Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Satellite-based flood inundation and damage assessment

Christine B. Mata (christine.b.mata@isu.edu.ph)
Isabela State University https://orcid.org/0000-0002-5047-0647

Orlando F. Balderama
Isabela State University

Lanie A. Alejo
Isabela State University

Jeoffrey Lloyd R. Bareng
Isabela State University

Sameh Ahmed Kantoush
Kyoto University

Research Article

Keywords: Google Earth Engine, Sentinel-1, flood mapping, flood damage assessment

Posted Date: June 21st, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1774502/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Satellite-based flood inundation and damage assessment

C B Mata[1], O F Balderama[2], L A Alejo[3], JL R Bareng[4], S A Kantoush[5]

[1] Water Research and Development Center, Isabela State University, Isabela, Philippines
[2, 3, 4] College of Engineering, Isabela State University, Isabela, Philippines
[5] Water Resources Research Center – Disaster Prevention Research Institute
Kyoto University, Kyoto, Japan

christine.b.mata@isu.edu.ph

Abstract

Because recurring floods in the Philippines have become more damaging throughout time, risk assessments, quantifying, and visualizing flood damages as accurately as possible become imperative. To deal with an up-to-date database and a practical assessment tool, a satellite imagery-based method was used which aimed to map flood inundation and estimate damages brought by the flood during Typhoon Ulysses. This paper presents a framework for an integrated flood risk management in a river basin context with the following components as follows: 1) collection of the comprehensive database containing information relevant for flood analysis; 2) use of a satellite-imagery based method for flood inundation map using Google Earth engine; 3) validation of map accuracy through quick post-flood participatory approach. Analysis of the recent flood inundation event in November 2020 in Cagayan Valley, Philippines showed the inundation of an extensive area of 620.88 km^2 affecting the Cagayan province at 55.91% and Isabela province at 44% share of inundation. The flood severely affected approximately 614.05 km^2 of the total croplands. Using a participatory validation approach, the overall accuracy of datasets used is 97.78% while flood extent is 95%. Through this study, the framework, approach, and methodology can be replicated in other locations in the Philippines and in other countries which recurrently experience flooding.

Keywords: Google Earth Engine, Sentinel-1, flood mapping, flood damage assessment

1 Introduction

Floods are one of the most destructive natural disasters in terms of socio-economic damages, both globally and in the Philippines. Due to geographic location and diverse topography, many countries especially in Asia including China, Bangladesh, Japan, India, and Philippines have been severely affected and suffered from floods. Over the last half-century, more than 80% of natural catastrophes in the Philippines are accounted for typhoons and floods (Jha et al. 2018).

The recent flooding in the Philippines 2020 was brought about by the succeeding occurrences of six (6) tropical cyclones in the country, the last of which is Typhoon Ulysses, bringing unprecedented rains to the Cagayan Valley region resulting in unexpected floods heights and extensive inundation to the provinces of Isabela and Cagayan. Flood risk assessment and decision-making necessitate the most precise quantification of flood risk damages feasible (National Research Council 2015; Uddin et al. 2019; Meyer et al. 2009). The availability of a detailed spatial database for damage assessment can potentially improve the ability to generate high-resolution flood damage maps. However, just extracting and mapping these resources alone is laborious while the adoption of the traditional approach is time-consuming and expensive. Flood damage estimate using GIS and RS has become a useful instrument for developing a near real-time flood mapping and effective flood risk mitigation policy (Shrestha et al. 2014; Manfre et al. 2012).

Many attempts have been made in the past to map flood vulnerability in the Philippines using LiDAR (Rodriguez et al. 2017; Puno & Amper 2016) but unfortunately, the coverage for a sufficiently high accurate Digital Terrain Model (DTM) is not complete, especially in the river basin context. Flood management based on water level forecasting is ineffective in providing a spatial flood region for mapping flood events (Lin et al. 2019; Jung et al. 2014). The limitations of the hydrological model-based method are addressed by satellite-based flood extent monitoring (Rahman & Di 2017). In the Philippines, Ghaffarian et al. (2020) suggest the use of Google Earth Engine (GEE) in post-disaster recovery monitoring in Leyte brought by Typhoon Haiyan in 2013. GEE also offers a rapid and direct flood damage estimation (UN-SPIDER 2019; Uddin et al. 2019; Lal et al. 2020) with the default embedded data and script in GEE. One of the satellite data in GEE is the Sentinel-1. Apart from multiple applications of Sentinel-1, it uses a wide area coverage with near real-time data acquisition making it a more feasible tool allowing for more efficient and cost-effective use. Over the last few decades, a considerable number of studies have been through on the SAR flood mapping method in combination with other Remote Sensing (RS) imageries (Mimich et al. 2021; Jokar et al. 2022) whereas other researchers suggest the use of Sentinel-1 radar image to calibrate (Elkhrachy et al. 2021) or validate the extent derived using other models (Ezzine et al. 2020).

All flood mapping-related research in the Philippines is useful in giving a geographic representation of the distribution of flooded regions however, no studies have yet been conducted to evaluate and map the actual flooding of the entire Cagayan River Basin using different datasets. GEE can offer an estimation of flood damages but in very low-resolution datasets (MODIS land cover 500m, JRC Population 250m) thereby affecting the accuracy of reports. With the readily available, free, up-to-date, and high-resolution data accessible in OpenStreetMap (OSM) and obtainable from National Mapping and Resource Information (NAMRIA), a comprehensive database containing information relevant for flood analysis was collected and analyzed in this study. Since GIS and RS have proven their capability in flood mapping, the study is very timely and significant, especially in the case of the Philippines.

Hence, this paper aimed to 1) collect the comprehensive database containing information relevant for flood analysis; 2) use a satellite-imagery-based method for flood inundation map using GEE; 3) validate map accuracy through a quick post-flood participatory approach. This resolution will exhort the Disaster Risk Management Council and the Cagayan Valley Regional Disaster Management Council in the Philippines to expedite the restoration of typhoon-damaged regions and provide basic needs to significantly affected people. The study's findings will be beneficial in developing flood risk reduction policies and preventive measures for future flood events.

