*Review Article*

FLOOD MAPPING IN GOOGLE EARTH ENGINE-A REVIEW

.

ABSTRACT

|  |
| --- |
| This article provides a comprehensive overview of flood mapping using Google Earth Engine (GEE), emphasizing its significance in disaster management and mitigation. Flood mapping is crucial for understanding risks and preparing for flood events, which are becoming more frequent and severe due to climate change. GEE's advanced capabilities in processing and analyzing vast datasets of satellite imagery offer a potent tool for rapid and accurate flood mapping. Studies reviewed demonstrate GEE's application in various contexts, highlighting its effectiveness in generating timely and precise flood maps using methodologies like image processing techniques, machine learning algorithms, and hydrological modeling. Challenges such as technical complexity and data availability are noted, alongside the potential for future advancements integrating AI and big data analytics to enhance flood risk management strategies. The paper underscores GEE's role in advancing flood mapping efforts, contributing to better preparedness and response to flood disasters worldwide. |

*Keywords: Flood Mapping, Google Earth Engine, Disaster Management, Satellite Imagery, Climate Change.*

1. INTRODUCTION

Flood mapping plays a crucial role in disaster management and mitigation efforts, providing vital information for planning, emergency response, and recovery activities. It involves the identification and mapping of areas susceptible to flooding, which helps in understanding flood risks and taking appropriate measures to minimize the impact on lives and property. The importance of flood mapping cannot be overstated, especially in the context of climate change, which is expected to increase the frequency and severity of flood events globally. Google Earth Engine (GEE) has emerged as a powerful platform for geospatial analysis and remote sensing, offering unparalleled capabilities in processing and analyzing large datasets. GEE facilitates the rapid assessment of flood extents, dynamics, and vulnerabilities by leveraging cloud computing and a vast repository of satellite imagery. Its application in flood mapping has been demonstrated in various studies, highlighting its effectiveness in generating accurate and timely flood maps. For instance, [Tellman et al. (2015)](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx) focused on dynamic flood vulnerability mapping using GEE, emphasizing the platform's potential for disaster preparedness and response. Similarly, [Nghia et al. (2022)](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx) applied GEE for flood mapping and monitoring in the Mekong River's downstream provinces using Sentinel-1 synthetic aperture radar (SAR) data, illustrating GEE's utility in assessing and addressing changes in flood patterns [(Nghia et al. 2022).](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx) The advantages of using GEE for mapping river dynamics were also discussed by [Wegman and Huthoff (2019](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx)), who noted its access to extensive satellite data, enabling the creation of detailed, up-to-date maps of river systems on a global scale. Further, the utilization of Sentinel-1 and Landsat data on GEE for rapid and robust monitoring of flood events was explored by [DeVries et al. (2020),](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx) showcasing the platform's capability for quick and reliable flood mapping [(DeVries et al. 2020).](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx) [Bioresita et al. (2022)](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx) conducted flood mapping in Kalimantan Selatan using Sentinel-1 imagery and GEE, achieving a high overall accuracy of 97% in identifying flood extents, which underscores GEE's precision and effectiveness in flood mapping efforts [(Bioresita et al.2022).](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx)The objectives of this review paper are to synthesize existing studies on flood mapping using Google Earth Engine, evaluate the methodologies employed, assess the accuracy and efficiency of GEE in flood mapping, and identify challenges and opportunities for improvement. By examining previous works and their outcomes, this paper aims to highlight the significance of utilizing GEE in flood mapping endeavors, contributing to enhanced disaster management and mitigation strategies.

**2. METHODOLOGIES AND DATA SOURCES**

The methodologies employed for flood mapping in Google Earth Engine (GEE) leverage its cloud-based platform to process and analyze vast datasets from various sources. These methodologies can be broadly categorized into image processing techniques, machine learning algorithms, and hydrological modeling, each utilizing different types of data sources such as satellite imagery, elevation data, and meteorological data.

