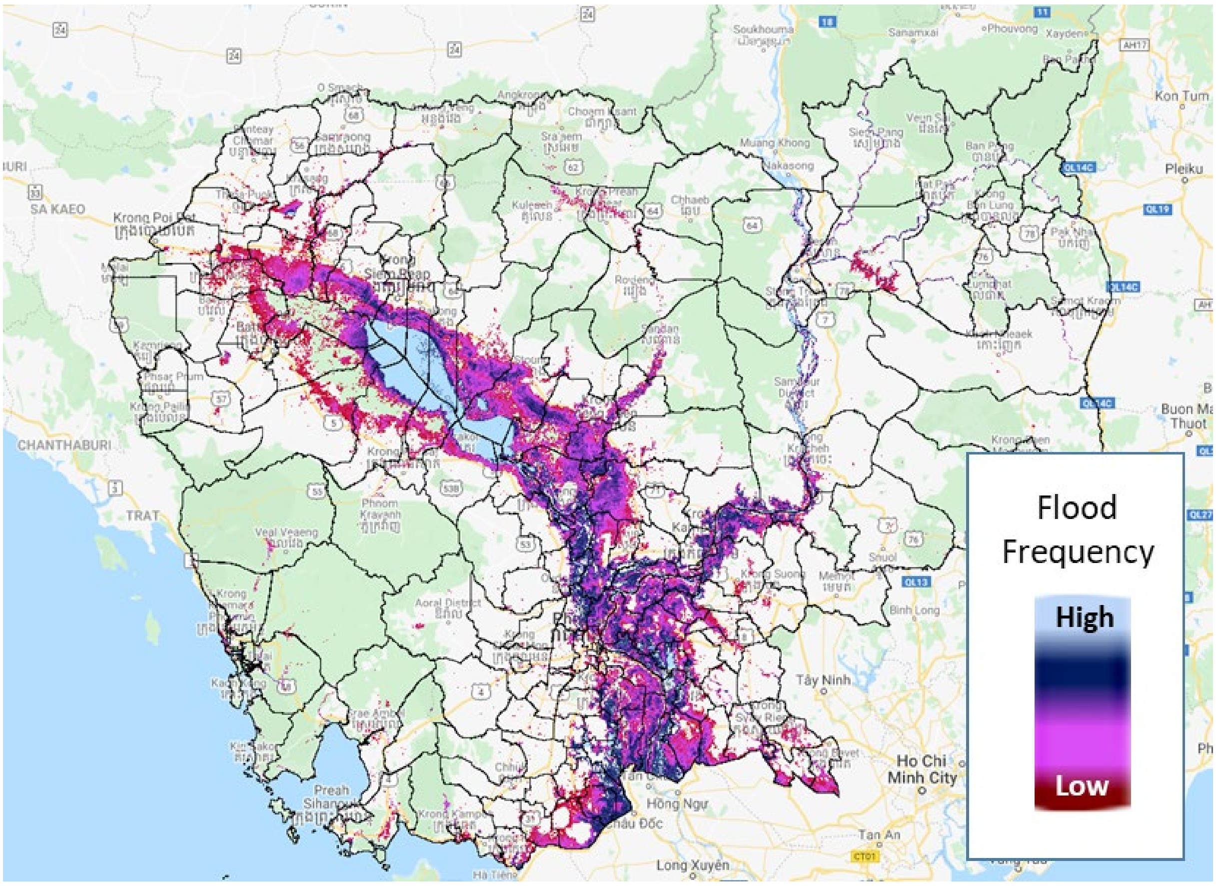


Figure 14. Frequency of flood occurrences

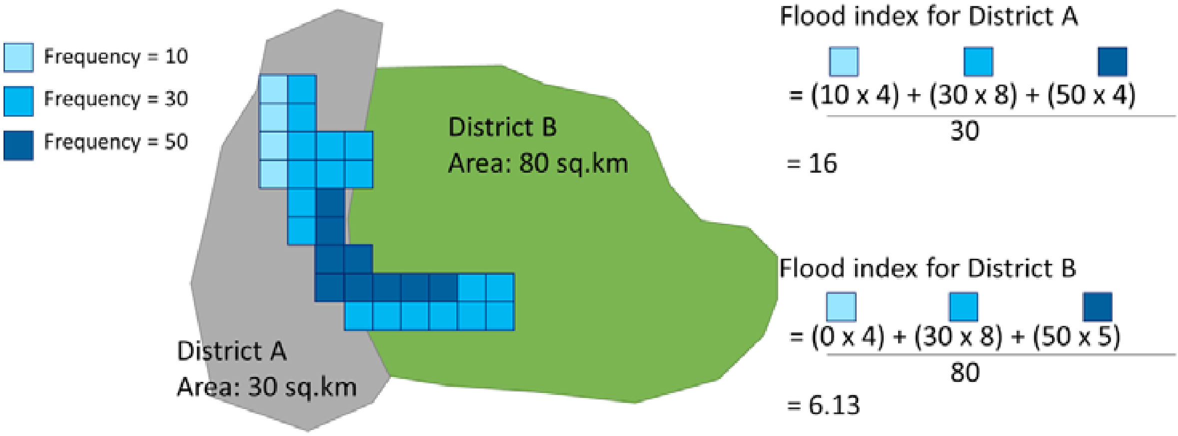


Figure 15. Methodology for integrated flood frequency within administrative boundary

Finally, the values were normalized so they had a value in the range of 0-100, which is easier for visualization and comparative purposes, as is illustrated in Figure 16. The value of the flood hazard index could be interpreted as lower values equating to a lower level of flood hazard. The color of the particular district indicates the different value of the flood hazard index. To interpret the layer, different colors represent different levels of the hazard. For example, green represents low hazard, yellow represents moderate hazard and red represents high hazard.