2 Materials and Methods

Figure 1 depicts the overall methodological framework used in the study. Two validations were performed: for datasets and flood extent. A post-flood survey was conducted to determine the threshold for estimating flood extent in GEE. Flood maps and flood-risked resources were quantified and tabulated. Validation of map accuracy through a quick post-flood participatory approach was done. A step-by-step procedure was presented for future replication of the study.

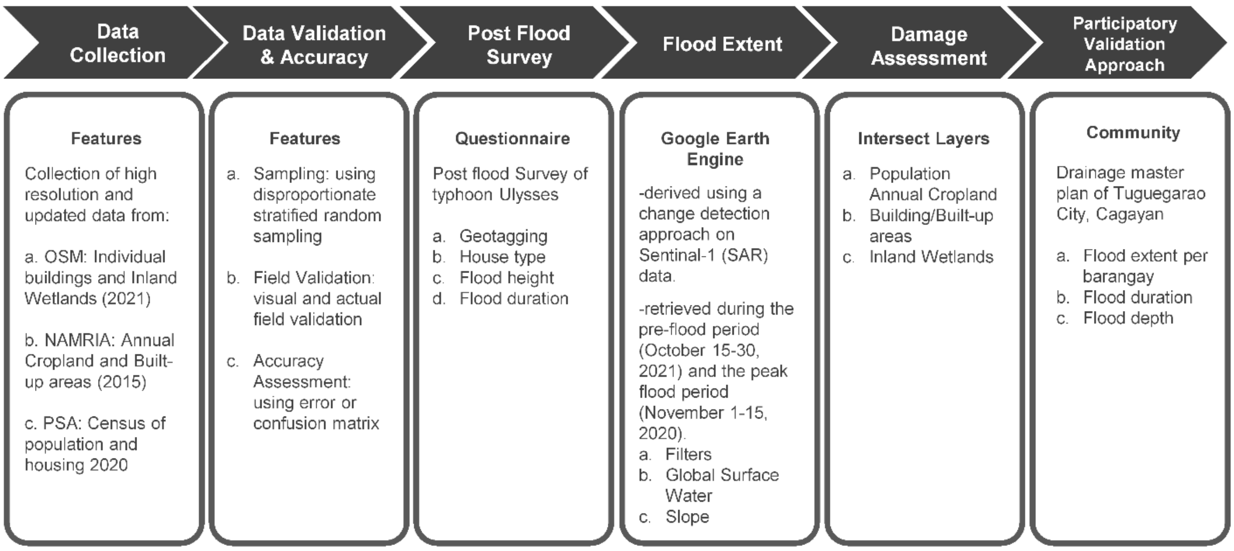

Fig. 1 A summary of the overall methodological framework used in the study

2.1 Data Collection, validation, and accuracy

A comprehensive and up-to-date database containing information relevant to flood analysis was collected. Data is characterized by different sources and dates depending on the latest and finest data there is. Flood damages were evaluated in the following features (Table 1).

Table 1 Definition of features and sources of data where damages were evaluated

Class Feature	Definition	Data Reference
Population	The number of people living in a place	Philippine Statistics Authority (PSA). 2020.

Annual Crop	Cultivated with crops with a growing cycle under one year, which must be newly sown or planted for further production after harvesting.	National Mapping and Resource Information Technology (NAMRIA). 2015.
Built-up	Composed of areas of intensive use with much of the land covered with structures	NAMRIA 2015
	Individual buildings or groups of connected buildings	OpenStreetMap (OSM). 2020.
Inland Wetland	Aquatic influence environments are sometimes referred to as freshwater and inland water/water bodies but also include brackish water located within land boundaries	NAMRIA. 2015.

Quality control and ground validation of datasets were implemented. The disproportionate stratified random sampling was used as a sampling method which means that features have an equal number of samples generated though there was a variation in the number of features. The accuracy of the map was computed through the confusion matrix also known as the error matrix which is commonly used to calculate thematic accuracy based on the results of validation (validation through ancillary maps and field). It provides three measures of accuracy – user accuracy, producer accuracy, and overall accuracy.

During the post-flood survey, on the other hand, data thru questionnaire surveys were conducted at the selected barangays in Cagayan River Basin. Eighty-four (84) locations (Figure 2) and households (Figure 3) were surveyed for the highest actual flood depth and flood duration. The data was used to determine the threshold value of flood extent using GEE. Figure 4 shows some pictures taken during the post-flood field survey.