**2.1 Image Processing Techniques:**

Image processing techniques involve the manipulation and analysis of satellite imagery to identify flood-affected areas. One common approach is the use of synthetic aperture radar (SAR) data from satellites like Sentinel-1, which can penetrate cloud cover and provide reliable flood extent information regardless of weather conditions. [Nghia et al. (2022)](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx) used Sentinel-1 SAR data in their study for flood mapping and monitoring in the Mekong River's downstream provinces, highlighting the capability of GEE to assess floods efficiently [(Nghia et al. 2022).](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx) Change detection methods, comparing pre- and post-flood conditions, are also widely used. [Bioresita et al. (2022)](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx) demonstrated this by using Sentinel-1 imagery in GEE for flood mapping in Kalimantan Selatan, employing change detection and threshold methods to achieve high accuracy [(Bioresita et al. 2022).](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx)Machine Learning Algorithms: Machine learning algorithms offer powerful tools for classifying flood-prone areas and predicting flood extents. Deep learning approaches, for example, have been used for mapping surface water using Sentinel-1 data on GEE, as explored by [Mayer et al. (2021),](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx) who leveraged Google's AI platform integrated with GEE for their study [(Mayer et al. 2021).](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx) These algorithms can analyze complex patterns in satellite imagery to identify flooded regions with high accuracy.

Hydrological Modeling: Hydrological models simulate water movement across landscapes to predict flood occurrences. These models can be integrated into GEE for flood forecasting and risk assessment. Such models often require elevation data like the Shuttle Radar Topography Mission (SRTM) data and meteorological data to simulate hydrological processes accurately. [Singh and Kansal (2019)](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx) utilized GEE and statistical thresholding for flood mapping in Bihar, India, demonstrating the platform's effectiveness in combining various datasets for comprehensive flood analysis [(Singh and Kansal et al 2019).](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx)

**2.2 Data Sources**

Flood mapping in Google Earth Engine (GEE) relies on a variety of primary data sources. Satellite Imagery, including Sentinel-1 SAR, Sentinel-2, and Landsat imagery, plays a crucial role in detecting flooded areas and assessing flood impacts. Elevation Data, such as SRTM datasets, are essential for modelling hydrology and determining floodplain topography. Additionally, Meteorological Data, encompassing precipitation and weather data, contribute significantly to understanding and modelling flood events. Advantages and Limitations: The utilization of GEE for flood mapping offers several advantages over traditional methods. Firstly, its Scalability allows for the processing of large datasets rapidly and efficiently due to its cloud-based platform. Secondly, Accessibility is a key benefit, as GEE provides access to a wide range of satellite data and analytical tools at no cost. Furthermore, Real-time Analysis capabilities enable near real-time flood monitoring and assessment, which is crucial for effective emergency response [(Bioresita et al, 2022 & Nghia et al. 2022)](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx).

However, there are also limitations associated with using GEE for flood mapping. Firstly, Technical Complexity is a significant challenge, as it requires expertise in advanced image processing and machine learning techniques. Secondly, Data Availability may be limited in some regions, with gaps or insufficient resolution in the available satellite imagery and data. Lastly, Computational Constraints, despite the cloud-based nature of GEE, may pose challenges for large-scale analyses. (Mayer et al, 2021)In conclusion, numerous studies, including those by [Nghia et al. (2022), Bioresita et al. (2022), and Mayer et al. (2021),](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx) have demonstrated the robustness and flexibility of methodologies and data sources utilized in flood mapping with GEE. Despite its limitations, GEE's advantages in handling complex geospatial analyses make it an invaluable tool in flood management and disaster response strategies.

**3. CASE STUDIES AND APPLICATIONS**

The application of Google Earth Engine (GEE) in flood mapping across different regions demonstrates its versatility and robustness, as evidenced by several case studies. For instance, [Nghia et al. (2022)](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx) showcased GEE's capability in assessing and adapting to changing flood patterns in the Mekong River's downstream provinces using Sentinel-1 SAR data, highlighting the importance of reliable datasets for accurate flood mapping despite cloud cover [(Nghia et al.).](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx) Similarly, in Kalimantan Selatan, Indonesia, [Bioresita et al. (2022)](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx) achieved a remarkable 97% accuracy in flood mapping by utilizing Sentinel-1 imagery and combining change detection with threshold methods, demonstrating GEE's computational prowess in processing large datasets efficiently [(Bioresita et al., 2022).](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx) Furthermore, the integration of GEE with statistical thresholding for flood mapping in Bihar, India, by [Singh and Kansal (2019)](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx) capitalized on the extensive satellite imagery and elevation data within GEE, underscoring the platform's utility in facilitating complex hydrological analyses. Additionally, real-time flood mapping in the Ganga Sub Basin by [Dwivedi et al. (2021)](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx) leveraged time-series data from Sentinel-1, showcasing GEE's capability for accurate and timely identification of inundated areas crucial for emergency response planning [(Dwivedi et al. 2021).](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx) These case studies illustrate not only the technical challenges, such as data availability, accuracy assessment, and computational requirements, but also the opportunities GEE presents for advancing flood risk management and disaster response strategies across diverse geographical settings.