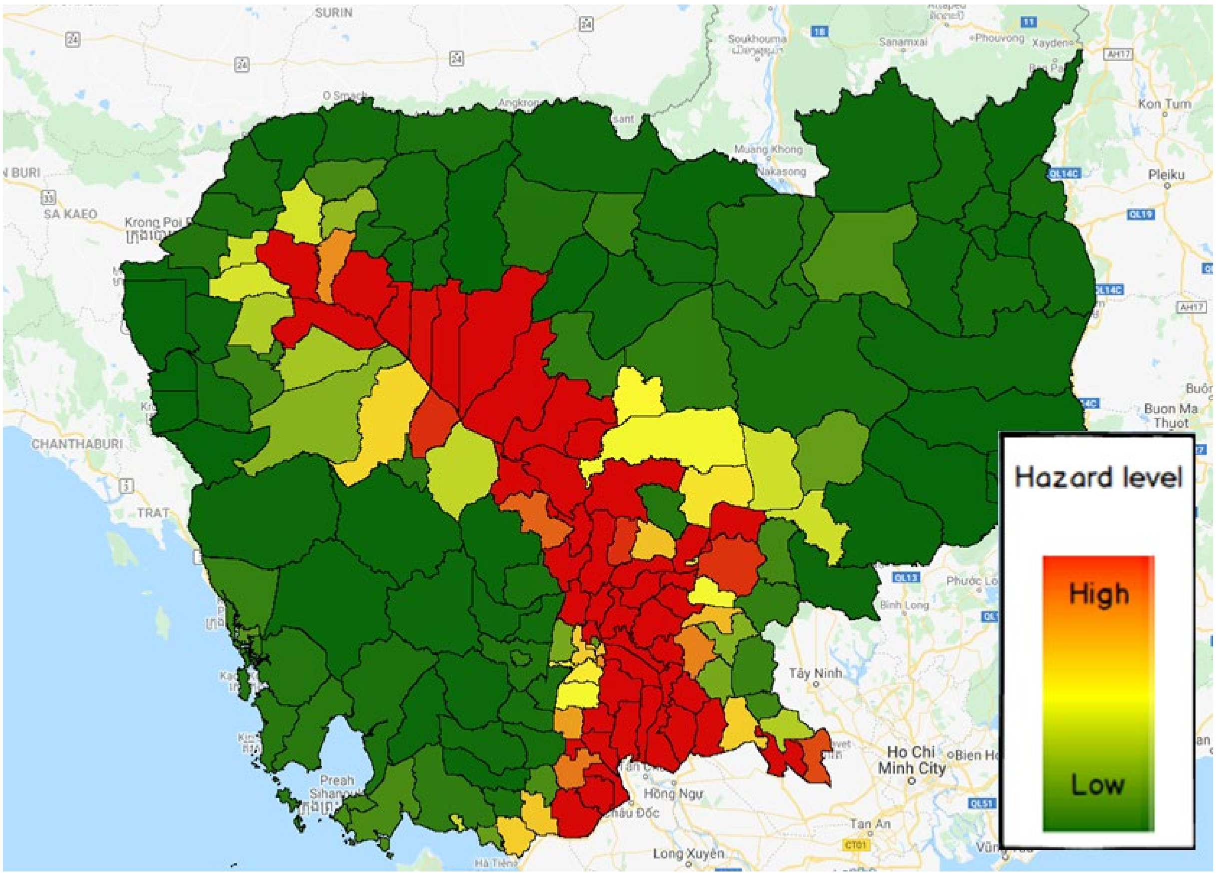


Figure 16. Normalized Flood Hazard Index Map

4. Near Real-Time Flood Extent Mapping

Cloud cover presents a real challenge for optical sensor generated imagery. To address this, ADPC has developed an innovative, multi-sensor, near real-time flood monitoring tool - HYDRAFloods (HYDrologic Remote sensing Analysis for Floods). HYDRAFloods utilizes microwave remote sensing data sources on an initial 24-hour time scale, generating near real-time (NRT) flood maps. Currently, Sentinel-1 SAR imagery and GEE cloud-computing platform is used to automatically generate NRT flood extent maps. All the data is stored as “assets” in GEE and are easily available to any users.

The PRISM system is actively used by NCDM in Cambodia as a primary data collection tool for capturing hazard exposure and impact information after an event. There is a real need for PRISM to integrate Earth Observation data for early warning and hazard monitoring. HYDRAFloods' outputs can be integrated into the PRISM system as new additional data products which can then be combined with other data for various types of analysis including impact and damage assessment. Therefore, the NRT flood extent data would be extremely beneficial with regards to disaster preparedness and emergency response decisions.

4.1 Methodology

For the NRT flood extent mapping all the processes are carried out in GEE and stored as "assets". The Copernicus Programme is the largest space data provider globally, providing satellite data freely and openly, including the provision of Sentinel satellite imagery. Sentinel-1 Synthetic Aperture Radar (SAR) data is useful for a wide range of applications due to its high spatial resolution, all-weather capabilities and high revisit frequency. In the case of NRT flood extent mapping, Sentinel-1 Ground Range Detected (GRD) data was used. Prior to running the machine-learning algorithms for flood water detection, pre-processing steps such as low entropy edges removal and speckle filtering were carried out to remove granular noise and improve the image quality. Following the pre-processing, satellite imagery for Cambodia is filtered by region and target date for the flood detection.

The flood extent mapping is implemented separately according to the orbit direction "ASCENDING" and "DESCENDING", with different training samples. Firstly, a series of covariates with the

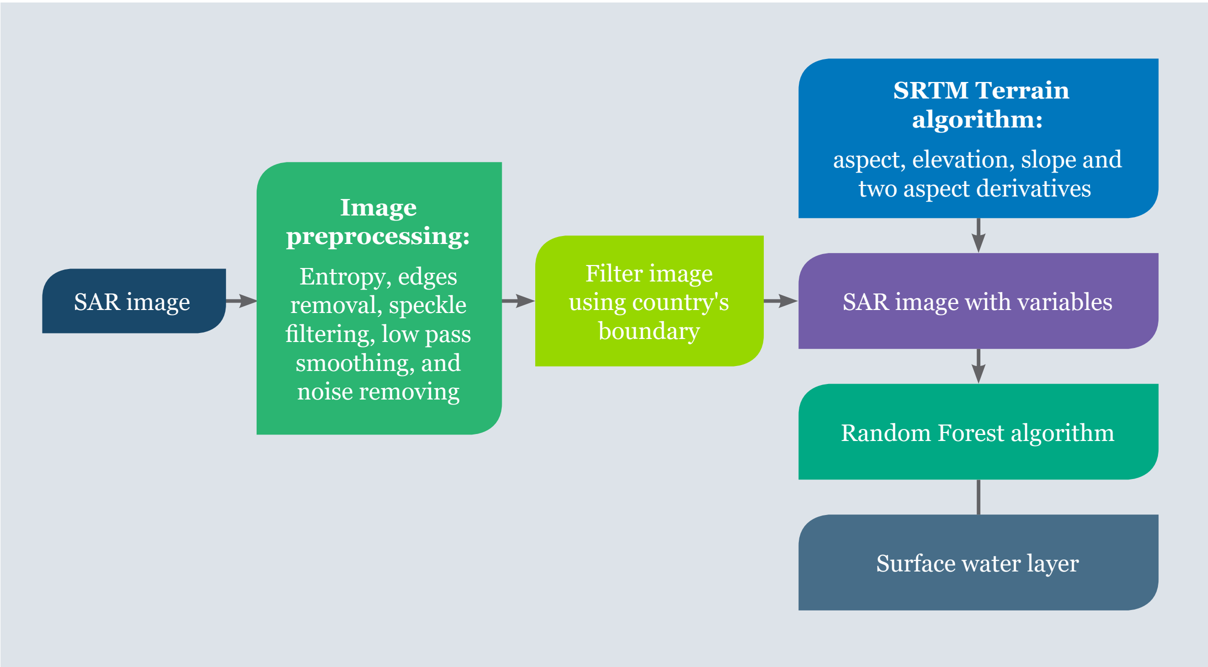


Figure 17. Near real-time flood extent mapping methodology

ratio band were calculated by dividing *VH* by *VV* where, *VH* and *VV* refer to the polarization, *VH* being cross-polarization (vertical transmit, horizontal receive) and *VV*, referring to co-polarization (vertical transmit, vertical receive). Subsequently, image smoothing was carried out by convolving with the boxcar kernel to create the associated smooth bands. Two of the most common morphological operations in remote sensing for satellite imagery are 'opening' and 'closing'. In this case, opening was included in the covariate calculations. Morphological opening is widely used as a noise removal transformation that erodes an image and subsequently dilates that eroded image. Topographic parameters derived from the SRTM digital elevation model were extracted by applying a terrain algorithm in GEE and were incorporated within the covariate calculations. The five topographic parameters included were aspect, elevation, slope and two aspect derivatives. All covariates were added to the image to perform classification of water and non-water classes using a machine learning algorithm called random forest. Training samples from 'ascending' and 'descending' data were created using all the covariates for the classification. Before training on the random forest algorithm, feature importance calculations using the smile random forest method were computed. Out of the 15 features, *VV*, *VH*, *ratio*, *slope* ,*VV_smooth*, *VH_smooth*, *ratio_smooth* were identified as high importance variables. Thus, the random forest algorithm was trained for the NRT mapping by using those key important variables identified.