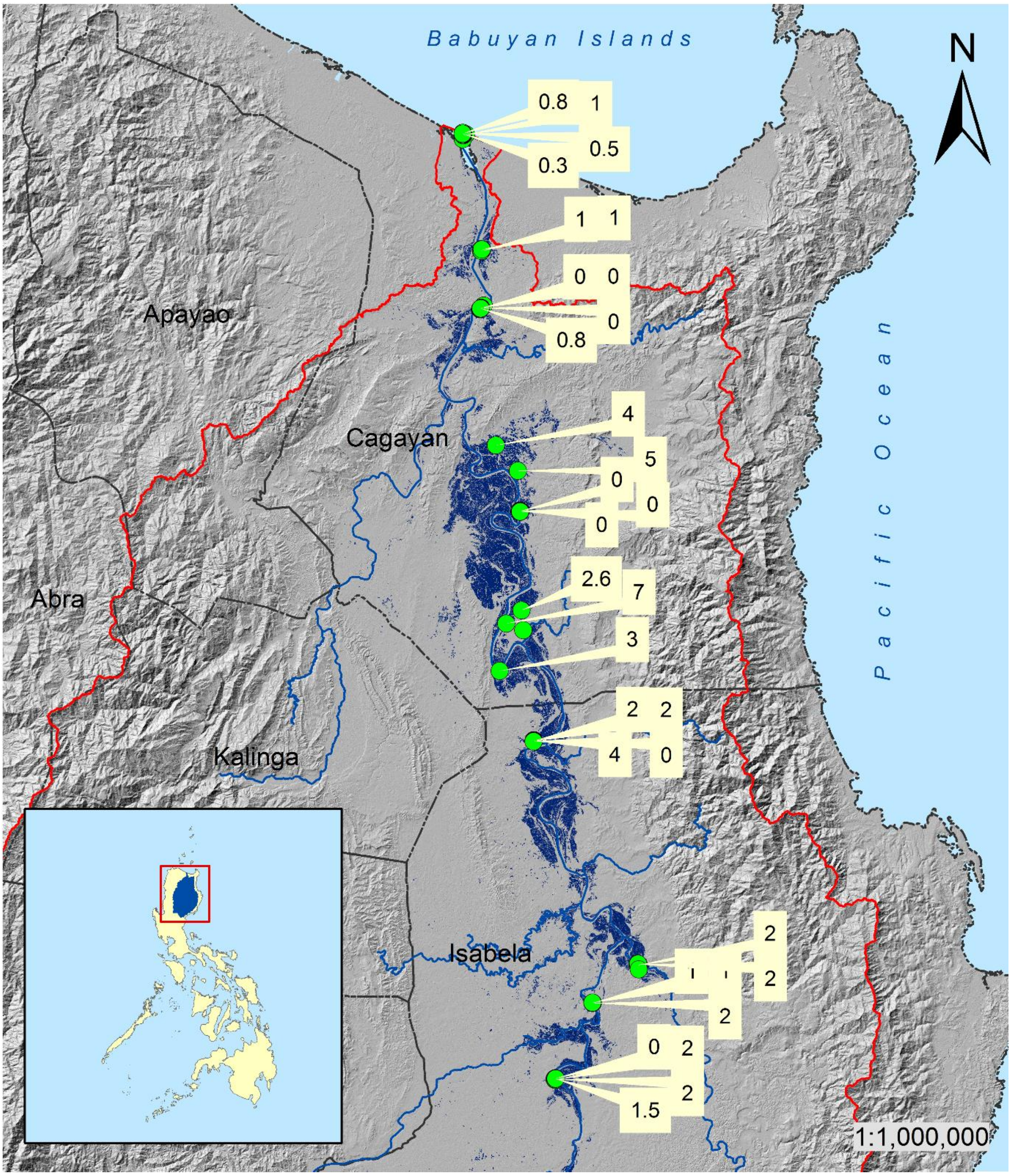

Fig. 2 Locations of households (green dots) interviewed during the post-flood survey of typhoon Ulysses showing the flood depths. Those with a zero value indicate that no flooding happened in that specific location.

Fig. 3 Ground photographs of sites where households were asked information such as flood duration and flood height to indicate water levels during flooding.

2.2 Flood inundation using GEE and damage assessment

Detailed workflow of flood extent derivation using GEE is shown in Figure 4. The workflow was based on the recommended practice developed by UN-SPIDER (2019). Flood inundation was derived using a change detection approach on Sentinal-1 (SAR) data. The Sentinel 1AVH polarization images were retrieved during the pre-flood period (October 20, 2021) and during the flood period (November 13-16, 2020). The various pre-processing techniques including radiometric calibration, removal of noise, and orthorectification were performed. The threshold of 1.10 was applied to deduce the flood hazard in the lower basin. The Global Surface Water dataset (2018, 30m resolution) was used to mask areas covered by water for more than 10 months.