**Table 1- Previous studies**

| **Study Title** | **Authors** | **Year** | **Key Findings** | **Reference** |
| --- | --- | --- | --- | --- |
| Mapping of Flood Areas Using Landsat with Google Earth Engine Cloud Platform | H. Mehmood, C. Conway, D. Perera | 2021 | Utilized Landsat 5, 7, 8 to map flood areas with 71-90% accuracy using MNDWI on GEE. | [Mehmood et al., 2021](https://consensus.app/papers/mapping-flood-areas-using-landsat-google-earth-engine-mehmood/3f92bc754f6e505db62ff9f2fc00422c/?utm_source=chatgpt) |
| GEE4FLOOD: Rapid Mapping of Flood Areas Using Temporal Sentinel-1 SAR Images with Google Earth Engine | V. S. K. Vanama, D. Mandal, Y. S. Rao | 2020 | Proposed GEE4FLOOD for rapid flood mapping, achieving 82% overall accuracy in Kerala 2018 flood. | [Vanama et al., 2020](https://consensus.app/papers/gee4flood-mapping-flood-areas-using-sentinel1-images-vanama/0a38f3e2d9295510b7f68053bad2aecf/?utm_source=chatgpt) |
| Flood Inundation Mapping- Kerala 2018; Harnessing the Power of SAR, Automatic Threshold Detection Method and Google Earth Engine | V. Tiwari, Vinay Kumar, M. Matin, A. Thapa, W. L. Ellenburg, Nishikant Gupta, S. Thapa | 2020 | Achieved 94.3% accuracy for flood maps using Sentinel-1 SAR data and Otsu algorithm on GEE. | [Tiwari et al., 2020](https://consensus.app/papers/flood-inundation-mapping-kerala-2018-harnessing-power-tiwari/48f2e57f98715cfbb2abd11ac1daac3e/?utm_source=chatgpt) |
| Flood Prevention and Emergency Response System Powered by Google Earth Engine | Cheng-Chien Liu, M. Shieh, M. Ke, Kung-Hwa Wang | 2018 | Describes FPERS for flood stages application, integrating remote sensing imageries and UAV photographs. | [Liu et al., 2018](https://consensus.app/papers/flood-prevention-emergency-response-system-powered-liu/9f83c2cbf4bd5c3ab04eeb7c210211e6/?utm_source=chatgpt) |
| Automatic Boosted Flood Mapping from Satellite Data | B. Coltin, S. McMichael, Trey Smith, T. Fong | 2016 | Introduced Adaboost algorithm for automatic flood mapping from MODIS imagery. | [Coltin et al., 2016](https://consensus.app/papers/automatic-boosted-flood-mapping-satellite-data-coltin/ac792581184059f487a02a7876f4f3d0/?utm_source=chatgpt) |
| Rapid and Large-Scale Mapping of Flood Inundation via Integrating Spaceborne Synthetic Aperture Radar Imagery with Unsupervised Deep Learning | Xin Jiang, Shijing Liang, Xinyue He, A. Ziegler, P. Lin, M. Pan, Dashan Wang, Junyu Zou, D. Hao, Ganquan Mao, Yelu Zeng, J. Yin, Lian Feng, C. Miao, E. Wood, Zhenzhong Zeng | 2021 | Proposed Felz-CNN, an unsupervised ML approach, for flood mapping with 93-94% accuracy. | [Jiang et al., 2021](https://consensus.app/papers/mapping-flood-inundation-integrating-aperture-radar-jiang/5f1a02723c3e5ff39cb51311177e5a40/?utm_source=chatgpt) |
| Flood Risk Mapping by Remote Sensing Data and Random Forest Technique | H. Farhadi, M. Najafzadeh | 2021 | Utilized GEE for flood risk indices analysis in Northern Iran, employing Random Forest for flood hazard mapping. | [Farhadi et al., 2021](https://consensus.app/papers/flood-risk-mapping-remote-sensing-data-random-forest-farhadi/81849281e3665587bb726c26689a7c20/?utm_source=chatgpt) |
| Rapid and Robust Monitoring of Flood Events Using Sentinel-1 and Landsat Data on the Google Earth Engine | B. DeVries, Chengquan Huang, J. Armston, Wenli Huang, John W. Jones, M. Lang | 2020 | Demonstrated rapid flood mapping using Sentinel-1 SAR and Landsat data, improving accuracy and speed with GEE. | [DeVries et al., 2020](https://consensus.app/papers/monitoring-flood-events-using-sentinel1-landsat-data-devries/0d77fff8f3115373802a482f36edee5b/?utm_source=chatgpt) |
| Flood Mapping Based on Synthetic Aperture Radar: An Assessment of Established Approaches | L. Landuyt, Alexandra Van Wesemael, G. Schumann, R. Hostache, N. Verhoest, F. V. Van Coillie | 2019 | Assessed established SAR-based flood mapping algorithms, finding tiled thresholding suited for automated detection. | [Landuyt et al., 2019](https://consensus.app/papers/flood-mapping-based-aperture-radar-assessment-landuyt/ac4a44136b0f5e458ee5289ac5a679ba/?utm_source=chatgpt) |
| Automated Mapping of Flood Inundation Areas using Cloud Based Processing Tools of Google Earth Engine for Efficient Disaster Management – A Case Study of Kerala Floods | Srinivasa Raju Kolanuvada, Kishore Kowtham Ilango | 2022 | Developed an automated flood mapping method for the 2018 Kerala floods, achieving 96% accuracy with Sentinel-1 data on GEE. | [Kolanuvada et al., 2022](https://consensus.app/papers/automated-mapping-flood-inundation-areas-using-cloud-kolanuvada/13d42460d9df580f9ab922c1fc655bbf/?utm_source=chatgpt) |