4.2 Validation

High resolution satellite imagery was used to validate the Sentinel-1 derived water maps. The green (*G*) and near-infrared (*NIR*) bands were used to calculate the NDWI. A random stratified sample was created for water pixels using a minimum threshold of 0.4. Another sample was also created for non-water pixels using a maximum threshold of 0.2. The total number of points and spatial distribution of those points are shown in Table 2, and in Figures 18 and 19. To validate our points' spatial distribution for the classification probability, histograms of Planet data are created for ascending and descending as shown in Figures 20 and 21.

Table 2: Number of points used for validation of Sentinel-1 derived water maps

Number of points	Water	Non-water
Descending	500	500
Ascending	500	500

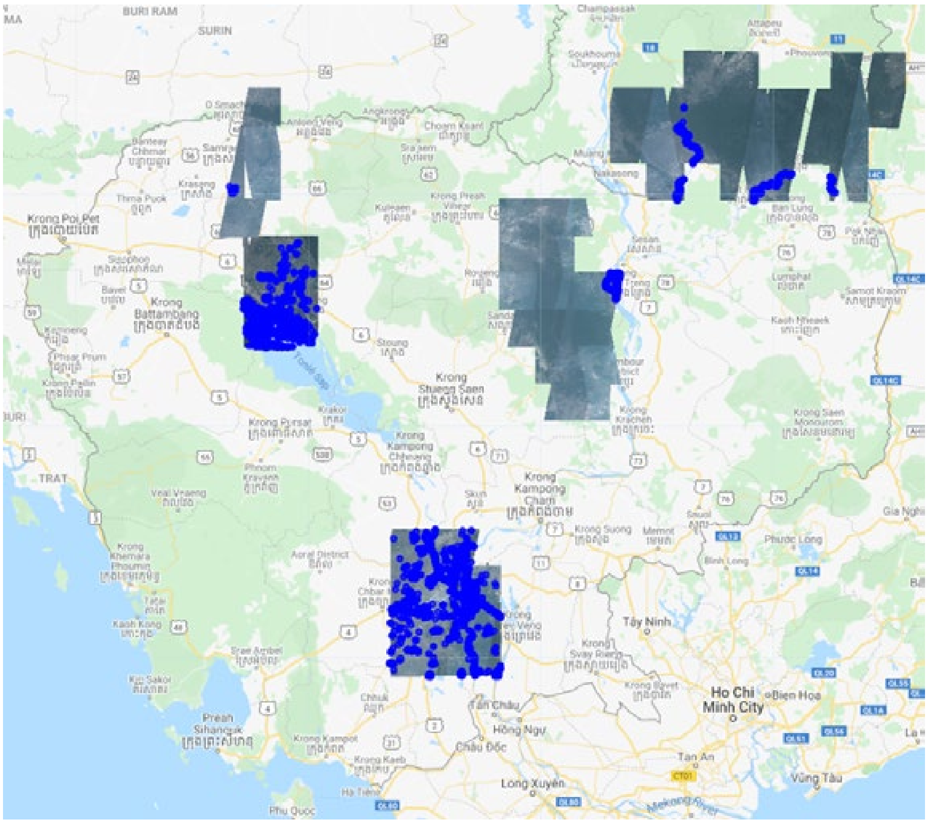


Figure 18. High resolution imagery with points generated for water

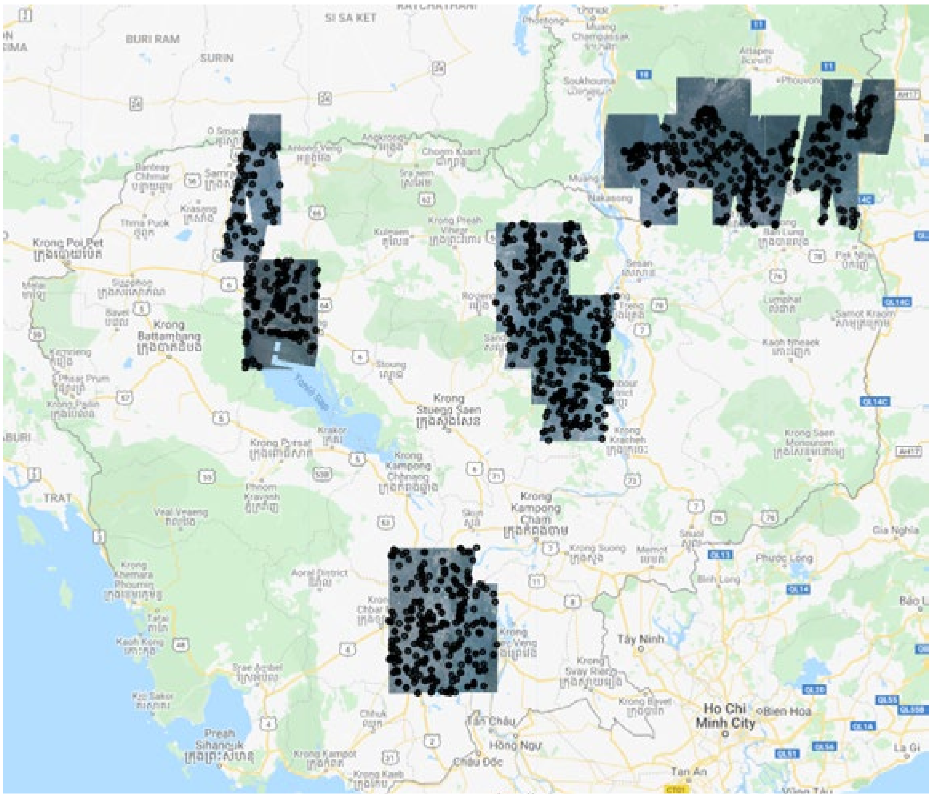


Figure 19. High resolution imagery with points generated for non-water

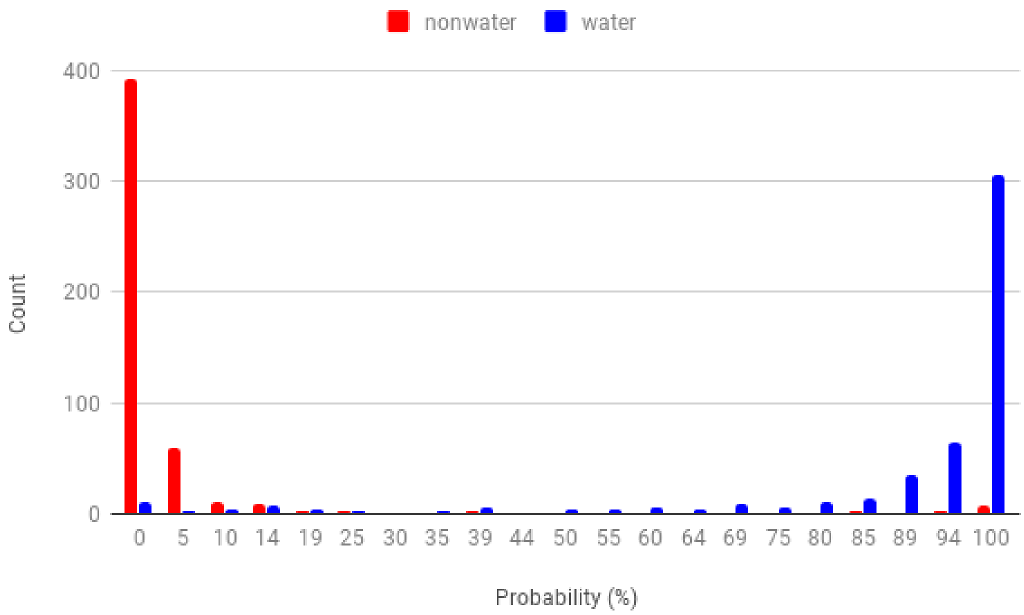


Figure 20. Histogram validation of data for 'ascending'