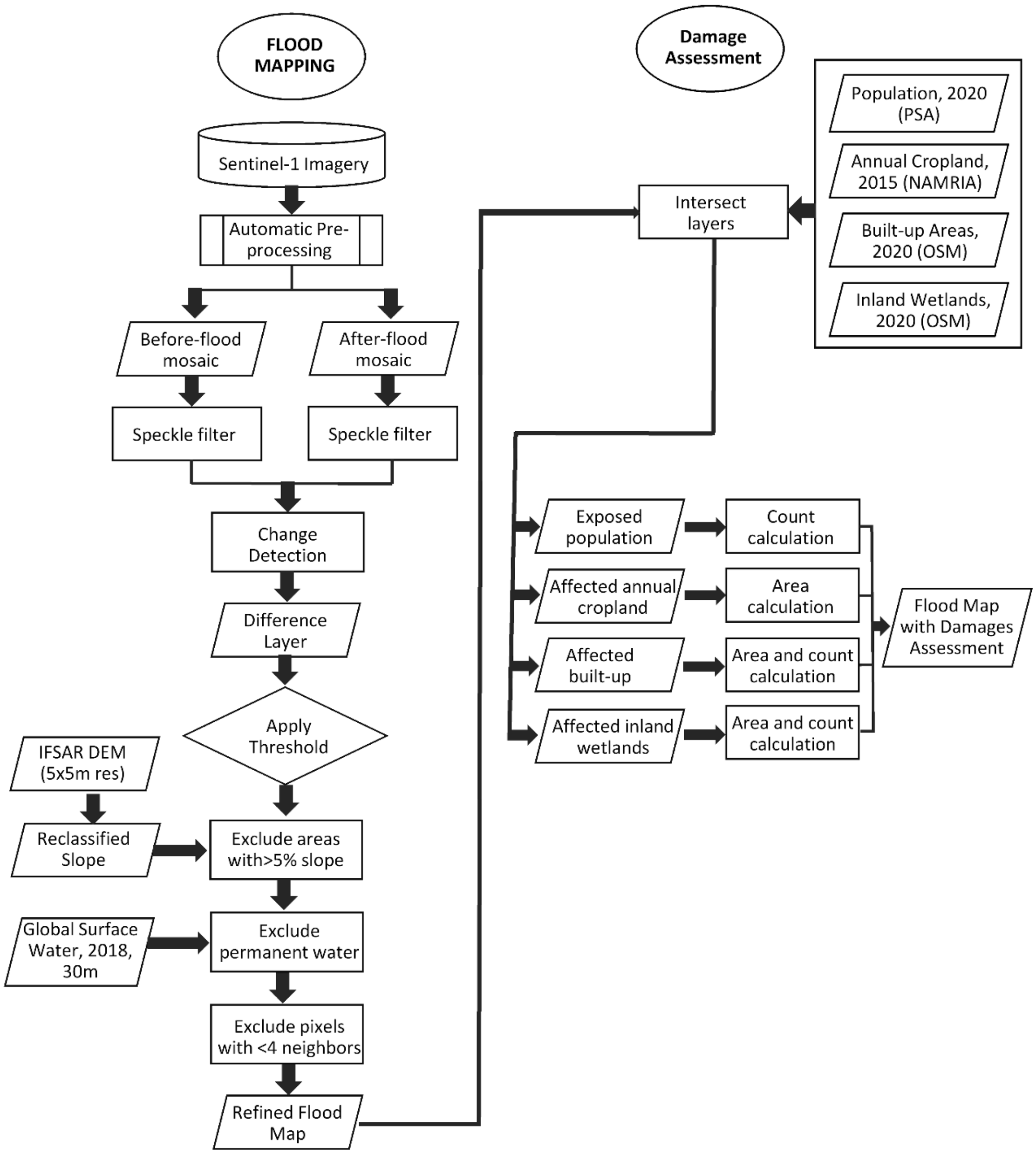

Fig. 4 Workflow of flood inundation using GEE and damage assessment in ArcGIS. The high-resolution datasets like DTM for slope and land cover maps were the two main inputs altered from the default dataset used by GEE.

In this study, IFSAR DTM of 5-m resolution was used to derive slope instead of World Wildlife Fund WWF HydroSHEDS hydrologically conditioned DTM which is based on Shuttle Radar Topography Mission (SRTM) and has a spatial resolution of 3 arc-seconds. To estimate the damage that occurred due to flood, elements discussed earlier like population, built-up, croplands, and inland wetland were intersected. The area and/or count of each inundated land cover was calculated and tabulated. This was done for all barangays affected. It should be noted that the damages were evaluated in a river basin context.

2.3 Quick post-flood participatory approach

Department of Public Works and Highways Region 2 in collaboration with Hdronet Consultancy, Inc. and barangay officials, mapped flood extents where they were instructed to assign appropriate colors to each region of their barangay-based on Typhoon Ulysses' results. Important areas wherein floodwater originates (Cagayan River, Pinacanuan River, and open drainage system) were explained to the participants for easier mapping. When they finished assigning colors and identifying important facilities and routes in their respective barangays, they were then tasked to list the priority areas which are usually flooded. Figure 5 shows the barangay personnel identifying the extent and time concentration of flood during typhoon Ulysses.

Fig. 5 Representatives from barangays (a), (b), (c) identify the subsidence and duration time in their area, and a sample color-coded flood depth map (d)
Source: Department of Public Works and Highways (2021) Consulting Services for the Drainage Master Plan of Tuguegarao City

The consulting agency carefully digitized the output maps in Google Earth producing laid-out maps in JPEG format, which were then georeferenced by our group for flood extent validation using GEE. Figure 6 shows the georeferenced photos and sampling points for validation of flood extent using GEE.

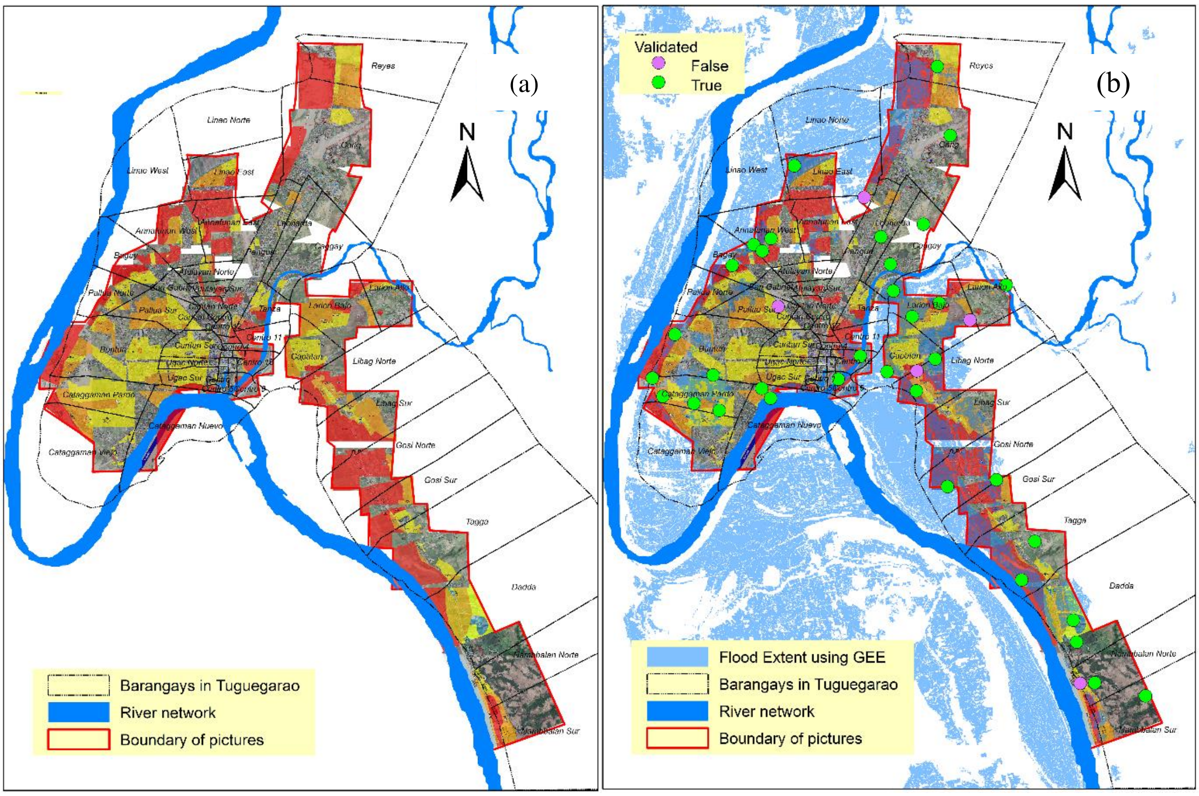

Fig. 6 Tuguegarao City featuring the (a) georeferenced flood maps and (b) sampling points (circle dots) for validation of flood extent (light blue) using GEE.