**3.1 EVALUATION AND VALIDATION**

Accuracy assessment and validation are pivotal in flood mapping using Google Earth Engine (GEE), ensuring the reliability and robustness of the generated maps. Existing methodologies for validating flood maps encompass a range of approaches, including ground truth data collection, comparison with other datasets, and statistical analysis. For instance, [DeVries et al. (2020)](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx) showcased rapid and robust monitoring of flood events using Sentinel-1 and Landsat data on GEE, emphasizing the critical role of accuracy assessment in their methodology [(DeVries et al. 2020).](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx) Similarly, [Trinh (2022)](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx) focused on automatic flood detection using Sentinel-1 images in GEE, employing the classification of super pixels and highlighting the necessity of validation through comparison with ground truth data [(Trinh et al, 2022).](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx) Studies like these underline the significance of robust validation techniques, including the use of observed data from hydrological stations, as demonstrated by [Nghia et al. (2022)](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx) in their flood mapping and monitoring study in the Mekong River basin [(Nghia et al. et al 2022).](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx)

Visual inspection and quantitative validation using high-resolution satellite imagery, such as Landsat-8/OLI and Sentinel-2, are common practices, as seen in the evaluation of the Global GEO-LEO Flood Mapping System [(Sanmei Li et al.).](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx) This approach provides a comprehensive understanding of the flood mapping accuracy by comparing the generated maps with aerial photos and existing datasets. Additionally, studies have leveraged statistical analysis to further validate their results, with methodologies employing satellite error sources assessment and comparisons against official maps made by river authorities to highlight the importance of timing and data selection in flood mapping [(Notti et al.; Inman and Lyons).](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx)The reliability and robustness of flood mapping results generated from GEE-based approaches have been validated through diverse methods, achieving high accuracy levels. For example, the overall accuracy of flood mapping in the study by [Bioresita et al. (2022)](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx) in Kalimantan Selatan reached 97%, demonstrating the effectiveness of GEE for accurate flood delineation [(Bioresita et al. 2022).](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx) Similarly, [Demissie et al. (2023)](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx) achieved an overall accuracy of 95% (Kappa = 0.90) in mapping and monitoring flooding in Dar es Salaam using Sentinel-1 imagery and GEE [(Demissie et al.),](file:///C:\Users\ACER\Desktop\Kia%201%20st%20RP\SDI-Paper-template%20(3).docx) showcasing the platform's capability in tropical urban regions. The accuracy assessment and validation of flood maps produced using GEE are crucial steps that ensure the utility and reliability of the maps for real-world applications. Through a combination of ground truth data, comparison with other reliable datasets, and comprehensive statistical analysis, researchers can evaluate the effectiveness of their flood mapping efforts, paving the way for more accurate and actionable flood risk management strategies.