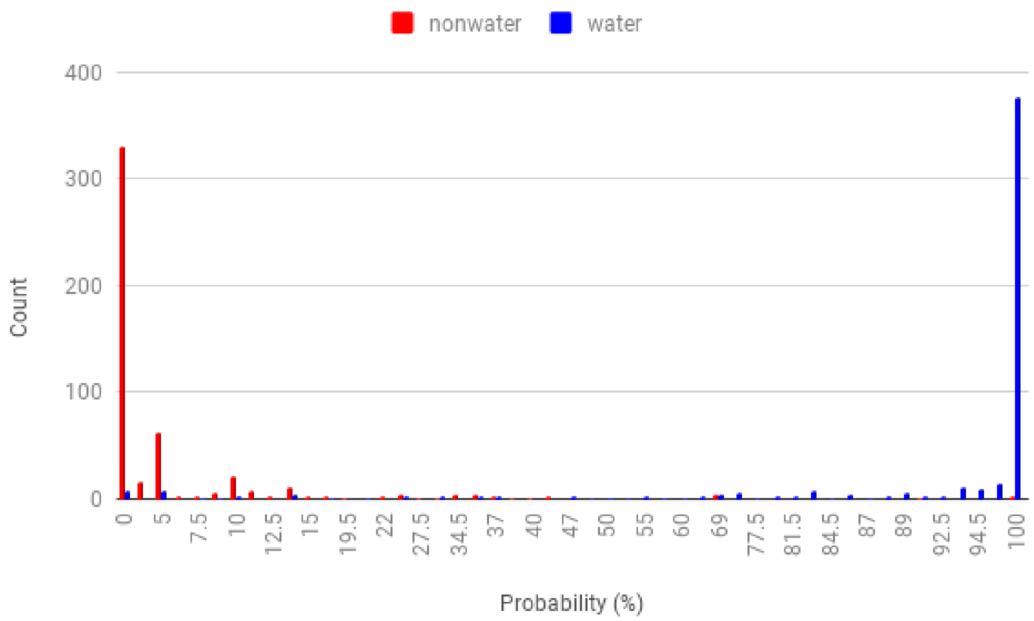


Figure 21. Histogram validation of data for 'descending'

Furthermore, additional validation of the flood mapping was carried out by random checks against specific flood events. Specific flood events were selected based on image availability to validate the method's performance. Figure 22 below shows an example of this visual validation, comparing the flood mapping result with Sentinel-2 (optical sensor) imagery taken from the same time period.

The visual comparison between Sentinel-2 imagery and our extracted flood layer aligns well, illustrating that the methodology we developed performs well for capturing flood extent. Figure 22 below shows the comparison between Sentinel-2 imagery and our flood extraction results for three separate flood events.

4.3 Results

Sentinel-1 SAR imagery and GEE Cloud computing platform was used to generate NRT flood extent maps. All the data is stored as Google Cloud assets and are easily available for WFP Cambodia. Currently, the dataset archive ranges from October 2014 when Sentinel-1 was launched, up until the present day. The system automatically generates the database once the new Sentinel-1 SAR image is available and added to GEE.

Figure 23 shows the surface water occurrence in Cambodia from the NRT flood dataset in assets. Each pixel of the image has a different probability value and therefore is displayed as different colors accordingly. Areas with less flooding (and low occurrence probabilities) are shown by white and light blue colors on the map. Whereas, areas of increasingly darker blue colors have higher occurrence probabilities and represent a greater flood risk compared to other areas.

Figure 24 shows an example of the comparison of an NRT extent map using the random forest approach with Sentinel-2 imagery. The top image is a false color composite of the Sentinel-2 image using RED, NIR, SWIR1 bands whilst the bottom image is the output of ADPC's approach using Sentinel-1 data. Both of the images were taken from the same time period (29-30 September 2018) in order to validate the performance of the NRT flood mapping system.

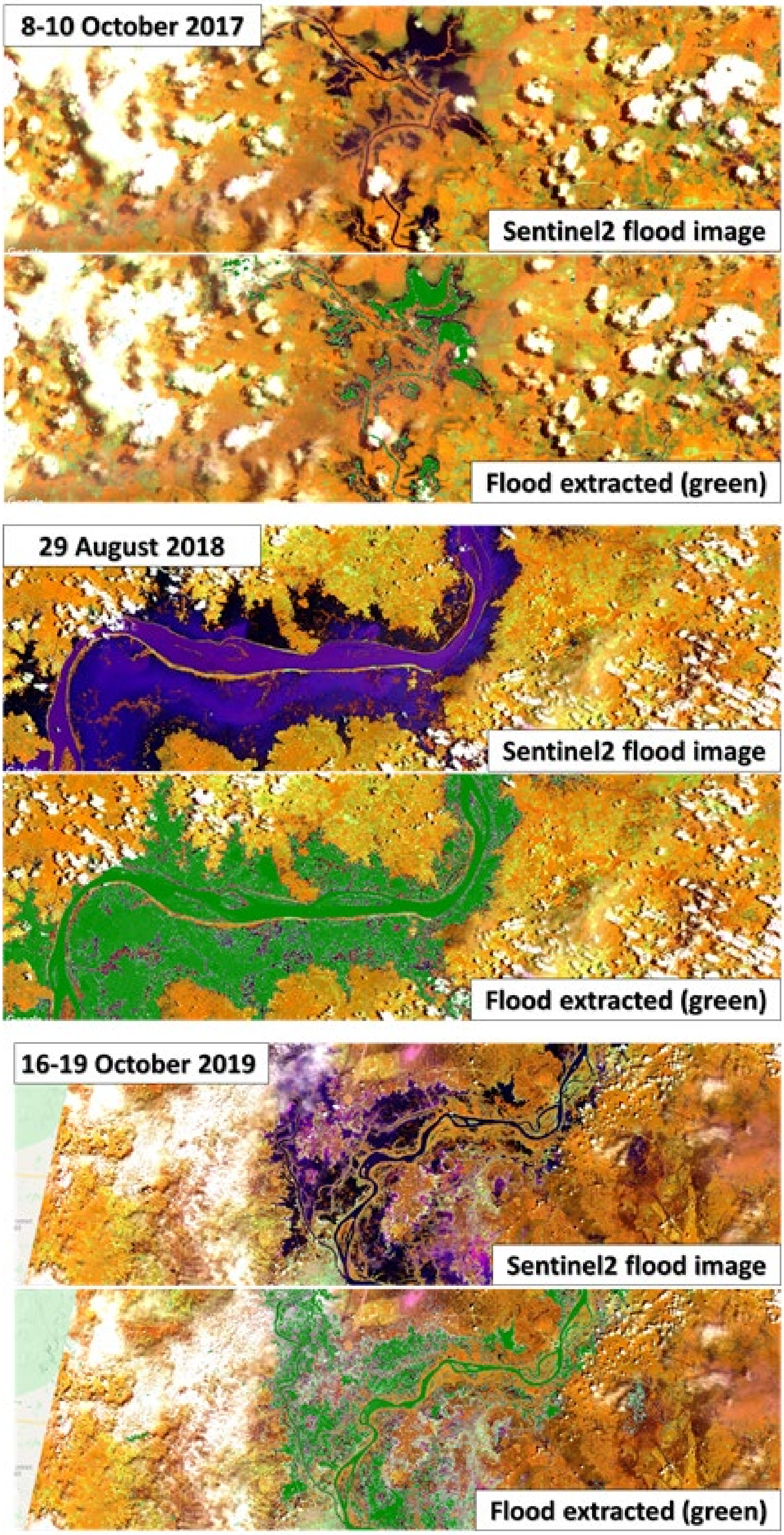


Figure 22. Visual validation by comparing optical image and flood extracted layer