3 Results and Discussion

The flood was caused by continuous and excessive rainfall in November from 1 to 13, 2020. The pre and post-flood datasets were determined based on rainfall data. As a result, an inundation map (Figure 7) dented by blue overlaid on the administrative boundaries of the region and the affected land cover map (Figure 8) were created with a total area of 620.88 km^2. The flood was most densely distributed along the low-lying stretch of the Cagayan River.

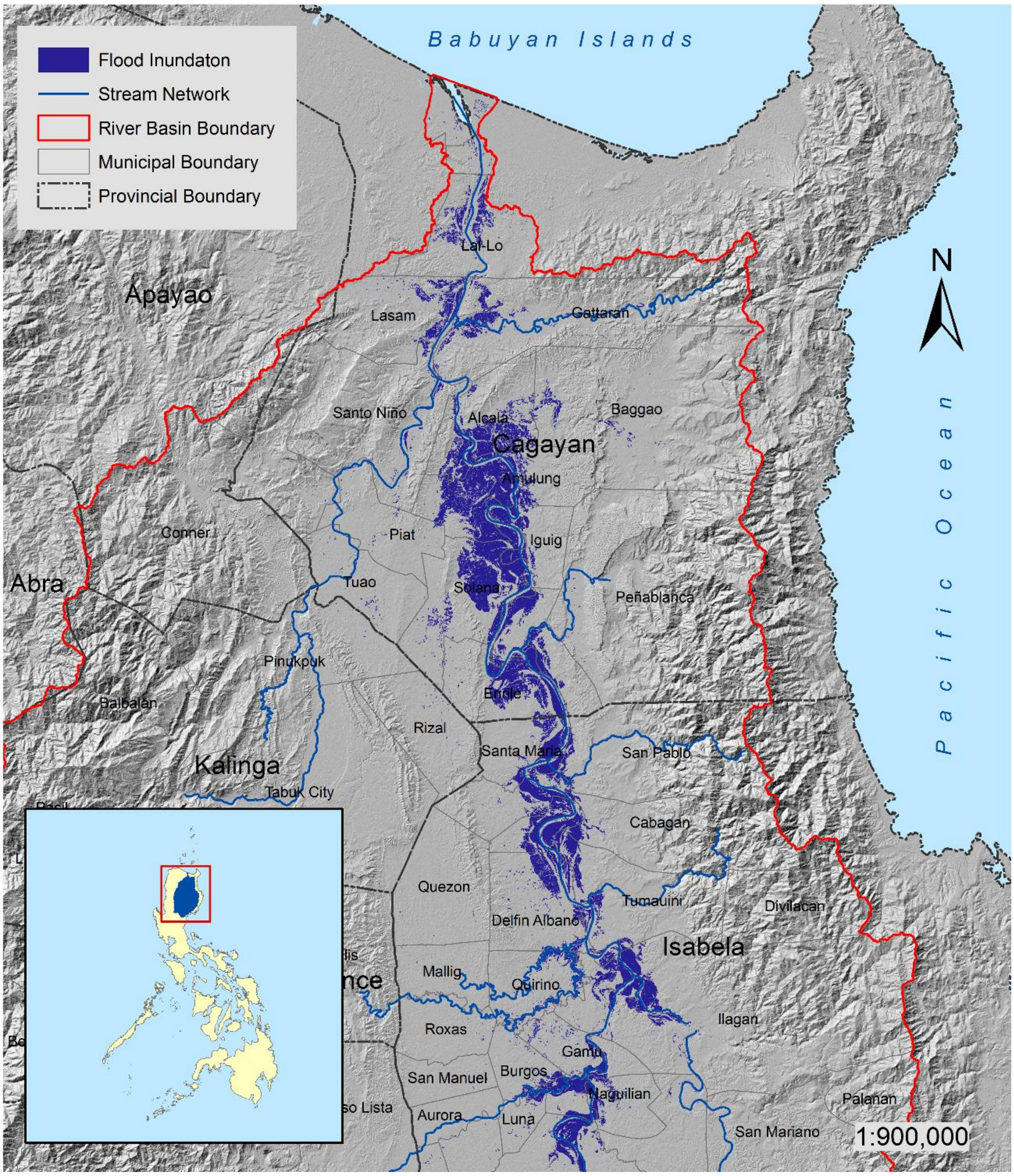

Fig. 7 Final flood inundation map of typhoon Ulysses using GEE showing the terrain and provinces affected