**4. FUTURE DIRECTIONS AND CHALLENGES**

The future of flood mapping with Google Earth Engine (GEE) is on the cusp of transformative advancements, primarily driven by the integration of artificial intelligence (AI), machine learning (ML), and big data analytics. These technologies promise to refine flood mapping techniques, moving from reactive to proactive measures by enabling predictive modeling with higher accuracy. AI and ML, in particular, are set to revolutionize the detection of flood extents through sophisticated image classification and pattern recognition, harnessing the vast datasets available in GEE for deeper insights into flood dynamics. Moreover, the amalgamation of satellite imagery with diverse data sources like social media, IoT sensors, and UAVs could offer a more comprehensive understanding of flood events, enhancing situational awareness and mapping accuracy. However, this integration introduces challenges such as data interoperability and the need for standardized formats to ensure seamless fusion of multisource data.

On the computational front, while GEE's scalability facilitates the handling of large-scale geospatial datasets, optimizing computational resources and developing efficient algorithms remain pivotal to addressing the computational intensity associated with processing and analyzing big data. The algorithmic complexity inherent in deploying AI and ML models also poses a challenge, necessitating research into simplifying these models for broader application and usability. Despite these challenges, the potential for significant advancements in flood mapping is clear. Overcoming obstacles related to data interoperability, computational scalability, and algorithmic complexity will be essential in harnessing the full capabilities of emerging technologies. The path forward will likely require interdisciplinary collaboration and sustained investment in research and development, aimed at developing innovative solutions that can leverage the power of GEE, AI, and big data analytics to enhance global flood risk management strategies.

**5. CONCLUISON**

In conclusion, Google Earth Engine (GEE) has proven to be a significant asset in flood mapping, offering advanced tools for accurate and efficient analysis of flood risks and dynamics. Its ability to process extensive datasets quickly allows for timely responses to flooding events, critical for effective disaster management and mitigation. While challenges such as technical complexity and data availability exist, the future integration of artificial intelligence and big data analytics holds the promise of overcoming these obstacles. By enhancing the precision and predictive capabilities of flood mapping, GEE is poised to play a crucial role in global efforts towards improved preparedness and resilience against flood disasters.

**COMPETING INTERESTS DISCLAIMER:**

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

1. Tellman, b., kuhn, c., max, s.a., & sullivan, j.a. (2015). Dynamic flood vulnerability mapping with google earth engine.

2. Nghia, b., pal, i., chollacoop, n., & mukhopadhyay, a. (2022). Applying google earth engine for flood mapping and monitoring in the downstream provinces of mekong river. Https://doi.org/10.1016/j.pdisas.2022.100235

3. Bioresita, f., ngurawan, m., & hayati, n. (2022). Identifikasi sebaran spasial genangan banjir memanfaatkan citra sentinel-1 dan google earth engine (studi kasus: banjir kalimantan selatan). Https://doi.org/10.12962/j24423998.v17i1.10383

4. Chandra pandey, a., & kaushik, k. (2022). Global flood mapper: a novel google earth engine application for flood mapping and risk assessment. Natural hazards, 1-175

5. Coltin, b., mcmichael, s., smith, t., & fong, t. (2016). Automatic boosted flood mapping from satellite data. International journal of remote sensing, 37, 1015-993.

6. Demissie, b., vanhuysse, s., grippa, t., flasse, c., & wolff, e. (2023). Using sentinel-1 and google earth engine cloud computing for detecting historical flood hazards in tropical urban regions: a case of dar es salaam. Https://doi.org/10.1080/19475705.2023.2202296

7. Devries, b., huang, c., armston, j., huang, w., jones, j. W., & lang, m. (2020). Rapid and robust monitoring of flood events using sentinel-1 and landsat data on the google earth engine. Remote sensing of environment, 111664. Https://doi.org/10.1016/j.rse.2020.111664