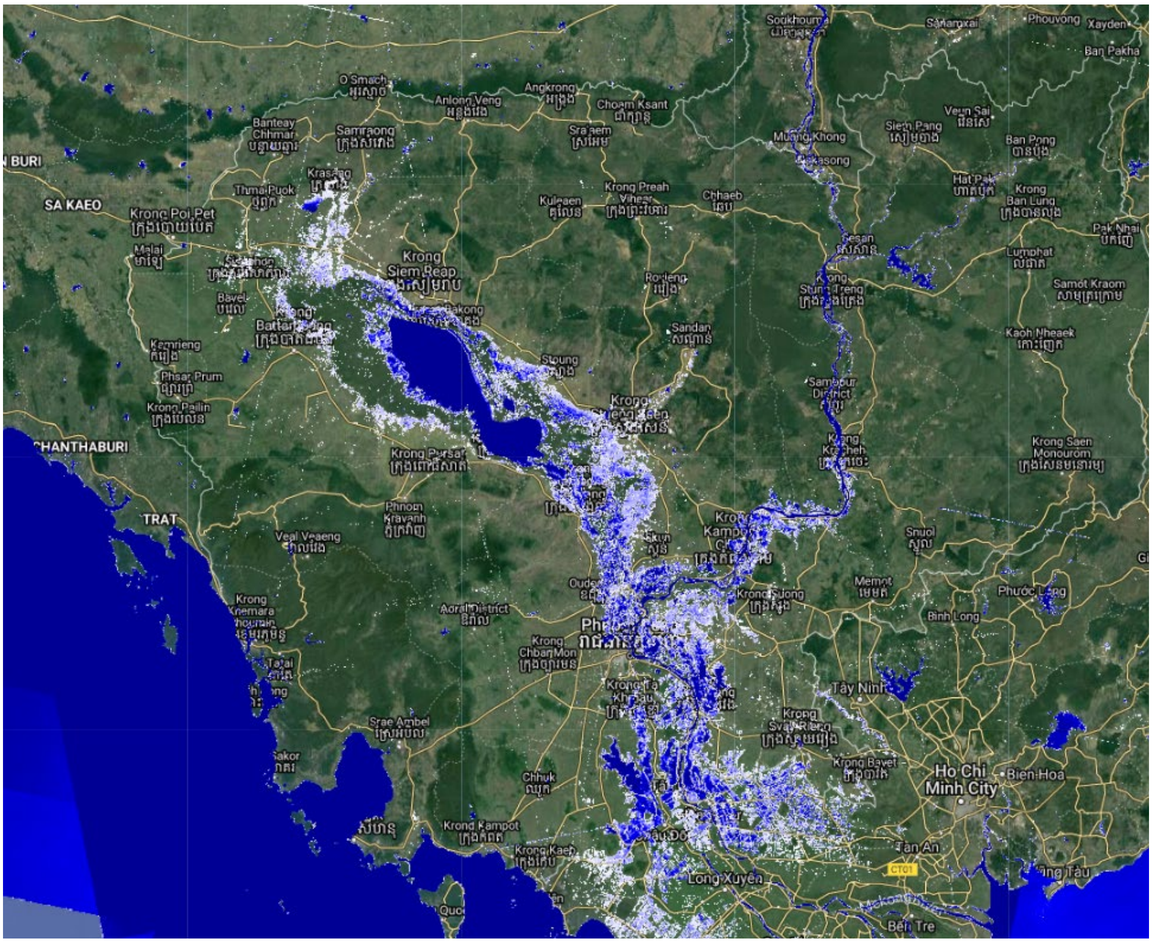


Figure 23. Surface water occurrence map for Cambodia. White and light blue colors indicate a low occurrence, dark blue colors indicate a high occurrence

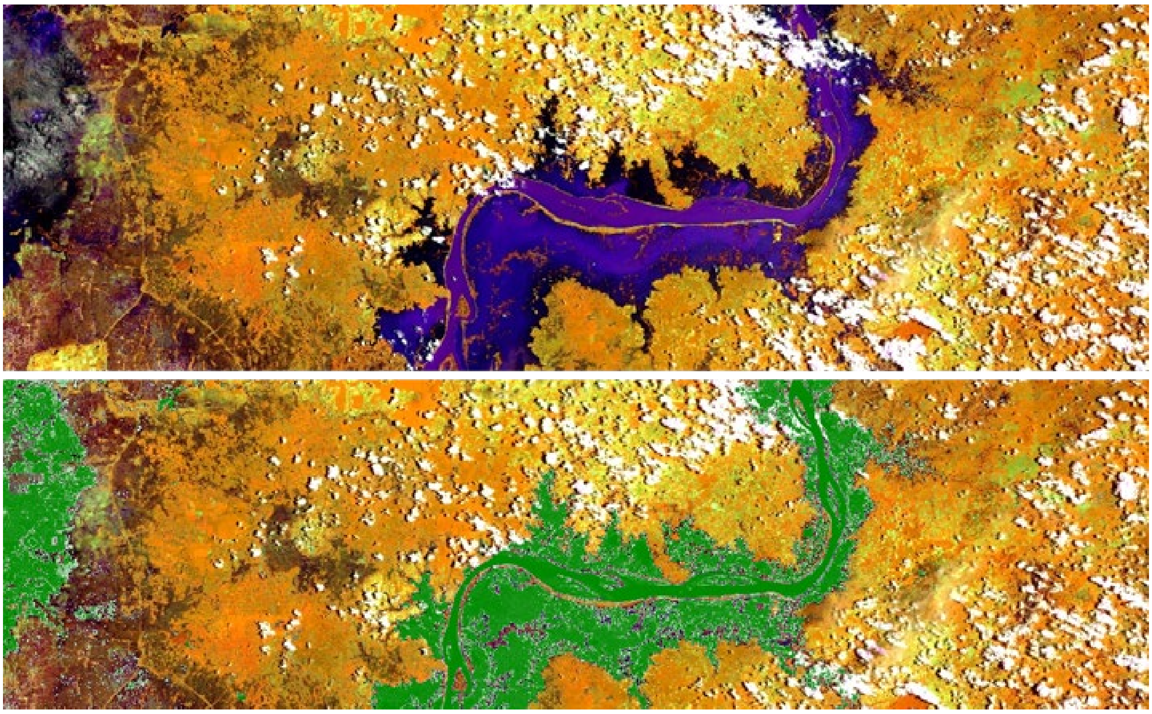


Figure 24. Comparison of Flood Extent Map with Sentinel-2 image (Top to Bottom: Sentinel-2 image, Flood Extent Map)

5. Recommendations

5.1 Flood data collection

Data collected from actual flood events can be used not only for analyzing the severity of the floods and for providing immediate relief to the people in the affected areas, but the data are also useful for further improving the flood extent algorithm in the future. Generally speaking, geographic identification of where the floods take place is of most importance which can be used to validate the satellite observation. Ideally, the locations should be geo-referenced and be recorded by the latitude and longitude coordinates. Understandably, most local communities and local authorities are not equipped to collect such detailed location information. It is at least recommended that the locations recorded are associated with different levels of administrative units, i.e., including names of the village, commune, municipality, district, and province.