125

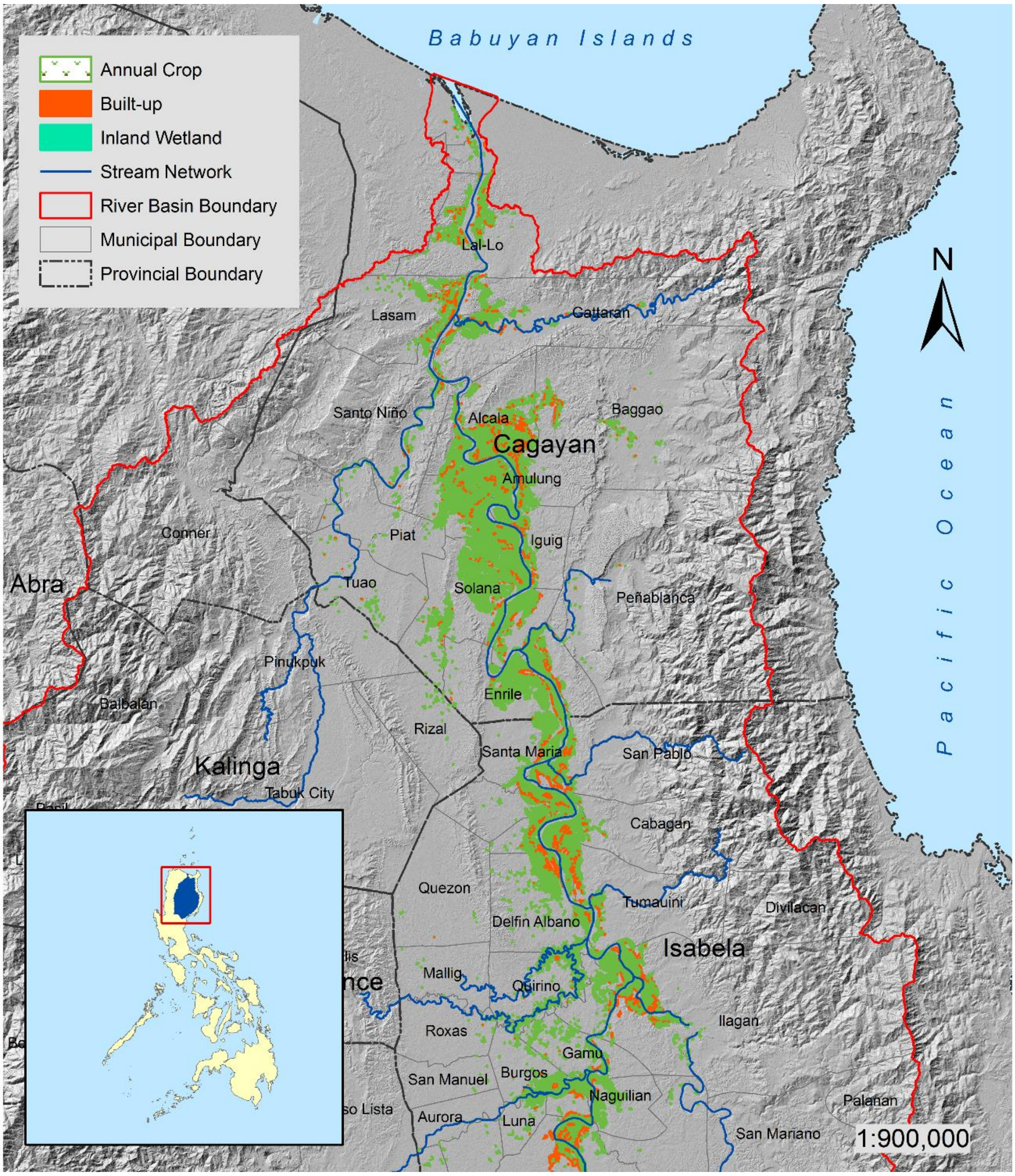

Fig. 8 Affected land cover in Cagayan River Basin during the flood due to Typhoon Ulysses

To estimate flooded area and damages per province, the final flood inundation (slope and GSW deducted) was used. As shown in Table 2, two provinces in the region were greatly affected by a series of typhoons in November 2020. Cagayan was the most affected (347.128%) with about 11.98% of its area flooded, followed by Isabela (273.162; 3.10%). On the other hand, Kalinga (0.545 km^2), Ifugao (0.043 km^2), and Apayao (0.0002 km^2) had minimal damage of less than a square kilometer flooded area due to their safer site and situation. The use of satellite-based flood inundation analysis like GEE will aid in the identification of the worst-affected districts in terms of submerged areas. Of the land classes listed, annual cropland was the most affected (98.90% of the total inundation), followed by built-up (1%) which affected a large population (~ 225,634). Therefore, it is critical to focus on lowering damage in annual croplands.

Table 2 Area and percentage distribution of inundation per province and affected land cover in Cagayan River Basin after intersecting inundation map using GEE

Province	Provincial Area (km^2)	Flooded Area (km^2)	% Area wrt province	% Area of inundation	Annual Crop (km^2)	Built-up		Inland Wetland (km^2)	Population Affected	% Affected Population
						Count	Area (km^2)			
Cagayan	2,897.67	347.128	11.9795%	55.9091%	344.36	4,355	2.19	0.55	113,636	50.36%
Isabela	8,813.95	273.162	3.0992%	43.9961%	269.10	2,981	4.03	0.03	111,959	49.62%
Kalinga	10,276.73	0.545	0.0053%	0.0879%	0.55	36			37	0.02%
Ifugao	2,503.45	0.043	0.0017%	0.0070%	0.04	4			3	0.00%
Apayao	3,913.88	0.0002	0.0000%	0.0000%	0.00	2			1	0.00%
TOTAL	28,405.68	620.879	2.1858%	100.0000%	614.05	7,378	6.22	0.58	225,634	100.00%

Two provinces are most affected: Cagayan (Table 3) and Isabela (Table 4). In Cagayan, Amulung has the largest total area affected in Cagayan Province and has the most population affected by the flood. Tuguegarao, the capital city is the 5th most affected with a total area of 24.91 km^2 flooded and 29,041 estimated affected population. There are 18 out of 28 municipalities affected in Cagayan Province.

Table 3 Summary of flooded areas and damages per municipality in Cagayan

Province	Annual Crop (km^2)	Built-up		Inland Wetland (km^2)	Population	Total (km^2)
		Count	Area (km^2)			
Amulung	81.40	702	0.29	0.00	17,101	81.70
Solana	71.32	745	0.11		3	71.44
Alcala	44.84	755	0.79	0.43	10,505	46.07
Enrile	38.19	401	0.07		10,248	38.26
Tuguegarao City	24.75	366	0.15		29,041	24.91
Gattaran	17.97	266	0.19	0.00	3,725	18.16
Iguig	17.97	131	0.15		5,285	18.11
Lasam	17.12	230	0.18		3,763	17.30
Lal-Lo	16.30	236	0.09	0.04	3,271	16.43
Baggao	6.18	153	0.06		2,337	6.24
Santo Niño	4.64	114	0.04		1,126	4.68
Piat	1.13	47	0.00		42	1.13
Tuao	1.08	85	0.01		448	1.09
Camalaniugan	0.59	36	0.02		190	0.61
Aparri	0.57	47	0.01	0.08	619	0.66
Peñablanca	0.28	32	0.01		114	0.29
Rizal	0.03	4			3	0.03
Allacapan	0.02	5			3	0.02
Cagayan	344.36	4355	2.19	0.55	111,959	347.13