8. Farhadi, h., & najafzadeh, m. (2021). Flood risk mapping by remote sensing data and random forest technique. Water.

9. Gorelick, n., hancher, m., dixon, m., ilyushchenko, s., thau, d., & moore, r. (2017). Google earth engine: planetary-scale geospatial analysis for everyone. Remote sensing of environment, 202, 18-273

10. Inman, v., & lyons, m. (2020). Automated inundation mapping over large areas using landsat data and google earth engine. Remote sensing, 12(8), 1348. Https://doi.org/10.3390/rs12081348

11. Institute of catastrophic loss reduction. (2019). Focus on flood mapping in canada. Toronto, canada1

12. Jiang, x., liang, s., he, x., ziegler, a., lin, p., pan, m., wang, d., zou, j., hao, d., mao, g., zeng, y., yin, j., feng, l., miao, c., wood, e., & zeng, z. (2021). Rapid and large-scale mapping of flood inundation via integrating spaceborne synthetic aperture radar imagery with unsupervised deep learning. Isprs journal of photogrammetry and remote sensing, 178, 36-50.

13. Kolanuvada, s. R., & ilango, k. K. (2022). Automated mapping of flood inundation areas using cloud based processing tools of google earth engine for efficient disaster management – a case study of kerala floods. Disaster advances.

14. Landuyt, l., van wesemael, a., schumann, g., hostache, r., verhoest, n., & van coillie, f. V. (2019). Flood mapping based on synthetic aperture radar: an assessment of established approaches. Ieee transactions on geoscience and remote sensing, 57, 722-739.

15. Lewis, a., lymburner, l., purss, m. B. J., brooke, b., evans, b., ip, a., … & mueller, n. (2016). Rapid, high-resolution detection of environmental change continental scales from satellite data—the earth observation data cube. Environmental research letters, 9, 106-1113

16. Li, s., sun, d., goldberg, m., kalluri, s., lindsey, d., & sjoberg, w. (2022). The global geo-leo flood mapping system. Https://doi.org/10.1109/igarss46834.2022.9884379

17. Liu, c.-c., shieh, m., ke, m., & wang, k.-h. (2018). Flood prevention and emergency response system powered by google earth engine. Remote. Sens., 10, 1283.

18. Mehmood, h., conway, c., & perera, d. (2021). Mapping of flood areas using landsat with google earth engine cloud platform. Remote sensing geoscience, 866, 13-161

19. Nghia, b., pal, i., chollacoop, n., & mukhopadhyay, a. (2022). Applying google earth engine for flood mapping and monitoring in the downstream provinces of mekong river. Https://doi.org/10.1016/j.pdisas.2022.100235

20. Pandey, a. C., kaushik, k., & parida, b. R. (2023). Google earth engine for large-scale flood mapping using sar data and impact assessment on agriculture and population of ganga-brahmaputra basin. Sustainability, 14(7), 42104

21. Perera, d., seidou, o., agnihotri, j., mehmood, h., & rasmy, m. (2018). Challenges and technical advances in flood early warning systems (fewss). In flood impact mitigation and resilience enhancement (pp. 65-78)1

22. Phongsapan, k., chishtie, f., poortinga, a., bhandari, b., meechaiya, c., kunlamai, t., … & saah, d. (2021). Detection of large-scale floods using google earth engine and google colab. Remote sensing, 15(22), 53683

23. Saah, d., tenneson, k., matin, m., uddin, k., cutter, p., poortinga, a., … & anderson, e. (2019). Land cover mapping in data scarce environments: challenges and opportunities. Frontiers in environmental science, 72

24. Tiwari, v., kumar, v., matin, m., thapa, a., ellenburg, w. L., gupta, n., & thapa, s. (2020). Flood inundation mapping- kerala 2018; harnessing the power of sar, automatic threshold detection method and google earth engine. Plos one, 15.

25. Trinh, l. (2022). Automatic flood detection using sentinel-1 images in google earth engine. Https://doi.org/10.56651/lqdtu.jst.v4.n02.341.sce

26. Vanama, v. S. K., mandal, d., & rao, y. S. (2020). Gee4flood: rapid mapping of flood areas using temporal sentinel-1 sar images with google earth engine cloud platform. Journal of applied remote sensing, 14.

27. Wulder, m. A., masek, j. G., cohen, w. B., loveland, t. R., & woodcock, c. E. (2016). Opening the archive: how free data has enabled the earth observation data cube. Environmental research letters, 9, 106-1113