Secondly, when collecting flood data as it happens, it is critical to record correctly the date when the data are collected. As flood water can linger over several days, data collection at the same location over those periods will be useful. Lastly, it is recommended that the depths of flood water, along with their locations, and the resulting damage to houses, infrastructure, and agricultural areas are recorded at several locations of the flooded areas.

Annex 2 gives an example disaster data collection form which could be used. However, to adopt it in the context of Cambodia and for floods specifically, a series of consultations with stakeholders is recommended including the National Committee for Disaster Management and its sub-national counterparts as well as provincial, district, municipality, commune, and village leaders, to customize the data collection for Cambodia.

5.2 Applications of the satellite-derived flood data

The flood extent data derived from satellites can be used to support decision makers on various aspects of the disaster risk management cycle (Figure 25), from before the flooding, during the flood, and after the flood water recedes.

Figure 25. Disaster Risk Management Cycle

Flood hazard indices

Firstly, the flood hazard indices derived from the frequencies of past flood occurrences are used to combine with the current locations of people and the indicators of their vulnerability and capacity, leading to an estimation of the flood risk. The risk information can guide decision makers to:

- Prioritize flood mitigation investment, i.e., to the areas of highest risk;
- Make flood preparedness planning prior to the flooding season (relief supplies distribution, training, community awareness raising);
- Pre-allocate contingency budget for flood response and relief according to the risk levels;
- Conduct public awareness activities in provinces and communes that are deemed at-risk;
- Develop flood-resistant construction guidelines for rural houses, as per the risk levels;
- Convince policy makers on the threat of flooding through visualization.

Near real-time (NRT) flood extent maps

Emergency responders can use the timely information on where flood water stands to take quick actions to help the people who are affected. Without satellite observation, the responders must wait to get flood reports from communities being sent through their leaders to the authorities. The time this process takes often hinders the effectiveness of the emergency response required in the situation. Quick access to the near-real-time flood extent information could help the authorities and the public alike to:

- Immediately identify the villages and communes being affected by floods;
- Provide relief support to the people affected by floods in a timely manner;
- Plan evacuation routes and logistics for the relief supplies to come in based on information on flooded roads;
- Start planning for retrofit, repair, and recovery;
- Assess damage after the floods.

These are actions that could be taken with the improved and timely information. However, the specific actions and plans will depend on the existing policy framework and institutions in Cambodia. It is recommended that those stakeholders are presented with the satellite-based information and engaged in applying the information for use in the country.

Annex 1: Historical Flood Events (2000-2019)[13]

Date (Day/Month/Year)	Location of flood event (Province)
7/12/2000	Stung Treng
1/9/2000	Banteay Meanchey, Ratanak Kiri, Prey Veng, Kampong Chhnang, Kampong Chhnang, Takeo, Kandal
--/10/2000	Preah Vihear, Pursat, Kandal, Svay Rieng
17/10/2000	Kampong Speu
--/07/2001	Pursat
22/8/2001	Kandal
15/9/2001	Prey Veng, Kampong Chhnang, Takeo, Kandal, Ratanak Kiri, Stung Treng, Kratie
1/10/2001	Pursat, Banteay Meanchey, Kampong Speu
22/10/2001	Kampot
30/10/2001	Svay Rieng
8/9/2002	Preah Vihear, Kampong Speu
--/9/2002	Kandal, Kampong Chhnang, Kampot, Takeo, Ratanak Kiri
2/9/2002	Stung Treng, Svay Rieng, Preah Vihear, Kratie
--/10/2002	Banteay Meanchey, Kampot, Pursat, Kampot
5/11/2002	Kampot
29/7/2003	Kampong Speu
--/9/2003	Kampong Chhnang, Takeo, Battambang
15/9/2003	Kratie
6/10/2003	Banteay Meanchey, Svay Rieng, Pursat
15/7/2004	Banteay Meanchey, Mondul Kiri, Prey Veng
15/9/2004	Mondul Kiri, Otdar Meanchey, Kampong Chhnang,Kandal,Battambang,Takeo,Kratie
--/10/2004	Banteay Meanchey, Kampong Chhnang
8/12/2004	Pursat
--/7/2005	Takeo
21/8/2005	Kampong Speu
--/9/2005	Battambang, Kampong Chhnang, Kampong Cham, Takeo, Ratanak Kiri, Preah Sihanouk, Kandal, Koh Kong

13 http://camdi.ncdm.gov.kh/DesInventar/profiletab.jsp?countrycode=kh855&continue=y

Date (Day/Month/Year)	Location of flood event (Province)
15/9/2005	Mondul Kiri, Kratie
17/10/2005	Kampong Speu
--/6/2006	Battambang
--/7/2006	Koh Kong
16/8/2006	Kampong Speu, Kampot, Ratanak Kiri, Pursat, Kampong Thom, Kratie, Kandal
19/8/2006	Kampot, Kampong Thom, Kampong Chhnang
--/9/2006	Battambang, Kandal, Stung Treng, Ratanak Kiri, Takeo, Kampong Chhnang, Kampong Thom, Preah Sihanouk, Koh Kong
1/9/2006	Kampong Thom
15/9/2006	Kratie
--/10/2006	Siem Reap
--/10/2006	Pursat
4/10/2006	Koh Kong
6/10/2006	Kampot
24/10/2006	Kampot
--/11/2006	Banteay Meanchey
14/12/2006	Kampot
--/7/2007	Banteay Meanchey
5/7/2007	Koh Kong
8/7/2007	Kampong Cham
4/8/2007	Preah Vihear, Kampong Chhnang, Ratanak Kiri
6/9/2007	Pursat, Stung Treng, Preah Vihear, Takeo, Battambang, Otdar Meanchey, Ratanak Kiri, Kampong Cham, Kratie
29/10/2007	Kandal, Otdar Meanchey, Kratie, Kampot
8/12/2008	Otdar Meanchey
--/09/2008	Siem Reap, Preah Vihear, Mondul Kiri, Takeo, Koh Kong, Takeo
16/9/2008	Preah Vihear, Kratie, Otdar Meanchey
--/10/2008	Banteay Meanchey
24/11/2008	Mondul Kiri
8/7/2009	Stung Treng, Preah Sihanouk, Kratie
7/8/2009	Stung Treng, Kratie
14/8/2009	Stung Treng, Kratie, Otdar Meanchey
6/9/2009	Battambang, Mondul Kiri, Kampong Thom, Ratanak Kiri, Otdar Meanchey, Kratie, Kampong Chhnang, Preah Sihanouk, Stung Treng, Takeo, Koh Kong, Pailin