Table 4 Summary of flooded area and damages per municipality in Isabela

Province	Annual Crop (km^2)	Built-up		Inland Wetland (km^2)	Population	Total (km^2)
		Count	Area (km^2)			
Ilagan	44.48	590	0.77	0.02	20,734	45.27
Santo Tomas	26.94	124	0.20		10,666	27.14
Delfin Albano	26.21	243	0.53		5,738	26.73
Santa Maria	24.50	166	0.12		8,724	24.62
Tumauini	23.78	189	0.58		10,963	24.36
Cabagan	23.31	146	0.25		14,655	23.56
Cauayan City	21.66	215	1.04		11,126	22.70
Reina Mercedes	14.70	61	0.23		7,452	14.93
Quirino	12.18	208	0.02		2,020	12.20
Gamu	10.23	142	0.05		3,968	10.27
Naguilian	9.14	72	0.03		4,372	9.16
Angadanan	6.28	134	0.02		1,984	6.31
Burgos	5.42	85	0.00		1,819	5.42
San Pablo	4.84	44	0.12		3,355	4.96

Luna	4.57	40	0.00		1,128	4.58
Alicia	4.01	185	0.04		986	4.05
San Isidro	2.40	110	0.00		1,169	2.41
Santiago City	1.42	60	0.01		1,405	1.44
Echague	0.78	34	0.01		766	0.79
Benito Soliven	0.45	14			49	0.45
Roxas	0.39	29	0.00		79	0.39
San Mateo	0.31	24	0.00		130	0.31
Cabatuan	0.23	12			155	0.23
Ramon	0.20	14	0.00	0.01	36	0.21
Quezon	0.19	8	0.00		17	0.19
San Manuel	0.16	6			47	0.16
Mallig	0.15	13			45	0.15
Aurora	0.10	8			28	0.10
Cordon	0.07	5	0.00		17	0.07
Isabela	269.10	2,981	4.03	0.03	113,633	273.16

Isabela province, on the other hand, has a total flooded area of 269.1 km^2 and more than 100 thousand people affected. Ilagan as the capital city is the most affected with an area of 43.27 km^2 and a 20,734 estimated population affected. There are 30 of 34 municipalities of Isabela affected by the flood.

Tuguegarao City and Ilagan City, two of the most populated riverine towns in the region are located approximately 50-600 m away from the Cagayan River. Cagayan River Basin (CRB) is the largest river basin in the Philippines but is densely populated along the flood-hit areas resulting in a high number of casualties.

The spatial variation in the extent of floods can be attributed to many factors such as the precipitation, land cover types, and topographic conditions. Since Cagayan province is surrounded by the Sierra Madre mountain range to the east while the western boundaries are generally hilly and the central area is dominated by a wide valley, the province forms the lower basin of the Cagayan River therefore receiving a higher volume of floodwater. In the Philippines, from June to October, the southwest monsoon brings heavy rainfall. This heavy rainfall extends up to the early part of November. The successive days of rain exacerbated by typhoons led to flooding.

Validation of flood extent using the data from the survey reveals 95% accuracy. In many studies, Sentinel 1 (SAR) was demonstrated suitable for mapping flood areas due to its ability to penetrate cloud forms among others. This result are in line and supports the findings of previously conducted researches (Uddin et al. 2019; Moharrami et al. 2021). Uddin et al., (2019) concluded that GEE algorithm performs well with an optimum accuracy of 96.44%. Moharrami et al. (2021) monitored flood events using multi-temporal Sentinel 1 images. The accuracy ranges from 92.8%-96.2% with an overall accuracy higher than 90%.

Sentinel 1 perfectly separates the distinction of submerged areas to non-flooded areas allowing an accurate flood mapping possible. GEE that uses Sentinel 1 with medium-high resolution can therefore be used for rapid mapping of events with high accuracy.

The assurance of high accuracy and more specific information embedded in local data is the primary benefit. The damage estimates provide useful information, not only in the form of numerical statistics but also in multi-boundary maps that can assist the decision-makers in visualizing areas that need the most help. This advantage of utilizing more detailed geospatial data and readily available for processing makes it appropriate for a rapid source of information.

4 Conclusion and Recommendation

This study has developed a methodology to determine the extent of damages not only in the area but also in number by integrating high-resolution datasets that are readily available in the Philippines. The use of these data instead of the default materials used by GEE may be utilized by local flood mappers without difficulty. The flood inundation and damage maps created using ArcGIS provide improved visualization of disaster severity across communities.

The concurrent flood study imposes adopting an integrated approach with an emphasis on disaster risk mitigation, preparedness, and streamlining of the relief distribution system, with an emphasis on self-reliance on Local

Government Units and Non-Governmental Organizations. Future work will be aimed to use the workflow applied in assessing flood damages for other typhoon events in the Philippines. A set of technical and institutional recommendations are to be firmed up in consultation with the Cagayan River Basin Management Council and the Cagayan Valley Regional Disaster Management Council. Through this study, the framework, approach, and methodology can be replicated across a range of geographical case studies arising due to floods. Further validations and comparisons against future similar studies are encouraged. The framework is also recommended to be applied in diverse catastrophic scenarios, i.e. storm surges, tsunamis, and flash floods. The framework could assist local authorities in estimating disaster impacted land features in a practical means.

Acknowledgment: The authors would like to express their appreciation for the support of the Department of Science and Technology-Philippines Council and the Industry, Energy, and Emerging Technology Research and Development (DOST-PCIEERD), the project Integrated Flood and Water Resources Management (IFWaRM) in the ASEAN Basins for Sustainable Development in collaboration with Thuy Loi University of Vietnam and Kyoto University of Japan.

References

Department of Public Works and Highways (2020) Consulting Services for the Drainage Master Plan of Tuguegarao City. Progress Report.