Date (Day/Month/Year)	Location of flood event (Province)
25/9/2009	Siem Reap, Kep, Preah Vihear, Kampong Cham, Kampong Thom, Banteay Meanchey
1/10/2009	Preah Vihear, Banteay Meanchey, Kampong Cham, Mondul Kiri, Kandal, Battambang, Prey Veng, Kratie, Kampot, Otdar Meanchey
8/10/2009	Kampong Chhnang, Ratanak Kiri, Siem Reap, Ratanak Kiri, Mondul Kiri, Svay Rieng, Kampong Thom, Kratie, Stung Treng
30/10/2009	Svay Rieng
--/11/2009	Kampong Cham
11/12/2009	Pailin
15/9/2010	Kratie, Banteay Meanchey, Kampong Chhnang, Otdar Meanchey, Stung Treng, Takeo, Pailin, Kandal
23/9/2010	Pursat
11/10/2010	Kampong Chhnang, Takeo, Banteay Meanchey, Kandal, Siem Reap, Kampong Speu, Svay Rieng
31/10/2010	Banteay Meanchey
30/7/2011	Kampot
13/8/2011	Kratie
--/9/2011	Kampong Chhnang, Prey Veng, Otdar Meanchey, Banteay Meanchey, Takeo, Kandal, Pailin, Siem Reap, Kampong Cham, Preah Vihear, Kampong Thom, Stung Treng
7/9/2011	Preah Vihear, Pailin
9/9/2011	Stung Treng, Siem Reap, Preah Vihear, Kampong Chhnang, Kratie, Pailin, Kampong Speu, Kampot, Battambang, Kep, Banteay Meanchey, Kampong Cham, Pursat, Svay Rieng, Takeo
1/10/2011	Siem Reap, Preah Vihear, Kratie, Kampot, Svay Rieng, Otdar Meanchey, Takeo, Pursat, Kampot
23/10/2011	Takeo, Preah Vihear, Svay Rieng, Takeo, Kampot, Banteay Meanchey
9/11/2011	Banteay Meanchey, Siem Reap, Svay Rieng, Kratie, Pailin
28/8/2012	Banteay Meanchey, Takeo, Preah Vihear, Pursat, Pailin
15/9/2012	Kratie, Kampong Thom, Pailin, Banteay Meanchey, Otdar Meanchey, Pursat
9/10/2012	Siem Reap, Banteay Meanchey, Svay Rieng, Otdar Meanchey
30/10/2012	Siem Reap
9/12/2012	Siem Reap
28/6/2013	Pailin
11/7/2013	Kampong Chhnang
27/7/2013	Banteay Meanchey

Date (Day/Month/Year)	Location of flood event (Province)
11/8/2013	Kampong Thom, Otdar Meanchey, Kratie
--/9/2013	Battambang, Prey Veng, Pursat, Otdar Meanchey
2/9/2013	Otdar Meanchey, Preah Vihear, Stung Treng
10/9/2013	Battambang, Prey Veng, Svay Rieng
18/9/2013	Banteay Meanchey, Kampong Cham, Kampong Cham, Kampong Thom, Kratie, Phnom Penh, Prey Veng, Ratanak Kiri, Siem Reap, Stung Treng, Otdar Meanchey, Kep, Pursat, Kandal, Preah Sihanouk, Svay Rieng
20/9/2013	Siem Reap, Otdar Meanchey, Preah Sihanouk, Kratie, Svay Rieng
25/9/2013	Kandal, Prey Veng
25/9/2013	Svay Rieng, Prey Veng, Kratie, Ratanak Kiri
30/9/2013	Kandal, Preah Vihear, Kampong Chhnang, Kandal, Takeo, Stung Treng, Kampong Thom, Svay Rieng, Siem Reap, Pailin
25/10/2013	Kandal
18/7/2014	Preah Vihear
25/7/2014	Stung Treng
29/7/2014	Kampong Cham, Kratie, Kampong Thom, Ratanak Kiri, Kep
6/8/2014	Prey Veng, Kratie, Kampong Cham, Kandal, Kampot, Mondul Kiri
25/8/2014	Stung Treng, Banteay Meanchey
9/9/2014	Phnom Penh, Stung Treng, Kratie, Preah Sihanouk
20/9/2016	Battambang, Kampot
15/10/2016	Kampong Cham, Takeo, Kampong Speu, Svay Rieng, Kampot
10/8/2017	Otdar Meanchey, Kampong Thom, Kampot, Preah Sihanouk, Ratanak Kiri, Kratie
31/8/2017	Kampong Cham, Kratie, Phnom Penh, Preah Vihear
17/7/2018	Kampong Speu, Battambang, Koh Kong and Phreah Sihanouk.
--/7/2018	Kampot province
--/7/2018	Phnom Penh
29/8/2018	Kampong Chhnang
11/9/2019	Mondulkiri, Ratanakiri, Kratie, Steung Treng, Preah Vihear, Kampong Chhnang, Tboung Khmum, Kampong Speu, Kampot, Kep and Koh Kong.
16/10/2019	Stung Treng

Annex 2: Example disaster data collection form

FORM I

Initial Report on (disaster incident)
To be submitted within 2 hours after the flash report

____

Origin of Report:

1. Profile of the Incident:

- What : ____
  (Type of disaster)
- When : ____
  (Date and time of occurrence)
- Where : ____
  (Exact locations)
- Why : ____
  (Probable cause of the incident)
- Who : ____
  (Affected population (________ **children**_____________**adults** **(women**)
  (Responding local agencies in the area)
- How : ____
  (How was the initial local response carried out?)

- Is there a need for:

  Search and rescue assistance? _____ Yes ______ No

  Evacuation? ________ Yes ________ No

____
Signed: Local DCC Chairman

Form II

Rapid Damage and Needs Assessment Checklist

(To be submitted within 12 hours upon occurrence of disaster)

A. Profile of the Disaster

1. Type of disaster/emergency ____________________
2. Date and time of occurrence ____________________
3. Areas Affected ____________________
   (barangays, municipalities/cities, provinces, regions)
4. Sources of reports ____________________
5. Date and time of reports ____________________

B. Initial Effects:

1. **Affected Population**: __________Families ____________Persons
2. **Displaced Population**: __________Families ____________Persons
   - Infants - 0-1 year old ____________________
   - Children - 2-12 years old ____________________
   - Adolescent - 13-17 years old ____________________
   - Adults (women) - 18 and above ____________________

3. **Casualties:**

	Location	**Number**	**Cause**
Dead	________________	_______	________________
Injured	________________	_______	________________
Missing	________________	_______	________________

C. Initial Needs Assessment

1. Search and Rescue

1.1 Exact locations ________________________________
(barangays, municipalities/cities, provinces, regions)

1.2 Approximate number of missing _____**children** ______**adults (women)**

1.3 Response Status ____________________
(local SAR and resources deployed by DCCs)

1.4 Unmet needs for which additional SAR resources are requested? ____________________
(teams, rescue boats, heavy equipment, expertise)

2. Evacuation

2.1 Exact locations ______________________________
(region, province, municipality, city, barangay)

2.2 Approximate number of people to be evacuated
____**infants,**______**children** ______**adults (women)**

2.3 Response status ______________________________
(number of people evacuated by local DCCs)

2.4 Unmet needs for which additional evacuation assistance is requested ? ______________________________

2.5 Names of evacuation centers ______________________________
____

2.6 Number of families or persons housed in evacuation centers who are in need of assistance ____________families ____________persons
(_____infants, _____children ______adults (women)

2.7 Daily requirements of affected families in the evacuation center ______________________________

2.8 Are there enough latrines in the evacuation centers? ______

3. Medical Health

3.1 Exact locations______________________________
(barangays, municipalities/cities, provinces regions)

3.2 Number of injured ______________________________
_____**infants**_____ **children** ______**adults (women)**

3.3 Displaced families or persons who are in need of medical attention ____________families ____________ persons
______**infants** ______**children** ______**adults (women)**

3.4 Response status ______________________________
(condition of medical facilities)

3.5 Unmet needs ______________________________
(medicines, medical supplies & teams required from national sources)

3.6 What specific effects has the situation had on health of survivors?______________________________

3.7 Are there any health–related cases prevailing in the area.? If so, what health care facilities exist where and what?____
____

3.8 Who is in charge of emergency health and medical services in the area?______________________________

3.9 Are there health workers in the community assessing the health and nutritional status of affected children in the evacuation centers? ______________________________

4. Shelter and Clothing

4.1 Exact locations ____
(barangays, municipalities/cities, provinces and regions)

Number of people requiring shelter and clothing__________

__________**Male** ____________ **female**

_______**infants** _______**children** _____**adults (women)**

Response Status ______________________________________
(number of people being provided with shelter and clothing by local DCCs)

4.4 Unmet needs ____
(number of people needing assistance and specify type of assistance required (tents, blankets, mosquito nets and clothing)

5. Food

5.1 Exact locations ____
(barangays, municipalities/cities, provinces, regions)

5.2 Total number of people requiring food ___________________
_______**infants,** _______**children** ____**adults (women)**

5.3 Response Status ____
(number of people provided with food by the local DCCs)
______**infants** _________**children** ______**adults (women)**

5.4 Unmet needs ____
(number of people for whom external supplies of food are requested)

5.5 Are food resources and local buffer stocks available ?
____

5.6 Is food assistance equally distributed? _________________

5.7 Are the children being provided with food assistance according to their needs?_______________________________

5.8 Are prime commodities locally available? ____yes _____no

6. Water

6.1 Exact locations ____
(barangays municipalities,/cities, province, regions)

6.2 Number of people without potable water ________________
_________**children** _________**adults**)

6.3 Response status____
(number of people being supplied with potable water by the local DCCs; condition of supply system and repair status; availability of surface water)

6.4 Unmet needs ____
(Number of people whom external supplies of water requested and need for treatment supplies, container and trucks)

6.5 Are there any arrangement for water storage & distribution system in the area ? ______________________

6.6 Is there water shortage? ___________yes ______________no
_____date______time ____________probable cause

6.7 Is it widespread or concentrated in one area? __yes ___no

6.8 Are there alternate sources of water? ____yes ____ no
If yes, specify ____

6.9 Did the service providers took immediate repairs? __yes ___no. If yes, how long will it take to restore the systems? number of days _________________________

7. Environmental Sanitation

7.1 Are there enough latrines for sanitary disposal of feces that are away from water sources, cooking and eating areas? ____

7.2 Are there washing facilities and adequate cleaning materials?
____

8. Restoration of Lifeline Systems

8.1 Exact Locations______________________________________
(barangays, municipalities/cities, provinces, regions)

8.2 Conditions of lifeline systems __________________________
(Roads, bridges, railways, power supplies and communication systems)

8.3 Is it operational or non operational? If not what are the emergency measures undertaken by the service providers?
____

8.4 Response Status ______________________________________

8.5 Unmet Needs ____
(list of personnel, supplies and equipment requested from external sources)

8.6 Was there power interruption? ______yes __________no
_______date _______ time and ______probable cause

8.7 Is it widespread or concentrated in one area?___yes___no

8.8 Are there electric posts toppled down? ____yes ______no

8.9 How long will it take before the service is restored?
Number of days _________________________________

8.10 What are the actions taken by the servicing companies?
____

9. Children's Educational Needs

9.1 Are there school buildings damaged? ______yes _____no
If yes, how many children are affected? ___________**boys**
___________**girls**

9.2 What is the extent of disruption caused by the emergency situation? ______________________________

9.3 How many children are in need of primary education?
_____________**boys** _______________**girls**

9.4 Location of the target groups ______________________

9.5 Level of formal and non-formal education of children
____

9.6 Instructional materials available ______________________
____

9.7 Existing physical facilities that could be used for non-formal schooling ______________________________

E. Local Initial Actions

1. Emergency Responders involved______________________________
2. Assets Deployed______________________________
3. Number of Families/Persons Initially Served ___________ families
   _________ persons (____**infants** ______**children** _______**adults)**
4. Extent of Local Assistance ______________________________

Signed : _______________
Local DCC Chairman

<u>Form III</u>

DAMAGE ASSESSMENT FORM

(to be submitted within 24 hours upon occurrence of disaster

A . Profile of the Disaster

1. Type of Disaster / Emergency ____________________________
2. Date and Time of Occurrence ____________________________
3. Source of Report ______________________________________
4. Date and Time of Report _________________________________

B. Summary of the Effects (as of reporting time)

1. Areas Affected

(barangays, cities/ municipalities, provinces, regions)

2. Population Affected (cumulative total)

Families ____

Persons ____

(no. of children with age ranging from 1-17 years old)

3. Population Displaced (cumulative total)

Families ____

Persons ____

Infants - 0-1 year old ____________________

Children - 2-12 years old ___________________

Adolescent-13-17 years old ___________________

Adults - 18 and above ____________________

4. Casualties (cumulative total)

Dead

Injured

Missing

5. Damaged Properties (structures)

Breakdown	Totally (Number)	Partially (Number)	Est Cost
Houses	_____	_______	_____________
School Buildings	_____	______	_____________
Hospital	_____	______	_____________

Gov't Offices	_____	______	_____________
Public Markets	_____	______	_____________
Flood Control (sea walls/dikes/dams/irrigation systems	_____	______	_____________
Commercial Facilities (factories,/malls/stores/supermarkets)	______	_______	_____________
Others (specify)	_____	_______	_____________

6. Damaged Lifelines

6.1 Transportation Facilities

	Location	Passable/Not passable	No.	Cost
Roads				
National	_____	______ / _______	____	____
Provincial	_____	______ / _______	____	____
Municipal	_____	______ / _______	____	____
City	_____	______ / _______	____	____
Barangay	_____	______ / _______	____	___
Bridges				
Bailey	_____	______ / _______	____	____
Concrete	_____	______ / _______	____	_____
Wooden	_____	______ / _______	____	_____
Railways	_____	______ / _______	____	_____

6.2 Communication Facilities

	Location	Operational/ Non Operational	No	Cost
PLDT	__________	______________	____	_____
Bayan Tel	______	_______________	____	_____
Cell Sites	______	_______________	____	_____
Radio repeaters	_______	______________	____	_____

6.3 Electrical Power

_______	______________	_____	______

6.4 Water Facilities

_______	_______________	_____	______

7. Agriculture

7.1 Crops

	Areas Damaged No. of Has)	(Metric Tons)	Losses (Peso Value)
Rice	________	________	________
Corn	________	________	________
Vegetables	________	________	________
Root crops	________	________	________
Fruit trees	________	________	________
Bananas	________	________	________
Others	________	________	________

7.2 Fisheries

Fishponds ________ ________ ________

Fishing boats (number) ________ ________

7.3 Livestock

Animals	No. of Heads	Peso value
Farm Animals	________	________
Poultry and Fowls	________	________

C. Local Actions

1. Emergency Responders Involved ________________________

____

2. Assets Deployed ____

____

3. Number of Affected Population Served

Families ____

Persons ____

4. Number of Displaced Population Served

Families ____

Persons ____

(_______infants, _______children and _______adults)

5. Extent of Local Assistance________________________________

____

Progress report to follow

____

Signed: Local DCC Chairman

World Food Programme Cambodia

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