Elkhrachy I, Pham Q, Costache RD, Mohajane M, Rahman K, Shahabi H, Linh N, Tran Anh D (2021) Sentinel-1 remote sensing data and Hydrologic Engineering Centres River Analysis System two-dimensional integration for flash flood detection and modelling in New Cairo City, Egypt. *Journal of Flood Risk Management*. https://doi.org/10.1111/jfr3.12692

Ezzine A, Saidi S, Hermassi T, Kammessi I, Darragi F, Rajhi H (2020) Flood mapping using hydraulic modeling and Sentinel-1 image: Case study of Medjerda Basin, northern Tunisia. *The Egyptian Journal of Remote Sensing and Space Science*. Volume 23, Issue 3, 2020. pp 303-310. ISSN 1110-9823. https://doi.org/10.1016/j.ejrs.2020.03.001

Ghaffarian S. Farhadabad AR, Kerle N (2020) Post-disaster recovery monitoring with google earth engine. *Applied Sciences 10* (13): 4574. 1-4. https://doi.org/10.3390/app10134574

Jha S, Martinez A Jr, Quising P, Ardaniel Z, Wang, L (2018) Natural Disasters, Public Spending, and Creative Destruction: A Case Study of the Philippines. *SSRN Electronic Journal.* https://doi.org/10.2139/ssrn.3204166

Jokar M, Bernal AL, Kamkar B (2022) The effect of spring flooding on management and distribution of cotton bollworm (Helicoverpa armigera) by flood mapping using SAR sentinel-1 and optical imagery landsat-8; a case study in golestan province, Iran. *International Journal of Pest Management*. https://doi.org/10.1080/09670874.2022.2039798

Jung Y, Kim D, Kim D, Kim, M, Lee S (2014) Simplified flood inundation mapping based on flood elevation-discharge rating curves using satellite images in gauged watersheds. *Water 6*(5), 1280-1299. https://doi.org/10.3390/w6051280

Lal P, Prakash A, Kumar A (2020) Google Earth Engine for concurrent flood monitoring in the lower basin of Indo-Gangetic-Brahmaputra plains. *Nat Hazards* 104, 1947–1952. https://doi.org/10.1007/s11069-020-04233-z

Lin L, Di L, Tang J, Yu E, Zhang C, Rahman, M., Shrestha, R., Kang, L (2019) Improvement and Validation of NASA/MODIS NRT Global Flood Mapping. *Remote Sens* 11(2), 205. https://doi.org/10.3390/rs11020205

Manfre L, Hirata E, Silva JB, Shinohara E, Giannotti M, Larocca A, Quintanilha J (2012) An analysis of geospatial technologies for risk and natural disaster management. *ISPRS Int. J. Gro-Inf* 312, 1(2), 166-185. https://doi.org/10.3390/ijgi1020166

Meyer V, Haase D, Scheuer S (2009) GIS-based multicriteria analysis as decision support in flood risk management. *Helmholtz Centre for Environmental Research* (UFZ) Discussion Paper No. 6/2007. Corpus IF: 128321410. p.4 http://hdl.handle.net/10419/45237

Mimich K, Brahim B, Gajbhiye S, Khedher K, Boudad L, Dridri A, Drisss S, Frison PL (2021) Flood Mapping Using Multi-temporal Sentinel-1 SAR Images: A Case Study—Inaouene Watershed from Northeast of Morocco. *Iranian Journal of Science and Technology, Transactions of Civil Engineering*. https://doi.org/10.1007/s40996-021-00683-y

Moharrami M, Javanbakht M, Attarchi S (2021). Automatic flood detection using sentinel-1 images on the google earth engine. *Environmental Monitoring and Assessment*. 193(5):248. https://10.1007/s10661-021-09037-7

National Research Council (2015) Tying Flood Insurance to Flood Risk for Low-Lying Structures in the Floodplain. Chapter 3: Methods for assessing flood risk. National Academies Press. ISBN: 978-0-309-37166-7. https://www.nap.edu/read/21720/chapter/5. Accessed 6 February 2022.

Puno G, Amper, RA (2016) Flood Modeling of Musimusi River in Balingasag, Misamis Oriental. *CMUJS* Vol. 20, No.3.150-165

Rahman, MS, Di L (2017) The state of the art of spaceborne remote sensing in flood management. Nat. Hazards. 85, 1223–1248.

Rodriguez M, Ong R, Baluyut R, Aying JA, Epino E (2017) Lidar-based flood hazard and exposure mapping of a critical river system in the Zamboanga Peninsula, Mindanao, Philippines. *Asian Conference on Remote Sensing 2017*. New Delhi, India

Shrestha B, Okazumi T, Miyamoto M, Nabesaka S, Tanaka S, Sugiura A (2014) Fundamental Analysis for Flood Risk Management in the Selected River Basins of Southeast Asia. *Journal of Disaster Research. 9*. 858-869. 10.20965/jdr.2014.p0858. 1-2 https://www.fujipress.jp/jdr/dr/dsstr000900050858/

UN-SPIDER (2019) Step-by-Step: Recommended Practice: Flood Mapping and Damage Assessment Using Sentinel-1 SAR Data in Google Earth Engine. Advisory Support, Recommended Practices, Retrieved September 25, 2021, from https://www.un-spider.org/advisorysupport/recommended-practices/recommended-practice-google-earth-engine-flood-mapping/step-by-step

Uddin K, Matin M, Meyer F (2019) Operational Flood Mapping Using Multi-Temporal Sentinel-1 SAR Images: A Case Study from Bangladesh. *Remote Sensing*. 2019, 11(13):1581. https://doi.org/10.3390/rs11131581

Statements and Declarations

Funding

This work was funded by the Department of Science and Technology (DOST) with the support of DOST-Philippines Council and the Industry, Energy, and Emerging Technology Research and Development (DOST-PCIEERD).

Author information

Authors and Affiliations

Water Research and Development Center, Isabela State University, Isabela, Philippines

Christine Mata

College of Engineering, Isabela State University, Isabela, Philippines

Orlando Balderama, Lanie Alejo, & Jeoffrey Lloyd Bareng

Water Resources Research Center – Disaster Prevention Research Institute Kyoto University, Kyoto, Japan

Sameh Ahmed Kantoush

Corresponding Author

Correspondence to Christine Mata

Contributions

All authors contributed to the study, conception, and design. OB, LA, and JL B helped in conceptualization and data collection; LA and SA K contributed to software, reviewing and editing; CM helped in conceptualization, writing and analysis.

Conflicts of Interest

The authors have no relevant financial or non-financial interests to disclose.